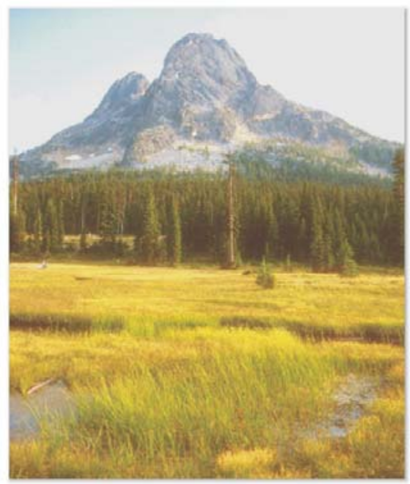
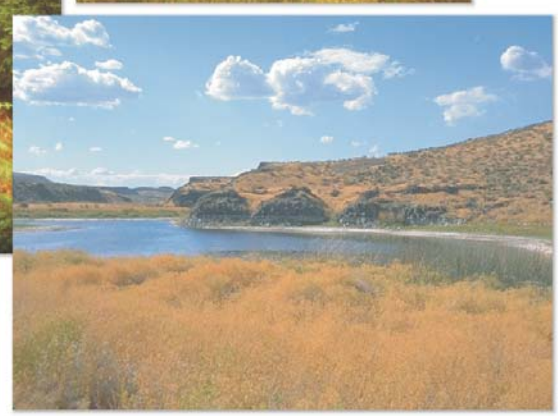
Wetlands in Washington State

Volume 1: A Synthesis of the Science





Final

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Washington Department of FISH and WILDLIFE

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Wetlands in Washington State

Volume 1: A Synthesis of the Science

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Written by: Dyanne Sheldon[1], Tom Hruby Ph.D.[3], Patricia Johnson[3], Kim Harper[2], Andy McMillan[3], Teri Granger[3], Stephen Stanley[3], Erik Stockdale[3]

1. Sheldon and Associates
2. Sheldon and Associates (currently with the Washington State Department of Ecology)
3. Washington State Department of Ecology

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For the *Responses to Comments* on the draft of this volume refer to
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For the Draft *Freshwater Wetlands in Washington State – Volume 1: A Synthesis of the Science* refer to Publication #03-06-016.

For Volume 2 of this two-volume series, *Wetlands in Washington State – Volume 2: Guidance for Protecting and Managing Wetlands*, refer to Publication #05-06-008.

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Chapter 1
Introduction to the Document

This is the first volume of a two-volume series. This volume contains a summary and synthesis of the recent literature relevant to the science and management of wetlands in the state of Washington. Volume 1 describes what the scientific literature says directly about the topics described below. In some cases where scientific information is lacking, the authors present their own hypotheses or conclusions based on a process of deductive reasoning or their own observations. Hypotheses and conclusions based only on the authors' reasoning or observations are clearly labeled as such.

The focus of Volume 1 is freshwater wetlands in Washington. Estuarine and marine wetlands are discussed in this document only in regard to the wetland rating systems covered in the second volume.

The topics covered in Volume 1 are:

- How environmental factors control the functions of wetlands across the landscape and at individual sites, how freshwater wetlands are classified according to these controls, and what functions are performed by different classes of freshwater wetlands in the state
- How human activities and land uses affect the environmental factors that control the functions of freshwater wetlands
- How disturbances caused by human activities and land uses impact the performance of functions by freshwater wetlands
- How wetlands are protected and managed using common tools such as buffers and compensatory mitigation, including what the literature says about the relative effectiveness of these tools
- How cumulative impacts can result from current approaches to managing and regulating wetlands

Volume 2 of this series translates these scientific findings into guidance to local governments and others regarding programs they can or currently do use to protect and manage wetlands.

This work was collectively prepared by the Washington State Department of Ecology (Ecology), the Washington State Department of Fish and Wildlife (WDFW), and a private consulting firm. The U.S. Environmental Protection Agency (EPA) provided funding and assisted in its production. Representatives from these agencies, as well as staff from the private consulting firm, made up a team (the Core Team) that guided the project. See Appendix 1-A for a list of members of the Core Team.

Both volumes will be of use to all those interested in protecting and managing wetlands. The authors hope they will find these documents useful in gaining a greater understanding of the current science regarding wetlands in the state, their ecology and functions, as well as their protection and management. Examples of groups who might use these documents include federal, state, and tribal staff; planners; resource managers; wetland scientists; builders; farmers; environmentalists; and other concerned citizens.

Local governments, however, are the primary audience for this document. They are a key group involved in wetland protection in the state. Through the Growth Management Act (GMA) (Revised Code of Washington (RCW) 36.70A), every county and city in Washington must designate critical areas (including wetlands) within their boundaries and protect them. In 1995, an amendment to GMA (RCW 36.70A.172 [1]) required that all city and county governments must include best available science (BAS) when developing their critical areas policies and regulations.

This synthesis, therefore, may be of special interest to local governments that do not have the resources to complete their own review of the scientific literature. All local governments, however, should also consider locally and regionally specific information not included in this synthesis if it meets the criteria of a valid scientific process, as described below.

1.1 Best Available Science (BAS)

The Washington Administrative Code (WAC 365-195-905) provides assessment criteria to assist in determining whether information constitutes the best available science, i.e., by having been developed through a valid scientific process. A valid scientific process is one that produces reliable information that is useful in understanding the consequences of regulatory decisions and in developing policies and regulations that will be effective in protecting the functions and values of wetlands and other critical areas.

Appropriate sources of scientific information as defined in WAC 365-195-905 include:

- Research
- Monitoring
- Inventory
- Survey
- Modeling
- Assessment
- Synthesis
- Expert opinion

Information derived from any one of these sources can be considered scientific information if it possesses the required characteristics in WAC 365-195-905 (see Table 1B-1 in Appendix 1-B). For example, a synthesis such as Volume 1 is considered best available science when it has undergone peer review, describes the methods used to obtain the information, presents conclusions based on reasonable assumptions that are logically derived, places the information in proper context, and is well referenced. See Appendix 1-B for a list of all the characteristics of a valid scientific process and their definitions, as well as a table displaying the characteristics needed for each of the sources listed above to be considered BAS.

Methods for preparing and reviewing Volume 1

The primary steps taken to arrive at publication of this document include:

- Searching the literature
- Reviewing, sorting, and prioritizing the reference lists
- Obtaining the reference documents
- Reading and entering information from the documents in a database
- Writing and revising the text
- Obtaining peer and public review
- Responding to comments, revising the text, and completing the document

The processes used for these steps, including the scientific databases and the key words used to search them, are described in Appendix 1-C.

1.1.1 Volume 1 as BAS

Volume 1 meets the definition and characteristics required for a synthesis in the WAC. Findings from scientific journal articles, government publications, technical books, and other sources that meet the definition and characteristics of BAS in WAC 365-195-905 were used and referenced in the synthesis. Conference proceedings and personal communications were occasionally used when no other information was available. In some cases, we were unable to ascertain to what level these additional sources were peer reviewed.

In a few instances, we have cited data collected during the calibration of the *Methods for Assessing Wetland Functions* (Hruby et. al. 1999, 2000) (also known as the Washington State wetland function assessment methods or WFAM) and the Washington State wetland rating systems (Hruby 2004a, b). These data have not been published in scientific journals. However, these observations reported as “unpublished data” in Volume 1, were collected in the field by interdisciplinary teams of wetland experts and used to support and calibrate the function assessment methods and the wetland rating systems. The methods and rating systems have been extensively reviewed and field tested by peer experts as well as the public. The data themselves were offered for review on request during public review and continue to be available on request.

A peer review of documents concerning wetlands, specifically the function assessment methods, wetland rating systems, and these two volumes, means that comments were solicited from a broad range of people on a mailing list of hundreds. This included experts from various disciplines, not just a select few that were in house or close associates. All comments received were addressed. For these volumes, a response to each comment, including rationales for those not used to modify the drafts, has been prepared. To read the comments on Volume 1 and the authors responses go to http://www.ecy.wa.gov/biblio/0506007.html.

1.1.2 Making Hypotheses and Assumptions

As mentioned previously, in some places in the document we offer our conclusions based on the literature when the references searched do not provide specific information on a topic important for wetland management. In such instances, the authors clearly state that a hypothesis, assumption, or conclusion is being made. For example, we use statements such as "in the absence of research to the contrary, it can be assumed….," "it is possible to hypothesize….," or "it can be inferred that…"

In these cases, a description of the logic being used is provided which meets the criteria in WAC 365-195-905 for expert opinion, one of the sources of valid scientific information. The criteria include logical conclusions and reasonable inferences, context, and the use of references (see Appendix 1-B for definitions of these criteria). These hypotheses can be considered expert opinion according to WAC 365-195-905 in which expert opinion is defined as a "Statement of a qualified scientific expert based on his or her best professional judgment and experience in the pertinent scientific discipline. The opinion may or may not be based on site-specific information." To be considered best available science according to the WAC, an expert opinion must meet three of the six characteristics listed in the table in Appendix 1-B: logical conclusions and reasonable inferences, context, and references.

Logical conclusions and reasonable inferences are defined as "The conclusions presented are based on reasonable assumptions supported by other studies and consistent with the general theory underlying the assumptions. The conclusions are logically and reasonably derived from the assumptions and supported by the data presented. Any gaps in information and inconsistencies with other pertinent scientific information are adequately explained."

Context is defined as "The information is placed in proper context. The assumptions, analytical techniques, data, and conclusions are appropriately framed with respect to the prevailing body of pertinent scientific knowledge."

References are defined as "The assumptions, analytical techniques, and conclusions are well referenced with citations to relevant, credible literature and other pertinent existing information."

The statements that are hypotheses in this document meet these criteria because they are presented with a clear and logical train of thought and the conclusions are based on reasonable assumptions supported by other credible studies that are relevant. They are placed in context and referenced.

In addition, the definition of *synthesis* in Webster's 7th Collegiate Dictionary is "deductive reasoning" and "the combining of often diverse conceptions into a coherent whole." The statements that present hypotheses and assumptions are based on deductive reasoning.

There are a few instances in the document where the authors of Volume 1 offer their observations based on their own professional experience. These are usually limited to statements relating to protection measures used to manage wetlands. Such statements are clearly labeled as those of the authors only.

1.2 Scope of Volume 1

The focus of this document is freshwater wetlands of Washington State. We have included information on wetlands in other regions and countries and on aquatic systems in general when more local information is lacking and the data are applicable to the wetlands in Washington. See the following section (1.3) for more discussion on this topic. Volume 1 does not address streams or riparian areas that are not wetlands. We do, however, summarize some of the literature related to buffers on streams where the information can be transferred to wetlands.

Marine and estuarine systems are discussed only in regard to wetland rating systems and wetland types for which specific management is needed. Marine and estuarine wetlands were excluded primarily to keep the scope of the project in the range of the available funding. Some recent scientific information on coastal and estuarine wetlands has been summarized by WDFW, Ecology, and other agencies through the Aquatic Habitat Guidelines Project, which is available on the internet (www.wa.gov/wdfw/hab/ahg).

There are several types of freshwater wetlands that are highlighted in the wetland rating systems (described in Volume 2) that are not specifically reviewed in this synthesis (e.g., bogs, interdunal wetlands, and vernal pools). These wetlands are subsets of wetlands in the different hydrogeomorphic (HGM) classes described in Chapter 2. At the level of detail provided in this document, general information summarized about wetlands also applies to these types of wetlands in whatever HGM class and region of the state is appropriate.

The effects of growing cranberries in wetlands are also not covered in this volume because of the time and funding constraints of the project. The limited area of the state that is affected by cranberry production was also a factor. In addition, information related to the effects of silviculture and forest practices on forested wetlands is not included because this subject is being addressed in another document currently being developed (Cooke in press).

In addition, the synthesis in Volume 1 is limited to information that has a practical application to the management and protection of wetlands. For the most part, available documents from the past ten years were used as the primary sources for this synthesis. It was assumed that this most recent literature would incorporate relevant science from the preceding years. Older documents were used in instances where they had not been superseded by more recent studies.

This volume DOES NOT contain agency recommendations or suggestions for implementation of any program to protect or manage wetlands. Any recommendations provided in Volume 1 (for instance, in the section of Chapters 5 and 6 addressing buffers and compensatory mitigation) are those that have been described in the literature. They are included here only as part of the synthesis of existing scientific information. Agency recommendations are provided in Volume 2.

1.3 Relevance of Scientific Information to Conditions in Washington

One of the tasks in reviewing scientific information was to determine what is relevant to wetlands found in the state of Washington. Determining the relevance of scientific information encompasses two aspects. The first is the degree to which general conclusions and principles developed from existing information can be used to predict what will happen in new or different situations. The conclusions of a scientific study done at one time in one wetland with specific characteristics may not be directly transferable to circumstances that develop in the future or at sites that have different characteristics or situations.

The first aspect also encompasses the concept that science doesn't often provide a "bright line." In other words, science rarely supplies us with precise solutions for protecting and managing natural resources. Very few experiments demonstrate true cause-and-effect relationships. For example, in reviewing the literature for this volume, we found few studies that actually documented the effectiveness of different ways for managing the wetland resource (such as the effectiveness of buffers of a specific width at protecting a specific wetland function). Rather, most studies, for example, discuss the impacts of human activities on wetlands. As a result, guidance on protection and management based on scientific information (as presented in Volume 2) is, to a large degree, extrapolation and synthesis of all the information collected.

The second aspect is the relevance of information collected in one region to the conditions found in another region. We have relied, whenever possible, on literature that was derived in the Pacific Northwest. However, in some cases, scientific information generated in other regions of the United States, and to a lesser extent from other countries, was used. Authors of this volume judged whether each "out-of-region" reference was applicable to Washington by extrapolating, interpreting, and synthesizing the information to determine how it pertains specifically to Washington.

We understand establishing what is relevant to Washington is a subjective decision; however, two criteria were used in the decision. First, an “out-of-region” reference was incorporated in the synthesis if the basic ecological principles on which it was based are relevant to most landscapes. Second, it was incorporated if the geomorphic setting of the wetland in a scientific report was similar to those found in the Pacific Northwest and no information specific to the region (that meets the criteria of BAS) was found in our search of the literature.

One of the basic assumptions in ecological and biological research is that environmental processes operate in a similar way if the basic conditions are similar. For example, water is expected to flow downhill whether it occurs in Minnesota or in Washington. Denitrifying bacteria are assumed to transform nitrate to nitrogen gas wherever they are found as long as the soils are anaerobic. The particular wildlife species that are closely associated with wetlands may differ regionally, but frequently fill the same habitat niches in Ohio or California as they do in Washington. Thus, much of the information on functions developed outside the region is transferable to Washington. Regional differences in functions occur when the basic conditions differ, and we have tried to point this out where possible.

As mentioned previously, the definition of *synthesis* in Webster’s 7th Collegiate Dictionary is “deductive reasoning” and “the combining of often diverse conceptions into a coherent whole.” This is the goal we have set for Volume 1. Part of the role of a synthesis, thus, is to summarize many studies and scientific articles; glean the general principles that apply in most areas as well as those that relate specifically to the state of Washington; and try to determine if they will apply to future conditions based on best professional judgment of the authors and the reviewers of the document.

1.4 Overview of Volume 1

Volume 1 is organized into seven chapters. The chapters share a common organization, beginning with a reader’s guide that describes the topics covered in the chapter and how the chapter is organized. An introduction then provides general background information, definitions, and clarifications. Each chapter describes the sources of information used and how well the subject is documented in the literature, particularly for the Pacific Northwest. The chapters also note gaps where information on an issue could not be found. Key points are summarized at the end of major sections and conclusions provided at the end of each chapter.

A brief summary of the contents of each chapter that follows and the appendices is provided below. In this document, page numbers are assigned to each chapter individually and are not sequential. The first number represents the chapter and the second the page number in that chapter (e.g., [3-2] represents page 2 in Chapter 3).

Chapter 2 – Wetlands in Washington and How They Function

Chapter 2 summarizes the information on how wetlands are categorized and how wetlands function in Washington State. It describes how functions are defined and introduces the concept that the performance of functions is controlled by a number of environmental factors within the wetland boundary (site scale) as well as in the broader landscape (landscape scale). The chapter then describes how some of the key factors that control functions are used to classify wetlands into groups that perform functions in similar ways.

The chapter goes on to describe functions of freshwater wetlands in Washington. Where applicable, the chapter discusses the differences in functions among wetland classes and in various areas of the state. The major functions described are those that were defined for the Washington State wetland function assessment methods (Hruby et al. 1999, 2000).

Chapter 3 – Environmental Disturbances Caused by Different Human Activities and Uses of the Land

In Chapter 3 the discussion shifts from wetland functions and the environmental factors that control the performance of functions to the major disturbances caused by human activities that affect wetlands and their functions. In this context, a *disturbance* is an event that changes an environmental factor that controls wetland functions. Ten disturbances (listed below) are discussed.

- Changing the physical structure within a wetland (e.g., filling, removing vegetation, tilling soils, compacting soils)
- Changing the amount and velocity of water in wetlands (increasing or decreasing the amount)
- Changing the fluctuation of water levels (frequency, duration, amplitude, direction of flow)
- Changing the amount of sediment (increasing or decreasing the amount)
- Increasing the amount of nutrients
- Increasing the amount of toxic contaminants
- Changing the acidity (acidification)
- Increasing the concentration of salt (salinization)
- Fragmentation (decreasing area of habitat and its spatial configuration)
- Other disturbances (noise, etc.)

The chapter continues with separate sections for four of the major types of human land uses in Washington State (agriculture, urbanization, forest practices, and mining) and the types of disturbances they cause. For each of these four land uses, the ten types of disturbances that change the factors controlling wetland functions (listed above) are discussed where applicable.

Chapter 4 – Negative Impacts of Human Disturbances on the Functions of Wetlands

Chapter 4 integrates the concepts discussed in Chapter 2 and Chapter 3. In Chapter 4, ten sections, one for each of the disturbances listed above, summarize how these disturbances ultimately leads to impacts on hydrologic functions, functions that improve water quality, and habitat functions.

Chapter 5 – The Effectiveness of Wetland Management Tools

Chapter 5 presents a synthesis of what the current literature reports on four tools currently used to protect and manage wetlands and their functions: the definition of wetlands, wetland delineation methods, wetland ratings, and regulatory buffers. In the section on definitions, the issues of biological versus regulated wetlands, small wetlands, isolated wetlands, and Prior Converted Croplands that are wetlands are discussed. This chapter does not provide language or recommendations for regulations or policy—those are provided in the second, separate volume containing guidance for protecting and managing wetlands in Washington (Volume 2).

Chapter 6 – The Effectiveness of Wetland Mitigation

Chapter 6 discusses another commonly used tool for managing and protecting wetlands, compensatory wetland mitigation. This topic is discussed in its own chapter because of the large volume of information available on this subject. Topics covered in this chapter include:

- Evaluation of the success of compensatory mitigation
- Compliance of mitigation projects with permit requirements
- Types of compensatory mitigation
- Replacement ratios and replacement of wetland acreage
- Functions provided by compensatory mitigation projects
- Reproducibility of particular types of wetlands (bogs, fens, vernal pools, alkali wetlands, and mature forested wetlands)
- Suggestions from the literature for improving compensatory mitigation

Chapter 7 - Cumulative Impacts on Wetlands

Chapter 7 discusses different types of cumulative impacts, and the loss of wetland area as the most easily assessed indicator of cumulative impacts. It goes on to present some of the causes of cumulative impacts in Washington. These include:

- Case-by-case permitting as a cause of cumulative impacts
- Lack of consistent plans and regulations between jurisdictions as a possible cause of cumulative impacts
- Implementation of regulatory programs at the local level as a possible cause of cumulative impacts

The chapter ends with a discussion in which the types of cumulative impacts are compared to the protection measures commonly taken by local governments.

Glossary

The glossary provides definitions for some of the technical terms used throughout Volume 1. Other terms are defined in the context of the sentence in which they appear and may not be included in the glossary.

References

The references cited in the text are listed separately at the end of Volume 1. Some of these references represent reviews or syntheses in which a researcher describes trends observed from numerous studies conducted in previous years. In these cases, we cite only the review document and not all the citations in the review.

Citations from the review by Adamus et al. (2001), however, are an exception. Portions of Adamus et al. (2001), a review of current scientific literature on the impacts of human activities on wetlands and their functions, were adapted and included in Chapter 4 with permission from Dr. Adamus. The list of cited references at the end of the document does include the literature sources from those portions of Adamus et al. (2001) that were adapted.

Appendices

The appendices of Volume 1 are as follows:

- Appendix 1-A identifies the team guiding the production of Volume 1 (the Core Team)
- Appendix 1-B describes the characteristics of a valid scientific process and types of scientific information defined by the Washington Administrative Code (WAC 365-195-905)
- Appendix 1-C details the methods used in the literature review and production of Volume 1
- Appendix 1-D lists the reviewers who commented on the draft of Volume 1
- Appendix 2-A provides information about various terms and methods that have been used to organize and group information about wetlands, such as classification, characterization, and rating
- Appendix 2-B lists the species of wildlife associated with wetlands in Washington and Oregon from Johnson and O'Neil (2001)

1.5 Public Involvement and Review of Volume 1

1.5.1 The Process of Public Involvement

The process for public involvement of Volume 1 included meetings of two focus groups, numerous mailings and extensive peer and public review. Ecology compiled a mailing list of scientists with wetlands expertise, local government planners, and other groups and individuals from various existing mailing lists used for other wetland-related projects.

In October 2001, Ecology sent out a focus sheet describing the project and a cover sheet that solicited the recipient's participation in the project. This sheet included a tear-off card that could be used to request that the sender be retained on the mailing list. The mailing list was then edited based on the returned cards.

Meetings of focus groups were held in January 2002 in Moses Lake and Olympia to begin the process of gathering input from the public on the project. These meetings were attended by various members of the Core Team, local planners, other staff from local government, and other interested parties. The purpose of these meetings was to help focus the project so that the synthesis would meet the needs of our primary audience, local governments. The meetings gave opportunities to the Core Team to present information on the project and to listen to questions and concerns from the attendees. Lists of keywords to use for the search of the literature were revised based on input from the focus groups.

In June 2002, Ecology sent out a mailer with an update on the project to the entire mailing list. It discussed the status of the project, timelines, and other issues.

In November 2002, Ecology staff contacted selected experts in various disciplines to solicit their review. The list of peer reviewers was not intended to be inclusive of all experts. The purpose was to make sure that each of the major topics in Volume 1 was reviewed by one or more recognized experts in that discipline. These expert reviewers were selected from academia, public agencies and private consultants.

In February 2003, Ecology sent another mailing to all those on the list to determine who wanted to comment on the draft of Volume 1. In June 2003, Ecology distributed a notice by email to update the public on revised target dates for distribution of the draft document for peer and public review.

The draft was distributed for general review in September 2003. Over 170 paper copies as well as CDs were sent to reviewers. An undetermined number of reviewers downloaded the draft from the project's web site. The experts asked to review the document were provided the draft at the same time as the general public. Instructions for providing comments and a questionnaire were also distributed with the draft document.

Several mailings were distributed since the fall of 2003 informing those listed about the status of revisions to Volume 1 as well as progress on the completion of the draft of Volume 2. The Core Team decided that a draft of Volume 2, containing guidance on protecting and managing, should be completed before Volume 1 was completed. The draft of Volume 2 was distributed for comment in August 2004, during which time the authors began writing responses to comments and revising Volume 1. The review process for Volume 2 is described in Chapter 1 of that document.

1.5.2 Responding to Comments and Reviewing Suggested Literature

Twenty-nine reviewers provided comments on the draft of Volume 1. The reviewer's comments varied from cursory to very detailed, approximately 900 comments were submitted.

Initially, the Core Team organized and reviewed the comments and developed responses to the most substantive comments as individual or synthesized comments. The responses were posted on the project's web site in the spring of 2004. In addition, Ecology posted a list of all the comments that were submitted, organized by chapter, section and page. After the draft of Volume 2 was completed, each of the original comments was addressed by the authors. Each comment and a response to it have now been posted on the project's web site at the address below. Comments are organized by chapter, except for the beginning section that contains answers to questions in a questionnaire distributed to reviewers with the draft document.

As a part of the questionnaire, the reviewers were asked to provide any additional references they felt were pertinent to the subjects discussed. In addition, those who suggested changes or additions to the text were asked to provide citations. As a result, reviewers submitted several hundred new references. The authors reviewed this list and rated each as high, medium, or low importance using the same criteria used in the original search (see Appendix 1-C). Attempts were made to obtain and review all citations rated as high or medium. The results of this process, whether the reference was or was not obtained and why, are documented in a table at the end of the document containing the responses to comments.

Volume 1 and the responses to comments are available online

Ecology has developed a web site for this project on the Shorelands and Environmental Assistance Program web site. The web site includes a project description, contact information, current status of the project, and copies of the updates that were sent. The web site also includes a copy of the final version of Volume 1, as well as Volume 2, along with two documents containing the comments received and the authors' responses, one for each document. http://www.ecy.wa.gov/programs/sea/bas_wetlands/index.html

1.6 Conclusions

Volume 1 provides a summary of relevant scientific information related to wetlands in the Pacific Northwest and their management. The document should be useful to all those who have an interest in the protection and management of wetlands including agency staff, consultants, interested organizations, and citizens. It should be particularly helpful to local governments that are required under the Growth Management Act, to include best available science when developing and revising regulations protecting critical areas including wetlands. Volume 1 has been reviewed by technical experts (peer reviewed) and other interested parties. The intention of the project and the review process was to produce a synthesis of the current science on wetlands in the state of Washington that is easily understood, yet thorough and scientifically rigorous.

Chapter 2

Wetlands in Washington and How They Function

2.1 Reader's Guide to This Chapter

Chapter 2 presents information on wetlands in Washington and how they function. It introduces the ecological principles that help us understand the impacts of decisions we make about wetlands. It then expands on the newer ecological concept that the performance of functions is controlled by a number of environmental factors within the wetland boundary (site scale) as well as in the broader landscape (landscape scale). The chapter then describes these controls relative to regions and wetland types (classification of wetlands) in Washington before turning to detailed descriptions of the functions performed by the wetlands east and west of the Cascade Mountains and in different wetland classes.

To protect and manage wetlands, an understanding of wetland functions must be supplemented by knowledge of how these functions are affected by human activities. Chapter 3, therefore, goes on to describe how various land uses and activities disturb the environment, for example by causing excess nutrients, increased runoff and fluctuating water levels, and reduction in habitat. These disturbances in turn affect the environmental factors that control wetland functions. Chapter 3 describes what the literature says about the disturbances created by different land uses, while Chapter 4 goes into detail regarding how each disturbance affects particular wetland functions, including the organisms that use wetlands.

2.1.1 Chapter Contents

Major sections of this chapter and the topics they cover include:

Section 2.2, Basic Ecological Principles Useful in Managing Wetlands and in Understanding the Impacts of Human Activities describes five basic ecological principles that are useful in managing wetlands as identified by the Ecological Society of America. The principles include time, place, species, disturbance, and landscape.

Section 2.3, Introduction and Background on Wetland Functions describes the evolution of our understanding of wetland functions over the last few decades. It also defines the term *wetland functions.* The section describes how environmental processes at many geographic scales control the functions provided by wetlands. The section includes a diagram summarizing the environmental factors that control functions and how they interact with human disturbances. The difference between *functions* and *values* is also explained.

Section 2.4, Classification of Wetlands in Washington as a Key to Understanding their Functions begins by describing the common classification systems used to categorize wetlands. It discusses ecological regions (ecoregions) in Washington State and how wetlands across the state are classified within the ecoregions into groups (classes and subclasses) that function in similar ways. The classes and subclasses of wetlands found in the state are described.

Section 2.5, Overview of Wetland Functions in Washington State introduces the functions of wetlands that are currently the focus of management efforts. These functions fall into three main categories: improving water quality, hydrologic functions, and providing habitat. Each category is described and the functions related to each are listed.

Section 2.6, How Wetlands Perform Functions in Washington State describes each of the wetland functions listed in Section 2.5. For each function, the text provides a general description of how the function is performed, and then goes into detail about how that function is performed by wetlands of various classes and in different areas of Washington.

Section 2.7, Chapter Summary and Conclusions summarizes the major concepts presented in the chapter.

2.1.2 Where to Find Summary Information and Conclusions

Each major section of this chapter concludes with a brief summary of the major points resulting from the literature review on that topic in a bullet list format. The reader is encouraged to remember that a review of the entire section preceding the summary is necessary for an in-depth understanding of the topic.

For summaries of the information presented in this chapter, see the following sections:

- Section 2.3.4
- Section 2.4.6
- Section 2.5.4
- Section 2.6.4

In addition, Section 2.7 provides a summary and conclusions about the overarching themes gleaned from the literature and presented in this chapter.

2.1.3 Sources and Gaps in Information

Our understanding of how wetlands function and the factors that control these functions has increased in the last two decades and much of this information has been published in the journal *Wetlands* (the journal of the Society of Wetland Scientists). Other journals that often carry papers on wetland functions include *Environmental Management*, *Restoration Ecology*, and the *Journal of the American Water Resources Association*.

Much of what we know about wetlands in Washington, their functions, and how functions are defined, is based on the collective expertise and judgment of teams of experts who developed the *Methods for Assessing Wetland Functions* (also known as the Washington State wetland function assessment methods of WFAM) (Hruby et al. 1999, Hruby et al. 2000) and who revised the

Washington State wetland rating systems (Hruby 2004a,b). These tools are methods that analyze the functions of wetlands in the state. This expert, regional information is critical because much of the knowledge in the scientific literature about wetland functions was developed outside the Pacific Northwest.

These tools can be considered a synthesis of the best available science for defining and understanding the functions performed by Washington's wetlands. The wetland scientists who developed these documents analyzed existing scientific information and extracted material that is relevant for Washington State. They also added their best professional experience, expertise, judgment, and field observations during development of these products. Existing scientific information is cited in these tools where it was judged relevant to Washington State.

The tools were developed using a formal process that was based on using consensus among wetland scientists in the region. The process included peer review and public comment. The documents resulting from the function assessment project and the rating system effort are cited in this synthesis as Hruby et al. (1999), Hruby et al. (2000), and Hruby (2004a,b). Information about these projects is also available at http://www.ecy.wa.gov/programs/sea/wetlan.html.

Major gaps in our knowledge of how wetlands in Washington function, however, still exist for the types of wetlands for which function assessment methods have not yet been developed. For example, there is little published information about the functions of "slope" wetlands and "flats" wetlands (see section 2.4.4 for a description of these wetland classes). There is also less published information on the wetlands in the arid region of the state.

2.2 Basic Ecological Principles Useful in Managing Wetlands and in Understanding the Impacts of Human Activities

Many decisions about the management and use of land are made with little attention to any of their ecological impacts. Thus, a better knowledge of the functioning of "ecosystems" is needed to broaden the scientific basis of decisions on using the land and managing it (Dale et al. 2000). In response to this need, the Ecological Society of America established a committee to examine the ways that land-use decisions are made and the ways that ecologists could help inform those decisions. The following discussion on the basic ecological principles that are useful in managing how we use the land (including wetlands) is derived from the report of the committee that was published in *Ecological Applications* (Dale, et al. 2000).

The committee identified five ecological principles that have implications for managing wetlands. The principles deal with time, place, species, disturbance, and landscape. Each is described briefly below and represents a summary of the information in Dale et al. (2000). (Note: the citations used by Dale et al. (2000) in developing these principles are not included in the summary.)

Time Principle - **Ecological processes function at many time scales; some long, some short; and ecosystems change through time.** For example, activities in cells occur on the scale of microseconds to minutes, decomposition occurs over hours to decades, and soil formation occurs over decades and centuries. In addition, ecosystems can change from season to season, year to year, and decade to decade. Human activities that alter the species found in ecosystems or alter the biological, chemical, or geological cycles can change the pace or direction of these "natural" changes. Human activities have effects that can last decades or centuries.

Species Principle – **Particular species and networks of interacting species have key, broad-scale effects on ecosystems**. Such "focal" species affect ecological systems in many ways. *Indicator species,* such as amphibians, help us understand the current condition of ecosystems. The status of indicator species helps us understand the status of larger groups of species, the status of key habitats, or as an indication of the action of some environmental stressor (disturbance). *Keystone species*, such as elephants, are those that have a greater effect on ecological processes than would be predicted from their abundance alone. *Ecological engineers,* such as beaver, alter habitat, and in doing so modify the survival and opportunities of many other species. *Umbrella species*, such as cougar, deer, or elk, either require large areas or use multiple habitats and thus overlap the habitat requirements of many other species. *Link species*, such as salmon, exert critical roles in the transfer of matter and energy across trophic levels or provide critical links in the transfer of energy in complex food webs.

Place Principle – **Local climatic, hydrologic, edaphic (resulting from soils), and geomorphological factors as well as biotic interactions strongly affect ecological processes and the abundance and distribution of species at any one place**. Conditions in any one place reflect the variations that occur along gradients of elevation, longitude, latitude, and the many physical, chemical, and edaphic factors at a micro-scale. These factors provide the ecosystem with a particular appearance (e.g., a wetland formed in a glacial "kettlehole" is quite different from a wetland that formed in the "pothole" left behind in the basaltic surface of the Columbia Basin after the ice-age floods).

Disturbance Principle – **The type, intensity, and duration of disturbances shape the characteristics of populations, communities, and ecosystems**. Disturbances are events that disrupt ecological systems. They may occur naturally (e.g., wildfires, storms, floods) or be caused by human actions (e.g., clearing land, building roads, altering stream channels). The effects of disturbances on ecological systems are controlled in large part by their intensity, duration, frequency, timing, and size and shape of area affected. Many ecosystems, such as Ponderosa pine forests, are maintained by a certain level and type of disturbance, such as fire. Changes in land use that alter the regime of natural disturbances or initiate new disturbances are likely to cause changes in species distributions, abundances, the composition of ecological communities and the functioning of the ecosystem.

Landscape Principle – **The size, shape, and spatial relationships of land-cover types influence the dynamics of populations, communities, and ecosystems**. The spatial array of habitats and ecosystems make up the "landscape," and all ecological processes respond, at least in part, to this "landscape template." The kinds or organisms that exist and their interaction with ecosystem processes (e.g., decomposition, nutrient fluxes) are constrained by the sizes, shapes, and patterns of interspersion of habitat across a landscape. Human activities that decrease the size of habitat patches or increase the distance between similar habitat patches can greatly reduce or eliminate populations of organisms.

These ecological principles underlie our understanding of how wetlands function and how they should be managed to protect their functions. They form the basis of the following discussion of how wetlands function, how human disturbances can impact those functions (Chapter 4), and how we should develop ways to protect and manage this resource (Volume 2).

2.3 Introduction and Background on Wetland Functions

2.3.1 An Evolving Understanding of Wetland Functions

The concept of wetland functions is relatively new in both the regulatory and scientific arenas. For many years wetlands were considered nuisances and wastelands (Washington State Department of Natural Resources 1998). The functions found within a wetland were not considered important enough to study and understand. Today, however, we know that the functions performed by wetlands are important and interacts with other aspects of the landscape around it. We have found that the structural components of a wetland and its surrounding landscape (such as plants, soils, rocks, water, and animals) interact with a variety of physical, chemical, and biological processes both within the wetland itself and the surrounding landscape. These interactions are called *functions*.

The concept of wetland functions has evolved since it was first introduced about four decades ago. Wetlands were first considered primarily to function as habitat for important species such as waterfowl. The factors that were thought to control how a wetland functions in this respect were the structural elements in a wetland. For example, how much open water did the wetland contain? What types of vegetation were found there? This interest in wetland structure led to the development of a classification system for wetlands in 1979 based on the vegetation and water regime (Cowardin et al. 1979). This system is still in use today. See Section 2.4.1 for more on this classification system.

It soon became apparent, however, that wetlands contribute more to the landscape than just habitat. During the 1980s much research was done on how wetlands filter pollutants and improve water quality. As a result, wetland engineers started to design and create wetlands specifically to treat wastewater (Hammer 1989). During the 80s wetlands were also recognized for their contribution to flood protection (Adamus et al. 1987).

The ongoing research in the 1980s also led to a realization that the functions performed within a wetland are controlled by a number of environmental factors both within and outside of the wetland. Climate was recognized as the major factor that affects how wetlands function at the largest geographic scale (Bailey 1995, Benda et al. 1998). Differences in temperature, rainfall, and seasonal and annual changes impact all aspects of interactions among organisms and their environment, including wetlands.

During the 1990's Brinson (1993b) and the National Academy of Sciences (National Research Council 1995) described and defined three other factors at a smaller geographic scale that can be considered primary controls of functions within a wetland:

- Geomorphic or topographic setting of the wetland
- Direct source of water to the wetland
- Hydrodynamics, or the direction of flow and strength of water movement within the wetland

More recently, however, scientists have become increasingly aware that functions performed by wetlands are also controlled by processes that occur at the scale of the watershed. There is currently an emphasis on trying to understand wetland functions in the context of how water, sediments, and nutrients move in a watershed (Bedford 1999). The surface geology and soils, the routing of water through the watershed, and the movement of sediments, large wood, nutrients, and other chemicals are all considered important factors in controlling how individual wetlands function (see Section 2.3.3).

2.3.2 How Wetland Functions Are Defined

The interactions that occur within a wetland occur at many scales as well, from the microscopic (such as bacterial decomposition of organic matter) to the continental (such as providing refuge and feeding for migrating waterfowl along the continental flyways). If every interaction that occurs within a wetland were identified as a separate function, the number of functions would be almost infinite. For example, the decomposition of organic matter by bacteria is a combination of many types of decomposition, one for each individual species of bacteria found in the wetland. Each bacterial species decomposes organic matter at a different rate and under different environmental conditions. Each of these could be considered a separate wetland function.

In contrast, a function can be a broad lumping of many environmental processes. For example, the "removal of imported elements and compounds" is a function identified in one method for assessing wetland functions (Brinson et al. 1995). At least a dozen nutrients and several hundred known contaminants can be found in surface waters. Therefore this function combines several hundred different processes of removal, one for each imported nutrient, contaminant, and other compound.

> ***Wetland functions*** **–** The physical, biological, chemical, and geologic interactions among different components of the environment that occur within a wetland. There are many valuable functions that wetlands perform but these can be grouped into three categories – functions that improve water quality, functions that change the water regime in a watershed such as flood storage, and functions that provide habitat for plants and animals.

Furthermore, wetlands perform many types of functions, but not all wetlands perform the same functions, nor do similar wetlands provide the same functions to the same level of performance (Clairain 2002).

One of the initial tasks in defining functions, therefore, is to identify and group the processes and interactions that occur in wetlands into some manageable number of "functions." Most functions are generally grouped in terms of three broad categories (Adamus et al. 1991):

- Biogeochemical functions, which are related to trapping and transforming chemicals and include functions that improve water quality in the watershed
- Hydrologic functions, which are related to maintaining the water regime in a watershed and include such functions as reducing flooding
- Food web and habitat functions

Functions are subdivided into more specific groups by the environmental processes or interactions within the wetland that are related and are on a similar temporal and spatial scale. They are also grouped based on the needs for managing wetlands (Hruby 1999). For example, managers may need to know how well a wetland removes specific constituents that contribute to poor water quality such as sediment, nutrients, and toxic compounds, rather than having only a general assessment of the removal of elements and compounds that cause problems with water quality.

Table 2-1 gives examples of how the many different processes and interactions that occur in wetlands have been grouped under different names for various policy and regulatory purposes. They are organized into the three broad categories above (water quality improvement, hydrologic functions, and food webs and habitat).

The names of the categories to some degree reflect how broadly the function is defined. "The removal of all imported elements and compounds" is a broadly defined function, whereas "removing sediment" is a more narrowly defined function. Section 2.5 describes in more detail the functions that have been chosen for the Washington State wetland function assessment project and the Washington State wetland rating systems.

Table 2-1. Different ways of dividing wetland functions.

Wetland Evaluation Technique (WET) [a]	HGM Guidebook for Riverine Wetlands [b]	Mill Creek Special Area Management Plan (SAMP)[c]	Methods for Assessing Wetland Functions – Lowlands of Western WA[d]
Biogeochemical Functions Related to Improving Water Quality			
Nutrient Removal/ Transformation	Nutrient Cycling	Nutrient Uptake	Removing Nutrients
Sediment Stabilization	Removal of Imported Elements and Compounds	Sediment Stabilization	Removing Sediment
Sediment/Toxicant Retention	Retention of Particulates	Retention of Toxics	Removing Metals and Toxic Organic Compounds
Hydrologic Functions Related to Maintaining the Water Regime			
Floodflow Alteration	Dynamic Surface Water Storage	Floodflow Alteration	Reducing Peak Flows
Groundwater Recharge	Long-term Surface Water Storage	Groundwater Discharge	Decreasing Downstream Erosion
Groundwater Discharge	Energy Dissipation		Recharging Groundwater
	Subsurface Storage of Water		
	Moderation of Groundwater Flow or Discharge		
Functions Related to Maintaining Food Webs and Habitat			
Aquatic Diversity/ Abundance	Maintain Spatial Structure of Habitat	Habitat for Aquatic Species	General Habitat
Wildlife Diversity/ Abundance/ Migration Wintering	Maintain Interspersion and Connectivity	Habitat for Anadromous Fish	Habitat for Invertebrates
Production Export	Maintain Distribution and Abundance of Invertebrates	Habitat for Resident Fish	Habitat for Amphibians
	Maintain Distribution and Abundance of Vertebrates	Habitat for Migratory Birds	Habitat for Anadromous Fish
		Habitat for Resident Birds	Habitat for Resident Fish
		Habitat for Other Species	Habitat for Wetland-Associated Birds
			Habitat for Wetland-Associated Mammals
Sources: [a] Adamus et al. (1987) [b] Brinson et al. (1995)	[c] U.S. Army Corps of Engineers (2000) [d] Hruby et al. (1999)		

Relationship of functions to values

The scientific literature has in the past confused the terms wetland *functions* and wetland *values*. In fact, the term *functional values* was in common usage during the 1980s and early 1990s (e.g., Amman et al. 1986). The correct interpretation of the term *functional values* suggests that wetland values were functioning, which was not the intent of the phrase. As mentioned previously, wetland functions are the environmental processes that take place in a wetland. Society, however, does not necessarily attach the same value to all functions. Value is usually associated with goods and services that society recognizes, and not all environmental processes are recognized or valued. The National Research Council (1995) says the following about the differences between values and functions.

> *Because value is a societal perception, it often changes over time, even if wetland functions are constant. Value can change over time as economic development changes a region. The value of a wetland in maintaining water quality near a source of drinking water can be great even if the wetland is small (Kusler 1994). Some values can be mutually exclusive if they involve direct or indirect manipulation, exploitation, or management of wetlands. For example, production of fish for human consumption could conflict with the use of a wetland to improve water quality of water that contains toxins.*

There are three reasons for maintaining a clear distinction between functions and the services that wetlands provide (King et al. 2000). First, people can attach values to services, but usually cannot attach values to the underlying environmental functions and processes on which they depend. Second, the factors that affect the level of services a wetland provides are different from those that determine the levels of function. Third, different questions need to be addressed when considering values and functions. When assigning a relative value to a wetland, questions involving the importance and scarcity of the services need to be answered. Depending on the landscape context of the wetland, these may, or may not, be related to the levels of function in the wetland.

Generally, the important values of wetlands cannot be assessed or rated using the same methods as those used to assess functions (Hruby 1999). Analyzing values requires understanding a different set of factors than those used for functions (King et al. 2000).

2.3.3 Environmental Factors that Control Wetland Functions

"*Ecosystems are not defined so much by the objects they contain as by the processes that regulate them*" (Christiansen et al. 1989)

Functions of wetlands, as defined previously, represent interactions among the different components of the ecosystem and the landscape. Thus, functions can be influenced or controlled by changes to any one of these components. For example, a wetland may perform the function of providing overwintering habitat for coho, for which the presence of seasonal or permanent surface water is critical. This function will, therefore, change if the wetland is drained so no surface water remains at any time. Changes in functions, however, can also be a result of alterations to the watershed outside the wetland boundary. For example, surface water in the wetland may also be eliminated if its water supply is diverted. Also if the gravel beds in which the coho spawn farther up in the watershed are disturbed, or if the flow in the stream is reduced to such an extent that the young can no longer swim to the wetland from the spawning areas, the wetland's support of coho overwintering habitat will be altered.

Likewise, the expression of one function in a wetland (such as habitat) can result in a change to the larger-scale environmental processes and the landscape. For example, if the conditions are right for beavers to settle in a wetland along a stream or river (i.e., the wetland functions as good habitat), the beavers will build a dam and create a ponded wetland. This will change the vegetation in the wetland and possibly alter other wetland functions such as improving water quality and storing flood waters. These changes may be important enough to change the water quality and the movement of water through that part of the watershed (a change in one of the primary controls of function).

Any factor that changes how well, or how much, a function is performed by a wetland can be considered a "control" of that function. Another term often used in the scientific literature is *driver*. The drivers of functions in wetlands determine how well the functions are performed. An action or occurrence that affects a control or driver is called a *disturbance* by ecologists (Dale et al. 2000). The type, intensity, and duration of disturbances can change the physical structure of the ecosystems and how they behave (ecosystem dynamics) (Dale et al. 2000).

> Human activities create a disturbance that causes a "stress" on the ecosystem to which it responds. Scientists often use the term *stressor* to distinguish those disturbances that have a significant impact on an ecosystem from those that have little impact (see for example Adamus et al. 2001, Laursen et al. 2002).
>
> In this document, however, we are not using the term *stressor*. All the disturbances discussed and reviewed here have documented negative impacts on wetlands and their functions. To avoid confusion, the term *disturbance* is used throughout this document.

Human uses of the land create a different set of disturbances than were present before human activities modified the land (Dale et al. 2000). The disturbances that are caused by human activities are discussed in Chapter 3, and the impacts these disturbances have on wetlands and their functions are described in Chapter 4.

The focus of research and management has been on functions and controls of functions that occur within the wetland itself and less on those that are a part of the landscape of the entire watershed. This has resulted from the fact that the need to define wetland functions has actually been driven by regulatory requirements and policy (Brinson et al. 1995, Clarain 2002). The policy has been to have a "no net loss of wetland area and function" at both the state and the national levels. However, this focus on functions confined to the wetland itself is changing. We are learning that managing wetlands requires an understanding of the "relationship of the individual wetlands to the landscape" (Bedford 1996) as well as the wetland itself.

A summary of the literature addressing the environmental factors that control wetland functions is presented below. First reviewed is the literature that addresses controls that occur at the scale of the wetland's contributing basin (that part of the landscape that contributes surface water to the wetland). The controls that are found within the boundary of the wetland (the site scale) are then described. The discussion includes a number of conceptual models that have been developed to help visualize and understand the complex interactions between wetland functions and environmental factors at different scales.

Terms used in this document to refer to environmental factors

Surface and subsurface water flows through the landscape within drainage systems. These drainage systems are often called basins, sub-basins, watersheds, or river basins depending on the size of the area. In this document, drainage systems are generally referred to using one of two terms:

- ***Watershed*** - A geographic area of land bounded by topographic high points in which water drains to a common destination.
- ***Contributing basin*** - The geographic area from which surface water drains to a particular wetland.

Environmental factors that affect wetland functions can occur at different geographic scales. In this document two scales are used.

- ***Landscape processes*** - Environmental factors that occur at larger geographic scales, such as basins, sub-basins, and watersheds. Processes are dynamic and usually represent the movement of a basic environmental characteristic, such as water, sediment, nutrients and chemicals, energy, or animals and plants. The interaction of landscape processes with the physical environment creates specific geographic locations where groundwater is recharged, flood waters are stored, stream water is oxygenated, pollutants are removed, and even wetlands are created.
- ***Site processes*** - Environmental factors that occur within the wetland itself or within its buffer. The interactions of site processes with landscape processes define how a wetland functions.

2.3.3.1 Environmental Controls of Functions at the Landscape Scale

Hydrogeologic Controls of Functions in Wetlands

Climate, geology, and the hydrologic characteristics in a watershed control how water, sediment, and nutrients move (Bedford 1999). Together, along with factors within the boundary of a wetland, these factors control the functions performed. Scientists call these large-scale, environmental factors the *hydrogeologic setting* of a wetland (Winter 1983, 1986, 1988, 1989, 1992, LaBaugh et al. 1987, Winter and Woo 1990). The following describes some models that have been developed to better understand these controls of wetland functions.

A hydrogeologic model created by Bedford (1996, 1999) concludes that wetlands develop and persist over time through the interaction of the hydrologic cycle with the landscape (Figure 2-1). This model views wetlands as part of an ecological system that is continuous with large-scale surface and groundwater systems. In this model, several geologic characteristics control the flow and chemistry of water, including the surface relief and slope of the land, the thickness and permeability of the soils, and the composition and hydraulic properties of the underlying geologic materials (Bedford 1999).

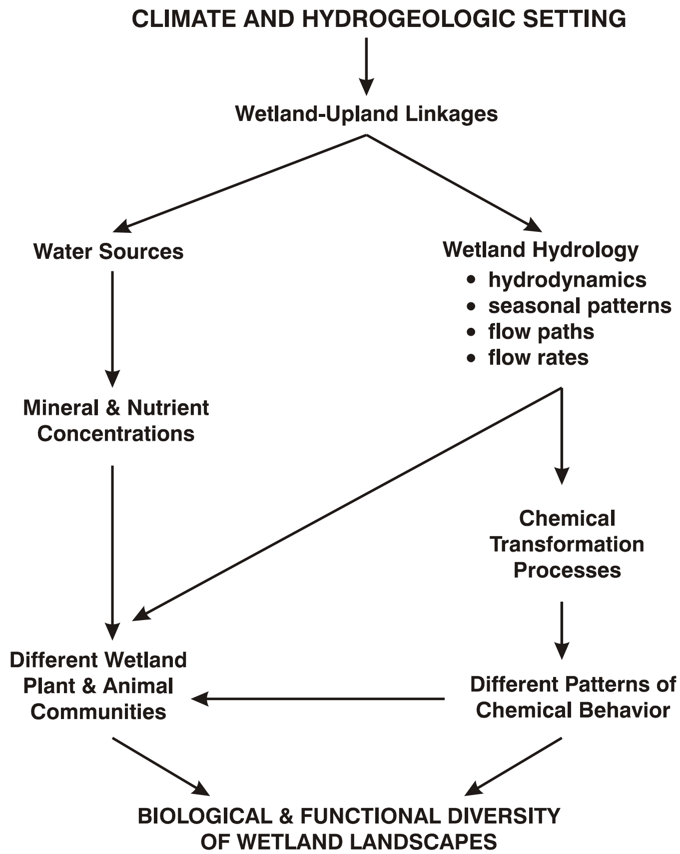

Figure 2-1. A model of the environmental factors that control wetland functions. (Bedford 1999; reprinted with permission)

In Bedford's hydrogeologic model, as in all the models discussed here, climate drives the large-scale water regime. Climate determines the precipitation and patterns of evapotranspiration that ultimately move surface and groundwater into and out of wetlands (see Figure 2-1). It also determines how sediments and chemicals (e.g., salts and nutrients) are eroded from bedrock and transported throughout the system.

A similar model to that of Bedford considers the contributing basin of a wetland in describing the factors that affect functions. This model, known as the "process-structure-function" model (Figure 2-2), was developed in conjunction with restoration plans for Northwest riverine systems. It is described in more detail in Beechie and Bolton (1999), Gersib (2001), and Stanley and Grigsby (2003). The model assumes that the biological, physical, and chemical characteristics (structure and functions) of aquatic systems including wetlands are determined by the interaction of many processes operating at the larger scale of the landscape (Kaufman et al. 1997, Beechie and Bolton 1999). These processes include the movement of (Naiman et al. 1992):

- Water (surface and subsurface)
- Sediment
- Nutrients and other chemicals (salts, toxic contaminants)
- Large woody debris
- Energy (in the form of sunlight)

According to the "process-structure-function" model, the interactions of these processes with climate and geomorphology determine the structure within wetlands (e.g., substrate, plant communities). The wetland structure, in turn, is one factor that influences the type and performance of wetland functions.

For example, a wetland may produce large quantities of plant material and support the function of a rich food web. In order to provide this function, the wetland needs to have waters rich in nutrients coming into it, good exposure to sunlight, and a way for the production of plant material to leave the wetland into surrounding aquatic resources. The major controls for this function are the movement of water to and from the wetland, the movement of nutrients into and within the wetland, and an adequate source of energy.

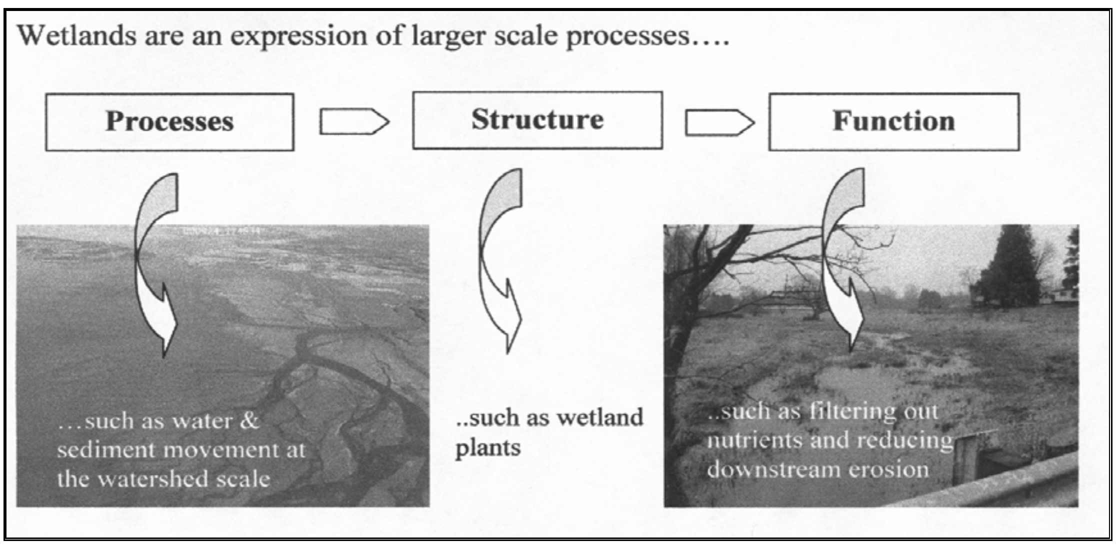

Figure 2-2. "Process-structure-function" model.

The "process-structure-function" model, like Bedford's, assumes that changes in land use affect processes such as the delivery of water, nutrients, sediment, and toxics to aquatic systems (Poiani et al. 1996, Mallin et al. 2000). These in turn affect structure and function within those aquatic systems.

Controls of the Habitat Provided by Wetlands

The abundance and richness of species within a wetland may be explained by the attributes of the surrounding landscape as well as by the characteristics found within the site itself (review in Dale et al. 2000). This is the landscape principle in ecology that was described in Section 2.2. The kinds of organisms that exist in a wetland and their interaction with landscape processes are constrained by the sizes, shapes, and patterns of interspersion of habitat across a landscape.

Understanding how animals and plants move between different habitats, and how the distribution of habitat "patches" affect the abundance of species, are the goals of a relatively new science called *landscape ecology*. The major result of recent research has been to highlight the fact that the distribution and abundance of species at an individual site, or "patch" is affected by the location, size, and shape of other patches of similar or different habitat in the surrounding landscape (Haila 2002, Manning et al. 2004). Some of the questions being asked in this research have been summarized by Bissonette and Storch (2002) and include:

- What is the relationship between species richness and the size of the patch of habitat?
- What is the relationship of species abundance to size of the patch of habitat?
- Are the interactions between different species modified as habitat is fragmented?
- Do the changes in the amount and quality of habitat along the edges of patches (edge habitat) change how an area functions as habitat?
- What are the relationships between relatively undisturbed corridors and the movement of species between habitat patches that have been separated by human activities?
- Do such connections increase species richness?

The research to date has highlighted the fact that there are no easy answers to these questions. The response of animals and plants to changes in patches, corridors, and distance between patches of the same habitat is very specific to the species involved (Haila 2002, Bissonette and Storch 2002, Haddad et al. 2003, Manning et al. 2004). For example, Haddad et al. (2003) studied ten different species living in the forests of South Carolina. Although the species were chosen because the authors thought they were likely to respond to the presence of corridors connecting patches of forest habitat, the abundance of only five of the ten species was positively correlated with presence of corridors. The abundance of the other five species was not correlated with the presence of corridors.

The study of patches and interaction between patches and species richness and abundance has taken on an increasing importance as human activities on the land have changed the distribution of habitats. The changes in habitat at the scale of the landscape caused by human activities are called *fragmentation*. The fragmentation of habitat consists of both reductions in the area of the original habitat and changes in the spatial configuration of what remains (Haila 2002). The results of current research on fragmentation have been difficult to interpret because much of it does not adequately separate the environmental factors that might cause differences in biodiversity (Haila 2002, Fahrig 2003, Manning et al. 2004). There is, however, one general conclusion that can be made from the current research. In reviewing over one hundred articles on habitat fragmentation, Fahrig (2003) found that the loss of area available as habitat that results from human uses of the land has a large, consistently negative effect on the abundance and richness of species.

2.3.3.2 Environmental Controls of Functions at the Site Scale

The environmental factors at the large scale ultimately affect the environmental factors within the wetland itself (the site scale). As introduced earlier, Brinson (1993b) has developed a model that defines three factors that can be considered as primary controls of wetland functions at the site scale. Brinson's (1993b) model also uses characteristics of the landscape as factors that control functions in a wetland, but his model focuses primarily on the wetland itself relative to the two models discussed earlier (Bedford 1999). For example, Brinson's model emphasizes the shape and location of the wetland in the landscape and the type of water movement in the wetland that is dominant. The three factors defined by Brinson (1993b) are:

- The **geomorphic setting** (landscape position) of the wetland. Geomorphic setting is the topographic location of the wetland within the surrounding landscape and the geology that underlies it. In other words, is the wetland in a depression, on a slope, in a floodplain, or on the shores of a lake? The underlying geology also determines the soils present in the wetland, and this for example has an effect on the type and abundance of the plants found there.
- The **source of water** to the wetland. The sources of water can be simplified to precipitation, surface flow, shallow subsurface flow, and groundwater.
- The **hydrodynamics** of the wetland (the direction of flow and strength of water movement within the wetland). Hydrodynamics refers to the movement of water in the wetland and its capacity to do work. There are three qualitative categories of hydrodynamics: (1) vertical fluctuations of the water levels or water table, (2) unidirectional surface or near-surface flows that range from strong currents contained in channels to slow sheet flow down a slope, and (3) bidirectional flows resulting from tides or wind-driven currents in lakes.

In contrast, the "hydrogeologic" and "process-structure-function" models describe the surface and subsurface conditions across the landscape that control water processes within the wetland's contributing basin. The Brinson model (1993b) is the basis of the hydrogeomorphic (HGM) classification system which groups wetlands into similarly functioning groups. The classification system and an earlier classification, used for habitat mapping, are described in Section 2.4.1.

2.3.3.3 Summary of the Controls of Wetland Functions

To summarize the literature on the environmental factors that control functions, the authors of this synthesis have combined the terms and information used by several different authors to arrive at the list of factors in Table 2-2. These terms will be used in the following chapters because no standardized terms have been defined to describe all that happens at the different geographic, temporal, or spatial scales. In fact, the many articles that have been written on the subject of wetland functions and how they are controlled by environmental factors have engendered some confusion in the terms used. For example, the term *process* has been used by different authors to describe a wide range of happenings that include the routing of water at a landscape scale as well as the chemical reactions by which bacteria change nitrate to nitrogen gas at the microscopic scale. Both of these factors are considered controls of functions.

The relationship between the environmental factors in Table 2-2 that control wetland functions and how they interact with human-caused disturbances is shown conceptually in Figure 2-3.

Table 2-2. Environmental factors that have been identified as controls of functions in wetlands. Most of the controls can occur at both the landscape scale and the site scale.

Environmental Factors that Control Functions in Wetlands	Scale at which the Control Occurs
Physical structure of wetlands (e.g., soils, vegetation, rocks)	Site
Biological structure of wetlands (e.g., physical structure of plants)	Site
Input of water (amount of water; maximum and minimum water levels)	Landscape and site
Fluctuations of water levels (frequency, amplitude, direction of flows)	Landscape and site
Input of sediment	Landscape and site
Input of nutrients	Landscape and site
Input of toxic contaminants	Landscape and site
Temperature	Landscape and site
Level of acid (pH)	Landscape and site
Concentration of salts	Mostly site
Size, connections, and distances of habitat patches in the surrounding landscape	Landscape
This table is a synthesis of the information presented by Winter (1983, 1986), LaBaugh et al. (1987), Winter and Woo (1990), Naiman et al. (1992), Brinson (1993a), Brinson et al. (1995), Bedford (1999), Beechie and Bolton (1999), Gersib (2001), Adamus et al. (2001), Stanley and Grigsby (2003).	

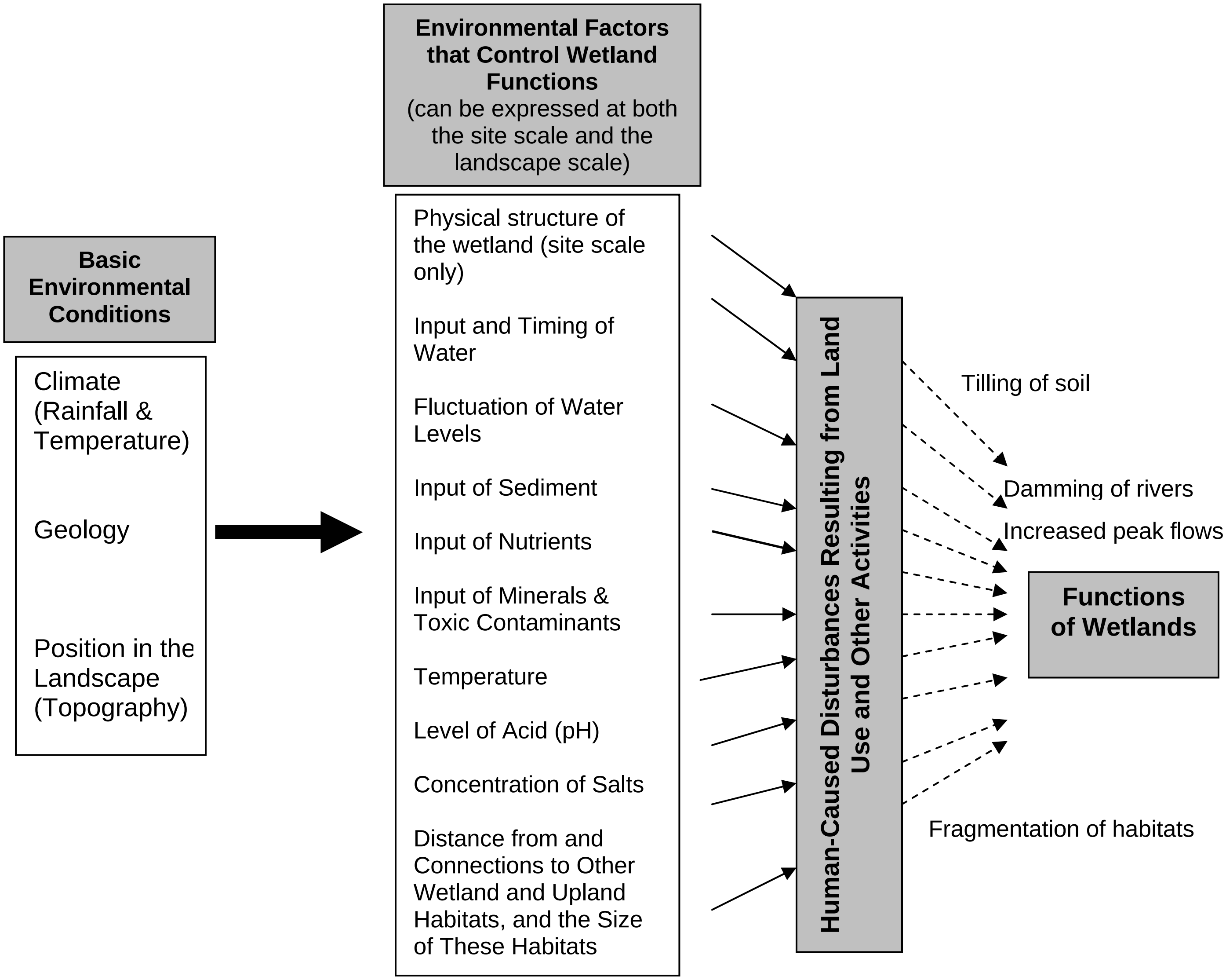

Figure 2-3. Diagram summarizing some major environmental factors that control functions of wetlands and how they interact with human-caused disturbances.

The basic environmental conditions establish and determine the factors that control the functions of wetlands. The controls can occur at both the landscape and site scales. Human activities cause disturbances that affect these controls in many different ways and thereby alter the performance of wetland functions. The figure gives some examples of the disturbances. This figure is a synthesis of the information presented by the same authors as listed in Table 2-2. The different models and information described above are the basis for Chapters 3 and 4 that describe the impacts of human activities on wetlands and their functions.

2.3.4 Summary of Key Points

- There are five basic ecological principles that are useful in managing wetlands. The principles deal with time, place, species, disturbance, and landscape.
- Wetland functions are the physical, biological, chemical, and geologic interactions among different components of the environment that occur within a wetland. There are many ways to define functions depending on specific needs for managing wetlands.
- Functions fall into three broad categories: biogeochemical, hydrologic, and maintenance of food webs and habitat.
- Society does not necessarily attach value, or equal value, to all functions.
- The functions that wetlands perform are controlled by environmental factors that occur in the broader landscape as well as within the wetland. The major controls of function are climate; geomorphology and soils; the source and quantity of water; the movement of water, nutrients, other chemicals, and sediments; energy in the form of sunlight; and biological interactions.
- The factors that control wetland functions interact with each other and there are many feedback loops. Environmental processes create the physical structure of the ecosystem and this in turn controls functions. Functions, in turn, can then modify the processes and structure as well.
- In order to gain a basic understanding of the ecological importance of functions provided by wetlands, they must be evaluated within the context of the landscape in which they exist.

2.4 Classification of Wetlands in Washington as a Key to Understanding Their Functions

This section presents a brief discussion of systems that scientists have developed to group or classify wetlands nationally and in Washington State in order to better assess how they function. It begins with an overview of two classification systems—the Cowardin classification, commonly used to inventory wetlands across the country, and the hydrogeomorphic or HGM classification, which is used to characterize how wetlands function. Understanding how wetlands are grouped and classified is a key to fully understanding how different types of wetlands in different areas provide different functions.

2.4.1 Commonly Used Classification Systems in Washington

2.4.1.1 The Cowardin Classification

The first commonly used classification system for wetlands was developed in 1979 by the U.S. Fish and Wildlife Service (Cowardin et al. 1979). The Cowardin classification system is hierarchical and includes several layers of detail for wetland classification that are based on:

- Water flow
- Substrate types
- Vegetation types
- Dominant plant species

The Cowardin classification system was developed to aid a national inventory of wetlands using aerial photographs (the U.S. Fish and Wildlife Service National Wetland Inventory or NWI). The wetlands in the state that can be identified from aerial photographs have been mapped using this classification system. The maps are available from the U.S. Fish and Wildlife Service in a digital form for GIS (http://www.nwi.fws.gov/). This information is a useful starting point for developing inventories of wetlands at the local level and looking at wetlands at the scale of watersheds and river basins.

> Methods for organizing our knowledge about wetlands have been called *classifications*, *categorizations*, *characterizations*, *ratings*, *assessments*, and *evaluations*. These groupings are meant to indicate the type of information a method provides. Unfortunately, the scientific community has been inconsistent in the use of these terms. Users of methods developed for analyzing wetlands should be aware of some of these problems with terminology. See Appendix 2-A for further discussion.

2.4.1.2 The Hydrogeomorphic Classification

Although the Cowardin classification is useful in developing wetland inventories from aerial photographs and incorporates some landscape factors, it was not designed to help understand how functions differ among wetlands. A more recent system of classification, called the *hydrogeomorphic (HGM) classification* (Brinson 1993b), was developed to specifically address differences in how various wetlands function. This classification method was chosen by the statewide wetland technical committee that guided the development of the Washington State wetland function assessment methods (Hruby et al. 1999).

As previously described in Section 2.3.3, the HGM classification is based on (Brinson 1993b):

- The position of the wetland in the landscape (geomorphic setting)
- The source of water for the wetland

- The flow and fluctuation of the water once in the wetland (hydrodynamics)

Classifying wetlands based on how they function narrows the focus of attention to a specific type of wetland. It also focuses on the functions that wetlands within that type are most likely to perform and the environmental factors that most likely control how wetlands of that type function.

The HGM classification also uses the concept of grouping wetlands by geographic units (domains and regions) in which some of the controls of functions that occur at the landscape scale are similar. The assumption is that many of the functions performed by wetlands are also similar.

The highest category in the HGM classification (called *class*) is defined nationally (Table 2-3) and is based on the geomorphic setting of the wetland (Brinson 1993b, Smith et al. 1995). Not all geographic units (domains and regions) contain all the wetland classes possible.

Within a region, wetland classes can be further divided by local experts into wetland subclasses and sub-subclasses (sometimes called *families* of wetlands) based on other geomorphic or hydrologic characteristics. The wetland experts in each region can, therefore, tailor the classification to address differences in the performance of functions by different wetland types in their region (Smith et al. 1995).

Geographic areas to which this classification system is applied in Washington and a description of the HGM classes in the state are described in Section 2.4.4.

Table 2-3. Characteristics of wetland classes in the hydrogeomorphic classification (from Brinson 1993a).

Hydrogeomorphic Class (Geomorphic Setting)	**Dominant Source of Water**	**Dominant Hydrodynamics (Movement of Water)**
Riverine	Overbank flow from a channel, or hyporheic (underground) flow in floodplain	One direction, horizontal
Depressional	Surface runoff, or the “daylighting” of groundwater	Vertical
Slope	“Daylighting” of groundwater on slopes	One direction, horizontal
Lacustrine (Lake) Fringe	Lake water	Two directions, horizontal
Flats	Precipitation	Vertical
Tidal Fringe	Overbank flow from estuary	Two directions, horizontal

2.4.1.3 Other Classifications Used in Washington

There have been several other classifications developed in Washington to group wetlands for the purpose of inventories and identifying different types of habitats. Kunze (1994) developed a classification of native, low elevation, freshwater wetlands in western Washington that is based on the dominant plant species found in the wetland. The purpose of this classification was to distinguish "natural heritage resources," whose identification was mandated by state law.

In eastern Washington, Kovalchik and Clausnitzer (2004) developed a classification of Aquatic, Riparian, and Wetland sites in the national forests that is also based on the dominant vegetation. The purpose of this classification was to describe the general geographic, topographic, edaphic (resulting from soils), functional, and floristic features of aquatic, riparian and wetland ecosystems. In addition, they developed it to describe successional trends in these ecosystems. Lastly it provides information on the values of the resources and opportunities for management (Kovalchik and Clausnitzer 2004).

2.4.2 Geographical Differences in Wetland Functions

Because hydrogeologic settings and the controls of functions vary across the landscape, it is important to identify the geographic areas in which these factors are similar. This allows the grouping of wetlands that function similarly.

For example, two conferences on wetland functions in the mid-1980s highlighted some of the differences between wetlands on the West Coast and those in the rest of the country (Horner 1986). Specifically, wetlands on the West Coast are different for the following reasons (Zedler 1985 as cited in Horner 1986):

- Drainage areas to West Coast wetlands are often smaller than those on the East Coast
- The coastal plain, with some exceptions, is not as large on the West Coast
- Soils in the West Coast region are often high in clay
- Conditions in a watershed are often highly erosive on the West Coast because of the steep topography
- Precipitation varies more seasonally on the West Coast than east of the Rocky Mountains

Even within Washington, the diverse areas of the state support many kinds of wetlands that vary in functions. For example, vernal pools on the scablands differ greatly from the floodplain marshes along the Snoqualmie River, and wetlands that formed in the potholes created by glaciers have different functions from those found along the shores of salt lakes in the Grand Coulee (Hruby et al. 2000).

Through the Washington State wetland function assessment project, there has been a major effort over the last eight years to build on previous work and to develop methods for assessing how wetlands function in different regions of the state. The methods are based on a formal process of quantifying the collective judgment of a group of local experts. This approach provides a scientific basis for rapid methods in the absence of rigorous, site-specific scientific studies (Hruby 1999).

A statewide technical committee was formed in 1994 to guide the technical components of the function assessment project. In addition, several assessment teams, composed of experts in different disciplines, developed methods for specific wetland types and areas of the state (Hruby et al. 1999, 2000). At present, methods for four wetland types in the lowlands of western Washington and three types in the Columbia Basin of eastern Washington have been completed. These documents are available on the project's web site (http://www.ecy.wa.gov/programs/sea/wfap/index.html).

Another major effort has just been completed to incorporate differences among geographic areas and wetland functions into the Washington State wetland rating systems for eastern and western Washington. The Washington State Department of Ecology has been coordinating this effort, and teams of regional wetland experts and local government staff have provided technical expertise in writing the documents.

The geographic regions where wetlands function in different ways that have been identified by these teams of regional experts are described in the next section.

2.4.3 Wetland Regions in Washington

Wetlands in Washington are grouped first into "domains" and "regions" based on climate and other landscape features, then into "classes" by geomorphic setting, and finally into "subclasses" and "families" by the sources of water for the wetland and how that water moves (Hruby et. al. 1999, 2000, Hruby 2004a,b). These are some of the primary controls of wetland functions as described earlier. This section focuses on the wetland domains and regions. Section 2.4.4 describes the wetland classes and Section 2.4.5 the subclasses for Washington State.

The wetlands in Washington were divided into two ecological domains, East and West, when the Washington State wetland rating systems were first developed (Ecology 1991, 1993). The teams of wetland experts who revised the rating systems have kept this division (Hruby 2004a,b). At this highest level, the domains are based on the national classification of the environment (called *ecoregions*) developed by federal agencies (Bailey 1995). Wetlands on the west side of the Cascade Crest fall within the domain called *Humid Temperate* and those on the east side are in the *Dry* domain.

The term *ecoregion* was coined by J.M. Crowley (1967) and popularized by Robert J. Bailey (1976) to define a classification of ecosystems in the United States. Ecoregions are generally considered to be regions where climatic conditions are similar. As a result, the ecosystems there, including wetlands, are relatively homogeneous (Omernik and Gallant 1986). The concept was developed to help resource managers better understand regional differences in the environmental factors that maintain ecosystems and the relative importance of different factors that can change ecosystems (Omernik and Gallant 1986). The local maps of the ecoregions and their definitions are continually being updated by the U.S. Environmental Protection Agency laboratory in Corvallis, Oregon. The latest maps of ecoregions are available on the web at http://www.epa.gov/bioindicators/html/ecoregions.html.

The wetland experts working on assessments of function in the state further divided the domains into smaller regions because the two domains are too coarse a division for understanding how wetlands function in the state in a more detailed way (Hruby et al. 1999, 2000). At present there are five regions in the state (Figure 2-4) including three regions in the eastern domain and two in the western domain:

- Eastern domain:
  - Montane
  - Columbia Basin
  - Lowlands of Eastern Washington
- Western domain:
  - Montane
  - Lowlands of Western Washington

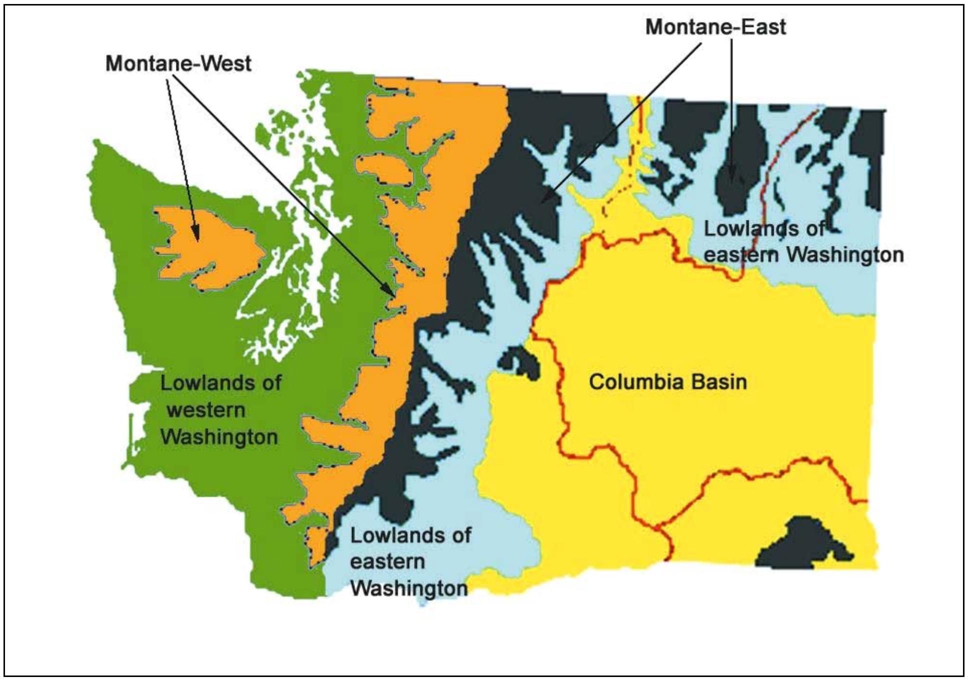

Figure 2-4. Regions in Washington used for classifying wetlands.

As mentioned previously, these regions of Washington are linked to the national classification of ecoregions developed by several federal agencies. The boundaries of the regions used in Washington, however, in some cases include parts of multiple ecoregions defined at the national level. The geographic extent of the Lowlands of Western Washington includes portions of three ecoregions within the Humid Temperate domain defined at the national level: the Coast Range, the Puget Lowlands, and the Willamette Valley (Hruby et al. 1999). Characteristics of these ecoregions are detailed in Omernik and Gallant (1986). The geographic extent of the Columbia Basin region, however, is the same as the Columbia Basin Ecoregion identified by Omernik and Gallant (1986).

At present, final definitions of regions have been developed only for the Lowlands of Western Washington and the Columbia Basin because these are the only two regions for which methods to assess wetland functions have been developed. The Montane regions (east and west of the Cascades) and the Lowlands of Eastern Washington have been defined with less detail because methods for assessing functions in these regions have not yet been developed. Generally the Montane regions include areas above 3,000 feet (915 m) elevation, and the Lowlands of Eastern Washington includes all other areas in the Dry domain, outside the Columbia Basin, and below 3,000 feet (915 m) elevation.

2.4.4 Description of the Wetland Classes for Washington

A brief description of wetlands in the different classes in Washington is given below. More detailed descriptions are available in Hruby et al. (1999, 2000).

2.4.4.1 Riverine Wetlands

The distinguishing characteristic of riverine wetlands in Washington is that they are frequently flooded by overbank flow from a stream or river (Hruby et al. 1999). Riverine wetlands are found in a valley or adjacent to a stream channel (Figure 2-5). They lie in the active floodplain of a river or stream and have important links to the water dynamics of the river or stream. The flooding waters are a major environmental factor that structures the environment in these wetlands and controls wetland functions. Riverine wetlands in some regions of Washington are defined by the frequency of overbank flooding (Hruby 2004a,b).

Figure 2-5. Riverine wetlands. Located in active floodplains where overbank flooding of the river or stream structures the wetland environment and controls its functions.

2.4.4.2 Depressional Wetlands

Depressional wetlands occur in topographic depressions that have closed contours on three sides (Figure 2-6). Elevations within the wetland are lower than in the surrounding landscape. The shapes of depressional wetlands vary, but in all cases the movement of surface water and shallow subsurface water is toward the lowest point in the depression. The depression may have an outlet, but the lowest point in the wetland is somewhere within the boundary, not at the outlet (Hruby et al. 1999).

Figure 2-6. Depressional wetlands. Located in topographic low areas that are closed on at least three sides (they may or may not have an outlet).

2.4.4.3 Slope Wetlands

Slope wetlands (Figure 2-7) occur on hill or valley slopes where groundwater surfaces and begins running along or immediately below the soil surface. They are usually found where the topography and local geologic conditions forces groundwater to the surface creating a zone of perennial or near-perennial moisture (Stein et al. 2004). Water in these wetlands flows only in one direction (down the slope) and the gradient is steep enough that the water is not impounded. The "downhill" side of the wetland is always the point of lowest elevation in the wetland (Hruby et al. 2000).

Figure 2-7. Slope wetlands. Located on slopes where groundwater daylights and runs at or just below the soil surface.

2.4.4.4 Lacustrine (Lake) Fringe Wetlands

Lacustrine fringe wetlands in Washington are found along the edges of deeper bodies of water such as lakes or reservoirs (Figure 2-8). These wetlands occur at the margin of topographic depressions in which surface water covers more than 20 acres (8 ha) and is deeper than 7 feet (2 m) in western Washington or 10 feet (3 m) in eastern Washington. The amount of open water and deep water also has to exceed 30% of the total area of wetland. The dominant surface water movement in lacustrine fringe wetlands has a horizontal component due to winds or currents, but there may also be a corresponding vertical component resulting from wind or seasonal water fluctuations (Hruby et al. 1999, 2000).

The definition of *lake fringe* is more specific than the definition of *lacustrine* used in the Cowardin classification described previously. The local teams of experts developing methods for assessing functions and the rating system decided to refine the definition of lacustrine to better reflect environmental conditions in the state.

Figure 2-8. Lacustrine fringe wetlands. Located along the edge of large bodies of water, such as lakes.

2.4.4.5 Flats Wetlands

Flats wetlands are rare in Washington. They occur in topographically flat areas that are hydrologically isolated from surrounding groundwater or surface water. The main source of water in these wetlands is precipitation. They receive virtually no groundwater discharge or surface runoff from areas outside the wetland boundary. This characteristic distinguishes them from depressional and slope wetlands (Hruby et al. 1999).

2.4.4.6 Tidal Fringe Wetlands

Tidal fringe wetlands occur along the coasts and in river mouths to the extent of tidal influence. The dominant source of water is from the ocean or a river that empties into the ocean; therefore these wetlands can be fresh or saline. The unifying characteristic of this class is the hydrodynamics. All tidal fringe wetlands have water flows dominated by tidal influences and water depths controlled by tidal cycles (Hruby et al. 1999). This document does not address tidal fringe wetlands.

2.4.5 Subclasses of Wetlands in Washington

Developing the HGM classification for Washington is an ongoing process, and not all subclasses for wetlands in the different regions have been defined. The wetland subclasses and families that have been defined in the four regions of Washington (as of February 2005) are listed in Table 2-4.

Although the HGM classification for wetlands in the state is not yet complete, the categories listed in Table 2-4 provide a useful tool to help separate wetlands into different types.

Table 2-4. Subclasses and families of wetlands in different regions of Washington State. (Hruby et al. 1999, 2000)

Class	Subclasses and Families by Region			
	Lowlands of Western WA	**Lowlands of Eastern WA**	**Columbia Basin**	**Montane (East and West)**
Riverine	• Impounding • Flow-through	ND	ND	ND
Depressional	• Outflow • Closed	ND	• Alkali • Freshwater • Long-duration • Short-duration	ND
Slope	ND	ND	ND	ND
Flats	ND	Probably does not occur in the region.	Probably does not occur in the region.	ND
Lacustrine (Lake) Fringe	ND	ND	ND	ND
Tidal Fringe	• Salt Water • Fresh Water	Does not occur in the region.	Does not occur in the region.	Does not occur in the region.
ND = Subclasses in the region have not yet been defined.				

2.4.6 Summary of Key Points

- The physical structure and functions of wetlands vary by region. The diverse regions of Washington support many kinds of wetlands that provide different functions. These differences are documented in the wetland function assessment methods and rating systems for Washington State.
- Wetlands in Washington are grouped first into domains and regions based on climate, then by geomorphic setting, and finally by the sources of water for the wetland and how that water moves. This is called the hydrogeomorphic (HGM) method for classifying wetlands.
- Hydrogeomorphic classes in Washington State include riverine, depressional, slope, lacustrine (lake) fringe, flats, and tidal fringe. Subclasses and families of wetlands are also defined by region (see Table 2-4).

2.5 Overview of Wetland Functions in Washington State

As described in the previous section, our current knowledge about wetland functions in different regions of Washington and among different HGM classes is based largely on the work of experts involved in developing the function assessment methods and ratings for wetlands in the state (Hruby et al. 1999, 2000, Hruby 2004a,b). Experts have developed methods to assess functions of riverine and depressional wetlands in several regions of the state. They have not discussed or identified the functions of freshwater wetlands in the flats, slope, tidal fringe, or lacustrine fringe classes, nor any functions of wetlands in the montane regions.

As mentioned in Section 2.3.2 there are many ways to group wetland functions. Functions that are currently defined for the state are listed on the following pages. The definitions are compiled from Hruby et al. (1999, 2000) and Hruby (2004a,b). Not all wetlands in a region, class, or subclass perform all of these functions. A more detailed description of each function is given in Section 2.6. As noted previously, functions are coarsely grouped into three main categories, those that improve water quality, those related to water regime in a watershed, and those that pertain to wildlife habitat.

> The functions selected for the Washington State wetland function assessment methods and the rating systems are narrowly defined to provide a level of specificity that is important to managing wetlands by decision-makers. The list of functions defined here does not represent all the functions performed by wetlands in the state. It does, however, represent the functions that were determined to be valuable by the experts that developed them and that need to be considered when managing wetlands (Hruby et al. 1999, 2000, Hruby 2004a, b).

2.5.1 Functions Related to Improving Water Quality

Removing Sediment: This function is defined in terms of the processes and characteristics that retain sediment within a wetland and prevent its downstream movement. A wetland performs this function if there is a net annual decrease of sediment load to downstream surface waters.

Removing Nutrients/Phosphorus: This function is defined in terms of the processes and characteristics within a wetland that remove phosphorus present in surface waters and prevent its movement into surface waters and groundwater.

Removing Nutrients/Nitrogen: This function is defined in terms of the processes and characteristics within a wetland that remove dissolved nitrogen present in surface waters or groundwater and prevent its further movement into surface waters or groundwater.

Removing Metals and Toxic Organic Compounds: This function is defined in terms of the processes and characteristics within a wetland that retain toxic metals and toxic organic compounds coming into the wetland and prevent their movement into surface waters and groundwater.

Removing Pathogens: This function can be defined in terms of the processes and characteristics within a wetland that retain or kill pathogenic organisms such as viruses and bacteria that can cause diseases in humans. This function was originally excluded from the water quality functions identified by the expert teams who developed the assessment methods and revised the rating system. They judged that the characteristics that determine this function are the same as those for removing sediment and removing toxic compounds. It has been added to the list of functions because reviewers of this document suggested it and it is a commonly recognized function (Kadlec and Knight 1996).

2.5.2 Functions Related to Maintaining the Water Regime in a Watershed (Hydrologic Functions)

Reducing Peak Flows: This function is defined in terms of the processes and characteristics within a wetland by which the peak flow in a watershed can be reduced during a major storm or snowmelt (i.e., events that would otherwise cause flooding).

Reducing Erosion: This function is defined in terms of the processes and characteristics within a wetland that detain high flows during storms and reduce the duration of erosive flows, thus decreasing downstream erosion in streams. This definition was developed for riverine and depressional wetlands. Wetlands along the shores of lakes (Jude and Pappas 1992) also protect resources from erosion but in a different way. For wetlands classed as lacustrine fringe, the function can be called "dissipation of erosive forces." This is defined as the processes by which wetlands reduce wave and current energies, thus reducing erosion of shorelines.

Recharging Groundwater: This function is defined in terms of the processes and characteristics within a wetland that allow surface water to infiltrate into the groundwater system.

2.5.3 Functions Related to Habitat

General Habitat: This function is defined in terms of the processes and characteristics within a wetland that indicate a general suitability and opportunity as habitat for a broad range of species. A suitable habitat for a suite of different fauna can be provided by a broad range of structures, vegetation, and interspersion of habitat types within the wetland and the upland habitats contiguous to a wetland. Characteristics in a wetland can be quite different and continue to provide highly suitable conditions for a range of species.

Habitat for Invertebrates: This function is defined in terms of the processes and characteristics within a wetland that help maintain a high number of invertebrate species.

Habitat for Amphibians: This function is defined in terms of the processes and characteristics within a wetland that contribute to the feeding, breeding, or refuge needs of amphibian species.

Habitat for Anadromous Fish: This function is defined in terms of the processes and characteristics within a wetland that contribute to the feeding, breeding, or refuge needs of anadromous fish species.

Habitat for Resident Fish: This function is defined in terms of the processes and characteristics within a wetland that contribute to the feeding, breeding, or refuge needs of resident native fish.

Habitat for Wetland-Associated Birds (called *Aquatic Birds* in the methods for eastern Washington): This function is defined in terms of the processes and characteristics within a wetland that provides habitats or life resources for species of wetland-associated birds. Wetland-associated bird species are those that depend on aspects of the wetland for some part of their life needs: food, shelter, breeding, or resting.

Habitat for Wetland-Associated Mammals (called *Aquatic Mammals* in the methods for eastern Washington): This function is defined in terms of the processes and characteristics within a wetland that support one or more life requirements of aquatic or semi-aquatic mammals.

Richness of Native Plants: This function is defined in terms of the degree to which the wetland provides a habitat for many different native plant species.

Supporting Food Webs (also called *Primary Production and Export* in the methods for western Washington): This function is defined in terms of the processes and characteristics within a wetland that support complex food webs within the wetland and surrounding resources through the export and assimilation of the primary productivity of the wetland. The function combines three major environmental processes: primary production, secondary production, and export of production.

2.5.4 Summary of Key Points

- Wetland functions are currently defined for Washington State in a relatively narrow manner to facilitate better wetland management and regulation by decision makers.
- Wetland functions defined in Washington fall into three general groups: functions related to improving water quality, functions related to the water regime in a watershed (hydrologic functions), and functions related to habitat.
- Not all wetlands in a region, class, or subclass perform all functions.

2.6 How Wetlands Perform Functions in Washington State

Table 2-5 summarizes the information on the functions that are, or are not, performed by the different freshwater wetland classes in Washington State. The following sections synthesize information available about each function and how the different wetland types in the state perform that function.

Table 2-5. Functions potentially performed by wetlands in different HGM classes in Washington. Data compiled from Hruby et al. (1999, 2000), Hruby (2004a, b).

Functions	Riverine	Depressional	Slope	Lacustrine Fringe	Flats
Improving Water Quality					
Removing Nutrients	P	P	P	P	P
Removing Sediment	P	P	P	P	NS
Removing Metals/Toxic Organic Compounds	P	P	P	P	P
Removing Pathogens	P	P	P	P	P
Hydrologic					
Reducing Peak Flows	P	P	N	N	NS
Decreasing Downstream Erosion/Dissipating Erosive Forces	P	P	P	P	NS
Recharging Groundwater	P	P	N	N	NS
Food Webs and Habitat					
General Habitat	P	P	P	P	P
Habitat for Invertebrates	P	P	P	P	P
Habitat for Amphibians	P	P	P	P	P
Habitat for Anadromous Fish	P	P	N	P	N
Habitat for Resident Fish	P	P	N	P	N
Habitat for Wetland-Associated Birds	P	P	NS	P	P
Habitat for Wetland-Associated Mammals	P	P	NS	P	P
Plant Richness	P	P	P	P	P
Support Food Webs	P	P	P	P	P
Key to symbols used in table: P = Functions are performed N = Functions are not performed NS = (not significant) Functions are performed to a minor degree, but probably not at levels that are of importance to society.					

2.6.1 Functions that Improve Water Quality

Wetlands greatly influence the quality of water in a watershed by removing many different types of contaminants. They help improve water quality, including that of drinking water, by intercepting surface runoff and removing or retaining inorganic nutrients, processing organic wastes, removing pathogens and reducing suspended sediments before they reach open water. The dominant processes for removing contaminants in wetlands are settling, chemical reactions in and with the soils, and biotransformations (reviewed in Hammer 1989, Moshiri 1993, Kadlec and Knight 1996).

Table 2-6 summarizes some of the major groups of contaminants that can enter wetlands and the primary mechanisms by which they are removed. The following sections discuss in more detail each of the major functions by which wetlands improve water quality.

Table 2-6. Primary mechanisms for removing contaminants in wetlands. Extracted from Hammer 1989, Moshiri 1993, Kadlec and Knight 1996.

Contaminant	Physical	Chemical	Biological
Sediment and other solids	Settling, Filtration		
Oxygen demand	Settling	Oxidation	Biodegradation
Hydrocarbons	Diffusion, Volatilization, Settling	Photochemical oxidation	Biodegradation, Evapotranspiration
Nitrogen compounds			Denitrification
Phosphorus compounds	Settling	Precipitation, Adsorption	
Metals	Settling	Precipitation, Adsorption, Ion Exchange,	Biotransformation
Pathogens	Residence time	UV radiation	Die-off, Other microbes

2.6.1.1 Removing Sediment

Sediment may enter wetlands in direct runoff from surrounding areas, as windblown dust, or in streams or rivers that flow through the wetland. Sediments deposited in wetlands are removed from surface flows, thereby improving water quality down-gradient. A wetland, however, will perform this function only if surface water contaminated with sediment actually enters the wetland.

Some general properties may be applied to all wetlands with respect to their ability to remove sediments (Phipps 1986). Within a given wetland, the deposition of sediment depends on several factors including (Phipps 1986, Johnston 1991, Fennessy et al. 1994, Gilliam 1994, Kadlec and Knight 1996):

- Residence time of the water that allows sediments to settle
- Wind and wave action that re-suspend sediments
- Size and amount of incoming sediment
- Vegetation

Generally, a high residence time for the water that allows settling and the filtration by vegetation are the major processes by which sediment is removed from surface water (Fennessy et al. 1994). Filtration is the physical adhesion and cohesion of sediment facilitated by vegetation (Adamus et al. 1991). The size of the particles that settle out is directly related to the increase in settling time achieved in the wetland (Adamus et al. 1991).

Typically a wetland with vegetation traps 80% to 90% of sediment from runoff entering the wetland (Johnston 1991, Gilliam 1994). Other studies have found that wetlands with open, deep, water may be as effective, or more effective, than vegetation in trapping sediments (Fennessy et al. 1994) because the residence time increased.

Wetlands can be more important for removing excessive amounts of sediments compared to other components of the landscape (Adamus et al. 1991). Another way to consider the importance of wetlands for removing sediments in a watershed is to analyze how much wetland area is needed to effectively remove sediments. Fennessy et al. (1994) report the following from their review of the literature:

- Watersheds in Wisconsin with only 5% of their area in wetlands trapped up to 70% of the sediment in the system
- In a North Carolina watershed, more than 20% of the total sediment deposition occurred in wetlands that represented only 11% of the area

The importance of any wetland for improving water quality depends, however, on the amount of sediment pollution in the watershed. Watersheds in which human activities loosen the topsoil (agriculture, development, and logging) are prone to have high sediment loadings. Wetlands in these watersheds are very important for maintaining water quality (National Research Council 1995).

Removal of Sediment by Wetlands of Various Classes and in Different Domains and Regions

The way wetlands remove sediment is not judged to be different in the two major domains of the state (the east side and the west side of the Cascades) (Hruby et al. 1999, 2000). However, the processes by which wetlands in Washington remove sediments differ somewhat among the different wetland classes as described below.

Wetlands in the Flats Class

Wetlands in the flats class, in general, do not remove sediment because by definition their major source of water is precipitation that falls within the wetland itself (Brinson 1993b). There is no opportunity for sediment-laden water to enter the wetland. All other types of wetlands perform this function to some degree because they receive surface water from outside their boundaries, and the surface water is never completely free of sediments.

Wetlands in the Depressional Class

Depressional wetlands that hold back all the surface water coming in (that is, those without a surface outlet) trap all the sediment they receive. Such wetlands are very effective at this aspect of water quality improvement wherever they are found in Washington (Hruby et al. 1999, 2000).

The removal of sediment in depressional wetlands with an outflow depends on how effectively they slow the water and allow settling, as well as the density of the vegetation that filters the incoming water. The same processes are present in depressional wetlands of both eastern and western Washington (Hruby et al. 1999, 2000).

Wetlands in the Lacustrine Fringe Class

Wetlands along the shores of lakes (lacustrine fringe) trap and retain suspended sediment by anchoring the shoreline, reducing resuspension of bottom mud by wind mixing, and slowing water velocities (Adamus et al. 1991). Even aquatic bed vegetation, which typically provides less resistance to water flow than emergent or woody plants, may reduce water movement enough to induce settling (Adamus et al. 1991).

Wetlands of this class have not yet been subjected to the thorough analysis required for developing a function assessment method. More definitive conclusions about Washington wetlands are, therefore, not available. However, no evidence has been reported that would negate the observations made in lacustrine wetlands in other parts of the U.S. that were reviewed by Adamus et al. (1991).

Wetlands in the Slope Class

Slope wetlands by definition (Brinson 1993b) do not impound surface water. The removal of sediment through settling is therefore not a factor in this class of wetlands.

Unpublished data collected during the calibration of the eastern Washington wetland rating system, however, suggest that slope wetlands may still play a role in removing sediment. For example, slope wetlands in eastern Washington have vegetation that is usually thicker than the vegetation in the surrounding uplands (Figure 2-9). This vegetation acts like a filter to trap sediments coming from further upslope because it provides more resistance to the water flowing down the hillside (Hruby 2004a).

Figure 2-9. Slope wetland in the Columbia Basin that formed at a break in the slope. It has dense emergent plants that can trap sediment coming from the upslope areas.

Slope wetlands in western Washington have not yet been analyzed in terms of their potential to remove sediments, and it is not possible to report if similar processes and structure are found there. Models for assessing slope wetlands have, however, been developed for the Willamette Valley in Oregon. Two characteristics of slope wetlands identified there that contributed to the retention of sediments were the amount of ground covered by vegetation and the relative area of the wetland covered in hummocks (Adamus and Field 2001).

Wetlands in the Riverine Class

The removal of sediment in riverine wetlands is a somewhat different process. The vegetation and depressions within these wetlands trap sediment, but sediments are eroded by floods that recur every few years. The function of riverine wetlands is to stabilize sediment during the period between floods (Adamus et al. 1991). Wetlands are an integral part of the cycle of erosion and deposition in floodplains.

Phipps (1986) stated that the efficiency of sediment trapping by riverine wetlands in the Pacific Northwest has not been measured. This conclusion is still valid today, since no studies were found that quantified this function. The process of trapping sediments is still judged to be an important function on a watershed scale in Washington State (Hruby et al. 1999) and was modeled during the development of function assessment methods. The characteristics of riverine wetlands that were judged important in removing sediments were as follows (Hruby et al. 1999):

- How much the stream or river meanders through the wetland
- How wide the wetland is relative to the width of the stream
- How much of the wetland is covered in vegetation that can act as a filter
- The amount of constriction in the outlet (if the wetland has an outlet)

2.6.1.2 Removing Phosphorus

Phosphorus can enter wetlands with suspended solids or as dissolved phosphorus. It is usually transported attached to particles rather than dissolved in the water (Raisin and Mitchell 1995). The major processes by which wetlands keep phosphorus from going farther downstream are (Mitsch and Gosselink 2000):

- The trapping of sediment on which phosphorus is adsorbed
- The removal of dissolved phosphorus by adsorption to soils that are high in clay content or organic matter
- Precipitation with calcium to form calcium phosphate

Wetlands that are effective at trapping sediments, therefore, are also effective at removing phosphorus. The discussion in Section 2.6.1.1 on the classes of wetlands that are effective at removing sediments also applies to removing phosphorus (Hruby et al. 1999).

The adsorption of phosphorus on soils is not permanent. Certain conditions during periods of extensive anoxia (lack of oxygen) may release phosphorus into the overlying waters (Adamus et al. 1991, Reddy and Gale 1994). In general, however, wetlands are a sink for phosphorus in watersheds (Adamus et al. 1991).

Other data also shows that phosphorus retention in wetlands is highly variable. Whigham et al. (1988) concluded that wetlands where waters had extensive contact with vegetation and/or organic litter were the most effective at phosphorus removal. Forested wetlands were only effective during flood events (when there was contact between waters and vegetation and more sediment deposition occurred). They found open water, lacustrine systems to be the least effective at phosphorus removal.

Johnston et al. (1997) observed that a wetland may remove phosphorus from incoming waters during one part of the year but at other times of year it may add phosphorus to water leaving the wetland. They hypothesized that the release of phosphorus from a wetland is due to the leaching of phosphorus from dying wetland vegetation.

The different pathways by which phosphorus can be trapped or released in wetlands are summarized in the quotation from a North Carolina State University web site in the box on the following page. Other sources that describe the many different ways phosphorus can be adsorbed, de-sorbed, precipitated and bound to soils depending on pH, alkalinity and hardness of the water are Kadlec and Knight (1996), Richardson and Vepraska (2001) and Wetzel (2001).

Mechanisms of phosphorus removal

The following discussion from North Carolina State University summarizes the scientific literature on the ways in which wetlands remove and process phosphorus. (North Carolina State University undated).

Phosphorus removal from water in wetlands occurs through adsorption by aluminum and iron oxides and hydroxides; precipitation of aluminum, iron, and calcium phosphates; and burial of phosphorus adsorbed to sediments or organic matter (Walbridge 1993, Johnston 1991, Richardson 1985). Wetland soils can, however, reach a state of phosphorus saturation, after which phosphorus may be released from the system (Richardson 1985). Phosphorus export from wetlands is seasonal, occurring in late summer, early fall and winter as organic matter decomposes and phosphorus is released into surface water.

Dissolved phosphorus is processed by wetland soil microorganisms, plants, and geochemical mechanisms (Walbridge 1993). Microbial removal of phosphorus from wetland soil or water is rapid and highly efficient; however, following cell death, the phosphorus is released again. Similarly, for plants, litter decomposition causes a release of phosphorus. Burial of litter in peat can, however, provide long term removal of phosphorus. Harvesting of plant biomass is needed to maximize biotic phosphorus removal from the wetland system.

The potential for long-term storage of phosphorus through adsorption to wetland soil is greater than the maximum rates of phosphorus accumulation possible in plant biomass (Walbridge 1993, Johnston 1991). In alkaline wetlands, such as found in the West, phosphorus precipitates with calcium as calcium phosphate (Novotony and Olem 1994, Walbridge 1993). However, the presence of aluminum is the significant predictor of dissolved phosphorus sorption and removal from water in most wetland systems (Reddy and Gale 1994, Walbridge 1993, Richardson 1985). The capacity for phosphorus adsorption by a wetland, however, can be saturated in a few years if it has low amounts of aluminum and iron or calcium (Richardson 1985).

Wetlands along rivers have a high capacity for phosphorus adsorption because as clay is deposited in the floodplain, aluminum (Al) and iron (Fe) in the clay accumulate as well (Gambrell and Trace 1994). Thus floodplains tend to be important sites for phosphorus removal from the water column, beyond that removed as sediments are deposited (Walbridge 1993).

Removal of Phosphorous by Wetlands of Various Classes and in Different Domains and Regions

The way wetlands remove phosphorus is considered to be similar in the two domains of the state (the east and west sides of the Cascades). Firstly, wetlands that are effective at trapping sediments are also effective at removing phosphorus regardless of their location (Hruby et al. 1999, 2000). Wetlands of all types in both domains have the potential of trapping sediments and therefore removing any phosphorus adhered to it. This conclusion is based on data showing that most of the phosphorus entering a wetland is bound to sediment (Dortch 1996, Mitsch et al. 1995, Mitsch and Gosselink 2000).

Secondly, phosphorus entering a wetland in a dissolved form can also be retained because it binds to clay and organic soils (see box on the previous page). The HGM classification, however, does not separate wetland types by soil content (Brinson 1993b), so the presence of clay or organic soils is not specific to a particular wetland class or region. As a result it is not possible to differentiate this function between wetland types. In the absence of research to the contrary, it can be hypothesized that wetlands in all domains and regions of the state and in all wetland classes have the potential to remove phosphorus if they contain organic or clay soils that can bind phosphorus.

2.6.1.3 Removing Nitrogen

Wetlands in general act as sinks for nitrogen under both nutrient-enriched and un-enriched conditions (Adamus et al. 1991, Jansson et al. 1994). Nitrogen enters a wetland in the form of ammonium from animal wastes in runoff, as nitrate/nitrite from fertilizers in runoff and groundwater, or from air pollution (Adamus et al. 1991).

The efficiency of nitrogen removal is greater with longer retention times of the water, earlier plant community stages, and lower loading rates (Dorge 1984 as reported in Adamus et al. 1991). Wetlands are far more efficient at removing nitrogen from up-basin loading than either rivers or streams (Saunders and Kalff 2001), even though soluble nitrogen may be flushed out of wetlands at times of high flow (Johnston et al. 1990).

The major biochemical processes by which wetlands remove nitrogen are nitrification and denitrification. These respectively occur in alternating conditions where oxygen is present (aerobic) and oxygen is absent (anaerobic) (Johnston et al. 1990, Mitsch and Gosselink 2000, Vought et al. 1995, Saunders and Kalff 2001). Denitrification transforms the majority of nitrogen entering wetlands into nitrogen gas, causing between 70% and 90% to be removed from the aquatic system (Reilly 1991, Gilliam 1994).

In aerobic substrates, the bacteria *Nitrosomonas* can oxidize ammonium to nitrite. The bacteria *Nitrobacter* oxidizes nitrite to nitrate. This process is called nitrification (Mitsch and Gosselink 2000).

Nitrogen is completely removed from the aquatic system only by anaerobic bacteria that reduce nitrate to gaseous nitrogen during denitrification. The gaseous nitrogen volatilizes, and the nitrogen is eliminated as a water pollutant. Thus, the alternating reduced and oxidized conditions (anaerobic and aerobic respectively) of wetlands complete the nitrogen cycle and maximize denitrification rates (Johnston 1991). First the aerobic bacteria change ammonium and organic nitrogen (decomposing plants and animals) to nitrate and nitrite, and then the anaerobic bacteria change the nitrate and nitrite to nitrogen gas.

Plants or microorganisms can use nitrate and ammonium for growth. Plant growth, however, does not really remove the nitrogen from the aquatic system because it becomes available again with the death of the plants or microorganisms that absorbed the nutrients (Adamus et al. 1991).

Nitrogen Removal by Wetlands of Various Classes and in Different Domains and Regions

The way wetlands are judged to remove nitrogen is similar east and west of the Cascades (Hruby et al. 1999, 2000, Hruby 2004a,b). Furthermore, the HGM classification does not separate wetland classes by the amount of oxygen in the soils (Brinson 1993b). The presence of alternating cycles of anaerobic and aerobic conditions is not specific to wetland types or regions. Therefore, it is not possible to differentiate this function between wetland types and regions.

Whether a specific wetland removes nitrogen or does not depends on the conditions found within the wetland, not on the type of wetland or its position in the landscape. The conditions that promote removal of nitrogen in wetlands of the state are seasonal inundation or saturation (Hruby et al. 1999, 2000). This indicates the soils alternate between aerobic conditions (when dry) and anaerobic conditions (when wet), and provides the optimal conditions for the gasification of nitrogen as described above.

2.6.1.4 Removing Metals and Toxic Organic Contaminants

The major physical, biological, and chemical processes by which wetlands reduce the amount of toxic materials moving into down-gradient waters are through sedimentation, adsorption, precipitation, oxidation, bio-degradation, and plant uptake (Adamus et al. 1991, Kadlec and Knight 1996, ITRC 2003).

- **Sedimentation** is a major process by which wetlands remove toxic compounds because some toxic compounds are bound to sediments or form insoluble compounds that settle out. For example, most heavy metals in urban runoff are adsorbed to sediment particles and are buried in sediment deposits within wetland soils (Newton 1989). Arsenic, Cadmium, Copper, Iron, Lead, Nickel, Silver, and Zinc are all metals that can be trapped through sedimentation (review in ITRC 2003). Thus, wetlands that are effective at removing sediments are also effective at trapping many toxic metals.

- **Adsorption** of the contaminants to the wetland soil is promoted by soils high in clay or organic matter (Adamus et al. 1991, Mitsch and Gosselink 2000). For example, wetlands can remove toxic metals from surface and groundwater if they contain clays, peat, aluminum, iron, and/or calcium (Gambrell and Trace 1994). Metals entering wetlands will bind to the negatively ionized surface of clay particles, or precipitate as inorganic compounds (metal oxides, hydroxides, and carbonates, depending on pH), or form a complex with humic materials (Gambrell and Trace 1994).

- **Chemical precipitation** is promoted by wetland areas that are inundated and remain aerobic, as well as those with pH values below 5 (Mengel and Kirkby 1982). Also, precipitation of dissolved iron is common in wetlands where anaerobic groundwater containing reduced iron compounds surfaces. In the aerobic surface environment the iron compounds oxidize into insoluble forms and precipitate out from solution. During this process metals and other compounds bind to the iron, and co-precipitate with the iron hydroxides (Kadlec and Knight 1996, Wetzel 2001).

- **Photochemical oxidation** is a pathway by which organic contaminants can be broken down into less toxic compounds through the action of sunlight (Kadlec and Knight 1996).

- **Biodegradation** is similar to oxidation, but in this case bacteria and other microbes break down organic contaminants. Degradation occurs under both aerobic and anaerobic conditions depending on the chemical structure of the contaminant (Kadlec and Knight 1996, ITRC 2003).

- **Plant uptake** of toxic compounds is maximized when there is significant wetland coverage by emergent plants (Kulzer 1990).

Removal of Toxic Contaminants by Wetlands of Various Classes and in Different Domains and Regions

Wetlands on the east and west sides of the Cascades were judged to function similarly in removing toxic contaminants (Hruby et al. 1999, 2000, Hruby 2004a,b). There may be some differences based on wetland class because some of the characteristics (such as effectiveness at trapping sediment) that are important for removing toxic compounds are dependent on the wetland class. Other differences do not depend on wetland class. In Washington, the experts who developed assessment methods judged that wetlands that remove sediments effectively are also effective at removing toxic compounds (Hruby et al. 1999, 2000).

The HGM classification, however, does not separate wetland types by the soils present or by how well they trap sediments (Brinson 1993b). The presence of clays, organic soils, aluminum, iron, or calcium in the soils is not specific to any wetland type. In the absence of research to the contrary, it can be assumed that wetlands in all regions of the state and in all wetland classes have the potential to remove toxic metals and organic compounds if they have the appropriate conditions that allow contaminants to sediment out, adsorb to soils, precipitate, biodegrade, or oxidize.

Wetlands with Clay Soils in Washington

As mentioned above, wetlands with clay soils can remove toxic contaminants because of the chemical properties of this type of soil. The term "clay" however, is applied both to materials having a particle size of less than 2 micrometers (25,400 micrometers = 1 inch) and to the family of minerals that has similar chemical compositions and common characteristics of crystal structure (Velde 1995). In Washington we find soils that are called "clays" that fit both aspects of the definition. In reviewing the descriptions of soils in the county soil surveys (e.g., Pringle 1990), there are three types of clay soils described in Washington.

- Those that consist of very finely ground rock formed by glaciers (called clays based on the size of the particles)
- Those that were deposited in lakes and the ocean (called clays either because of size or mineral composition)
- Those derived from the weathering of rocks in place (called clays based on mineral composition)

The scientific literature on the chemical properties of clays in relation to the adsorption of metals and organic pesticides, however, is based on the clays that are defined by their mineral composition and that are derived from weathered rocks such as bentonite, montmorillonite, and kaolinite (Fushiwaki and Urano 2001).

There is little information on the chemical properties of clays derived from glacial activity or aquatic sediments. County soil surveys (e.g., Debose and Klugland 1983) indicate that glaciers have played an important role in forming clays in western and northeastern Washington. Lacustrine (lake) and marine clays are also common in Whatcom County (Natural Resources Conservation Service 1992). These clays may contain chemically reactive minerals but it was not possible to confirm this assumption. Information from the soil survey of Whatcom County (Table J2 on the chemical properties of soils, released November 18, 2002), however, suggests that the clay soils of marine origin have a high cation exchange. This would indicate a high potential to bind metal and organic contaminants.

Wetlands with Volcanic Ash

Washington is relatively unique in the U.S. because it contains extensive areas where soils developed in volcanic ash (called Andisols). In addition, wetlands in the Columbia Basin often have a very fine layer of volcanic ash near the surface from the Mt. St. Helens eruption in 1980 (observations made by the technical team during the calibration of the methods for assessing wetland functions, Hruby et al. 2000).

In general, the cation exchange capacity of volcanically derived soils is high, due to a high surface area of the mineral and organic compounds (McSweeney 2004). Furthermore, volcanic ash that is washed or deposited into wet areas is in time transformed into bentonite clays (Bohor et al. 1976, Bohor et al. 1979). Thus, the ash found in wetland soils of Washington can be hypothesized to perform as clays to remove toxic compounds.

Wetlands with Organic Soils

Soils with a high content of organic matter have a high cation exchange capacity, and they are thus able to bind contaminants (Kadlec and Knight 1996). This is because the break down of plant material produces organic colloids that form complexes with contaminants (McSweeney 2004). Wetlands with organic soils such as peat bogs and fens in Washington State have the necessary soil conditions by definition (high content of organic matter) to react with and adsorb toxic contaminants.

Wetlands in the Depressional Class

A number of the characteristics that enhance the removal of toxic compounds are present more often in depressional wetlands, although all depressional wetlands do not have these characteristics. A higher number of depressional wetlands have slower moving water and finer sediments compared to riverine or slope wetlands (Brinson 1993b). Wetlands in which water moves slowly are better at removing toxics than those in which water moves rapidly. Slow moving water allows more time for chemical processes to occur before the water moves out of the wetland. This promotes the settling of fine sediments and the formation of organic soils (North Carolina State University 2002).

Depressional wetlands in the state more often have organic soils than wetlands in the other classes (observation is based on unpublished data collected by Ecology during the calibration of the Washington State wetland function assessment methods and the wetland rating systems 1998-2004). Depressional wetlands, therefore, can be assumed to usually have a higher potential to remove toxic compounds than wetlands in the other classes.

2.6.1.5 Removing Pathogens

Surface runoff coming into wetlands often contains large quantities of bacteria, particularly coliform bacteria and pathogens such as *Salmonella* (Hemond and Benoit 1988). Probably the most important mechanism for removing pathogenic bacteria from surface water is detention which is a function of residence time (reviews in Hammer 1989, Kadlec and Knight 1996).

Detention of the water in wetlands results in a natural die-off, and therefore removal from the water column, because many pathogenic bacteria cannot survive for long periods outside their host organism (Hemond and Benoit 1988). In addition, protozoa and other micro-organisms often found in wetlands actively feed on bacteria and can speed up the process of die-off (Hemond and Benoit 1988).

Removal of Pathogens by Wetlands of Various Classes and in Different Domains and Regions

The HGM classification does not separate wetland classes by their retention time or their populations of protozoa and other micro-organisms. Since these are the two major factors that account for the die-off of pathogens, it is not possible to differentiate how wetlands perform this function based on regional and hydrogeomorphic differences. Whether a specific wetland removes pathogens depends on the conditions found within the wetland, not on the type of wetland or its position in the landscape.

2.6.2 Functions Related to Maintaining the Water Regime in a Drainage Basin (Hydrologic Functions)

Wetlands play an important role in the water regime of watersheds (Mitch and Gosselink 2000, Bullock and Acreman 2003). Sipple (2002) provides a good summary of their role:

> *Because of their low topographic position relative to uplands (e.g., isolated depressions, floodplains), wetlands store and slowly release surface water, rain, snowmelt, groundwater and flood waters. Trees and other wetland vegetation also impede the movement of flood waters and distribute them more slowly over floodplains. This combined water storage and slowing action lowers flood heights and reduces erosion downstream and on adjacent lands. It also helps reduce floods and prevents water logging of agricultural lands. Wetlands within and downstream of urban areas are particularly valuable in this regard, counteracting the greatly increased rate and volume of surface-water runoff from pavement and buildings.*
>
> *Because of their position on the landscape, wetlands at the margins of lakes, rivers, bays, and the ocean help protect shorelines and stream banks against erosion. Wetland plants hold the soil in place with their roots, absorb the energy of waves, and break up the flow of stream or river currents. The ability of wetlands to control erosion is so valuable that some states (e.g., Florida) are restoring wetlands in coastal areas to buffer the storm surges from hurricanes and tropical storms by dissipating wave energy before it impacts roads, houses, and other man-made structures.*

The information available, however, indicates that the role of a wetland in the hydrologic cycle of a watershed is highly varied and depends on many factors. Bullock and Acreman (2003) reviewed 169 publications that report the results of scientific studies that quantified the hydrologic functions of wetlands. Their review confirms that wetlands exert a strong influence on the hydrologic cycle, but the actual functions performed by individual wetlands vary greatly. In many cases wetlands reduce floods and recharge groundwater while in other cases they may exacerbate floods or cause a net loss of groundwater (Bullock and Acreman 2003).

The following sections describe the characteristics of wetlands that reduce peak flow, reduce erosion, and recharge groundwater in Washington as determined by the teams of experts developing the methods for assessing functions and the rating system.

2.6.2.1 Reducing Peak Flows

Surface water that may otherwise cause flooding is stored to a greater degree in wetlands than typically occurs in terrestrial environments (Adamus et al. 1991). As a result, peak flows in streams and rivers are directly related to the total area of wetlands in the watershed, or to the area of wetlands in the headwaters of the system (National Research Council 1995). Wetlands reduce peak flows in streams and rivers by slowing and storing water in overbank areas and by holding back runoff that would otherwise flow directly downstream and cause more severe flooding (Reinelt and Horner 1995).

The function of reducing peak flows as defined in Washington State also includes the process of "floodflow desynchronization" (Hruby et al. 1999). This is a process that occurs at a larger, landscape scale. Desynchronization occurs when floodwaters are stored in many wetlands within the watershed. The release of water from these wetlands is staggered and gradual, resulting in more persistent flows but much lower peak flows (Adamus et al. 1991).

The characteristics of a wetland that indicate a potential to reduce peak flows include (Hruby et al. 1999, Mitsch and Gosselink 2000):

- The volume of water storage (depth of water stored multiplied by wetland area)
- The *live storage*, which is the storage above the bottom of the outlet
- Proximity of the wetland to flood waters
- Location of the wetland (e.g., along a river, lake, or stream)
- The amount of storage in the wetland relative to the volume of the flooding waters
- Lack of other upstream storage areas such as ponds, lakes, and reservoirs

Reduction in Peak Flows by Wetlands of Various Classes and in Different Domains and Regions

The importance of wetlands in reducing peak flows and how they perform this function differ in eastern and western Washington. This is a result of differences in the patterns of precipitation and snowmelt between the two areas (Hruby et al. 1999, 2000). The processes by which wetlands in Washington reduce peak flows also vary among wetland classes.

Wetlands of Western Washington

In **depressional wetlands of western Washington**, the characteristics within a wetland that reduce peak flows are the short-term storage capabilities of the wetland and the relative amount of flow captured from the upgradient contributing basin (Hruby et al. 1999). Short-term storage is often called *live storage* by hydrologists. It is the amount of water stored above the level of the outlet (if the wetland has one). Water stored below the outlet is called *dead storage* and was not considered to be important in reducing peak flows in western Washington (Hruby et al. 1999). The dead storage is usually filled by the time a flood event occurs and thus is not available to capture storm flows. Since most flooding events occur later in the fall, winter, and early spring, reductions in peak flow will occur only when a depressional wetland has some live-storage as well (Adamus et al. 1991, Hruby et al. 1999).

The expert teams who developed assessment methods for the state determined that the same assumption applies to the storage within the interstices of the soil (spaces between soil particles). Wetland soils in western Washington are usually saturated by the time most flood events occur, and storage in the soils was not judged to be important in reducing peak flows (Hruby et al. 1999) although it has been suggested as an important characteristic in other parts of the nation (Adamus et al. 1991).

Depressional wetlands with no outlet store all surface waters coming into them and therefore have the highest potential to reduce peak flows (Hruby et al. 1999).

In **riverine wetlands of western Washington**, the major characteristic judged to reduce peak flows is the storage provided by overbank areas (Hruby et al. 1999). As floodwaters rise, the waters overtop the banks of the river and fill the adjacent areas, many of which are riverine wetlands. The presence of a wide surface with an elevation at or near that of the river bank is the most important factor in reducing peak flows. As the flood waters overtop the banks they are slowed down and the height of the flooding is reduced because the excess water is stored in these wetlands longer than the duration of the peak flows (Adamus et al. 1991, Hruby et al. 1999).

The **lacustrine fringe, flats, and slope classes of western Washington** have not been analyzed relative to reducing peak flows. The information available suggests wetlands in the flats and slope class do not play a major role in this function. Wetlands in the flats class by definition do not receive any runoff from surrounding areas (Brinson 1993b). Their effectiveness at reducing peak flows is to store only the precipitation that falls within their boundaries.

Wetlands in the slope class do not provide storage because by definition they do not impound any surface water (Brinson 1993b). Water flows to the lowest point on the slope and is then discharged. In fact, some studies show that slope wetlands may increase peak flows relative to surrounding uplands because their surface is saturated and rainfall in the wetland does not infiltrate (Bullock and Acreman 2003). The one role slope wetlands may play is to reduce the velocity of surface runoff by way of the thick vegetation often growing there (see Figure 2-9 for an illustration). The importance of vegetation on slopes in reducing flows has been well documented in studies of logging, though not specifically for slope wetlands (Lewis et al. 2001). It can be assumed that vegetation in slope wetlands plays the same role as vegetation in forested areas in reducing velocities of surface runoff (Hruby 2004a,b).

Wetlands of Eastern Washington

In **depressional wetlands of eastern Washington**, the characteristics within the wetland that reduce peak flows are the total storage capacity of the wetland and the relative amount of flow it captures from the upgradient contributing basin (Hruby et al. 2000).

The events that cause flooding in eastern Washington are different than in the western part of the state. Summer thunderstorms can cause flooding at times when most depressional wetlands are dry. As a result, the entire storage capacity of the wetland is available rather than just the live storage (Hruby et al. 2000). Depressional wetlands with no outlet store all surface waters coming into them and therefore have the greatest potential to reduce peak flows.

Riverine wetlands in eastern Washington are judged to function in a fashion similar to those on the west side (Hruby 2004a). Although function assessment methods have not been developed, the field work undertaken in calibrating the revised wetland rating system suggests that the major characteristic that reduces peak flows is also the storage provided by overbank areas (Hruby 2004a). See the previous discussion of riverine wetlands in western Washington for a more detailed description of storage by overbank areas.

Wetlands in **the lacustrine fringe and slope class** have not been analyzed in eastern Washington for their ability to reduce peak flows. The information collected during the calibration of the eastern Washington rating system, however, suggests wetlands in these two classes provide this function but not at the same levels as riverine or depressional wetlands (Hruby 2004a). Wetlands along the shores of lakes and reservoirs in eastern Washington tend to be small relative to the area of the lake (based on unpublished data, Hruby 2004a). They have some capacity to store water as the water levels in a lake rise, but the extra amount stored is often very small compared to the storage in the lake itself.

Furthermore, many lakes and reservoirs in this region have controlled and manipulated outlets. This means that the reduction in peak flows is directly controlled by humans and not by ecological processes. It is not possible, therefore, to assess how well these wetlands function to reduce peak flows based on their characteristics without an understanding of the protocols used to regulate the water levels in each reservoir.

By definition, wetlands in the slope class do not provide storage because any water flows to the lowest point and then is discharged (Brinson 1993b). However, their frequently dense vegetation reduces the velocity of surface runoff (see Figure 2-9) and thus can reduce the velocity of water somewhat. A wetland with dense vegetation will intercept more runoff and be more capable of reducing runoff velocity (and thus peak flows) than a wetland with less dense vegetation (Richardson and McCarthy 1994).

The importance of vegetation on slopes in reducing flows has been well documented in studies of logging (Lewis et al. 2001) though not specifically for slope wetlands. In eastern Washington the assumption is that vegetation in slope wetlands plays the same role as vegetation in forested areas in reducing peak flows (Hruby 2004a).

2.6.2.2 Reducing Erosion

The major process by which wetlands reduce downstream erosion is by slowing the velocity of water flowing downstream (Reinelt and Horner 1995, Adamus et al. 1991). The reduction in velocity depends on (Adamus et al. 1991):

- Channel constrictions that slow the flow of water
- Frictional resistance of the bottom
- Frictional resistance of vegetation

Jadhav and Buchberger (1995) state that the drag induced by plant stems increases with water velocity. This means that the relative reduction in velocity caused by plants increases as the speed of the water increases.

Reduction of Erosion by Wetlands of Various Classes and in Different Domains and Regions

The ways by which wetlands decrease erosion are somewhat different east and west of the Cascades. This is a result of the differences in the patterns of precipitation and snowmelt between the two areas (Hruby et al. 1999, 2000). The processes by which wetlands in Washington reduce erosion can also differ among wetland classes, as described below.

Wetlands of Western Washington

In **depressional wetlands of western Washington**, several characteristics were judged to influence a wetland's function in reducing water velocities (Hruby et al. 1999):

- Short-term storage capabilities of the wetland
- Characteristics of its outlet

- Amount of woody vegetation present
- Relative amount of flow captured from the upgradient contributing basin

Depressional wetlands with no outlet store all surface waters flowing into them. They have the greatest potential, therefore, to decrease erosion because no water leaves the wetland that could cause erosion (Hruby et al. 1999).

In **riverine wetlands of western Washington**, the major characteristic that reduces erosion is the amount of woody vegetation present that can provide a barrier to water flows (Hruby et al. 1999). As flood waters overtop the river banks, they are slowed down. The width of the wetland relative to the channel indicates how well the wetland can reduce velocity; the wider the wetland, the more water can spread out, becoming shallower and slowing down (Hruby et al. 1999).

Methods for assessing functions have not been developed for the **lacustrine fringe, flats, and slope classes in western Washington** and there is little information available on how these types of wetlands may perform this function. Wetlands in the flats class, however, are not expected to play a major role in this function. By definition, they do not receive any runoff from surrounding areas and therefore do not intercept waters that can cause erosion (Brinson 1993b).

Wetlands in the slope class, however, may decrease erosion to some degree because they often have thick vegetation relative to the surrounding uplands that reduces the velocity of surface runoff. Jadhav and Buchberger (1995) state that under dynamic conditions (high flows such as those found on slopes during storms) velocity is reduced by the drag induced by plant stems. Wetland detention time is therefore increased with vegetation density.

It can also be hypothesized that wetlands along the shores of lakes in western Washington (lacustrine fringe) may reduce erosion along the shore because of the vegetation they support. This would both anchor the shoreline and dissipate erosive forces (Adamus et al. 1991). Wetlands that have extensive, persistent (especially woody) vegetation provide protection from waves and currents associated with large storms and snowmelt that would otherwise penetrate deep into the shoreline (Adamus et al. 1991).

Wetlands of Eastern Washington

In **depressional wetlands of eastern Washington**, the characteristics within the wetland that decrease erosion are the total storage capacity of the wetland and the relative amount of flow captured from the upgradient contributing basin (Hruby et al. 2000). The events that cause erosion in eastern Washington are different than in the western part of the state. Summer thunderstorms can cause highly erosive flows at times when most depressional wetlands are dry (Hruby et al. 2000). As a result, the entire storage capacity of the wetland is usually available to reduce water velocities rather than just the live storage. Depressional wetlands with no outlet store all surface waters coming into them and therefore have the most potential to decrease erosive flows.

Riverine wetlands in eastern Washington function in a similar fashion to those on the west side (Hruby 2004a). Although experts have not developed function assessments, the field work undertaken in calibrating the revised wetland rating system suggests that woody vegetation within the wetland is key in reducing erosive flows by slowing velocities during floods.

Function assessment methods for the **lacustrine fringe and slope classes** have also not been developed in eastern Washington. There is therefore no clear understanding of how they function to decrease erosion. It can be hypothesized, however, that wetlands of both classes can function to reduce erosion to some degree in a manner similar to these types of wetlands in western Washington (see discussion above).

2.6.2.3 Recharging Groundwater

The recharge of groundwater is the movement of surface water, usually downward, into the ground. In wetlands, the function is described in terms of the wetland structures and processes that allow surface water to infiltrate into the groundwater system. Adamus et al. (1991) and the expert teams developing the Washington State wetland function assessment methods (Hruby et al. 1999, 2000) concluded that the movement of water into the ground depends primarily on:

- The elevation of the wetland relative to the groundwater
- The mass and pressure of water ("pressure head") in the wetland
- The physical characteristics and frictional resistance of the sediments and strata underlying the wetland (hydraulic conductivity)

If the surface of the water in a wetland is groundwater, or the primary source of water to the wetland is groundwater (e.g., a seep), the wetland cannot recharge that groundwater. By definition, recharge occurs only if water from surface runoff infiltrates into groundwater.

The information available on the potential for wetlands to recharge groundwater is contradictory. In a review of scientific studies that quantified the hydrologic functions of wetlands, Bullock and Acreman (2003) found 32 studies that documented that recharge occurs and 18 studies where no recharge was found. Adamus et al. (1991) conclude, from an extensive review of the literature, that four site-specific conditions determine how well a wetland performs this function:

- Groundwater flow rates under the wetland (linked to hydraulic conductivity)
- The storage capacity of the wetland (linked to the pressure head of water)
- Water movement within the wetland (linked to elevation relative to groundwater and hydraulic head)
- Evapotranspiration (linked to "pressure head" of water in the wetland)

These conclusions about these site-specific conditions were more recently confirmed by Hunt et al. (1996).

Adamus et al. (1991) were unable to find any patterns among wetland types or regions of the country. They also concluded that "for recharge, adjacent undeveloped uplands are usually, but not always, more important than wetlands." This conclusion was confirmed by Bullock and Acreman (2003).

Groundwater Recharge by Wetlands of Various Classes and in Different Regions

The characteristics within a wetland that result in the recharge of groundwater are the same for wetlands in both the eastern and western parts of the state. The potential for recharge in a wetland occurs when wetlands hold back precipitation and surface flows to create ponded areas. This ponded water then infiltrates into the groundwater system because of the "head" or pressure created by the depth of water on the surface. If the hydraulic head created by upslope groundwater is greater than the hydraulic head created by the ponded water, recharge will not occur (Adamus et al. 1991).

Groundwater recharge occurs only in a subset of **depressional wetlands** and some **riverine wetlands** that impound and hold surface water. Wetland types that do not impound surface water do not have the potential to recharge groundwater (Hruby et al. 1999, 2000, Hruby 2004a,b).

A new perspective on the function of supporting baseflow

One aspect of groundwater recharge that is often attributed to wetlands in Washington is called *baseflow support*. Wetlands are assumed to augment base flows in streams during the drier seasons because of the water they store. The information available, however, indicates this assumption is not valid in most cases, and in fact wetlands may reduce baseflow because of water lost through evapotranspiration. In a review of scientific studies that quantified the hydrologic functions of wetlands, Bullock and Acreman (2003) found that 49 out of 75 studies (2/3) conclude that wetlands reduce the flow of water downstream during dry periods. Only 16 studies conclude that wetlands sustain low flows and ten studies found that wetlands had no impact on low flows.

In Washington, the teams of experts that developed the methods for assessing functions and the rating systems concurred with the majority of studies (Hruby et al. 1999, 2000, Hruby 2004a,b). Surface outflow from wetlands was not judged to be an important factor in maintaining low flows in streams in Washington State. A wetland may be in a location where groundwater is discharged, but the source of this groundwater is not within the wetland itself. Thus, the discharge is not a function of the wetland; rather it is, as reported by Adamus et al. (1991), a function of the entire groundwater system.

Given the highly seasonal rainfall patterns in the region, the teams also judged that most surface water will be discharged into streams before the late summer when low flows as biologically the most critical. Water stored in the soils of wetlands was not considered to be a factor because of the types of soils present. Wetlands on alluvial soils would not hold water long enough into the dry season to support baseflow because they are so permeable (review in Bullock and Acreman 2003). On the other hand, wetlands with organic and peat soils would hold water and not release very much of it because the hydraulic conductivity is generally very low. The hydraulic conductivity of water in peat soils ranges between 0.000001 cm/sec to as high as 0.001 cm/sec (less than 3 ft per day) (Reeve et al. 2000) depending on the structure of the peat or the mineral soil.

2.6.3 Functions Related to Habitat

This section focuses on three aspects of wetlands as habitat:

- Structures and processes found within wetlands that make them an important habitat feature of the landscape
- The number and types of vertebrate species using wetlands in the Pacific Northwest
- Important features of wetlands that meet the habitat requirements of some groups of species that are closely associated with wetlands and that were modeled in the Washington State wetland function assessment methods

The discussion is not subdivided by wetland class or domain and region of the state because habitat requirements differ widely for various species. Furthermore, habitat requirements for a single species may even differ between locations (Adamus et al. 1991). Therefore, this literature review does not attempt to identify all the life requirements of all wildlife species that use wetlands in Washington. The intent of this synthesis is to identify some of the basic structures and processes in wetlands that are important habitat features.

2.6.3.1 The Use of Wetlands by Species of Wildlife

Animals use wetlands to varying degrees depending upon the species involved. Some live in wetlands for their entire lives; others require wetland habitat for at least part of their life cycles; still others use wetlands much less frequently, generally for feeding (Johnson and O'Neil 2001). Thus, species using wetlands are often grouped by their dependency on the habitat provided by wetlands, but unfortunately there is no consistency in the terms used to describe the dependency.

For example, Adamus et al. (1991) grouped species into two categories. *Wetland-dependent species* are those that: "(a) normally use wetlands exclusively for food and cover throughout most of their U.S. range and spend most of their lifetime within wetlands, or (b) would be extirpated from a large region if all wetlands were to be filled." The latter case includes species that may use wetlands for only part of their life cycles such as amphibians and many insects. The larvae of amphibians and many insects are aquatic even though the adults migrate out of the wetlands. The species are still considered to be wetland dependent because they could not survive without the presence of wetlands. *Wetland users* are those species that use wetlands for occasionally obtaining some life requirements such as sources of drinking water, winter cover (e.g., white-tailed deer and ring-necked pheasants), or dispersal centers within urban areas (e.g., opossum) (Adamus et al. 1991).

Adamus et al. (1991) also state the following about how species use wetlands:

> *The degree of dependence by any given species on wetlands often varies greatly depending on the abundance and distribution of wetlands and on suitable alternative habitats within the region. For example, urban wetlands and riparian wetlands in the arid Southwest support species that, in other parts of their ranges, are much less likely to inhabit wetlands.*

The Washington State wetland function assessment method uses the terms *wetland dependent* for western Washington (Hruby 1999) and *wetland associated* for eastern Washington (Hruby 2000). More recently, Johnson and O'Neil (2001) have developed a grouping based on three categories that are specific to wildlife in Washington and Oregon that is based on the consensus of numerous experts in the region. These authors use the terms *closely associated*, *generally associated*, and *present* when describing the relationship between species and wetlands, and these are defined as follows:

- *Closely Associated* – A species is widely known to depend on a habitat for part or all of its life history requirements. Identifying this association implies that the species has an essential need for this habitat for its maintenance and viability.
- *Generally Associated* – A species exhibits a high degree of adaptability and may be supported by a number of habitats. In other words, the habitat plays a supportive role for its maintenance and viability.
- *Present* – A species demonstrates occasional use of a habitat. The habitat provides marginal support to the species for its maintenance and viability.

2.6.3.2 Characteristics that Make Wetlands Important as Habitat

Wetlands are among the most productive ecosystems in the world, comparable to rain forests and coral reefs (Mitsch and Gosselink 2000, Sipple 2002). As a result, wetlands support numerous species from all of the major groups of organisms—from microbes to mammals (Sipple 2002). The support they provide for these organisms includes sources of food, shelter, and refuge. All of these aspects are generalized by the term *habitat*.

General reviews of wetlands as habitat (Adamus et al. 1991, Mitsch and Gosselink 2000) conclude that physical and chemical characteristics (factors that control the suitability of a wetland as habitat) determine what plants and animals inhabit various wetlands, including:

- Climate
- Topography (landscape shape)
- Geology
- Nutrients
- Hydrologic regime (quantity and movement of water)

In addition, some of the larger organisms such as beaver and muskrats manipulate wetlands to create habitat suitable for themselves and other organisms, such as fish, amphibians, waterfowl, insects, and other mammals (Mitsch and Gosselink 2000).

Four general ecological features contribute to species richness and abundance in a landscape (Knutson and Naef 1997):

- Structural complexity
- Connectivity with other ecosystems
- Abundant food source and available water
- Moist and moderate microclimate

Wetlands have all of these attributes, especially wetlands that are linked to riparian areas and floodplains. The following sections describe each of these features in more detail.

Structural Complexity

Structural complexity is a term used to represent the variety of environmental characteristics that increase the number of niches for wildlife (Knutson and Naef 1997). These characteristics can include biological features such as a high richness of plant species or physical features such as open water, rocks, and mudflats. The interspersion in wetlands between open water and vegetation, or between types of vegetation, is important because the edges created between these elements (see Figure 2-10) increase the number of niches present (Adamus et al. 1991). Wetlands also often contain different vegetation communities within their boundaries that add structure (and therefore niches). For example, a higher interspersion of plant types in wetlands is likely to support a higher diversity of invertebrates (Dvorak and Best 1982, Lodge 1985).

Figure 2-10. Features of wetlands that increase structural complexity. This wetland has open water and plants of different heights and different types (woody, herbaceous, aquatic bed) as well as snags and woody debris.

Riparian wetland systems in the semi-arid West often provide the only structurally complex habitat in regions dominated by open land or land cleared for agriculture (Adamus et al. 1991). This has also been found to be true in the semi-arid areas of eastern Washington, especially in the areas where rainfall is less than 12 inches per year (Hruby et al. 2000). Figure 2-11 shows a wetland with high structural complexity in the semi-arid terrestrial environment of eastern Washington that otherwise does not have much complexity.

Figure 2-11. Depressional wetland in the Columbia Basin. A structurally complex ecosystem in a terrestrial environment with low complexity. The average annual rainfall at this site is 8 inches per year.

Connectivity to Other Natural Resources

Many wetlands are linked to other aquatic or terrestrial resources by surface water, riparian corridors, or by relatively undisturbed vegetated corridors. Riverine wetlands form part of riparian corridors, depressional wetlands may be part of a small stream system or may be linked by surface water, and lacustrine fringe wetlands are connected to adjacent lakes. The role that corridors play in maintaining biodiversity, however, is very complex. For some species corridors are essential to maintain populations and genetic exchange (Kauffman et al. 2001, Haila 2002, Fahrig 2003). In other cases they may reduce populations of some species because they facilitate the movement of predators or invasive species (review in Fahrig 2003). See Chapters 3 and 4 for further discussion of habitat connectivity and corridors to both aquatic and terrestrial habitats.

Abundant Food Sources

The wet and moist microclimate of wetlands and their rich soils lead to the enhanced growth of plants. Wetlands are known for their high primary productivity (production of plant material) and the subsequent movement of this “food” to adjacent aquatic ecosystems (Mitsch and Gosselink 2000).

"Wetlands can be thought of as biological supermarkets" (Sipple 2002). For example, the number of invertebrates in small seasonal wetlands can exceed 700,000 animals per square meter (Leeper and Taylor 1998). Many of these invertebrates serve as food for larger predatory amphibians, reptiles, fish, birds, and mammals (Wissinger 1999).

Moist and Moderate Microclimate

The presence of water and thick vegetation in wetlands results in a microclimate that is generally more moist and that has milder temperature extremes than the surrounding areas. These conditions provide a habitat that is desirable to many species, particularly amphibians, ungulates, and other large mammals during hot, dry summers and severe winters (Knutsen and Naef 1997).

2.6.3.3 Use of Wetlands by Vertebrates in Washington

Wetlands in the state have been shown to be critical in maintaining regional biodiversity. Although wetlands represent only 2.1% of the area of the state (Dahl 1990), over two-thirds of all terrestrial vertebrate species in Washington can be considered "wetland users" (Knutson and Naef 1997, Kaufmann et al. 2001). A comprehensive review of wildlife in Washington and Oregon (Johnson and O'Neil 2001) provides a compilation of all wildlife species found in Washington and the different habitats in which they are found. Of the 32 types of habitat identified in the review, four are specific to wetlands. Table 2-7 lists the four types of wetland habitats identified in the compilation and the number of wildlife species found in each type. Appendix 2-B lists all the species found in each type of wetland as compiled in the review.

Table 2-7. Number of wildlife species by type of wetland habitat and by their association. From O'Neil and Johnson 2001. See Appendix 2-B for definitions of the types of wetlands.

Habitat Type	Total	Closely Associated	Associated	Present	Unsure
Herbaceous wetland	228	105	90	31	2
Westside Riparian-Wetlands	256	74	145	35	2
Montane Coniferous Wetlands	148	17	101	28	2
Eastside Riparian-Wetlands	271	81	149	36	5

Reptiles and Amphibians

There are 59 species of reptiles and amphibians in Washington and Oregon. Two species of reptiles, the western pond turtle (*Clemmys marmorata marmorata*) and the painted turtle (*Chrysemys picta*), are wetland dependent. Many more species of reptiles are wetland users. On the other hand, all but one species of amphibians are wetland dependent and require an aquatic habitat for part of their life cycle (Kauffman et al. 2001). Figure 2-12 shows how many of the 59 species of reptiles and amphibians in the two states are found in three of the four types of wetland habitat.

In Figures 2-12 to 2-14 the data are from (Kauffman et al. 2001). The lists of actual species in each type of habitat and the definitions of each type of habitat are summarized in Appendix 2-B.

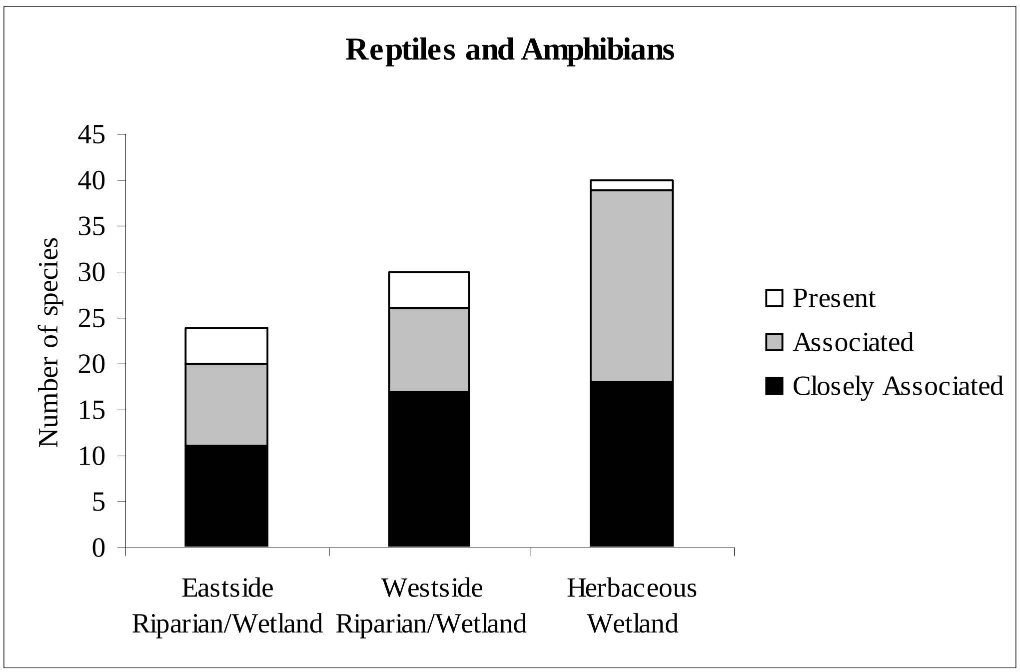

Figure 2-12. The number of reptile and amphibian species found in wetlands in Washington and Oregon. (from Kauffman et al. 2001)

Birds

Overall, 266 (72%) of the 367 species of birds in Oregon and Washington use freshwater, riparian, and wetland habitats. More striking, 204 (77%) of the 266 species of inland birds that breed in the two states do so in wetland environments (Kauffman et al. 2001). Figure 2-13 shows the number of bird species that use three types of wetlands in the region.

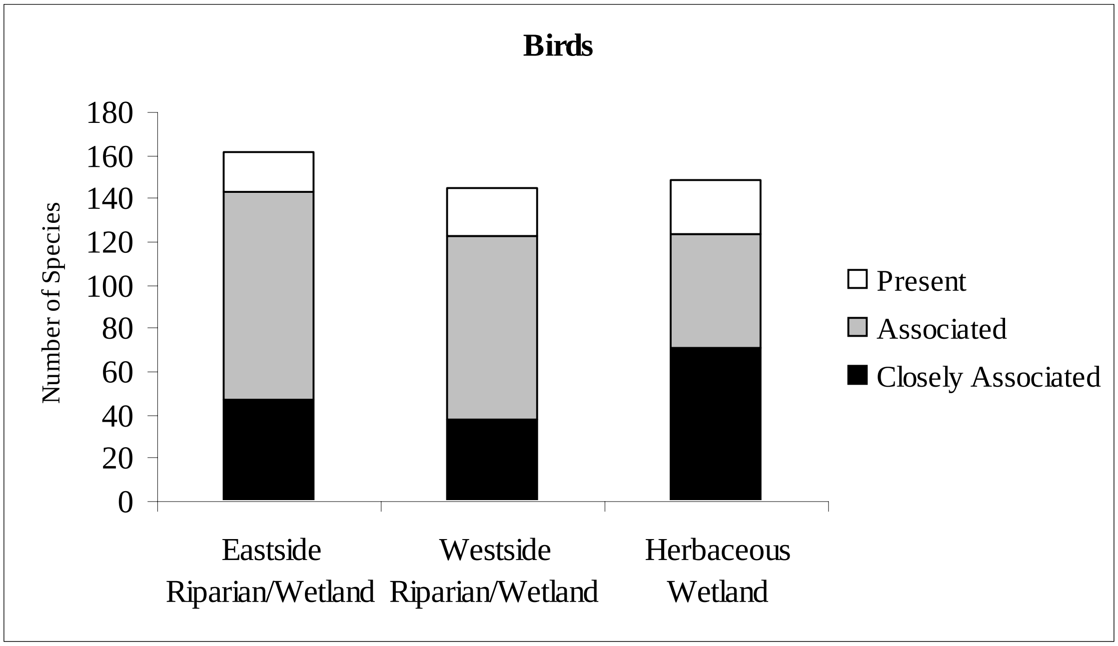

Figure 2-13. The number of bird species found in wetlands in Washington and Oregon (from Kauffman et al. 2001).

Mammals

Ninety-five of the 147 mammal species (65%) in the two states use the riparian/wetland ecosystem (Kauffman et al. 2001). All the "furbearers" (e.g., mink, otter, beaver, raccoon, etc.) use these habitats, and all but one of the big game animals (deer, elk, moose, etc. with the exception of bighorn sheep) rely on these areas for part of their habitat requirements. Figure 2-14 shows the number and degree of association of mammals to the three types of wetland habitats considered in Kauffman et al. (2001).

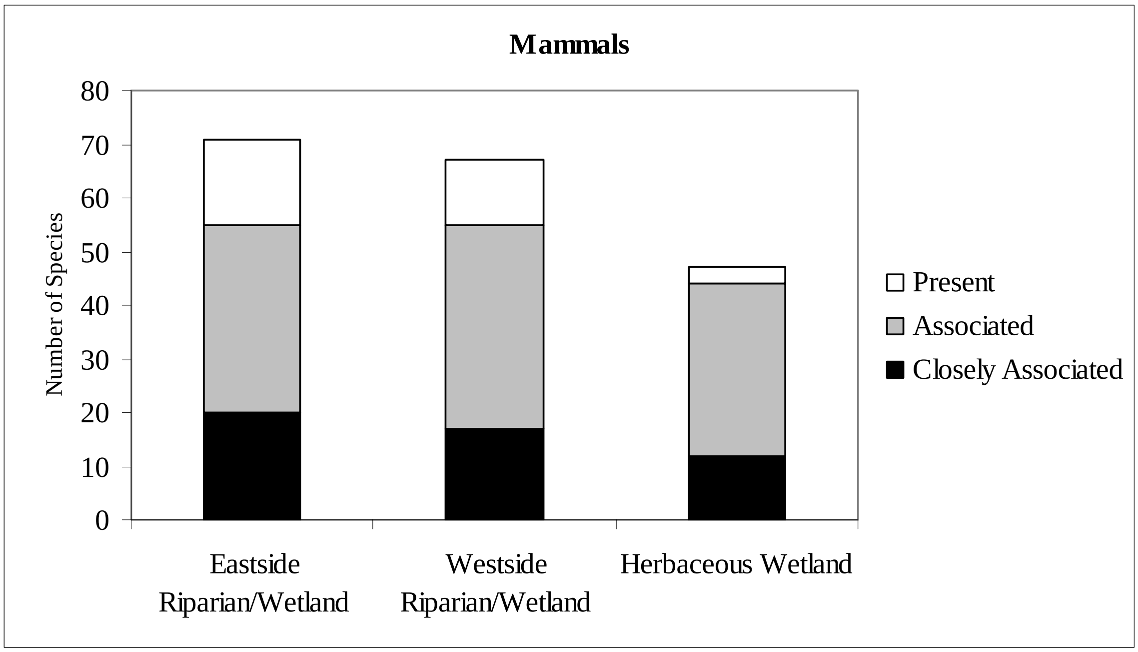

Figure 2-14. The number of mammal species found in wetlands in Washington and Oregon (from Kauffman et al. 2001).

2.6.3.4 Habitat Requirements of Some Wetland-Dependent Species in Washington

Invertebrates

Invertebrates have evolved unique adaptations enabling them to occupy most wetland habitats and most parts of the food web. In fact, wetland invertebrates can be distinguished from terrestrial and aquatic species at multiple taxonomic levels (family and genus) (Wissinger 1999). Wetlands are dominated by invertebrate families that are uniquely adapted to shallow and often fluctuating water levels (Wissinger 1999).

Wetland invertebrates are considered pivotal components of the food webs in wetlands (Mitsch and Gosselink 2000). As filter feeders, shredders, and scrapers, insects convert microorganisms and vegetation into biomass, providing much of the food for animals higher in the food web (secondary and tertiary consumers). Research focusing on aquatic invertebrates in wetlands indicates the importance of invertebrates in energy and the transfer of nutrients within aquatic ecosystems (Rosenberg and Danks 1987, Wissinger 1999). Invertebrates have adapted to processing the plant material produced in wetlands of every type and geomorphic setting. They are considered a major link in the movement of energy in the food web of wetlands (review in Wissinger 1999).

The abundance of invertebrates in wetlands can be extremely large. Leeper and Taylor (1998) measured annual densities in excess of 700,000 organisms per square meter in shallow depressional wetlands of South Carolina.

Factors found to influence the distribution, richness, and abundance of invertebrates in wetlands include the following:

- **Water interspersed with stands of emergent vegetation** in wetlands result in high species richness of invertebrates (Voigts 1976).

- **Decaying wood** provides an important habitat for invertebrates (Maser et al. 1988).

- A **mix of plant assemblages** exhibits greater richness of invertebrate species than a single assemblage (Andrews and Hasler 1943, Dvorak and Best 1982, Lodge 1985, Balla and Davis 1995). Furthermore, the density of invertebrates varies considerably among species of submerged aquatic plants (Murkin and Batt 1987), and different invertebrate species are found on different plant species (Cyr and Downing 1988). Vegetation is a major factor shaping wetland invertebrate communities (Krieger 1992, Wissinger et al. 1999).

- **Permanent flowing water** is a habitat feature that supports a unique assemblage of invertebrate species (Needham and Needham 1962, Wiggins et al. 1980, Rolauffs et al. 2001). Furthermore, the invertebrates in flowing permanent channels are an important resource for many other aquatic species such as fish (Needham and Needham 1962).

- **Marked seasonal changes in water regime** in wetlands result in higher richness of invertebrate species compared to wetlands with little water level fluctuation (Balla and Davis 1995).

- **Water regime** in wetlands is an important factor for individual species of invertebrates. Factors associated with water regime include: permanence of surface water, predictability of drying and filling, seasonal timing of drying and filling, duration of dry and wet phases, and the harshness during dry and wet phases(temperature, salinity, oxygen levels) (reviewed in Wissinger 1999).

Not much is known about invertebrate distributions in different soil surfaces within a wetland. However, data from rivers, streams, and lakes show that the local invertebrate species have preferences for specific surfaces (Gorman and Karr 1978, Dougherty and Morgan 1991). In streams it is well known that the composition of midges (chironomids) is strongly affected by characteristics of the sediment surface (McGarrigle 1980, Minshall 1984).

Amphibians

Amphibians are a vertebrate group that, in the Pacific Northwest, includes wetland-breeding frogs and salamanders. Both the richness and abundance of amphibians in wetlands indicate that they are important in wetland food webs (Leonard et al. 1993, Hruby et al. 1999). Some native species only breed for a short time in wetlands and then live in uplands as adults. Other species are found in or close to wetlands throughout the year. However, the eggs and larvae of all wetland-breeding species require water for development (Hruby et al. 1999).

Other information known about amphibians in wetlands includes the following.

- The **presence of buffers and undisturbed uplands and forest cover** leading to other wetlands or to upland habitat is critical. Relatively undisturbed migration routes between a wetland and upland feeding and hibernation sites are important for many amphibian species (Heusser 1968, Berven and Grudzien 1990, Beebee 1996). Moreover, dispersal routes for recolonization are critical when populations are eliminated by random processes including drought (Pounds and Crump 1994), disease (Bradford 1991), or pollution (K. Richter, PhD. personal communications 2000), or when populations produce insufficient offspring to permanently occupy a site (Gill 1978a, 1978b, Sinsch 1992). Finally, inbreeding is minimized when the amphibians within a wetland are members of a population that extends across several wetlands (Gulve 1991, 1994, Pechmann and Wilbur 1994).

- **Conditions in the buffers** of a wetland are especially important in providing cover to amphibian females and to newly metamorphosed animals. Female red-legged frogs (*Rana aurora*), Northwestern salamanders (*Ambystoma gracile*) (K. Richter, PhD. personal communication, 2000), and long-toed salamanders (*A. macrodactylum*) (Beneski et al. 1986, Leonard and Richter 1994) generally wait in buffers near wetlands until environmental and biological conditions are favorable to spawning. They then enter wetlands during one or a few nights to spawn, thereafter quickly retreating to the cover provided by buffers. Buffers are important to the tiger salamander (*A. tigrinum*, a species found in eastern Washington) seeking shelter in rodent burrows during the first days following emigration from ponds in which they are born (Loredo et al. 1996).

- Most species of amphibians select **areas with interspersed vegetation and exposed water** in which to lay eggs (K. Richter, PhD. personal communication 2000). Most species of amphibians generally avoid both exposed water and densely vegetated sites, instead selecting habitats with an interspersion of both features (Strijbosch 1979, Ildos and Ancona 1994).

- **Stable water levels** provide optimum habitat conditions for amphibians from spawning through hatching. Water level fluctuations are known to have a significant influence on amphibians (Richter 1996, 1997). Most species of amphibians in temperate climates minimize exposure of eggs to fluctuating depths and temperatures by both spawning at mid-depth and by submerging eggs below the surface (Richter 1997). Amphibian egg development also depends on permanent or partial submergence. In most Puget Sound species stable water levels occurs from mid-December through mid-May. Although mean water level fluctuations exceeding approximately 8 inches (20 cm) have been correlated to decreased amphibian richness in wetlands , experiments by Azous and Richter (1995) suggest that extended drops of more than approximately 3 inches (7 cm) from the time of egg laying through hatching may harm the Northwestern salamander.

- **Vegetation structure**, particularly plant shape and stem diameter, rather than the species of the plant has been suggested to be most important to salamanders. Wetland surveys and controlled field studies of several Northwest salamanders confirm that distinct stem widths are preferred (Richter 1997).

Anadromous Fish

Anadromous fish are those that spend all or part of their adult lives in salt water and return to freshwater streams and rivers to spawn. There are 12 species of anadromous fish in the Pacific Northwest (PSMFC 2001), but not all are regular users of wetlands.

The Pacific Northwest salmonids (species of the genus *Oncorhynchus*) have recently been the focus of much research because of the status of some species as threatened or endangered. The most common anadromous species that uses wetlands is the coho salmon (*Oncorhynchus kisutch*). Other anadromous fish noted in wetlands found in side channels, or old oxbows, of rivers and streams (off-channel wetlands) include cutthroat trout (*O. clarki*) and steelhead (*O. mykiss*) (Peterson 1982).

It is not the intent of this review to summarize all the information available on the habitat needs of salmonids. Some of the most important habitat structures in wetlands that have been found to be important for anadromous fish are summarized below:

- The **presence of ponded or impounded surface water** that is either seasonal or permanent is critical. "Slope" wetlands in Washington are the only class of wetlands that do not have the potential to provide habitat for anadromous fish because, by definition (Brinson et al. 1995) they do not have ponded or impounded surface water that is either seasonal or permanent.

- A wetland must have a **surface water connection** to a salmon-bearing stream or river if fish are to enter or exit the wetland (Hruby et al. 1999).

- **Interspersion between land and water** in a wetland is important because the contact zones between exposed water and vegetation provide protection from wind, waves, and predators, and may provide natural territorial boundaries (Golet and Larson 1974).

- Anadromous fish need a certain **water depth** for optimum habitat conditions. Narver (1978) observed juvenile coho moving into areas with water depth over approximately 18 inches (45 cm) and lower velocities (6 inches [15 cm] per second) when temperatures decline below approximately 41^{o}F (7^{o}C). Beaver ponds and off-channel areas with similar depths also provide habitat (Reeves et al. 1989). Survival and growth of overwintering fish may be maximized in systems that contain both shallow pools and deeper ones (Peterson 1982).

- **Cover** provided by wetlands is important for salmonids**.** Overhanging vegetation provides both temperature control and protection from predation. McMahon (1983) reported the need for streamside vegetation for shading. Small coho juveniles tend to be harassed, chased, and nipped by larger juveniles unless they stay near the bottom, obscured by rocks or logs (Groot and Margolis 1991). Cover for salmonids in wetlands can be provided by (Giger 1973):

- Overhanging vegetation
- Submerged vegetation
- Submerged objects such as logs and rocks
- Floating debris
- Deep water
- Turbulence
- Turbidity (the assumption seems to be that cloudy water reduces the visibility of fish in open water where birds may prey on them)

Resident Fish

Fish that do not migrate out of wetlands are considered "resident fish." Many different fish species use wetlands and it is not practical to list all that occur in Washington's wetlands.

Before the late 1800s, the only resident freshwater game fish living in Washington State were trout, char, whitefish, burbot, and squawfish. Since then there has been a widespread and often indiscriminate introduction of game species from other parts of the nation (Washington State Department of Fish and Wildlife 1999b).

Some of the characteristics in wetlands that provide habitat for resident fish include the following.

- Resident fish, like anadromous fish, need a **range of water depths** for different parts of their life cycles (Hruby et al. 1999). Shallow waters provide refuge for young fish, while the deeper waters provide refuge for the larger adults. Varying water depths also provide different potential food sources since they are host to different populations of plants and invertebrates (see the earlier discussion of invertebrate habitat). Olympic mud-minnows rear in wetlands with water only a few inches deep in floodplains (R. Ziegler, Washington State Department of Fish and Wildlife, personal communications 2003).

- **Shorelines between exposed water and vegetation** provide protection from wind, waves, and predators, and may provide natural territorial boundaries (Golet and Larson 1974).

- **Overhanging vegetation** provides both temperature control and protection from predation (McMahon 1983).

- **Large woody debris** plays an important role in the Pacific Northwest, creating and enhancing fish habitat (Bisson et al. 1987).

Birds That Are Closely Associated With Wetlands

Bird species that are *closely associated* with wetlands are those that depend on part or all of its life requirements; these include food, shelter, breeding, or resting. Kauffman et al. (2001)

reviewed the literature and found a very high richness and abundance of birds in wetlands of the Pacific Northwest. They found that:

> *All 23 species of waterfowl that breed regularly in the western U.S. south of Alaska do so in riparian and wetland environments. Similarly, all 14 western species of waders, a group consisting of cranes, rails, herons, and ibises, depend on riparian and wetland habitats for most of their life cycles. Shorebirds, which include stilts and avocets, sandpipers, and plovers are typically dependent on freshwater, riparian, and wetland habitats. Interior wetlands (i.e., east of the Cascades) also provide crucial stopover habitat for 37 species during migration.*

A review of the specific habitat requirements of all birds using wetlands is beyond the scope of this document. General characteristics of wetlands and their buffers that provide good habitat for wetland-dependent birds include the following:

- The **condition of the wetland buffer** is an important characteristic for bird habitat. Trees and shrubs provide screening for birds, as well as providing additional habitat in the buffer itself (Johnson and Jones 1977, Milligan 1985).

- The **width of the buffer** as well as its condition is important (see Chapter 5 for a more detailed discussion of the use of buffers by birds).

- **Snags** are a source of cavities and perches for wetland-associated birds. Several species of birds use already existing cavities for nesting and/or refuge locations. Dead wood attracts invertebrates and other organisms of decay, which in turn provide a food source for many species of birds (Davis et al. 1983).

- Some bird species may require **several habitat types** such as open water and grasslands in close proximity to aid their movements from one type to another (Gibbs et al. 1991, Hunter 1996).

- **Embayments and peninsulas** in a wetland with open water provide “micro-habitats” for certain species that require hiding cover or those seeking security within a more enclosed system (U.S. Department of the Interior 1978).

- The **proximity of a wetland to open water or large fields** increases its utility to migrant and wintering waterfowl. If there is strong connectivity between relatively undisturbed aquatic areas, the suitability of a wetland as waterfowl habitat increases (Gibbs et al. 1991).

- **Open water of varying depths** provides greater diversity of foraging habitat for a greater variety of water birds (U.S. Department of the Interior 1978).

- A **full canopy can limit access** to open water in a wetland because birds have difficulty flying in and out. This may be best illustrated by great blue herons (*Ardea herodias*), which will be reluctant to fly down to a body of water if the tree canopy above is totally closed because rapid escape may be difficult or impossible (U.S. Department of the Interior 1978).

Mammals That Are Closely Associated With Wetlands

For the purpose of this review it is not practical to synthesize the specific habitat requirements of all mammal species using wetlands. The richness of mammal species using wetlands can be very high. Kauffman et al. (2001) report that 79 mammal species east of the Cascades and 69 on the west side use riparian wetlands. The wetlands associated with stream corridors characteristically have greater species richness than upland sites and provide habitat for some species that are not found elsewhere. About half of the species using riparian wetlands in the Pacific Northwest breed and feed in them (Kauffman et al. 2001.)

The following bullets summarize some general information about the characteristics of wetlands that provide good habitat for four mammal species that were modeled as wetland dependent in the Washington State methods for assessing functions (Hruby et al. 1999). These species include the beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), river otter (*Lutra canadensis*), and mink (*Mustela vison*).

- Wetlands with a **relatively undisturbed buffer** are important to these four species (and others) because the buffers:
  - Minimize disturbance (Allen and Hoffman 1984, Burgess 1978)
  - Provide habitat for prey species and food sources for mammals (Allen 1983, Dunstone 1978, Brenner 1962)
  - Provide cover from predators (Melquist et al. 1981)
  - Allow den sites for resting and reproduction (Allen 1983)
- Beavers prefer a **seasonally stable water level** (Slough and Sadleir 1977). Large fluctuations in water levels may also affect the suitability of a wetland for muskrats (Errington 1963). Wetlands subject to heavy spring runoff or flash floods that rapidly raise the water level may cause flooding of burrows (Errington 1963).
- For beavers and muskrats, **water depth must be of sufficient depth. For beavers the water must be deep enough** to accommodate lodges and bank dens and to allow free movement from the lodge to food caches during the winter. For example, freezing of the food cache is a limiting factor on beaver and muskrat survival in the Columbia Basin (J.Tabor, Washington State Department of Fish and Wildlife, personal communication 2000). Freezing of a pond to the bottom can be disastrous to muskrat populations (Schmitke 1971). Deep water will also provide protection from predators (Easter-Pilcher 1987). In the Columbia Basin beavers and muskrats need at least 4 feet (1.3 m) of permanent water to allow access to food caches during the winter when the surface is frozen (Hruby et al. 2000).
- **Vegetated corridors** leading to and from wetlands are considered an important feature in assessing the suitability of a wetland as habitat for wetland dependent mammals (Hruby et al. 2000). Dispersal is a fundamental process in regulating populations among these and other mammals (Kauffman et al. 2001).

- Muskrats and beavers use **persistent emergent cover** for security and feeding (Errington 1963). Allen (1983) believes that beavers prefer herbaceous vegetation over woody vegetation during all seasons, if available.

- **Interspersion of vegetation and open water** is an important characteristic of wetlands as habitat for mammals. High interspersion rates increase the abundance of prey for mink and river otter (i.e., muskrats, water birds, fish) (King 1983). Food abundance and availability appeared to have the greatest influence on habitat use by river otter in Idaho in studies by Melquist and Hornocker (1983). Classic studies of muskrats by Dozier (1953) and Errington (1937) indicate that optimum muskrat habitat is 66% to 80% of the wetland in emergent vegetation with the remainder in open water.

2.6.3.5 Habitat for Plants

Relatively few plant species of the thousands on Earth have adapted to the harsh conditions in wetlands. Major stressors are lack of oxygen, salt, and water level fluctuations in an environment that is neither fully aquatic nor terrestrial (Mitsch and Gosselink 2000). These strong selective pressures have produced a group of plant species that is unique to wetlands and whose maintenance has become an issue in regional biodiversity (Gibbs 2000). Furthermore, wetlands can provide habitat for a wide range of other plant species when conditions are not as harsh. Of the 2969 plant species found in Washington, 1515 (or 51%) have been found in wetlands (FEMAT 1993).

All wetlands provide the four basic requirements for plant growth (space, water, light, and nutrients) to some degree. Differences can be found among wetlands in the number of plant species they contain. Recent research has been focused on the characteristics of wetlands that affect plant richness, as summarized below:

- **Specific water regimes**, such as permanent inundation, seasonal flooding, or saturation, result in unique plant communities (Mitsch and Gosselink 2000).

- The **duration of individual flooding events** is important in separating plant communities because the duration affects germination of seeds in different ways (Casanova and Brock 2000).

- The **water regime** in a wetland can either limit the number of species present or enhance it, depending on types of water level fluctuations and physical energy of the water regime (Mitsch and Gosselink 2000).

- Plant richness in a wetland generally follows the ecological theory that maximum richness occurs at **intermediate levels of environmental stress** (Johnson and Leopold 1994). For example, water level fluctuation is an environmental stress (Mitsch and Gosselink 2000). Wetlands with large water level fluctuations, therefore, would be expected to have fewer plant species than those with moderate water level fluctuations. On the other hand, wetlands with very small water level fluctuations (low stress) would also be expected to have fewer plant species.

- Wetlands with **different water depths** tend to have higher richness than those with fewer (Hruby et al. 1999). Observations show that the distribution of species within a wetland is primarily a function of water depths (Spence 1982 as cited in van der Valk et al. 1994).
- The **proximity of other wetlands** as a source of seed (Brock et al 1994, Brown 1998).

2.6.3.6 Supporting Food Webs (Primary Production and Export)

Wetlands are known for their high primary productivity (i.e., production of plant material) and the subsequent export of this organic matter to adjacent aquatic resources. The exported organic matter provides an important source of food for most downstream aquatic ecosystems (Mitsch and Gosselink 2000).

Plant material produced in wetlands breaks down into smaller and smaller particles and becomes increasingly nutritious due to the activity of bacteria, fungi, and protozoa (Sipple 2002). This decomposed plant material, including the various microbes that colonize it, feeds many small aquatic invertebrates and small fish. These invertebrates and fish then serve as food for larger predatory amphibians, reptiles, fish, birds, and mammals (Sipple 2002).

The following summarizes general characteristics of wetlands that have high production and provide excellent support for aquatic food webs.

- In general, wetlands **where water flows through the system** have higher levels of primary production and export than those where water is impounded without leaving (Mitsch and Gosselink 2000).
- The **water level fluctuation** as well as movement of water mentioned above through the wetland and its **soils** is one of the most important determinants of primary productivity (Mitsch and Gosselink 2000).
- Performance of this function requires both that **organic material** is produced and that a mechanism is available to move the organic matter to adjacent or contiguous aquatic resources (Hruby et al. 1999).

2.6.4 Summary of Key Points

- The residence time of water in the wetland and filtering by wetland vegetation are major processes influencing removal of sediments, phosphorus, and toxics from surface water. Wetland vegetation typically removes 80% to 90% of sediment from runoff. Wetlands with seasonal inundation or saturation have conditions that promote removal of nitrogen from surface runoff. In order for a wetland to provide functions that improve water quality, however, surface water containing pollutants must first enter the wetland.
- The capacity of a wetland to store surface water affects its ability to reduce peak flows, as do the amount of flow from the upper watershed that enters the wetland and the amount of woody vegetation present. Reducing peak flows helps to decrease downstream erosion.

- Only wetland types that impound surface water have the potential to provide groundwater recharge.

- Wildlife species can be *wetland dependent* or *wetland users*. Wetland-dependent species (such as amphibians) require a wetland for at least part of their life cycles. Wetland users (such as deer) come to wetlands for such needs as water or cover.

- The characteristics of wetlands that provide habitat depend on species and life stage. Characteristics that are important for many species include vegetation structure, water depth, water level fluctuation, buffers, snags, and connections to other habitats and wetlands in the landscape.

- Wetlands have high productivity of plant material. Decomposed plant material can be exported downstream, providing food for insects, fish, and other organisms in the food web.

2.7 Chapter Summary and Conclusions

The functions of wetlands are things that wetlands “do.” They represent the many interactions possible among the different components of the environment found in wetlands. There are many interactions that occur in wetlands and they occur at many scales. In general, however, functions are grouped into three broad categories: 1) biogeochemical interactions, 2) hydrologic interactions, and 3) interactions that maintain food webs and habitats for plants and animals.

The primary factors that control wetland function are climate, geomorphology, the source of water, and the movement of water. These factors affect wetland functions directly or through a series of secondary factors including nutrients, salts, toxic contaminants, soils, temperature, and the connections created between different patches of habitat. The factors that control wetland functions interact with each other and there are many feedback loops. A number of conceptual models have been developed to help visualize and understand the complexity of the interactions between environmental factors, environmental processes, and wetland function.

The major environmental factors of geomorphology, source of water, and the movement of water are the basic characteristics used to classify wetlands in Washington into groups of wetlands that have similar functions. These groups can be expected to perform these functions in similar ways. Freshwater wetlands in Washington are divided, based on how they function, into two domains, five regions, and six classes.

The environmental factors that control the structure and functions of a wetland occur at both the landscape scale and the site scale. For example, riverine wetlands will be affected to a great degree by processes operating at the scale of the entire watershed of the river. Depressional wetlands will be subject to processes that occur only within the basin that contributes surface or groundwater to the wetland.

The most important factors that control functions at an individual site may occur somewhere else in the landscape. Information about factors that control functions at the larger scale is still evolving. The importance of the environmental factors that occur at the larger, landscape scale, however, should not be minimized for lack of information. Ongoing research is continually strengthening our understanding of these critical factors.

The links between wetland functions and the landscape have been well described by the National Academy of Sciences (National Research Council 1995):

> *Individual wetlands function to a large degree through interaction with the adjacent portions of the landscape and with other wetlands. For example, wetlands whose principal source of water is groundwater depend on that water infiltrating in the surrounding uplands. If these uplands are paved, clear-cut, or farmed, the amount of water recharge is significantly reduced and the wetland may dry up or become smaller. No single wetland or aquatic site could support anadromous fish. The connections between individual wetlands, aquatic systems, and terrestrial systems are critical to the support of many species. Furthermore, flood control and pollution control are determined by the number, position, and extent of wetlands within watersheds. Thus, the landscape gives proper context for the understanding of some wetland functions.*

An understanding of wetland functions for the purposes of managing and protecting them will require knowledge of how the major controls of functions change or are impacted by humans at all scales. We need to understand how climate, topography, and the movement of water, nutrients, sediment, etc. are affected by human activities in the entire watershed, as well as in the immediate vicinity of the wetland. Chapter 3 describes the environmental disturbances caused by different human uses of the land. Chapter 4 then carries this information forward to discuss how the disturbances caused by human activities affect specific functions of wetlands.

Chapter 3

Environmental Disturbances Caused by Human Activities and Uses of the Land

3.1 Reader's Guide to this Chapter

In Chapter 3, the discussion shifts from wetland functions and the environmental factors that control the performance of functions to the major disturbances created by human activities and uses of the land and water. In this context, a *disturbance* is an event that changes an environmental factor that controls wetland functions.

3.1.1 Chapter Contents

Major sections of this chapter and the topics they cover include:

Section 3.2, Introduction to Human-Caused Disturbances provides an overview of how human land uses change the dynamics and structure of the ecosystems by creating various types of disturbances. The section provides a general overview of how human activities affect the movement and quality of water and connections between habitats across the landscape.

The chapter continues with separate sections for four of the major types of human land uses in Washington State (agriculture, urbanization, logging, and mining) and how they cause disturbances. The different uses of the land by humans are divided into these four categories because most of the literature found discusses the disturbances and impacts of human activities in these terms.

Each major land use is addressed in a separate section, as follows:

Section 3.3, Disturbances Caused by Agriculture, discusses the changes in the physical structure of wetlands such as conversion to fields or pasture, changes in water regime such as changes to the amount and fluctuation of water, and the input of nutrients, salt, sediment and contaminants caused by agriculture.

Section 3.4, Disturbances Caused by Urbanization, discusses the changes urbanization has made, causing a loss of wetlands as well as changes to the water regime in watersheds. It describes how this land use has resulted in sedimentation, increase in nutrients, input of contaminants, and fragmentation of habitat.

Section 3.5, Disturbances Caused by Forest Practices, refers the reader, after a brief summary, to another synthesis that summarizes the literature on the disturbances created by logging.

Section 3.6, Disturbances Caused by Mining, discusses the increased level of heavy metals and acidity in surface waters that results from mining.

Section 3.7, Chapter Summary and Conclusions, ties together the major concepts presented in the chapter in a tabular form. Also, the disturbances caused by each of the four land uses are summarized.

3.1.2 Where to Find Summary Information and Conclusions

Each major section of this chapter concludes with a brief summary of the major points resulting from the literature review on that topic in a bulleted list. The reader is encouraged to remember that a review of the entire section preceding the summary is necessary for an in-depth understanding of the topic.

For summaries of the information presented in this chapter, see the following sections:

- Section 3.2.6
- Section 3.3.11
- Section 3.4.9

As previously mentioned, Section 3.7 provides a summary and conclusions about the main themes synthesized from the literature and presented in this chapter.

3.1.3 Sources and Gaps in Information

There is abundant data on some of the topics related to wetlands and the effects of land uses on water quantity, water quality, and some habitat issues. For example, the Puget Sound Wetlands and Stormwater Management Research Program was one important source of scientific information on how changes in land uses affect the physical, chemical, and biological factors that control wetland functions in the lowlands of Puget Sound. The research program has published numerous articles in scientific journals and has summarized much of the information developed in a book by Azous and Horner (2001).

In contrast, information on the effects of agricultural practices in the Pacific Northwest, especially in eastern Washington, is limited. Most studies originate from the prairie pothole region of the United States, the high mountain West, or California. The literature related to agriculture from outside the Pacific Northwest region has been included in this synthesis when it was judged to be relevant to Washington.

No scientific studies were found that examined the question of whether some wetlands in eastern Washington existed before the onset of irrigation projects. Research has been conducted by Adamus on irrigated agricultural lands from the high basin country of Colorado (Adamus 1993), but may not be germane to eastern Washington because soils and the surface geology are different. However, this study is included in the section on the influence of irrigation on wetlands because it discusses some of the issues that are relevant to the Columbia Basin.

3.2 Introduction to Human-Caused Disturbances

Human activities on the land increasingly represent a fundamental source of change in the global environment (Dale et al. 2000). Alterations to land use and land cover can often change the environmental factors that control functions within a wetland. Modifications in the environment that cause changes in how ecosystems function are called *disturbances*. Pickett and White (1985) define *disturbance* as “any relative discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment.”

Disturbances to ecosystems are commonly viewed negatively as a disruption of equilibrium in an ecosystem. A growing science based on non-equilibrium theory, however, indicates that disturbances are an essential ecological process. They are necessary at some level of intensity and periodicity for the long-term maintenance of most, if not all, ecosystems (Averill et al. 2003). Disturbance occurs as a continuum from frequent intervals of low intensity to infrequent occurrences of high intensity (Pickett and White 1985). The average frequency of a given disturbance is inversely proportional to its intensity (Waldrop 1992). Large, intense, disturbances are rare and small ones frequent. Ecosystems have evolved in response to specific regimes of disturbances that have recurred over millions of years (Averill et al. 2003).

The disturbances caused by humans, however, often differ from those that occur naturally. They occur at different scales, different intensities, and different geographic locations (Dale et al. 2000). As a result ecosystems tend to respond in unexpected ways to human activities and many functions that ecosystems provide change or are diminished. Scientists sometimes use the term *stressor* to distinguish those disturbances that have a major impact on an ecosystem from those that maintain the usual structure and function of an ecosystem (see for example Adamus et al. 2001, Laursen et al. 2002). For the purposes of this discussion, however, only the term *disturbance* is used to simplify the discussion. All the disturbances discussed herein are stressors considered to have major impacts on ecosystems, and they are not the ones that maintain the existing structure and functioning in an ecosystem.

3.2.1 The Link between Wetland Functions, Human Land Uses, and Changes in Wetlands

In terms of wetlands and their functions, a disturbance can be considered as a condition or event that changes one of the environmental factors that control wetland functions. For example, nutrients are a factor that controls wetland functions. If nutrients from residential lawns flow to a depressional wetland that has limited nutrients, such as a bog, the excess nutrients can change the dominant plants in the bog and its habitat structure. In this case, the addition of nutrients that are in excess of those found in the absence of human activities is a disturbance on the functions of the wetland.

This example illustrates how changes in land use can influence large-scale environmental processes, resulting in disturbances to the factors that control wetland functions. It also illustrates how the topics discussed in Chapters 2, 3, and 4 of this volume are linked:

- The movement of nutrients throughout a basin, as described in the example, is one of several environmental factors that control wetland functions. These factors and the way in which they control wetland functions are the subject of Chapter 2.
- The maintenance of residential lawns is an example of a human activity that may affect the movement of nutrients in a basin. The application of excess nutrients (fertilizer) creates a disturbance when the nutrients flow from the lawn into a bog. This chapter (Chapter 3) describes how different kinds of human activities and uses of the land create environmental disturbances.
- When the excess nutrients reach the bog, they cause a change in its plant community and its habitat structure because the plant communities are adapted to a low-nutrient, acidic environment. Chapter 4 describes how disturbances caused by human land uses result in changes to wetland functions.

Figure 3-1 reviews the connection between the factors that control wetland functions, human-caused disturbances, and the functions of wetlands.

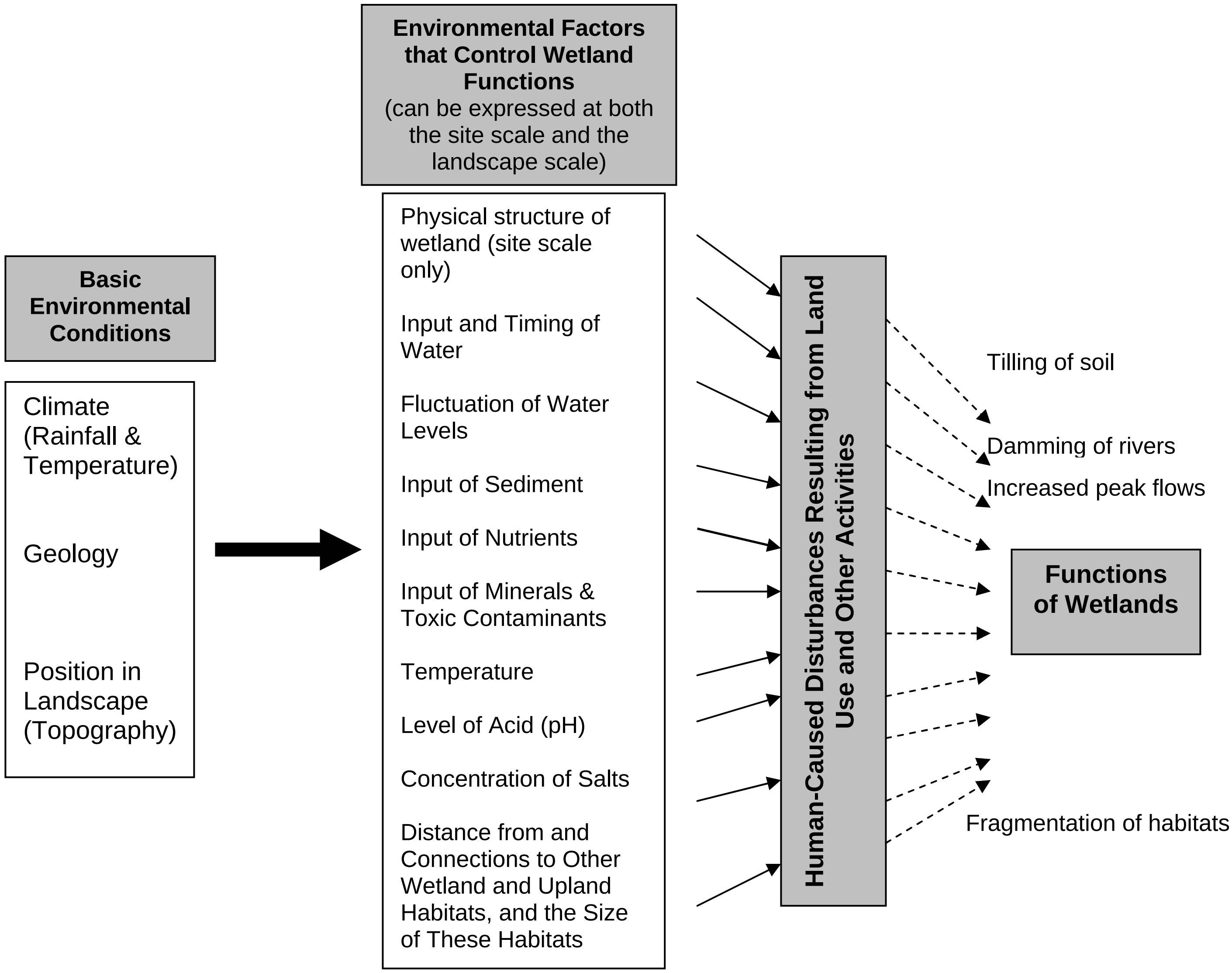

Figure 3-1. Diagram summarizing some major environmental factors that control functions of wetlands and how they interact with human-caused disturbances.

The basic environmental conditions establish and determine the factors that control the functions of wetlands. The controls can occur at both the landscape and site scales. Human activities cause disturbances that affect these controls in many different ways and thereby alter the performance of wetland functions. The figure gives some examples of the disturbances. This figure is the same as that in Chapter 2, Figure 2-3.

3.2.2 Types of Disturbances Resulting from Human Land Uses

Many different types of disturbances have been identified in the literature. For the purposes of organizing the information in this chapter, the list developed by Adamus et al. (2001) and shown in Table 3-1 is used because it was developed specifically to address impacts to wetland functions. Table 3-1 lists the types of disturbances that can impact wetlands and the scale at which the disturbances can occur. Many disturbances that result from human uses of the land can occur over large areas such as basins and sub-basins (called the landscape scale), as well as in the wetland itself and in its immediate vicinity (called the site scale).

Table 3-1. Summary of human-caused disturbances and the scale at which they can occur.

Disturbance	Scale of Disturbance
Changing the physical structure within a wetland (e.g., filling, removing vegetation, tilling soils, compacting soils)	Site
Changing the amount and velocity of water (either increasing or decreasing)	Landscape and site
Changing the fluctuation of water levels (frequency, duration, amplitude, direction of flow)	Landscape and site
Changing the amount of sediment (increasing or decreasing the amount)	Landscape and site
Increasing the amount of nutrients	Landscape and site
Increasing the amount of toxic contaminants	Landscape and site
Changing the temperature	Mostly site
Changing the acidity (acidification)	Landscape and site
Increasing the concentration of salt (salinization)	Mostly site
Fragmentation (decreasing area of habitat and its spatial configuration)	Landscape
Other disturbances (noise, etc.)	Landscape and site
This table is a synthesis of the information presented by Adamus et al. (2001) and in the literature review done for this document.	

3.2.3 Disturbances to the Movement of Water at the Landscape Scale

The movement and sources of water in the landscape are two critical factors controlling how wetlands function. Many human land uses change the movement and sources of water, thereby creating a disturbance that affects the performance of functions in wetlands. The following provides some background on how human activities result in disturbances to the movement and sources of water.

The literature is quite clear that the frequency, timing, and duration of water in the landscape determine the presence of a wetland and the functions that it provides (see Chapter 2). How water enters a wetland, how long it is present, and the depths to which it is impounded all influence the functions that a wetland can provide or perform (Brinson 1993a, Mitsch and Gosselink 2000).

Surface and subsurface water flows through the landscape within “drainage systems.” These drainage systems are often called basins, sub-basins, watersheds, or river basins depending on the size of the area. In this document, drainage systems are generally referred to using one of two terms:

- ***Watershed*** - A geographic area of land bounded by topographic high points in which water drains to a common destination.
- ***Contributing basin*** - The geographic area from which surface water drains to a particular wetland.

Booth (1991) succinctly summarizes the concept of a drainage system as follows:

> *Drainage systems consist of all of the elements of the landscape through which or over which water travels. These elements include the soils and the vegetation that grows on it, the geologic materials underlying that soil, the stream channels that carry water on the surface, and the zones where water is held in the soil and moves beneath the surface. Also included are any constructed elements, including pipes and culverts, cleared and compacted land surfaces, pavement and other impervious surfaces that are not able to absorb water at all.*

The movement and routing of water above and below the surface is the primary force in transporting nutrients, sediment, salts, and contaminants, and this in turn affects the functions provided by wetlands (Naiman et al. 1992). Water moves (or carries) sediment, nutrients, and energy throughout a watershed (Naiman et al. 1992). Changes in the amount of water, as well as in the frequency and fluctuations of water volumes, can alter how sediments, nutrients, and toxic contaminants come into a wetland. Changes in the movement of water resulting from human activities at the scale of the landscape can therefore have severe impacts on wetland functions throughout a watershed.

The following subsections provide background on how water moves in undisturbed landscapes as well as those that have been changed by human activities. The purpose of this discussion is to provide a context for understanding how human activities and uses of the land create the disturbances discussed later in the chapter.

Terms used to describe water regimes: hydrology vs. hydroperiod vs. hydrologic

Hydrology and hydroperiod are often used interchangeably to mean how water moves. *Hydrology*, as defined by Webster, is "the scientific study of the properties, distribution, and effects of water in the atmosphere, on the earth's surface, and in soil and rocks." The term hydrology means the study of how water moves.

Hydroperiod (not defined by Webster) is commonly used to refer more precisely to the periodicity of water; the timing (seasonal or otherwise) and duration of water's presence or absence within a particular aquatic feature, such as a wetland. It is "the seasonal occurrence of flooding and/or soil saturation, encompassing the depth, frequency, duration and seasonal pattern of inundation" (Azous et al. 2001). Mitsch and Gosselink (2000) define hydroperiod as "the seasonal pattern of the water level of a wetland . . . a hydrologic signature of each wetland type." Hydroperiod, in this context, refers to seasonal changes in wetland water level conditions caused by regular annual changes in water availability. This should be differentiated from the water level fluctuations driven by single or serial storm events.

Hydrologic is an adjective derived from the word "hydrology." It refers to the properties, distribution, and effects of water. Thus a term such as "hydrologic processes" refers to the environmental processes that involve the properties, distribution, and effects of water.

In this document, "hydroperiod" is used to refer to the pattern of water movement in a particular wetland or type of wetland. The term "hydrology" has been retained when direct quotes from sources use that term even if it has been misused. "Hydrologic" is used when an adjective is needed to describe the patterns of water movement.

3.2.3.1 Movement of Water in Undisturbed Landscapes

In undisturbed conditions, very little of the precipitation falling on the ground ends up in surface runoff, even in areas of high annual rainfall such as the Pacific Northwest. Areas with natural vegetation provide high rates of interception, infiltration, and evapotranspiration (Ziemer and Lisle 1998). The water either drips off leaves to the soil below; flows down the stems, leaves, and bark to the soil; or evaporates into the air, never reaching the ground.

Water that infiltrates into permeable surfaces either moves downgradient as shallow groundwater, infiltrates into a deeper water table, or is taken up by plant roots and transpired back into the atmosphere. Shallow groundwater flows downgradient through the pore spaces in the soils until it surfaces in a stream, wetland, or swale, sometimes in the form of a seep or spring.

Precipitation falling onto naturally impervious surfaces (e.g., bedrock), however, flows along the surface. Precipitation also flows along the surface if the soils become saturated and cannot hold any more water.

3.2.3.2 Movement of Water in Disturbed Landscapes

Human activities on the land change the movement of water across and through the landscape such that there are significant changes in runoff patterns and hydroperiods in a watershed (Booth 1991, Vought et al. 1995, Azous and Horner 2001). Surface runoff, rather than infiltration, comes to dominate water flows, as shown conceptually in Figure 3-2. The movement of water in a landscape can be altered by any of the following conditions:

- Removal of vegetation
- Compaction of soil (through grazing, earthwork, lawns, or playfields)
- Reduction in size of soil particles or the spaces between particles (through tilling or grading)
- Reduction in the organisms that aerate the soil
- Placement of drain tiles, ditching, road cuts, utility lines
- Construction of impervious surfaces
- Construction of dams and reservoirs

These conditions result from human land uses such as agricultural conversion, urbanization, and forest practices (Dunne and Leopold 1978, Booth 1991, Euliss and Mushet 1996). The disturbances from specific land uses to the movement of water and its sources are described later in this chapter. Information on the resulting impacts on wetland functions is synthesized in Chapter 4.

Removing vegetation allows precipitation to reach the soil surface faster, and therefore soil saturation occurs more rapidly. As soils become saturated, additional precipitation accumulates more rapidly on the surface and moves as sheet or surface flows. When soils are compacted, the precipitation cannot enter the soils readily and surface water accumulates more rapidly. Loss of permeability in the soil can persist even after compacted soils become vegetated as urban lawns, playfields, and in some agricultural conditions (Dunne and Leopold 1978).

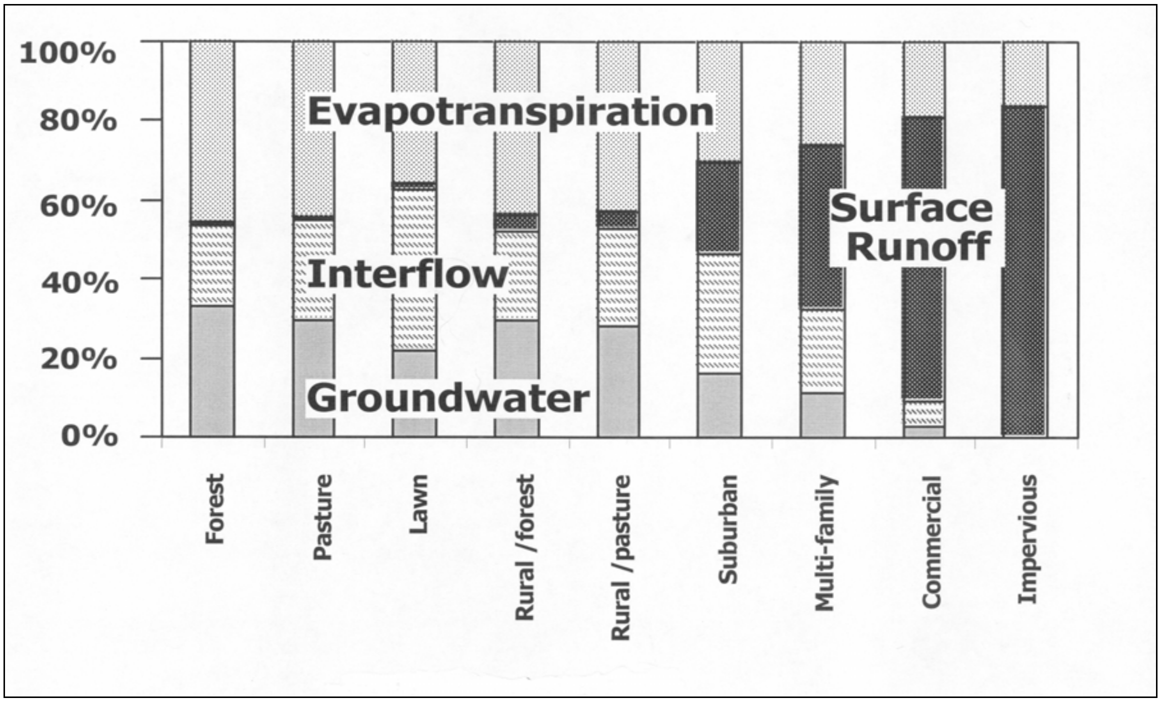

Figure 3-2. Changes in the proportion of groundwater, interflow, evapotranspiration, and surface runoff with different types of land cover in western Washington (Beyerlein 1999; reprinted with permission).

Under any of these conditions, runoff essentially becomes surface flow. Water flowing along the surface carries sediment and any other dissolved or adsorbed materials downgradient more rapidly than if the water is allowed to infiltrate in undisturbed soils (Ziemer and Lisle 1998). Studies in the Puget Sound region found that peak flows increase during storms as a result of urban development, but that the annual mean flow decreases (Konrad 2000).

In general, alteration of water flow in uplands results in a "shortening" of the path that water would naturally follow on its route through a watershed. It reduces the residence time of water in the ground and in bodies of surface water, such as streams or wetlands, within the watershed. On the other hand the construction of dams and weirs has resulted in the retention of water and a reduction in water velocity once the water reaches a stream or river.

Changing the water flow in uplands also results in increased rates and volumes of stormwater and changes the timing of stormwater entering aquatic systems. This can have numerous effects on aquatic systems as described in Section 3.4.2 on the effects of urbanization. For example, these changes circumvent or reduce:

- The removal of nutrients, pathogens, and toxics in the soil
- The filtering of sediment from surface flows through vegetated buffers and wetlands
- The reduction of downstream peak flows

3.2.3.3 The Role Of Impervious Surface In Changing Water Regimes

According to research throughout the country and in the Pacific Northwest described below, the degree of alteration in hydrologic processes and the subsequent impacts to aquatic habitats (including wetlands) is governed by the percent of impervious area and the percent of forested cover within a watershed. When soil is covered with impervious surfaces there is no opportunity for infiltration. All precipitation that falls on an impervious surface becomes surface water which flows downgradient.

Research in western Washington generally indicates that increases in the amount of impervious cover within a watershed can result in significant impacts to the habitat structure and function of freshwater aquatic systems (Azous and Horner 2001). Reinelt and Taylor (2001) discovered that 20% impervious cover in upstream development increased the peak and volume of stormwater runoff to the point that it began to dominate the hydroperiod of downstream wetlands. However, some scientists have concluded that trying to identify a specific threshold may not be accurate. As stated by Dr. Richard Horner "We are thoroughly convinced that there is no threshold; deterioration begins immediately and progresses at a rapid rate as soon as any amount of urban development begins" (Horner, University of Washington, personal communication 2004).

Defining and assessing impervious surface

The term *impervious surface* as used in the literature and in this document means more than just a hard impermeable surface such as an asphalt parking lot. There are many actions humans take that reduce the permeability of soils, and these are included in the calculations of "percent impermeable surface." For example, compacted soils found in lawns and landscaped areas function just as impervious surfaces do during storm events (May 1996).

Total impervious area (TIA) is sometimes challenging to assess without high-resolution aerial photographs and accurate GIS mapping capabilities (especially in watersheds with extensive forested coverage). Reinartz and Warne (1993) found that using road density as an indicator of basin impervious area resulted in findings nearly identical to those resulting from estimation of imperviousness from aerial photographs.

Reinelt and Taylor (2001) concluded that removing as little as 3.5% of the forested cover in a rural, low-density residential area resulted in changes in the pattern of water movement in the basin. Looking at percent forested cover in the Puget Sound Basin; Booth et al. (2002) have determined that natural hydrologic processes are maintained if 65% of a watershed remains in a forested condition. Because each watershed has different physical, chemical, and biological characteristics and patterns of impervious cover, the threshold at which aquatic resources experience significant effects will vary.

Table 3-2 summarizes additional findings on the effects of impervious cover on various biological characteristics of aquatic resources. As noted previously, specific impacts to wetland functions are described in Chapter 4.

Table 3-2. Summary of findings on the impacts of impervious cover.

Reference	Impacts to:	Key Finding
Booth (1991)	Fish habitat; channel stability	Channel stability and fish habitat quality declined rapidly with over 10% impervious cover
Taylor (1993)	Wetland plants and amphibians	Mean annual water level fluctuations are inversely correlated to density of plants and amphibians. Sharp declines occur when impervious cover exceeds 10%
Steedman (1988)	Invertebrates	Negative correlation between biologic integrity and increasing development at 209 streams. Degradation started at 10% impervious cover

3.2.3.4 The Role Of Dams In Changing Water Regimes

The construction and operation of dams affects the movement of water across large areas of the landscape. Regardless of their purpose, all dams trap particles to some degree and most alter the flood peaks and seasonal distribution of flows (Kondolf 1997). Dams disrupt the continuity of processes that occur at the landscape scale. Areas where water flowed fast may now have slow water movement and vice-versa (Kondolf 1997). In cases where water is transferred for irrigation or other purposes the reductions in discharge may greatly influence the hydrophysical conditions in the floodplain (Fjellheim and Raddum 1996).

There are four major aspects of changes to water regimes that result from the construction of dams (Bunn and Arthington 2002). These are:

- Reduction of the variability in flows
- Loss of some seasonal fluctuation in the wet/dry cycle
- Erratic daily patterns in the flow below hydroelectric dams
- Conversion of river and floodplain water regime (and habitat) to a lake water regime

Thus dams can change the water regime in a riverine and floodplain system to one that was not there previously, nor that could have been easily created by non-human factors.

For example, there are 211 major dams in the Columbia River Basin, 34 of which are on the main stems of the Columbia and Snake Rivers. The water levels in the reservoirs behind the dams operated by the Army Corps of Engineers rise and fall on a schedule unrelated to natural fluctuations. Levels in reservoirs may drop suddenly on a daily basis. The 211 dams also significantly reduce and slow the movement of water (Northwest Environmental Advocates, http://www.advocates-nwea.org/programs/U.html, accessed October 7, 2004).

3.2.4 Disturbances to the Quality of Water at the Landscape Scale

Two principal mechanisms have been documented to describe how land uses in a watershed change water quality in that watershed:

- Changes in hydroperiod increase erosion and sedimentation (Booth 1991, Booth and Reinelt 1993, Horner et al. 1996)
- Human uses of the land generate pollutants that are then transported into aquatic systems (Reinelt and Horner 1995)

Larger volumes of water, moving at faster rates, scour channels and cause rills in unvegetated soils. Moving water picks up and transports sediment and the pollutants associated with sediment particles. In addition, research shows that water flowing across the ground surface tends to pick up and convey dissolved nutrients and toxics directly into receiving waters (Young et al. 1980, Emmett et al. 1994, Gilliam 1994, Brenner 1995, Reinelt and Horner 1995, Vought et al. 1995, Crosbie and Chow 1999, Sheridan et al. 1999, Azous and Horner 2001).

Pollution conveyed by surface runoff (called *non-point-source pollution* by the U.S. Environmental Protection Agency) has been identified as the dominant source of pollutants in surface water. Non-point-source pollution is not discharged from the "end of a pipe" such as a large factory. Instead it is caused by sediment, metals, excess nutrients, and bacteria from a variety of dispersed sources (Reinelt and Horner 1995) such as stormwater, contaminated runoff from urban settings, agricultural runoff, and construction runoff (Baker 1992). These pollutants can have numerous impacts on wetlands and their functions as described in Chapter 4.

3.2.5 Disturbances to Habitats at the Landscape Scale (Fragmentation)

Human activities within a landscape often break up environment into small patches of habitat that are separated by roads, buildings, or tilled fields. The breaking up of the environment into habitat "patches" separated by areas altered by human land uses is a disturbance that is called *fragmentation*. Habitat fragmentation consists of both the reduction in the area of the original habitat and a change in spatial configuration of what remains (Haila 2002).

Suburban and urban development, farmlands, roads, railroads, powerline corridors, and other land uses cause various kinds and degrees of fragmentation (Heinz Center for Science 2002). These are discussed in more detail in subsequent sections of this chapter. In addition, human activity can create landscapes that are less varied than the landscapes historically present. Particularly in the West, natural fires create a patchy landscape, where forest and grasslands are intermingled in a mosaic. Fire suppression and the large fires that result after long periods of suppression can create broad expanses of very similar vegetation (Heinz Center for Science 2002).

All environments, with or without human activities, are fragmented to some degree and are subjected to continuous change due to “natural” causes. As a result, no straightforward standard is available for assessing human-caused fragmentation. Furthermore, different ecosystems and the species they support experience the effects of fragmentation in variable, even contradictory ways (Haila 2002). For example, the breaking up of a certain habitat into patches may increase the populations of certain species by keeping predators from moving between patches. Such patches, however, will reduce the populations of predators because their access to prey will be reduced (Fahrig 2003).

The effect of human-caused fragmentation needs to be considered at different spatial and temporal scales, and the relevant scales will vary across species, geographic regions, and types of environment (Haila 2002). The types of fragmentation caused by the major land uses is described in this chapter, and the impacts of fragmentation on the functions of wetlands are described in Chapter 4.

3.2.6 Summary of Key Points

- Many human land uses change the movement and sources of water in a watershed, thereby creating a disturbance that affects the performance of functions in wetlands.
- In general, alteration of water flow by human uses of the land results in a “shortening” of the path that water would follow on its route through a watershed. It reduces the residence time of water in the ground and in the bodies of surface water, such as streams or wetlands, within a watershed.
- Changes in the amount of water and the frequency and fluctuations in water volumes can also change how sediments, nutrients, and toxic contaminants come into a wetland.
- Research in western Washington generally indicates that increases in the amount of impervious cover within a watershed can result in significant impacts to the habitat structure and function of freshwater aquatic systems.
- Two principal mechanisms have been documented to describe how land uses in a watershed change the water quality in that watershed: (1) land uses increase erosion and sedimentation, and (2) human uses of the land generate pollutants that are then transported into aquatic systems.
- Human activities within a watershed often break up the nevis and habitats into small patches and this disturbance is called fragmentation.

3.3 Disturbances Caused by Agriculture

This section describes the types and severity of disturbances that can be caused by agricultural practices. As mentioned previously, these disturbances can, in turn, affect factors that control wetland functions and are discussed in Chapter 4.

Wetlands have historically been some of the first places on the landscape that were used for agriculture. In western Washington, sites with flat topography suitable for agriculture were often located in river or stream floodplains. Many areas of these floodplains were wetlands with high water tables that persisted late into the growing season. Most early descriptions of Northwest rivers tell of valleys so wet that trails followed 'the borders of mountains' (Sedell and Luchessa 1982). Much of the flooding was a result of beaver activity that modified the flood plain and created areas where sediments could accumulate. Because the bottom land had accumulated fine silts and organic matter of alluvial origin, the land was fertile and drained early in the development of Oregon and Washington (Sedell and Luchessa 1982).

Agricultural practices play a significant role in influencing water movement in many regions of Washington. However, much of the research on wetlands in Washington over the last 10 years has been on the effects of urbanization. Although some of the consequences and effects of agriculture and urbanization may be the same or similar, others may be quite different. For example, agricultural practices in some parts of the state such as the Columbia Basin may have resulted in the creation of wetlands, or the expansion of pre-existing wetlands through the introduction of water from irrigation (Foster et al. 1984).

Cranberry growing operations in Washington are a type of agricultural land use that affects wetlands. However, cranberry production is limited to very small areas along the southern Washington coast in Pacific and Grays Harbor counties. The types of impacts that occur from conversion of wetlands to cranberry production are very different from other types of agricultural impacts. Due to the limited area affected, and time and funding limitations, this synthesis does not attempt to address the effects of cranberry production on wetlands in the state.

3.3.1 Loss of Wetlands and Changes to the Physical Structure of Wetlands from Agricultural Practices

Agriculture disturbs the physical structure of wetlands directly through conversion of the wetland to fields or pasture that often leads to the elimination of wetlands themselves. Conversion activities include filling or tilling, draining through tiles or channels, or removing the wetland vegetation and planting upland vegetation or crops. For example, tilling the soil within a wetland will disturb its soil structure (Nowak 1980, Hayes 1995). Livestock grazing in riparian wetlands also has well documented effects on the structure of plants and soils in wetlands as described below. Another example of disturbing the physical structure of riparian wetlands is the building of dams for irrigation since water flow is a major determinant of the physical habitat in aquatic systems (Bunn and Arthington 2002). The disturbances created by dams are discussed in Section 3.2.3.4.

In studying riparian wetlands, Chappell et al. (2001) concluded that wetland loss in western Washington has been caused primarily by conversion to land development and agriculture. Although Chappell et al. (2001) do not estimate the loss that can be attributed to the different types of land uses, Bell (2002) found that 40% of the losses to peat wetlands in King County between 1958 and 2000 could be attributed to agriculture.

A recent study in the Willamette Valley (an urbanizing area similar to the Puget Sound Area) found that wetlands continue to be lost due to agriculture. Approximately 2.1% of the wetland area (3,800 hectare) was lost, and of this 70% was associated with agriculture, 6% to urbanization, and 24% to other causes (Bernert et al. 1999).

Outside of Washington, tremendous loss of wetland acreage has been attributed to agricultural filling, draining, and ditching in the prairie pothole regions of North America (Tiner 1984, Turner et al. 1987, Bardecki 1988). Researchers in Canada estimated 73% to 95% of the original wetlands in the area studied had been lost to agricultural conversion by the late 1960s (Snell as quoted in Bardecki 1988). Their work in Canada parallels the findings of Tiner (1984) that up to 87% of wetland loss in the United States was related to agricultural practices.

The literature on the effects of grazing on the physical structure of wetlands is focused primarily on riparian habitats, including riparian wetlands. Only a few of the studies found on this topic are located in the Pacific Northwest. However, much of the literature from the Midwest and even some from Australia may also be relevant because the types of disturbances caused by grazing are not geographically isolated. Many of the studies focused on riparian areas without differentiating between riparian upland and riparian wetland areas.

In summary, the effects of grazing in riparian areas include (Armour et al.1991, Busby 1979):

- Loss of the structure provided by vegetation
- Trampling and related sloughing and erosion of streambanks
- Shallower and wider streams

The effects of grazing on riparian vegetation vary significantly depending on the frequency and intensity of grazing (Clary 1995, Clary et al. 1996, Jansen and Robertson 2001). Soil compaction and a reduction in ground-cover vegetation lead to erosion and greater volumes of runoff from the compacted areas. Also, as native plant species are trampled and grazed and shading is reduced, there is more opportunity for establishment of species that can tolerate disturbance (see Chapter 4).

3.3.2 Increased Amounts of Water in Wetlands Resulting from Agricultural Practices

Water availability was a limiting factor for agricultural practices in the areas of low rainfall until the U.S. Bureau of Reclamation began intensive damming and irrigation projects in the early 1900s (Lemly 1994). Since then, irrigation practices have been influencing the presence of wetlands and their functions in areas in the rain shadow of the Olympic Mountains and the arid parts of eastern Washington. Most of the scientific literature concerns western states such as Colorado and Wyoming as well as Washington east of the Cascade Mountains. No information was found regarding the disturbances caused by irrigation practices on the Olympic Peninsula.

Irrigation can increase the amount of water at or near the surface (Adamus 1993). This may result in the creation and maintenance of wetlands in locations where they did not previously exist. New wetland areas have formed because of the sustained higher water table from seepage out of irrigation reservoirs, irrigation channels, and irrigation runoff. Leakage from irrigation channels and ditches often allows the formation of wetlands along channel margins or immediately downslope of ditches. Excess irrigation water applied to fields that exceeds the capacity of the soils to absorb water ("tailwater") may also form wetlands in low-lying areas that collect excess runoff. Tailwater also includes the spillage that occurs during operation of the irrigation system (Adamus 1993). For example, the Potholes Reservoir area within the Columbia Basin Irrigation Project contains wetland complexes that exist because of high groundwater caused by the high water levels in the reservoir (Tabor, Washington State Department of Fish and Wildlife, personal communication 1998).

Studies in Wyoming by Peck and Lovvorn (2001) support the idea that irrigation can be significant in creating and supporting wetlands and the biotic communities that depend upon them. The authors noted that 65% of inflows into wetlands in the Laramie Basin were derived from irrigation waters. They reached this conclusion by studying the loss of wetlands when irrigation practices were made more efficient (this is discussed further in Section 3.3.3).

In some instances, pre-existing wetlands experience deeper water for longer durations in the summer due to runoff from irrigation. Wetlands in the Potholes Reservoir that may have been seasonally inundated have become permanently inundated because of irrigation (Creighton et al. 1997).

In Colorado, Adamus (1993) differentiated between types of irrigation-related wetlands during a study of bird use of wetlands associated with irrigation waters. His work is cited here for relevant insights into the complexities of wetlands associated with irrigation.

However, due to physiographic and climatic differences between the Colorado Plateau and Washington, not all of his findings may be directly relevant to irrigated agricultural lands of the state. He identified the following types of irrigation-related wetlands:

- ***Irrigated wetlands*** are those that are created on farmed lands as the result of the duration and frequency of inundation from irrigation waters. The wetlands are most often created on the farmed lands within the actual zone of irrigation.
- ***Enhanced wetlands*** are those that are enlarged or their hydrologic regime extended (i.e., longer inundation or saturation) as the result of runoff from irrigation waters.
- ***Induced wetlands*** are those that develop as a result of irrigation runoff (from the farmed lands) where wetlands did not exist previously. These wetlands may or may not be located on the lands that are irrigated, but the source of the runoff water that creates these wetlands is excess runoff from irrigated fields.

Adamus (1993) also noted:

> *However, even after visiting a site it is difficult to determine conclusively the primary source of water that sustains a wetland. Irrigated wetlands, as considered by this project, can range from wetlands that are completely supported by irrigation runoff at all seasons, to wetlands that exist naturally but for which any measurable amount of their water originates from irrigation, however indirectly (e.g., through seepage or raised water tables). …determining whether the* <u>*primary*</u> *water source of a wetlands is irrigation-related in many cases requires considerable judgment, and no highly replicable approach exists that is applicable to all situations.*

Adamus (1993) determined that the following are <u>*not*</u> adequate criteria to distinguish the water source and, therefore, whether the major source of water to a wetland is irrigation:

- **Seed species richness.** Wetlands that are the result of irrigation water and are more than a few decades old are difficult to distinguish from pre-existing wetlands based on the species richness of the seed bank.
- **Organic content of soils.** Organic material is not an appropriate indicator of water origin. Organic detritus likely accumulates at different rates based on a variety of influencing factors. Much of the organic detritus appears to mineralize by the end of the growing season.
- **Presence of large willows and black cottonwoods.** A lack of large mature stands of black cottonwood and willows is also not an indicator of pre-existing vs. irrigated systems. Cottonwood stands may have been harvested or may never have become established. Anecdotal information concludes that cottonwood regeneration may not occur as frequently in irrigated wetlands due to overgrazing and the effects of flood management.

In the Wyoming setting studied by Peck and Lovvorn (2001), salinity of groundwater was also a factor in wetlands receiving shallow groundwater inputs from irrigated fields. Vegetation and biotic communities in the wetlands were correlated to both the water availability and the relative salinity of waters reaching wetlands. In summary, "…different irrigation practices have contrasting effects on a range of wetland types. These effects will change seasonally to impact different organisms with varying life histories, flooding requirements, and salinity tolerances" (Peck and Lovvorn 2001). The effects of changes in salinity are discussed in Section 3.3.8.

3.3.3 Decreased Amounts of Water in Wetlands Resulting from Agricultural Practices

Creighton et al. (1997) note that extensive areas of the landscape in the Columbia River Basin of eastern Washington have been altered by irrigation and the building of dams. One result of irrigation projects, they note, was "a sharp reduction in the amount of water available to native wetlands." In some instances sources of fresh water for wetlands, not resulting from irrigation, were diverted for agricultural uses and less water reached the wetlands.

In Wyoming, Peck and Lovvorn (2001) investigated the potential consequences of increasing efficiency in irrigation practices by lining ditches and using sprinkler systems (rather than flooding the fields). The authors noted that 65% of inflows into wetlands in the Laramie Basin were derived from irrigation waters. Therefore, with increased efficiency of water used for irrigation, the presence of wetlands in irrigated arid lands could decline. (The Wyoming data may be relevant to eastern Washington although the underlying geology and irrigation practices may not be identical.)

In California, the drought of 1985 through 1992 resulted in implementation of greater water conservation measures and therefore a decrease in the production of irrigation tailwater. There was a subsequent decrease in the volume of water reaching wetlands (Creighton et al. 1997).

Lower water levels in a wetland can also result from the direct ditching and draining for agricultural purposes. In this case the water entering the wetland is not reduced, rather it is shunted through the wetland and the storage capacity of the wetland is diminished. The ditching may be so effective that the area becomes upland. If, however, the draining is only partial the wetland may remain, but with lower water levels and probably a reduced area. The literature review did not disclose any information on how many wetlands in Washington may be impacted in this way.

3.3.4 Increased Fluctuations of Water Levels in Wetlands Resulting from Agriculture

The findings of Euliss and Mushet (1999) in North Dakota on the effects of agriculture on water level fluctuations in wetlands are probably significant for wetlands in the arid grasslands of the Columbia Basin. These areas have similarities in precipitation and geologic patterns. These authors found that the hydroperiods for temporary, seasonal, and semi-permanent wetlands were all significantly affected by agricultural practices within the wetland's contributing basin. There was a three-fold increase in water level fluctuations of wetlands within tilled agricultural landscapes (average 5.5 inches [14 cm] fluctuation) compared to those surrounded by natural grasslands (average 1.6 inches [4 cm] fluctuation). The authors concluded, "Tillage reduces the natural capacity of catchments to mitigate surface flow into wetland basins during precipitation events, resulting in greater water level fluctuations in wetlands with tilled catchments."

3.3.5 Increased Input of Sediment Resulting from Agriculture

Tillage and grazing adjacent to a wetland or in a watershed can disrupt the soil, creating a source of sediment for surface runoff to transport downstream into wetlands and other aquatic systems. In addition, ditching wetlands in agricultural areas increases the rate of water movement by removing or reducing vegetation that acts to decrease the velocity of water. Unvegetated channels and ditches may be the source of sediment through increased erosion within the ditch (Brown 1988).

Baker (1992) compared sediments in agricultural runoff to those of wastewater plant effluent. He found that agricultural runoff can have suspended solids in the range of 100 to 1,000 milligrams per liter (mg/l), compared to less than 30 mg/l for wastewater that had received secondary treatment. Baker (1992) also found that non-point-source pollution from agricultural lands is driven by storms. It is therefore highly variable in extent and timing. He noted that in agricultural settings large storms can increase the sediment load by two to three orders of magnitude in a year, while the loads in wastewater discharge remain relatively consistent.

Wind-borne sediments that are eroded from tilled fields also generate high sediment loads to wetlands and streams in eastern Washington. The U.S. Department of Agriculture estimates that about half of the total farmland in Washington lost more than 2 tons of soil per acre per year through the action of wind in 1997. About 10% of the total farmland lost more than 10 tons per acre per year (Natural Resources Conservation Service 1997). By adding up the estimates of erosion rates and area that is farmland, it can be estimated that in 1997 about 15 million tons of topsoil were lost through wind erosion from fields in the state.

Sediment will eventually be transported into rivers and streams or deposited in wetlands. Wetlands found in depressions are often the low points in a landscape and will receive sediments that fall in the surrounding areas. The field teams that are calibrating both the methods for assessing wetland functions and the Washington State Wetland Rating System have observed wind-blown sediments in many wetlands of eastern Washington that were several inches deep.

3.3.6 Increased Input of Nutrients Resulting from Agriculture

In the United States the export of phosphorus and nitrogen from agricultural land can be three times higher for phosphorus and 12 times higher for nitrogen than from forested lands (Omernik 1977). Many of these nutrients are transported to wetlands, streams, rivers, and lakes because they are washed out of fields or infiltrate into groundwater. In Washington State, Williamson et al. (1998) found elevated levels of nutrients in the groundwater below irrigated fields on the Columbia Plateau. Their assumption is that the source of these nutrients is their application to fields above the groundwater.

The changes in the input of nutrients as a result of agriculture are illustrated by a study in Estonia in eastern Europe that documented what happened when agricultural fertilizers were no longer placed on agricultural lands. There was a four-fold to 20-fold decrease in pollutants associated with agricultural runoff after the collapse of agricultural collectives and the subsequent decline in the application of commercial fertilizers and manure (Mander et al. 2000). Based on 10 years of data (1987 through 1997), the researchers determined that total nitrogen, total phosphorus, biochemical oxygen demand (BOD), and sulfate all declined significantly with the demise of agricultural practices in the contributing watersheds. Forested portions of the watersheds upstream of the agricultural lands did not experience measurable changes in water quality parameters, eliminating the possibility that climatic change was the cause.

3.3.7 Increased Input of Toxic Contaminants Resulting from Agriculture

Several authors have identified agriculture across the country as one of the primary causes of non-point-source pollution in aquatic systems (Brenner 1995, Reinelt and Horner 1995, Thurston 1999). Agricultural chemicals are used to control noxious weeds, insect pests, and damaging fungi and bacteria.

Agricultural chemicals applied to fields enter downstream aquatic resources such as wetlands through three primary pathways (Neely and Baker 1985):

- Adsorbed to sediment particles
- Dissolved or suspended within surface flows
- Dissolved within subsurface drainage

Farming practices and the type of chemicals used determine how the pollutant is transported into wetlands. For example, some herbicides applied to corn are water soluble. Neely and Baker (1985) reported that water flowing across crop residue left after harvesting may wash off remnant herbicides. The concentration of such an herbicide in wetlands downgradient of a corn field may increase as a result. Similarly, Donald et al. (1999) documented that wetlands in the Canadian, prairie-pothole region receive high levels of pesticides when pesticides are applied to fields prior to significant rains (precipitation totaling more than 2 inches [50 mm] after application). Another study, in California's Central Valley, found that surface water runoff from irrigated fields could have elevated levels of pesticides and herbicides if there had been aerial application of the chemicals or a recent land-based application (Lemly 1994).

Subsurface drainage may also contain pollutants at low levels. Lemly (1994) reported that subsurface waters from irrigated fields had low levels of herbicides or pesticides. These substances were removed from the water column through adsorption as the water filtered through the soils before draining into the subsurface collection system. Williamson et al. (1998) found elevated levels of pesticides in the groundwater below irrigated fields on the Columbia Plateau.

3.3.8 Increased Levels of Salt Resulting from Agriculture

Agricultural practices in irrigated areas can increase the salt content of water in a watershed or in areas immediately adjacent to a field. This means that wetlands receiving water from irrigated areas may also be subject to higher salt concentrations.

The soils in dry areas have developed in an environment of limited rainfall and significant periods of drying. In these areas the rate of evapotranspiration is higher than rainfall, and this draws water from below the ground's surface and causes many soluble minerals to accumulate in the upper soil horizons (Caltech 2003).

Soluble salts in irrigation water will be deposited in soils near the root zones of plants because much of the water in arid regions is lost by evaporation rather than downward transport. This salinization occurs with nearly any type of irrigation. Even if the irrigation water is only slightly saline, repeated cycles of evaporation lead to build-up of toxic salt levels in the soil (Caltech 2003). Thus, irrigation return waters are often high in salt content (Adamus et al. 2001) and this may impact wetlands that receive runoff from irrigation.

3.3.9 Fragmentation of Habitat Resulting from Agriculture

No information specific to fragmentation, the disruption of the connections between wetlands and between wetlands or other habitats, resulting from agricultural activities was found in the literature. It can be hypothesized, however, that such fragmentation has occurred because agricultural practices have fragmented habitats in general (Dale et al. 2000, Fahrig 2003). The direct loss of wetlands through conversion to uses such as agriculture increases fragmentation by removing "patches" of wetlands in the landscape. The conversion of wetlands to agricultural uses is discussed in the beginning of this section.

3.3.10 Other Disturbances Resulting from Agriculture

Several other types of disturbances that have been attributed to agricultural activities:

- Alteration of soils
- Construction of roads
- Noise
- Invasion by exotic plant and animal species

These disturbances are not discussed in detail in this chapter because little information was found describing how agricultural practices create these disturbances. The impacts of these disturbances, however, have been documented and are summarized in Chapter 4.

3.3.11 Summary of Key Points

- Agriculture may affect wetlands directly through conversion of the wetland to fields or pasture. This is often done by direct filling or tilling, by draining through tiles or channels, or by removing the wetland vegetation and planting upland vegetation.
- Livestock grazing in streams and riparian wetlands also has documented effects on the physical structure of wetlands.
- Irrigation can result in the creation and maintenance of wetlands in locations where they did not previously exist. This is a controversial regulatory issue in areas of the state that are irrigated.
- Conversely, agriculture can reduce the amount of water available to wetlands by either diverting water that would otherwise reach pre-existing wetlands, or imposing more efficient irrigation practices that reduce the amount of leakage reaching irrigation-related wetlands.
- Wetlands in tilled areas may experience greater water level fluctuations.
- Disruption of the soil through tilling and grazing can create a source of sediment than can be transported further downgradient. Sediments may also be carried by winds from tilled fields.
- Agricultural areas can have an increased load of nutrients and pesticides in surface runoff and groundwater.
- Agricultural practices in irrigated areas can lead to accumulation of salts in the upper soil horizons. Irrigation may leach out the accumulated salts.
- Fragmentation of wildlife habitat is a secondary consequence of loss of wetlands through agricultural practices. Clearing land for farming removes natural cover and connections between habitats.

3.4 Disturbances Caused by Urbanization

Urbanization creates disturbances that affect wetland functions, both at the scale of the watershed and within individual wetlands. These disturbances impose a variety of changes that profoundly affect watershed processes and, therefore, the downgradient drainage system and the wetlands found there. Changes include filling wetlands, clearing of vegetation, compaction of soil, modifications to water conveyance, alterations to riparian corridors, human intrusions, introduction of chemical contaminants, and increased areas of impervious surface.

A summary report by the U.S. Environmental Protection Agency (1993) concludes that urbanization strongly affects water movement within a watershed by increasing rates of surface flow, reducing subsurface volumes, and reducing baseflow. These pervasive, landscape-level changes commonly affect virtually all areas of an urban watershed (Dunne and Leopold 1978, Booth 1991, Booth and Reinelt 1993, Hollis and Thompson 1998).

Much of the scientific research on urbanization in the Pacific Northwest comes from the Puget Sound Wetlands and Stormwater Management Research Program initiated in 1986 in King County. Published results include theses by Azous (1991), Chin (1996), Ludwa (1994), and Taylor (1993). The book *Wetlands and Urbanization: Implications for the Future,* edited by Azous and Horner (2001), is a summary of the significant findings of the research. More information about the research done is available on the web site for the Center for Water and Watershed Studies at the University of Washington http://depts.washington.edu/cuwrm/ .

3.4.1 Loss of Wetlands Resulting from Urbanization

Approximately 13% of the wetland losses in the United States can be attributed to urbanization, road building, and other types of conversion (Tiner 1984). Kusler and Niering (1998) estimate that 85% of the wetlands in urban areas of the nation have been destroyed, and most of the remaining 15% are moderately to severely impaired in function. Data specific to Washington are very limited. One study (Bell 2002) found urban and residential development in King County accounted for 28% of the peat wetlands lost between 1958 and 2000.

The information available suggests that this trend will likely continue. It is estimated that more than 80% of the U.S. population will be living in urban areas by 2025, up from 74% in 1989 (Gerguson and Robinette 2001). Increases in urban population are generally accompanied by increased development density and sprawl. Wetlands in these areas are either converted to urban land uses or, if they are not directly disturbed, are degraded through a variety of causes as described in the following sections.

3.4.2 Increased Amount of Water in Wetlands Resulting from Urbanization

Urbanization is recognized as both increasing and decreasing the flows that reach downgradient aquatic systems such as wetlands. Greater volumes of water are generated more quickly while smaller, long-duration flows that would occur under less developed conditions are reduced or perhaps eliminated. Research has shown that collecting stormwater through modern storm drains, culverts, and catchments results in the rapid transport of large volumes of stormwater runoff into rivers, lakes, and wetlands at much faster rates and higher volumes than under predevelopment conditions (Dunne and Leopold 1978, Booth 1991, May 1996). Although some of the research has focused on the effects of urbanization on streams, the findings on changes in flow volumes, rates, and frequency apply equally to wetlands that receive storm drainage. Streams and wetlands are "intimately interconnected in the watersheds of western Washington" (Booth 1991).

Research conducted in the Puget Sound lowlands has shown statistically significant correlations between the effects of urbanization in a watershed and the hydrologic regime in that watershed (Konrad and Booth 2002). The amount of impervious surface within a contributing basin is a key influence on hydrologic patterns, and even small changes in watershed conditions have measurable influences on the flows and volumes of water in the system (Azous and Horner 2001).

3.4.2.1 Increased Frequency of Erosive Flows

One consequence of urbanization is an increase in the frequency of erosive flows within a watershed. As reported by Booth (1991), several studies concluded the most common effect of urbanization was an up to five-fold increase in peak flow rates from a given storm event. The largest relative increases in erosive flows were found for the smallest storm events. This is very significant because small storm events are the most frequently occurring storms. A small storm event is the *two-year-event*, a storm with a given volume of rain falling within a 24-hour period that has the statistical likelihood of occurring every two years (the statistics are based on over 40 years of measured rainfall). That means that small storm events have the greatest percent increase in flows over natural conditions, and frequent small storms have the greatest relative increase in erosive flows. Contrary to what might be expected, it is these recurring small storms that have the greatest cumulative effect on erosion and sedimentation, not the large, less frequent storm events (Booth 1991).

Thus, larger volumes of water enter channels and wetlands more rapidly after a given storm event in a basin where the removal of forests and the increase in impervious surfaces have altered hydrologic processes (Booth 1991). After an area has been developed and the forest canopy removed, high rates of flow continue for a longer duration. These flows may carry sediment and other pollutants into downgradient wetlands.

3.4.2.2 Increased Volume of Runoff and Longer Duration of Flows

Booth and Reinelt (1993) notes that a basin with increased imperviousness will experience an increase in the magnitude of runoff volume from a given storm event. The "typical" event occurs far more frequently. For example, the peak flows created from a two-year storm event, after urbanization, will occur far more frequently than every two years. Small storm events that did not create measurable peak discharges in forested conditions create measurable peak runoff flows in urbanized conditions, because the removal of the forest canopy makes the same size storm event result in far greater volumes of water reaching aquatic resources such as wetlands and streams. Modeling based on detailed data from basin monitoring identified that larger flows with more erosive force may occur in urbanized basins with much greater frequency, for example increasing from once or twice per decade to several times per year.

In urbanizing watersheds, stormwater ponds are designed to hold the excess volume of stormwater generated from the impervious surfaces. The ponds are designed to release stormwater at the same rate as that modeled for the natural vegetated basin for a given storm in pre-existing conditions (Booth 1991). However, in order for the ponds to discharge the increased volume of water at the same low rates, they must take more time, or cause an increased duration of flows.

3.4.2.3 Consequences of Changes in Water Regime

The consequences of the interplay between rates, volumes, and durations are complex. Research on the impacts of urbanization on stormwater and watershed processes indicates that urbanization results in several disturbances that can impact wetlands (Booth 1991, Azous and Horner 2001, Reinelt and Taylor 2001, Thom et al. 2001):

- Increased erosion
- Sediment movement and deposition
- Burying of vegetation
- Increased depths of inundation
- Water level fluctuations
- Downcutting of natural channels (which can remove riparian vegetation from the floodplain)
- Changes in the seasonal extent and duration of saturation and inundation
- Unstable substrates

Urbanization can also cause a decrease in interflow (shallow, subsurface flow) and base flow from the urbanized watershed (U.S. Environmental Protection Agency 1993). Changes in the volume of interflow may influence the hydroperiod of downgradient wetlands if they are fed by that shallow subsurface flow.

Roads and parking lots are an important component of the impervious surface area in a watershed. The City of Olympia in 1994 determined that transportation features (roads and parking lots) typically composed between 63% and 70% of total impervious area within suburban areas (Schueler and Holland 2000).

3.4.3 Increased Fluctuations of Water Levels Resulting from Urbanization

Reinelt and Taylor (2001) used water level fluctuation as the primary measure of wetland hydroperiod, stating: "Water level fluctuation is perhaps the best single indicator of wetland hydrology, because it integrates nearly all hydrologic factors." They documented four factors in a depressional wetland and its watershed that have the strongest influence on water level fluctuations:

- Forest cover in the watershed
- Impervious cover in the watershed
- Constriction of the wetland outlet
- Ratio of wetland to watershed area

Wetlands in basins with the highest degree of impervious area had the highest water level fluctuations. Wetlands in basins with 90% or more forested land cover and less than 3% impervious area generally exhibited smaller ranges in water level fluctuations (Reinelt and Taylor 2001). Further information on thresholds at which impervious surface influences aquatic resources is provided in Section 3.2.3.3.

Wetland size is also important in determining the effects of urbanization on water level fluctuations. Reinelt and Taylor (2001) observed that wetlands that were small in relation to their contributing watersheds had greater water level fluctuations and were dominated by surface inflow. Wetlands that were larger in comparison to their contributing watersheds had smaller water level fluctuations and more groundwater influence. Wetlands with a constricted outlet (undersized culvert, beaver dam, or embankment) had a greater water level fluctuation than wetlands with less constricted outlets.

Stormwater runoff from urbanization, as well as other land-use alterations, frequently causes several changes in how water levels fluctuate in wetlands. All aspects of fluctuations in water levels are changed by urbanization:

- The **magnitude** of the effect of storms is changed by causing a two-year event to act like a larger storm. A larger volume of water reaches the wetland more often. Urbanization can also prevent infiltration through native soils into the shallow groundwater zone (Booth 1991, Azous and Horner 2001).

- The **timing** of water's presence and duration is changed by the use of engineered stormwater systems. Water is collected from impervious surfaces into stormwater ponds. Infiltration into shallow groundwater is prevented. The stormwater is discharged at given rates for longer durations into downstream receiving waters (Booth 1991, Azous and Horner 2001).
- The **frequency** of runoff volumes from storm events increases. The volume of runoff normally generated from small storm events is generated by smaller volumes of precipitation (Booth 1991, Azous and Horner 2001, Reinelt and Taylor 2001, Thom et al. 2001).
- The **duration** of particular flows becomes extended as large volumes of stormwater are discharged at metered rates over longer periods of time (Booth 1991, Thom et al. 2001).
- The **rate of change** is increased through increasing the frequency and magnitude of water level fluctuations in urbanizing watersheds (Azous and Horner 2001, Reinelt and Taylor 2001, Thom et al. 2001).

3.4.4 Increased Input of Sediment Resulting from Urbanization

Researchers in the Puget Sound area have documented that urbanization increases erosion and this, in turn, increases the movement and deposition of sediment in depressional and riverine wetlands (Booth 1991, Azous and Horner 2001, Reinelt and Taylor 2001, Thom et al. 2001).

Studies at the national level undertaken by the U.S. Environmental Protection Agency confirm that sediment in urban runoff is a problem nationwide (Tasker and Driver 1988). Sediments and solids constitute the largest volume of pollutant loads to receiving waters in urban areas (U.S. Environmental Protection Agency 2003).

A major source of sediment in urban areas comes from construction when the surface of the soils is disturbed and exposed to erosive forces. Runoff from construction sites is by far the largest source of sediment in urban areas under development (U.S. Environmental Protection Agency 1993).

3.4.5 Increased Input of Nutrients Resulting from Urbanization

Research on the impacts of urbanization in the Puget Sound area (Booth 1991, Azous and Horner 2001, Reinelt and Taylor 2001, Thom et al. 2001) has also documented that urbanization increases the amount of nitrogen entering aquatic systems including wetlands. Studies at the national level undertaken by the U.S. Environmental Protection

Agency confirm that nitrogen in urban runoff is also a problem nationwide (Tasker and Driver 1988).

Nutrients are introduced into runoff from a number of different sources that include nutrients bound to sediment from construction sites, fertilizers applied to lawns, and decomposing grass clippings and leaves left on impervious surfaces (Johnson and Juengst 1997). Nutrients are also increased in groundwater in areas where wastewater is treated by septic systems (Valiela et al. 1993). More specifically, nutrients from septic systems have been correlated with an increase in nutrients in the groundwater that flows into lakes and their associated wetlands in urbanizing areas (Moore et al. 2003).

In addition to the application of fertilizers in residential areas, nitrogen is introduced into aquatic systems and wetlands from the release of nitrogen compounds in car and truck engines and through the burning of wood and coal (Paerl and Whitall 1999). The amount of nitrogen coming from the deposition of these air pollutants in the United States is about 20% of the total excess nitrogen derived from human activities (Prospero et al. 1996). In heavily urbanized areas such as the Eastern Seaboard, the total amount of nitrogen coming from combustion can be as high as 40% or more of the total input by all human activities (Valigura et al. 1996).

3.4.6 Increased Input of Toxic Contaminants Resulting from Urbanization

In addition to sediment and nutrients, urban land uses generate a wide range of pollutants that include the following (U.S. Environmental Protection Agency 1993):

- Heavy metals (copper, lead, zinc)
- Hydrocarbons
- Organic matter that reduces oxygen
- Pesticides

Schueller and Holland (2000) cite a number of studies indicating that urban pollutant loads are directly related to the amount of impervious surface in the watershed. Impervious surfaces such as roads, parking lots, and storage yards are places where toxics from numerous sources collect. Precipitation falling on the impervious surfaces washes the collected chemicals and particles into the storm drain system (Schueller and Holland 2000).

The runoff from many different types of land use in urban areas can be toxic to aquatic life. Pitt et al. (1995) studied the relative toxicity of the runoff from different types of land uses in urban and suburban areas. Parking areas, storage areas, and landscaped areas (lawns, gardens) had the highest toxicity with approximately 20% of the samples being highly toxic. Over half of the samples of runoff from these urban land uses were moderately toxic.

Sriyaraj and Shutes (2001), working in London, documented that hard rains after extended dry periods result in the greatest concentrations of pollutants. This is also known to occur in Washington, where the greatest concentration of pollutants in surface runoff is typically observed in the fall with the first rains following summer drought (Booth 1991).

3.4.6.1 Heavy Metals and Hydrocarbons

Most heavy metals in urban runoff are adsorbed to sediment particles, although copper and zinc can occur in dissolved forms (Canning as referenced in Newton 1989). The sources of heavy metals are various including motor vehicle brake linings, tire particles on roadways, emissions from vehicles, and industrial sources.

Sriyaraj and Shutes (2001) found that sediment from road runoff had high to moderate levels of heavy metals associated with it, and the metals were deposited within the sediments of the receiving wetland. Heavy metals, such as lead, zinc, copper, and cadmium, are some of the pollutants that accumulate on roads during dry summers. These pollutants are particularly concentrated when they are washed off during intense storms following long dry periods (Sriyaraj and Shutes 2001). Thurston (1999) found that lead and petroleum hydrocarbons were the most common pollutants attached to particles in an urban wetland receiving direct runoff from a municipal garage parking lot.

Most of the adsorbed metals are buried in sediment deposits within wetland substrates, thereby becoming substantially “locked up” from further biological activity (Canning as referenced in Newton 1989) when covered by un-contaminated sediment. Where contaminated sediments are constantly being discharged to wetlands (e.g., urban stormwater discharges), however, new contaminated sediments are constantly coming in. Thus, there is always contamination in the biologically active zone. Also, if the pH of the incoming water changes some toxic metals may be released (see Section 2.6.1.4).

3.4.6.2 Organic Matter

Another contaminant present in runoff from urban areas is organic matter (examples listed below). As this organic matter decomposes in the water, it uses up oxygen that is dissolved in the water (called dissolved oxygen or DO). DO plays the same role as atmospheric oxygen in that it is critical for biological activity in aquatic communities. Oxygen is used by aquatic organisms. It is also used by bacteria for the decay of organic matter. This is called the biological oxygen demand (BOD) of the system. In natural systems, BOD fluctuates as oxygen use and organic inputs vary both daily and seasonally. The natural BOD of a system is thrown out of balance when there is excessive organic matter in the system. An increased BOD results in a decreased availability of dissolved oxygen.

Contaminants in urban runoff that cause increases in BOD include:

- Septic system effluent
- Oil and grease
- Organic matter such as dog and cat feces
- Incidental sources from atmospheric fallout

Direct urban runoff can create a demand for oxygen that is equal to or greater than that from sewage effluent. BOD from urban runoff can have substantial cumulative effects (Canning as referenced in Newton 1989).

3.4.6.3 Pesticides

Pesticides in urban areas are used for residential and commercial landscaping. According to studies conducted in the Puget Sound Basin, more types of pesticides were detected in urban streams than in agricultural streams (Bortleson and Davis 1997). Furthermore, more pounds of pesticides were applied in urban areas than in agricultural areas (Tetra Tech 1988 as reported in Voss et al. 1999). Voss et al. (1999) found 23 pesticides in urban streams in King County of which five exceeded the recommended maximum concentrations set by the National Academy of Science. Although all these data were collected from streams it can be assumed that riverine wetlands that intersect these urban streams can be subject to these pesticides as well.

3.4.7 Fragmentation of Habitat Resulting from Urbanization

Urbanization causes fragmentation of habitat as new developments divide undisturbed areas (COST-Transport 2003). Conversion of the land for urbanization has turned large, continuous patches of habitat into numerous small patches, which are isolated from each other and surrounded by land uses that are not hospitable to many native wildlife species (Aurambout 2003). The fragmentation of habitat continues to increase as the human population grows (Dale et al. 2000). Developed lands in the U.S. increased by 18% between 1990 and 2000 to total 4.4% of the area of the country (Dale et al. 2000).

Wetlands, as part of an undisturbed landscape, are also subject to the fragmentation that results from urbanization. Gibbs (2000) analyzed the distribution of wetlands along urban to rural gradients in New York State and in Maine and found statistically significant correlations between the density of human population and two measures of fragmentation – the average distance between wetlands and the percent of the landscape that was in wetlands.

3.4.8 Other Disturbances Resulting from Urbanization

Several other types of disturbances have been attributed to human activities in urbanizing areas:

- Alteration of soils
- Construction of roads
- Noise
- Recreational access
- Invasion by exotic plant and animal species, including household pets

These disturbances are not discussed in detail in this chapter because little information in the literature was found quantifying how urbanization creates these disturbances. The impacts of these disturbances on wetlands have been documented and are summarized in Chapter 4.

3.4.9 Summary of Key Points

- Increases in urban population are generally accompanied by increased development density and sprawl. Wetlands in these areas may be converted to urban land uses or may be degraded through a variety of causes.
- Urbanization results in modifications to water movement, alterations to riparian corridors, human intrusions, introduction of chemical contaminants, and increased areas of impervious surface. These changes profoundly affect environmental processes in contributing basins and, therefore, the downgradient drainage systems.
- Urbanization alters the movement of water into aquatic systems. Consequences of increased amounts of water include an increased frequency of erosive flows, greater volume of runoff, and longer duration of high flows.
- With urbanization comes increased transport of sediment, nutrients, metals, oil, pesticides, and other contaminants in surface runoff.
- Fragmentation of habitat results as the total area of wetlands is reduced and the connections between wetlands and other habitats are eliminated.

3.5 Disturbances Caused by Forest Practices

In general, forest practices cause several types of disturbance that can impact the factors that control wetland functions and therefore affect the performance of those functions. These disturbances include (as reviewed in Cooke in press):

- Increased peak flows
- Increased water level fluctuations
- Increased nutrients
- Increased sedimentation
- Changes in soils
- Invasion by exotic species

The effects of forest practices have recently received much attention. As a result, the scientific literature is being reviewed and synthesized by the Washington State Department of Natural Resources and is now in a draft form (Cooke in press). Therefore, this review of the literature does not cover the disturbances that result from forest practices and their impact on wetland functions.

3.6 Disturbances Caused by Mining

Surface mining generates large quantities of unusable rock that is often left on the surface after it is extracted. This exposes the rock (called spoils) to an oxidizing environment, resulting in a complex series of chemical reactions. The minerals contained in the spoils are not in equilibrium with the oxidizing environment and almost immediately begin weathering and mineral transformations.

The reactions are analogous to "geologic weathering" which takes place over extended periods of time (hundreds to thousands of years) but the rates of reaction are orders of magnitude greater than in "natural" weathering systems. The accelerated reaction rates can release damaging quantities of acidity, metals, and other soluble components into the environment (U.S. Department of the Interior, Office of Surface Mining 2003).

Thus, the two major disturbances created by surface mining are (Adamus et al. 2001):

- An increase in the levels of heavy metals that are toxic to many organisms
- An increase in the acidity of surface waters

Another type of mining activity that occurs in the state is gravel mining in streams and floodplains. We were unable to find any published information on the impacts of gravel mining on wetlands, and research into this question is only beginning at the national level by the U.S. Geological Survey (Spooner 2004). As a result, we were unable to synthesize the information on the impacts of this activity.

3.7 Chapter Summary and Conclusions

The focus of Chapter 3 has been to describe how different land uses may change the environmental factors that control wetland functions. A general conclusion that can be made from the scientific literature is that disturbances of environmental factors can occur at several geographic scales. Much of the early research focused on disturbances that occur at a single site or wetland. More recent research has documented the significance of disturbances that occur at the much larger scale of a watershed (called the landscape scale). The disturbances created by different land uses are summarized in Table 3-3 (at the end of this section) by the type of land use, the severity of the disturbance, and the scale at which the disturbance occurs. This table represents a synthesis of the severity of impacts by the authors of this document based on the information in the literature.

The effects of different land uses on the flow and fluctuations of water are well documented. Changes in land uses and vegetation communities on the land, whether for agriculture or as a result of urbanization, alter the patterns of surface and shallow groundwater movement across a landscape. Flows of water can be reduced or increased by different land uses as can the frequency and amplitude of water levels.

Removal of vegetation and/or compaction of native soils through agricultural practices, creation of lawns or grazed pastures, or creation of impervious surfaces all have the same relative consequence: increased volumes of water and rates of flows after a given storm event. The threshold of roughly 10% imperviousness within a basin appears to be the point above which significant impacts begin to occur to aquatic resources based on research in the Puget Sound Basin.

While the effects of urbanization on water movement have been extensively studied, agriculture can also influence the water regime of wetlands, leading to loss of wetlands in some areas and creation or maintenance of wetlands in other areas where wetlands did not originally exist, such as areas influenced by irrigation.

Human activities also increase sediment and other pollutants in runoff. In agricultural areas, pesticides and fertilizers can contribute to contamination of surface waters. In urban areas, stormwater runoff frequently contains sediment, organic matter, phosphorus, metals, and other pollutants. Pollutants often adhere to sediment particles that enter wetlands. Mining increases the acidity of surface waters as well as adding toxic heavy metals. Logging increases sediments in a watershed and can also change the amount of water and its fluctuations.

Fragmentation of habitats is of increasing concern. As connections between wetlands and other habitats are broken and more wetlands across the landscape are converted to other uses, the remaining habitat becomes more isolated.

A key finding of this chapter is that different land uses may cause the same change in the controls of wetland functions. For example, urban land uses, agricultural practices, and logging have all been shown to increase sediments in a watershed. From the wetland's "point of view," the source of the sediment is irrelevant—the impact of excess sediments on wetland functions is similar, regardless of the source of sediments.

Chapter 4 shifts from a focus on the disturbances caused by human land uses (agriculture, urbanization, logging, and mining) to describe how these disturbances impact wetlands and their functions.

Table 3-3. Disturbances resulting from different land-use practices that can change the factors that control wetland functions.

Disturbance	Scale of Disturbance	Agriculture	Urbanization	Mining
Changing the physical structure within wetlands (filling, vegetation removal, tilling of soils, compaction of soils)	Site scale	xx	xx	h
Changing the amounts of water	Landscape scale Site scale	xx xx	xx xx	? h
Changing fluctuations of water levels (frequency, amplitude, direction of flows)	Landscape scale Site scale	xx xx	xx xx	? h
Changing the amounts of sediment	Landscape scale Site scale	xx xx	xx xx	h h
Increasing the amount of nutrients	Landscape scale Site scale	xx xx	xx xx	nm nm
Increasing the amount of toxic contaminants	Landscape scale Site scale	xx xx	xx xx	x xx
Changing the acidity	Landscape scale Site scale	nm nm	nm nm	x xx
Increasing the concentrations of salt	Landscape scale Site scale	x x	nm nm	nm nm
Fragmentation	Landscape scale	xx	xx	h
Other disturbances	Site scale	xx	xx	h

Key to symbols used in table:
(xx) land use creates a major disturbance of environmental factors that affects large areas in the state
(x) land use creates a disturbance
(nm) studies on impacts of this land use do not mention this disturbance
(h) literature is lacking but disturbances can be hypothesized based on authors' experience
(?) information lacking

Chapter 4

Negative Impacts of Human Disturbances on the Functions of Wetlands

4.1 Reader's Guide to This Chapter

Chapter 4 integrates the concepts discussed in Chapter 2 and Chapter 3. Chapter 2 described the functions performed by wetlands and the environmental factors that control functions of wetlands. Chapter 3 discussed the major disturbances to the environment caused by different human activities and uses of the land. This chapter continues by summarizing how each of the disturbances ultimately leads to impacts to wetland functions.

As mentioned in Chapter 3, disturbances to wetlands can alter how they function. Changes that are caused by human disturbances are often called *impacts* to separate them from changes that are caused by "natural" or non-human disturbances. From a legal perspective (National Environmental Protection Act), human impacts are divided into *direct impacts*, those which are caused by the action and occur at the same time and place, and *indirect impacts*. Indirect impacts are caused by an action but occur later in time or are farther removed in distance, but are still reasonably foreseeable. (http://ceq.eh.doe.gov/nepa/regs/ceq/1508.htm#1508.1)

Impacts can be either beneficial or detrimental to the ecosystem, environmental process, or species. Defining an impact as either beneficial or detrimental depends on the values of the society or group making the decision (Beanlands and Duinker 1983). The natural system does not judge a change as either good or bad; it is we, as a society, that make that judgment. Social values, as represented by its laws, provide the means of determining the importance of human impacts (Beanlands and Duinker 1983).

The Growth Management Act and the state and federal clean water acts all have the protection of wetland functions and values as a goal. Thus, human impacts to wetlands, from this perspective, need to be considered in terms of those that reduce the level of functions they perform or the values they represent.

Therefore, the objective of the synthesis in this chapter is to summarize the information on the changes caused by human disturbances that reduce the level of different functions performed by wetlands. For this reason the chapter is titled *negative impacts*. When the word *impact* is used it assumes there is a reduction in the levels of functions and the societal values they represent.

4.1.1 Chapter Contents

Major sections of this chapter and the topics they cover include:

Section 4.2, The Geographic Scale of Impacts to Wetland Functions describes how disturbances that impact functions of wetlands can occur either within the wetland itself or in the surrounding landscape. While the literature generally does not distinguish the scale of the disturbance when assessing impacts on wetland functions, there are some disturbances at the site scale that can remove all or most functions of the wetland (such as changing the physical structure of the wetland through filling).

Following this introduction, the chapter continues by describing how the major types of disturbances resulting from human activities affect wetland functions. As discussed in Chapter 3, different land uses may create the same type of disturbance (for example, both agriculture and urbanization may cause sedimentation). Therefore, each of the remaining sections of this chapter focuses on the different types of disturbances, without division by land-use type, and their impact on each wetland function. The following is a list of the disturbances discussed in this chapter:

Section 4.3, Impacts from Changing the Physical Structure within a Wetland

Section 4.4, Impacts from Changing the Amount of Water in a Wetland

Section 4.5, Impacts from Changing the Fluctuation of Water Levels within a Wetland

Section 4.6, Impacts from Changing the Amounts of Sediment Coming into a Wetland

Section 4.7, Impacts from Increasing the Amounts of Nutrients Coming into a Wetland

Section 4.8, Impacts from Introducing Toxic Contaminants to a Wetland

Section 4.9, Impacts from Changing the Acidity (pH) of Soils or Water in a Wetland

Section 4.10, Impacts from Increasing the Concentrations of Salt in a Wetland

Section 4.11, Impacts from Fragmenting Wetland Habitats

Section 4.12, Impacts from Other Human Disturbances on Wetlands

Within each section, the impact of each disturbance is summarized in terms of the following wetland functions:

- Impacts on hydrologic functions
- Impacts on functions that improve water quality
- Impacts on plants
- Impacts on invertebrates
- Impacts on amphibians and reptiles

- Impacts on fish
- Impacts on birds (species closely associated with wetlands)
- Impacts on mammals (species closely associated with wetlands)

Section 4.13, Chapter Summary and Conclusions ties together the major concepts presented in the chapter.

4.1.2 Where to Find Summary Information and Conclusions

Each major section of this chapter concludes with a brief summary of the key points resulting from the literature on that topic in a bullet list format. The reader is encouraged to remember that a review of the entire section preceding the summary is necessary for an in-depth understanding of the topic.

For summaries of the information presented in this chapter, see the following sections:

- Section 4.3.9
- Section 4.4.9
- Section 4.5.9
- Section 4.6.9
- Section 4.7.9
- Section 4.8.9
- Section 4.9.9
- Section 4.10.9
- Section 4.11.9
- Section 4.12.6

In addition, Section 4.13 provides a summary and conclusions about the overarching themes gleaned from the literature and presented in this chapter.

4.1.3 Sources and Gaps in Information

Data on some of the subjects related to the negative impacts of human disturbances on wetland functions are abundant for select areas in the state. For example, the Puget Sound Wetlands and Stormwater Management Research Program (summarized in Azous and Horner 2001) has provided several studies on how changes in land uses in a watershed affect the physical, chemical, and biological processes in wetlands of the Puget Sound lowlands. The impacts on wetlands in other areas of the state are less well studied.

Similarly, studies on the effects of changes in wildlife habitat resulting from physical changes within wetlands and fragmentation between habitats have been performed in Washington for some species and some types of habitat changes. The impacts to other species are less well studied or have only been examined in other states or other countries. Information from other locales is included for these topics when relevant.

This chapter contains text that was adapted (re-organized and paraphrased) from a review of current scientific literature on the impacts of human activities on wetlands and their functions undertaken by the U.S. Environmental Protection Agency (Adamus et al. 2001). This review represents a very detailed summary of the literature published between 1990 and 2000 regarding wetlands across the United States. Portions of the review that were considered relevant to wetlands in Washington State were adapted for inclusion in this chapter, with permission from Dr. Adamus. The sections of this chapter that incorporate text adapted from the Adamus et al. (2001) review include:

- **Sections 4.3.3 – 4.3.8**, the impacts on plants, and habitat for invertebrates, reptiles and amphibians, fish, and mammals from changing the physical structure in the wetland
- **Sections 4.4.3 – 4.4.7**, the impacts on plants, invertebrates, amphibians and reptiles, fish, and birds from changing the amount of water in the wetland habitat
- **Section 4.5.4**, the impacts on invertebrates from changing the fluctuations of water levels in the wetland habitat
- **Sections 4.6.3 – 4.6.4**, the impacts on plants and invertebrates from changing the amounts of sediment in the wetland habitat
- **Sections 4.7.3, 4.7.4, 4.7.7**, the impacts on plants, invertebrates, and birds from increasing the amount of nutrients in the wetland habitat;
- **Sections 4.8.3 – 4.8.7**, the impacts on plants, invertebrates, amphibians and reptiles, fish, and birds from increasing the amount of toxic contaminants in the wetland habitat;
- **Section 4.9.3 – 4.9.7**, the impacts on plants, invertebrates, amphibians and reptiles, and birds from changing the acidity in the wetland habitat;
- **Sections 4.10.4, 4.10.7**, the impacts on invertebrates and birds from increasing the concentration of salts in the wetland habitat;
- **Section 4.12.1, 4.12.5.4**, the impacts on plant communities from altering soils and the impacts of exotic invertebrates on native invertebrates in wetlands.

The literature sources cited in the portions of the text that were adapted from the report by Adamus et al. (2001) are included in the list of references at the end of Volume 1. These sources, however, were not obtained and reviewed independently.

4.2 The Geographic Scale of Impacts to Wetland Functions

The disturbances that impact functions in wetlands can occur either within the wetland itself or in the surrounding landscape. Chapter 2 introduced the idea that the controls of wetland functions occur at both the “site scale” and the broader “landscape scale.” As with the controls of wetland functions, disturbances caused by human activities can also occur at the same two scales (site and landscape).

For example, increased nutrients can flow into a wetland directly from an adjacent lawn or from animals grazing within the wetland (disturbance at the site scale). The nutrients could also originate from development or fertilized fields somewhere higher in the contributing basin (disturbance at the landscape scale). As another example, the water levels in a wetland can be increased through the direct discharge of stormwater into a wetland (the site scale) or by adding impervious surface higher in the contributing basin (the landscape scale).

Much of the discussion in this chapter does not differentiate the scales at which the disturbance occurs. For example, the impacts on wetland functions resulting from excess nutrients or higher water levels can be expected to be the same whether they are delivered directly to the wetland or come from a distant source in the contributing basin. The literature does not usually differentiate between scales when discussing the impacts on wetland functions.

However, an alteration to the physical structure of the wetland itself is a type of disturbance that occurs only at the site scale. Filling, removing vegetation, tilling, or grazing within a wetland has a direct impact on the functions at that site. The most extreme impact to a wetland is the complete removal of all the factors that contribute to the existence of the wetland. Thus, filling a wetland or draining all the water eliminates all of the wetland functions because the wetland no longer exists.

4.3 Impacts from Changing the Physical Structure within a Wetland

Disturbances that directly change the structure of wetlands can be so severe that the wetland is destroyed. Filling or draining a wetland can so alter the water regime that the land can no longer support the wetland vegetation and maintain hydric soils. If a wetland is lost, most if not all of its wetland functions are also lost. Dahl (1990) estimated that 31% of the wetlands in Washington State had been lost prior to the 1980s as a result of filling or draining to the extent there is no longer enough water to maintain areas as wetland.

There are, however, some human alterations of the structure in wetlands that do not result in the complete loss of functions, including:

- Human removal of vegetation (e.g., logging, mowing, or application of herbicides)
- Animal grazing
- Alteration of the soil through tilling or compaction
- Partial draining

This section describes what the literature reports about how these alterations impact wetland functions. The impacts of grazing and removal of vegetation are better understood than those of alterations to the soils. Information was not available on how some of these alterations affect wetland functions described in the following sections, and some impacts are hypothesized based on synthesizing other information.

4.3.1 Impacts on Hydrologic Functions from Changing the Physical Structure

No information was found on how changing the physical structure of wetlands impacts their hydrologic functions (reducing peak flows, reducing erosion, and recharging groundwater). One could hypothesize that removing erect and persistent vegetation (emergent, shrub, or forest species) may impact the reductions in water velocity that occur in wetlands. The density of vegetation is a factor in reducing water velocity during flooding or storm flows (Adamus et al. 2001). If this vegetation is removed, the wetland will probably not be as effective at slowing these flows (in other words, there will be a change in how this wetland function is performed). As a result, downstream erosion and flooding may increase.

4.3.2 Impacts on Functions that Improve Water Quality from Changing the Physical Structure

No information was found on how changing the physical structure of wetlands affects how well wetlands remove pollutants. Removal of vegetation has impacts on both bacteria and plants, and this may affect the uptake and transformation of nutrients and toxic compounds in a wetland. The same can be hypothesized for direct alteration of soils, which may affect the chemical properties in a wetland. It is not possible, however, to predict or hypothesize how such changes might alter the wetland functions (that is, whether functions to improve water quality will increase or decrease).

4.3.3 Impacts on Plants from Changing the Physical Structure in a Wetland

Plants are one of the major factors that determine the physical structure within a wetland. Thus, changing the physical structure in a wetland means that the plants, and the structure they provide, have been removed or modified. Examples of structure that is based on plants include different layers within a forest (e.g., canopy, sub-canopy, ground cover) or the sub-surface root mass of perennial plants. In addition, removal of any vegetation causes at least a short-term change in plant biomass and possibly a change in the composition of plant species.

Vegetation can be removed by fire, tilling, mowing, or grazing (Newman 1991, Naiman and Rodgers 1997). Mortality from logging, dredging or construction activities, flooding, as well as contaminants such as herbicides can also cause loss of plants (Adamus et al. 2001). The process by which vegetation is removed or damaged appears to influence the type, duration, and magnitude of the impact on plants. Vegetation patterns in some wetlands result in part from the differing causes of plant removal and whether those causes are lethal or not (Heitschmidt and Stuth 1991, Baldwin and Mendelssohn 1998).

Impacts to the population of plants in a wetland also depend partly on the process through which the plants re-establish. When all or nearly all of the plants are removed through methods lethal to vegetation (such as with herbicides), recovery occurs mainly via recruitment of seeds. When removal is by non-lethal methods (such as grazing), recovery often is by re-growth of the plants.

The effects of grazing on plants and other aspects of ecosystems has received much attention in the last three decades because of the potential impacts in semi-arid areas (see review in National Research Council 1984). Impacts on wetlands have been studied less intensively, but some information is available. The impacts of grazing on wetland plants depend partly on the density of grazers, how long, and when they are present in the grazed area, the availability of food and water in nearby alternative habitats, and the season (Clary 1995, Fitch and Adams 1998). Specifically:

- In a laboratory experiment Crossle and Brock (2002) found that simulations of grazing changes the reproductive output of plants in wetlands in different ways and that this can change the populations by changing the proportions of seed produced.
- A study of riparian vegetation in eastern Oregon used different simulated grazing treatments to determine the effects of light and heavy grazing (Clary et al. 1996). While not clearly identified, it is evident that some of the plots were in riparian wetlands and others in non-wetland riparian habitats. The authors observed that herbaceous plants increased in growth and vigor in the ungrazed and moderately grazed plots, particularly if the grazing occurred only in the spring. Heavier grazing that lasted all season had detrimental effects on the vegetation.
- In another study in Oregon of riparian meadows, Clary (1995) found that the biomass of the grass redtop (*Agrostis* sp.) remained stable or increased at a low-elevation site

the year following simulated grazing treatments. At higher elevations, sedge species (almost all of which are found mostly in wetlands) either maintained or declined in biomass production the following year. The author concludes that grazing only annually (for several months once a year as opposed to year-round) would significantly reduce sedge production, while not decreasing redtop production.

4.3.4 Impacts on Invertebrates from Changing the Physical Structure of the Habitat

The presence of invertebrate species in a wetland is influenced by the type of plants that grow there. For example, in a Washington pond, some leeches (*Helobdella*), aquatic sowbugs (*Asellus*), mayflies, and some dragonflies (especially the large-bodied *Anax*) were more commonly associated with emergent vegetation than with submerged vegetation or open water areas. Midges, freshwater shrimp (*Hyalella azteca*), and mollusks (especially *Lymnaea* sp., *Gyraulus* sp., and *Anodonta* sp.) were more common on the submerged plants (Parsons and Matthews 1995).

The removal of vegetation either mechanically or through grazing, therefore, has a significant impact on the presence and abundance of invertebrate species in a wetland. Wetland managers often manipulate the structure of vegetation by mowing, burning, plowing, or planting to encourage or discourage populations of desirable or undesirable invertebrates (Batzer and Resh 1992, Kirkman and Sharitz 1994, de Szalay et al. 1996, de Szalay and Resh 1997).

Adamus et al. (2001) conclude from their literature review that the removal of vegetation:

- Removes substrates that would otherwise provide additional vertical space in the water column for invertebrates to colonize
- Removes shade, thus increasing water temperature and causing stress for invertebrates
- Increases the circulation and perhaps the velocity of water, with accompanying increases in dissolved oxygen and possible resuspension of sediments; this may result in changes to the habitats that favor different species of invertebrates
- Reduces inputs of leaf litter that provide food to some invertebrate taxa
- Reduces structures that otherwise shelter invertebrates from predators (Jordan et al. 1994)

Complete removal of vegetation generally reduces the richness of the wetland invertebrate community, but patchy removal or moderate grazing sometimes increases richness (McLaughlin and Harris 1990, Gray et al. 1999).

4.3.5 Impacts on Amphibians and Reptiles of Changing the Physical Structure of the Habitat

The information on the impacts of direct disturbances to the physical structure of a wetland on amphibians is ambiguous for Washington and the impacts cannot be predicted. In the Puget Sound Basin of Washington, surveys of 19 wetlands found no correlations that were statistically significant between amphibian richness and vegetation form (i.e., structure of plants) (Richter and Azous 1995). Plant stem diameter is apparently more important than plant species (Richter 1997).

Removing dense emergent vegetation, however, may impact populations of amphibians. A survey of 40 wetlands in the Puget Sound area found more native species of amphibians among wetlands containing dense emergent vegetation (Adams et al. 1998). Dense vegetation may help protect the larvae of native aquatic amphibians from larger predators. It can be hypothesized, therefore, that removing dense emergent vegetation would probably impact the populations of amphibians.

Other studies have focused on the impacts of grazing. Based on personal observations, Maxell (2000) asserts that livestock grazing can impact amphibians through:

- Trampling of vegetation that results in loss of habitat and reduces insect populations that are food sources for amphibians
- Changes in substrate composition and bank structure
- Increased sedimentation

These observations have been confirmed by Knutson et al. (2004) who reported a statistically significant negative effect of grazing and direct access of livestock to ponds on the reproduction of amphibians.

However, a study of the Columbia spotted frog in 127 ponds in northeastern Oregon does not support these findings. Bull and Hayes (2000) found no significant differences between grazed and ungrazed ponds in terms of the numbers of frog egg masses and the abundance of recently metamorphosed frogs. The volume of egg masses was larger at grazed sites, possibly due to a greater presence of adults or an older population (older, larger females lay bigger egg masses). Six of the eight most productive ponds (those with 20 or more egg masses) were grazed, indicating that grazing had no detrimental effect on this frog in these wetlands.

The differences in the conclusions between these studies may be a result of different intensities of grazing in the wetland. Jansen and Healy (2003) found a clear relationship (statistically significant) between the condition of a grazed wetland (as measured by vegetation and water quality) and the species richness of frogs. They also found a direct correlation between the intensity of grazing and the condition of a wetland.

4.3.6 Impacts on Fish from Changing the Physical Structure of the Habitat

Information in the literature did not differentiate between the responses of resident and anadromous fish to changes in the physical structure in wetlands. The information available addresses impacts to fish in general. For example, the removal of vegetation can have a significant impact on the fish present in a wetland as a result of (Adamus et al. 2001):

- Increased water temperature that may go above the tolerance limits of certain species
- Decreased cover and thereby increased susceptibility to predation
- Changes in foods and their availability

Woody material is especially important as a source of cover for fish in off-channel wetlands such as oxbows and sloughs and in lakes (Leitman et al. 1991, Dewey and Jennings 1992, Fausch and Northcote 1992, McIntosh et al. 1994).

In wetlands along the fringes of lakes, submerged plants are particularly important and their removal can change the habitat for fish. For example, declines in plants resulting from introductions of grass carp (Bain 1993) have been linked to an increase in the proportion of fish species found in limnetic areas (open water) (Bettoli et al. 1991, Maceina et al. 1991, Martin et al. 1992). However, intentional thinning of plant beds can sometimes result in higher growth rates of some age classes of lake fish, presumably by giving them better access to invertebrates that are their food source (Olson et al. 1998).

One impact that has been hypothesized in situations where the physical structure of wetlands is changed is the "stranding of fish (R. Friesz, K. March, B. Zeigler, Washington State Department of Fish and Wildlife, personal communications 2000-2004). Changing the shape or drainage of wetlands can create situations where shallow surface water is connected to streams such as during flood events or high precipitation and then isolated as water levels drop. This may result in the stranding of fish in these shallow pools, and their subsequent demise as the temperatures rise and oxygen levels decrease.

4.3.7 Impacts on Birds of Changing the Physical Structure of the Habitat

Many guilds of birds are sensitive to the presence and type of vegetation and its location in relationship to open water (Kauffman et al. 2001). The removal of vegetation can, therefore, be expected to change the distribution and abundance of birds in wetlands. For example, the rearing success of waterfowl in wetlands is reduced by removing herbaceous cover because it exposes the young to predation (Skovlin 1984).

Grazing has also been found to change the distribution of birds. In a study in southeastern Oregon on the effects of grazing on birds, researchers used exclosures to remove livestock from portions of riparian meadows (Dobkin et al. 1998). They found that the richness and abundance of bird species increased within the exclosures in comparison to the plots that remained available for livestock grazing. Moreover, the exclosures were dominated by wetland-associated birds while the open plots were dominated by upland bird species.

The changes in physical structure of wetlands that result from grazing can have both positive and negative impacts on shorebirds that use freshwater wetlands (Buchanan, 2004). The negative impacts he reported include the direct trampling that destroyed eggs and nests, the compacting of soil that reduce populations of invertebrate prey, and an increased erosion that reduced populations of invertebrate prey in semi-arid regions.

The changes in the structure of vegetation that result from the conversion of forested wetlands to emergent and open water wetlands can alter species composition and richness of breeding birds. For example, 53% of the bird species that formerly used forested wetlands no longer occur regularly where such forests have been logged and converted to emergent wetlands (Doherty 2000 as reported in Adamus et al. 2001). In the Columbia Basin, where forests are not present, changes in the vegetation of the buffer also had impacts. Heavy grazing next to wetlands removed buffer vegetation and reduced waterfowl production by 50% (Foster et al. 1984).

4.3.8 Impacts on Mammals from Changing the Physical Structure of the Habitat

Many mammals are sensitive to the presence and type of vegetation and its location in relationship to open water. The removal of vegetation is therefore expected to change the distribution and abundance of mammals in wetlands (Adamus and Brandt 1990).

Adamus and Brandt (1990) created a synthesis of the literature on mammal habitat which serves as the basis for the following discussion.

The species richness of small mammals in wetlands has been correlated with the complexity of vegetation structure (Arner et al. 1976, Searls 1974, Landin 1985, Nordquist and Birney 1980, Stockwell 1985, Simons 1985). Removal of vegetation and associated long-term destruction of den sites in both wooded and emergent wetlands have caused changes in furbearer populations and small-mammal communities (Krapu et al. 1970, Malecki and Sullivan 1987). In contrast, restoration of riparian vegetation has led to increases in use by mink (Burgess and Bider 1980).

Grazing at levels recommended by the Natural Resources Conservation Service had no significant effect on the abundance or distribution patterns of small mammals in a cottonwood floodplain in Colorado (Samson et al. 1988). Based on this study, controlled grazing that does not contribute to structural changes in vegetation, appears to have no significant effect on the abundance and distribution of small mammals.

4.3.9 Summary of Key Points

- Filling or draining a wetland can so alter the water regime that the land can no longer support wetland vegetation and maintain hydric soils. If a wetland is lost, most if not all of its functions are also lost.

- Some direct disturbances of wetlands, such as removal of vegetation, grazing, and alteration of the soil, change the wetland functions but do not result in the complete loss of functions.

- Impacts of removing vegetation on the habitat functions in wetlands have been documented for invertebrates, fish, birds, and mammals. Impacts on amphibians, however, are ambiguous. Impacts to the hydrologic and water quality functions resulting from vegetation removal can only be hypothesized since no information was found in the literature.

- Impacts of grazing on habitat functions have been documented for invertebrates and birds and are somewhat conflicting for amphibians. The one study of mammals suggests that low levels of grazing in a floodplain may have minimal impacts on the habitat of this group. No information was found on impacts of grazing on the hydrologic and water quality functions.

- No information was found on the impacts of soil alterations (through tilling and compaction) on any of the functions performed by wetlands.

4.4 Impacts from Changing the Amount of Water in a Wetland

The quantity of water in the landscape is a critical factor in controlling how wetlands function. Many human land uses change the amount of water flowing into and out of wetlands, thereby creating a disturbance that affects the performance of functions in wetlands. The literature is quite clear that the frequency, timing, and duration of water in the landscape determine the presence of a wetland and the functions that it provides (see Chapter 2). How water enters a wetland, how long it is present, and the depths to which it is impounded all influence the functions that a wetland can provide or perform (Brinson 1993b, Mitsch and Gosselink 2000).

The movement and routing of water above and below the surface is the primary force in transporting nutrients, sediment, salts, and contaminants, and this in turn affects the functions provided by wetlands (Naiman et al. 1992). Water moves (or carries) sediment, nutrients, and energy throughout a watershed (Naiman et al. 1992). Changes in the amount of water and thereby the depth of inundation in a wetland, can alter how sediments, nutrients, and toxic contaminants come into a wetland and how they are “processed” within the wetland.

4.4.1 Impacts on Hydrologic Functions from Changing the Amount of Water

Specific documentation was lacking on how increasing or decreasing amounts of water may affect wetland functions in reducing flooding or erosion or recharging groundwater. It can be hypothesized, however, that the storage capacity of a wetland in a depression that drains to areas prone to flooding will be reduced if water levels increase. The volume that would have been available to store floodwaters is used instead to store the increased volumes coming into the wetland. This suggests that the functions related to reducing flooding would also decline because storage is a large component of flood reduction. On the other hand, wetlands in which water is deeper or covers more of the wetland may provide better recharge of groundwater because infiltration depends on the depth of water in the wetland (hydraulic head) and the area that is submerged (Hruby et al. 1999).

The converse can be hypothesized if water levels in wetlands decrease. The potential amount of water that can be stored in a wetland will increase as it becomes drier, thereby increasing the "flood reduction" functions. The function of recharging groundwater would decrease because less water would be present and it would be shallower.

4.4.2 Impacts on Functions that Improve Water Quality from Changing the Amount of Water

Increasing the amount of water in a wetland brings a greater volume of surface water in contact with wetland plants, soils, and the chemical processes that lead to water quality improvement. Increased flooding in wetlands can change residence time, the distribution of aerobic and anaerobic environments, and a variety of microbial and non-microbial chemical processes (Kadlec and Knight 1996). These factors can all change how wetlands remove contaminants.

Because there are so many factors involved in removing individual contaminants it is not possible to generalize the response of a wetland to changes in water levels. Kadlec and Knight (1996) provide further discussion on the many different ways water levels affect the capacity of wetlands to remove toxic compounds. The discussion below provides only a few examples.

For example, the activity of microbes potentially increases conversion of inorganic mercury to the much more toxic form, methyl mercury (Kelly et al. 1997). In this case flooding would reduce the effectiveness of a wetland at improving water quality because the wetland may become a source of this more toxic compound. We do not have specific data about mercury in Washington's wetlands, although mercury is a water quality issue in some waters of the State (e.g., the high levels of mercury found in freshwater fish) (Ecology 2003). We can hypothesize, therefore, that mercury is present in some of the state's wetlands and can be released under anaerobic conditions.

In addition, a change in the rate of nitrogen removal can be hypothesized to result from a shift in the amount of water present in a wetland. In Washington, the area that is seasonally inundated was judged to be a critical factor in determining nitrogen removal by wetlands (Hruby et al. 1999). If the increase in water levels expands the area that is seasonally flooded, the rates of nitrogen removal will probably increase. If, however, increases in the amount of water in a wetland expand the amount of permanent water at the expense of the areas that were seasonally flooded, the rates of removal can be hypothesized to decrease. Thus, wetlands in which the water regime has been changed will probably have a different rate of nitrogen removal than they had previously.

4.4.3 Impacts on Plants from Changing the Amount of Water

Much of the literature on how changing amounts of water affect plant populations in wetlands of the Pacific Northwest is in terms of changes in the dynamics of water movement (hydroperiod). This concept combines both changes in water levels and changes in how water levels fluctuate (the latter is addressed as a separate disturbance in Section 4.5).

The composition and richness (number of species) of the plant community are influenced by the water in the root zones of wetland plants. This is influenced by:

- The **duration** of saturation (Dicke and Toliver 1990, Merendino and Smith 1991, David 1996, Vivian-Smith 1997, Silverton et al. 1999, Casanova and Brock 2000)
- The **timing** of saturation (Merendino et al. 1990, Squires and van der Valk 1992, Scott et al. 1996, 1997, Gladwin and Roelle 1998)
- The **frequency** of saturation (van der Valk 1994, Pezeshki et al. 1996, 1998, Smith 1996, Pollock et al. 1998, Casanova and Brock 2000)
- The **depth** of water (Casanova and Brock 2000).

Disturbances to any of these factors in a wetland can cause major changes in the distribution and richness of plant species. The response of an individual wetland to such changes, however, is difficult to predict. The existing information indicates that each plant species responds in a different way to changes in water levels. This means that overall the response of the plant community in a wetland will depend on the sum of the responses of the individual species. The following discussion summarizes some of the studies documenting how plant communities change with changes in water levels. It is beyond the scope of this document to provide detailed information on the response of individual plant species.

> Responses of hundreds of plant species to specific hydrologic variables that have been studied are presented in a database at EPA's web site (Adamus and Gonyaw 2000). The database is available at
> http://www.epa.gov/owow/wetlands/bawwg/publicat.html

The changes in plant communities are linked to differences among plant species in their ability to resist drought and flooding. The life history and physical characteristics of plants play a role (Earnst 1990, Koncalova 1990, Voesenek et al. 1993, Kirkman and Sharitz 1993, Teutsch and Sulc 1997). The characteristics of seed dispersal and germination of plants relative to water dynamics may have the greatest effect on the relative abundance of species, according to a simulation conducted by Ellison and Bedford (1995) using six years of data from a southern Wisconsin sedge meadow. Some species, such as cattail (*Typha* spp.), are able to keep pace with rising water levels because their stem tissue elongates rapidly and to a greater degree than other species (Waters and Shay 1992, Galatowitsch et al. 1999) or they sprout adventitious roots (Voesenek et al. 1993).

Increases in inundation may change the exposure of plants to competitors and herbivores (Wilson and Keddy 1991) and cause a shift in the location of plant communities within a wetland (van der Valk et al. 1992). The opposite extreme—dehydration—kills plants partly by removing the pathway for taking up nutrients and maintaining tissues. Dehydration may also increase or decrease competition and plant exposure to herbivores (Adamus et al. 2001).

Woody plants are particularly sensitive to prolonged inundation, especially for longer than 80 days (Niswander and Mitsch 1995, Toner and Keddy 1997, Sharitz and Gresham 1997). Their seedlings consequently are most affected during years when flooding occurs at or shortly after the beginning of the growing season, or when flooding persists for more than 40% of the growing season (Toner and Keddy 1997). Annual (as opposed to perennial) species tend to increase proportionately in response to drought and some other severe disturbances (Poiani and Johnson 1989).

Species with small, light seeds seem particularly adept at colonizing mudflats exposed during drawdowns and after disturbances (Poiani and Johnson 1989, Ellison and Bedford 1995). These species tend to emerge early in the season and may be more successful by taking advantage of greater light availability (Toner and Keddy 1997).

Successive years of annual drawdowns can favor the spread of many non-native plant species within wetlands (van der Valk 1994). Dominance of a wetland by just a few species is sometimes a sign that the wetland has experienced prolonged drought or drawdown (Wilcox 1995).

Many species have only a narrow "window" in which they can germinate. For example, there may be only a few weeks when favorable water levels or a temporary lack of competitors must coincide with favorable temperatures and acceptable water quality (Rood et al. 1998).

4.4.4 Impacts on Invertebrates from Changing the Amount of Water in the Habitat

Disturbances to the amount of water in a wetland can cause major changes in the distribution and richness of invertebrate species. Because each species responds in a different way to increases or decreases in water regime, the overall response of the invertebrate community in a wetland will depend on the sum of the responses of the individual species.

Responses of hundreds of invertebrate species to specific hydrologic variables that have been studied (Adamus and Gonyaw 2001) are presented in a database at EPA's web site. The database is available at http://www.epa.gov/owow/wetlands/bawwg/publicat.html

In general, the amounts of water in a wetland influence the distribution and richness of invertebrates by:

- Altering the amount and pattern of horizontal and vertical habitat space available for colonization (Adamus et al. 2001)
- Changing the types of algae and vascular plants that occur, the proportions of these two major food sources for invertebrates, and the seasons in which they occur (Murkin et al. 1992)
- Changing the extent of contact between plants and water, thus influencing attachment space, availability of detrital foods, shade, and shelter (Ross and Murkin et al. 1991, de Szalay et al. 1996)
- Influencing the access of predators (Reice 1991, Martin et al. 1991, Mallory et al. 1994, Johnson et al. 1995, Wellborn et al. 1996)
- Affecting the intensity of competition (Wissinger et al. 1999)
- Causing mortality if complete desiccation or freezing occurs (Layzer et al. 1993)

4.4.4.1 Impacts on Invertebrates from Reducing the Amount of Water in the Habitat

Some of the most dramatic changes to wetland invertebrate communities occur when wetlands that seldom or never dry out completely are subjected to drought or complete drawdown (Adamus et al. 2001). Less dramatic changes to invertebrate communities occur with slight alterations in the timing, duration, predictability, and depth of surface water (Eyre 1992, Giberson et al. 1992).

Drought and drawdown render the less mobile species of invertebrates more vulnerable to predation, as well as causing their direct loss due to desiccation and related factors (e.g., Stanley et al. 1994). Drought also seems to favor non-insect invertebrates, which can increase at the expense of the insect component of the invertebrate community (Hershey et al. 1999). References to drought and drawdown section are for a desert stream (Stanley et al. 1994) and Minnesota (Hershey et al. 1999), respectively. It is reasonable to extrapolate the findings of these studies to eastern Washington, which may have climates and conditions that are somewhat similar to those in the cited literature, but they may not apply to western Washington.

Coupled with the studies that show invertebrate richness increasing with longer periods of inundation, these observations indicate that removing water from a wetland may reduce the species richness of invertebrates.

4.4.4.2 Impacts on Invertebrates from Increasing the Amount of Water in the Habitat

An increase in the amount of water in a wetland seems to change the composition of the invertebrate community. Densities of swimming (nektonic) and bottom-dwelling (benthic) predatory invertebrates do not increase with flooding as much as the numbers of nektonic and benthic herbivores and detritivores. Predatory species can even decrease after flooding (Murkin et al. 1991), and they often increase as drought or drawdown progresses.

Although flooding generally increases the density and richness of invertebrates in wetlands, the increase may be short-lived. For example, flooding of Manitoba marshes (Murkin et al. 1991) to a level 3 feet (1 m) above normal caused a major increase in numbers of nektonic invertebrates in both vegetated and open water areas for only one year. Furthermore, densities of benthic invertebrates increased in flooded vegetation but not in open areas. The biomass of nektonic invertebrates increased only in the vegetated areas (Murkin et al. 1991).

Some researchers have observed that food webs become more complex and taxa numbers increase as wetlands become wetter, such as those that are ponded for longer periods. This has been observed in seasonal wetlands of eastern Washington (Lang 2000). Also, the use of emergence traps in 19 wetlands in King County yielded more taxa from permanently flooded than seasonally flooded wetlands (Ludwa and Richter 2001b), suggesting that wetlands in which the water levels fluctuate more often will have fewer invertebrate species.

These results suggest that disturbances that cause water to remain longer in a wetland will probably increase species richness at first. The long-term effects of such increases, however, are not well understood.

4.4.5 Impacts on Amphibians and Reptiles from Changing the Amount of Water in the Habitat

Most amphibians cannot tolerate prolonged dry periods. Drying of seasonal pools, especially when it occurs ahead of normal seasonal schedules, can greatly diminish the breeding success of amphibians (Rowe and Dunson 1993). This is partly because many amphibian species disperse only short distances (Berven and Grudzien 1990).

Amphibian populations scattered across wetlands of varying depth and water permanence can enable species to survive long-term droughts or floods. The availability of numerous, scattered wetlands can protect amphibians against effects of localized drought. Some frog and toad species living in relatively intact landscapes seem mostly unaffected, at the level of populations, by significant periods of drought (Dodd 1995).

In addition, both prolonged desiccation and extreme floods can increase opportunities for invasion of wetlands by exotic plant species. This change in water regime can impact the suitability of a wetland as habitat for amphibians by changing the structure of the wetland. Patterns of vegetation typically become more homogeneous, prey abundance may decline, and the habitat may become less suitable for amphibians (Ludwa 1994).

Changing the amount of water in wetlands can also impact the populations of reptiles. During a two-year drought in Washington, a local population of painted turtle (*Chrysemys picta belli*) suffered a 70% decline (Lindenman and Rabe 1990). This appeared to be due to both mortality and movement of turtles out of the wetland. Growth of the turtles was suppressed but it recovered as conditions improved. Drawing down the water level in the autumn to allow wetland management, flood control, or for other reasons can cause high mortality among juvenile turtles that are overwintering due to freezing. This occurs if the drawdowns follow abnormally high water levels in late summer that attracted turtles (Galat et al. 1998).

These results indicate that changing the amounts of water in a wetland affects both amphibians and reptiles. Impacts may occur both from lowering the water levels (for example, through ditching, draining, or pumping) or raising the levels through increased flooding as a watershed is developed.

4.4.6 Impacts on Fish from Changing the Amount of Water in the Habitat

Declines in the amounts of water alter the community structure of wetland fish. Fish experience a greater need to use overlapping resources and face an increased risk of predation when wetlands become drier (Adamus et al. 2001). Low water also increases the chance of fish freezing in winter or dying from thermal stress in summer (Adamus et al. 2001).

Sustained drawdowns can also reduce competition among fish that return to wetlands when water levels rise again by temporarily eliminating larval dragonflies and other large invertebrates that normally compete for food with the fish or prey on larval fish (Travnichek and Maceina 1994).

Impacts of increasing water levels on fish in wetlands were not documented in the literature.

4.4.7 Impacts on Birds from Changing the Amount of Water in the Habitat

Disturbances to the amounts of water in a wetland can cause major changes in the distribution and species of birds. As with plants and invertebrates, the overall response of the bird community in a wetland will depend on the sum of the responses of the individual species.

4.4.7.1 Impacts on Birds from Reducing the Amount of Water in the Habitat

Drainage and some other disturbances in the amounts of water in wetlands have been well documented as contributing to the decline of many wetland bird species (David 1994, DeAngelis et al. 1997). In Manitoba, for example, wetland drainage has made breeding and brood-rearing areas for waterfowl less available (Rotella and Ratti 1992). As wetlands are drained or converted to other land cover types, local densities of wetlands decline and the average distances between individual wetlands increase.

Drought conditions also expose duck nests to greater predation. With drought, plants are less dense and vigorous, and islands that formerly were inaccessible gain new access points (Hallock and Hallock 1993, Jobin and Picman 1997).

Widespread drawdown of water tables reduces the number and perhaps the variety of wetlands and their vegetation communities. This in turn diminishes the richness, density, and breeding success of birds in many individual wetlands and wetland complexes (Higgins et al. 1992, Bethke and Nudds 1993, Bancroft et al. 1994, Greenwood et al. 1995, Dobkin et al. 1998).

4.4.7.2 Impacts on Birds from Increasing the Amount of Water in the Habitat

Increasing the duration of saturation or inundation can change the use of wetlands by a variety of birds. This change can occur when shallow ephemeral ponds are dredged to make areas with longer periods of standing water (such as stock ponds). In the Columbia Basin, Creighton et al. (1997) found an increase in use by several species of diving and dabbling ducks, coots, and terns when shallow, densely emergent wetlands were dredged to create deeper pools of open water. They also documented an increase in the biomass of zooplankton, a food source for several guilds of birds. However, there was a decrease in use by sora (*Porzana carolina*) and Virginia rails (*Rallus limicola*) as well as red-winged blackbirds (*Agelaius phoeniceus*). The use of the excavated habitats by rails was expected to increase over time as emergent vegetation became reestablished in the excavated pools because rails prefer vegetation that is a mix of robust and thin-stemmed species. An increase in use by shorebirds was one short-term benefit. The shorebirds fed on the moist, fresh dredge spoils and exposed unvegetated soils of the newly excavated basins. Once the soils became vegetated, use by shorebirds declined.

On the other hand, while construction of reservoirs raises water levels, this affects birds by eliminating many wetlands through flooding and destabilizing water levels in the remaining wetlands (Nilsson and Dynesius 1994). Associated changes in river morphology influence the species composition of wintering waterfowl (Johnson et al. 1996).

4.4.8 Impacts on Mammals from Changing the Amount of Water in the Habitat

Information on how disturbances to the amount of water in a wetland may affect their ability to provide habitat for mammals was not found. It is not possible at this stage to hypothesize either positive or negative impacts on habitat for mammals because no logical deductions could be made from the available information.

4.4.9 Summary of Key Points

- Impacts of reducing water levels on the habitat functions of wetlands have been documented for invertebrates, fish, birds, and amphibians. All these groups have reduced species richness and abundance when wetlands dry up.
- Impacts of increasing water levels in wetlands on its functions as habitat have been documented for invertebrates and birds. The species richness of invertebrates may increase for a short time if a wetland becomes wetter. The impacts on the populations of birds are mixed. In some cases the richness of birds increases and in some cases it decreases.
- Impacts to the suitability of wetlands as mammal habitat resulting from either increasing or reducing water levels have not been studied.
- Reducing the amount of water changes the distribution of plants in a wetland, but the studies did not address if species richness will increase or decrease. Data suggest that woody species will tend to be replaced by more grass-like species when water levels in a wetland increase.
- Impacts to the hydrologic and water quality functions from either increasing or reducing water levels can only be hypothesized since no information on these topics was found in the literature.

4.5 Impacts from Changing the Fluctuation of Water Levels within a Wetland

A major finding of the Puget Sound Wetlands and Stormwater Management Research Program was that fluctuations in water level are key in determining biological responses. There are different types of fluctuations in water levels in a wetland and these are described in the shaded box below. The researchers found a decline in the biotic diversity of wetlands associated with an increase in water level fluctuations caused by expanding impervious area within the contributing basin (Reinelt et al. 1998, Azous and Horner 2001).

Prolonged inundation (that is, less frequent water level fluctuations) resulting in a lack of oxygen in the soils has been indicated as a factor in changing the biota of wetlands. Although many hydric soils may be anaerobic, changing the length of time the soils are inundated results in prolonged anaerobic conditions and chemical changes in the soils. These changes in soil chemistry influence the survival of vegetation and microbes in the soil that were adapted to shorter periods of inundation (Thom et al. 2001).

Mechanisms for how fluctuations of water levels affect aquatic systems

Richter et al. (1996) developed a method to model “indicators of hydrologic alteration” based on assessing changes in 32 hydrologic parameters. They identified these parameters as being relevant to the biotic integrity of aquatic ecosystems. They divided the parameters into the following five fundamental factors that characterized how fluctuations in water levels influence biotic communities in aquatic systems:

Magnitude. A measure of the availability or suitability of aquatic habitat. It defines such habitat attributes as wetted area or habitat volume, or the position of a water table relative to the rooting zones of wetland or riparian areas.

Timing. The timing of occurrence of a particular water condition. It can determine whether certain life-cycle requirements are met. It can also influence the degree of stress or mortality associated with extreme water conditions such as floods or droughts.

Frequency. Refers to the frequency of occurrence of specific hydrologic conditions, such as droughts or floods. It may be tied to events such as the reproduction or mortality of various species, thereby influencing population dynamics.

Duration. The length of time over which a specific hydrologic condition exists. It may determine the success of the life cycle of a particular species or the accumulation of stressful effects.

Rate of change. In hydrologic conditions may be linked to stranding of individuals (in isolated pools or along a wetted edge). It may also be related to the ability of sensitive species to maintain root contact within the phreatic zone (the portion of the soil that is influenced by proximity to the groundwater table).

4.5.1 Impacts on Hydrologic Functions from Changing the Fluctuations in Water Levels

The literature did not provide explicit information on possible impacts of changes in water level fluctuations on factors within a wetland that affect its hydrologic functions. It is not possible at this stage to hypothesize either positive or negative impacts on hydrologic functions because no logical deductions could be made from the available information. The major questions that need to be addressed include:

- Will changes in the frequency or amplitude of water level fluctuations change the flood storage capacity of a wetland?
- Will changes in the frequency or amplitude of water level fluctuations change the way in which a wetland reduces water velocity?
- Will changes in the frequency or amplitude of water level fluctuations change the way in which a wetland recharges groundwater?

4.5.2 Impacts on Functions that Improve Water Quality from Changing the Fluctuations in Water Levels

How changing fluctuations in water levels impact the ability of wetlands to improve water quality was not detailed in the literature. It is not possible to hypothesize either positive or negative impacts on water quality functions because no logical deductions could be made from the available information. The major questions that need to be addressed include:

- Will changes in the frequency or amplitude of water level fluctuations change how a wetland traps sediment?
- Will changes in the frequency or amplitude of water level fluctuations change the way in which a wetland removes nitrogen?
- Will changes in the frequency or amplitude of water level fluctuations change the way in which a wetland captures or transforms toxic compounds?

4.5.3 Impacts on Plants from Changing the Fluctuations in Water Levels

In general, the amplitude and rate of water level fluctuations have been found to influence the species composition, biomass, and germination of plants (Hudon 1997, Shay et al. 1999). Furthermore, the timing of inundation and duration throughout the seasons also influences plant species richness and survival (Ewing 1996, Reinelt et al. 1998, Owen 1999, Azous et al. 2001). If these hydrologic factors change as a result of human activities as described in Chapter 3, one can then hypothesize changes in plant communities.

Researchers in the Puget Sound regions correlated a decline in plant species richness in urbanized watersheds where water level fluctuations had increased (Azous and Cooke 2001). Among 26 wetlands in the Seattle area, the degree of seasonal fluctuation in water level was negatively associated with richness found in emergent and shrub wetlands. However, it had no statistically significant effect on species richness in forested wetlands (Cooke and Azous 2001). These authors found that fluctuation during the early spring seemed to have an especially detrimental effect on plant richness in the emergent and shrub wetlands.

Reinelt et al. (1998) found that the development of plant communities in lowland wetlands of Puget Sound was related to water level fluctuations and depth of inundation during the early growing season. They noted that shifts in the "hydrologic profile" of the wetland caused a subsequent shift in the species composition of the wetland's plants. The emergent and scrub-shrub communities of the wetland tended to have lower plant richness when average, annual water-level fluctuations increased to over 8 inches (20 cm).

Azous and Horner (2001) determined that the duration of flooding, as well as depth, also strongly influenced plant diversity. They noted greatest plant diversity when:

- Flooding events were less than 0.5 feet (0.2 m) above predevelopment levels
- Floods were limited to an annual average of three or fewer events per month
- The cumulative duration of flooding was less than six days per month above predevelopment averages

On the other hand, a lack of fluctuation in water level can be just as damaging as excessive fluctuation to some wetland plant species (Rood and Mahoney 1990). This is because many species need a period of desiccation in order to germinate. Furthermore, the loss of wet-dry cycles in floodplain wetlands that result from the construction of dams favor exotic species that replace the native plant community (Bunn and Arthington 2002).

On the other hand, evidence from some studies suggests that the relative tolerance to increases in water level fluctuations is greatest among several non-native or invasive species (Figiel et al. 1995, Haworth-Brockman and Murkin 1993, King and Grace 2000). Increases in water level fluctuations and duration of inundation favor generalist plants (plants that are found under a wide range of environmental conditions) in the Pacific Northwest (Azous et al. 2001).

These results indicate that changes to water level fluctuations in wetlands are likely to result in shifts in the composition, distribution, and abundance of plants, especially in situations where there is a relatively stable hydroperiod with low level fluctuations. Furthermore, either decreases or increases in water level fluctuations will probably facilitate the invasion of non-native or “aggressive” native species by increasing the level of disturbances to which plants are subject.

4.5.4 Impacts on Invertebrates from Changing the Water Level Fluctuations in the Habitat

In the Northwest, researchers have observed a decline in the number of invertebrate species in wetlands as the impervious area in the basin increases (Ludwa 1994, Hicks 1996, Ludwa and Richter 2001a, Thom et al. 2001). Since changes in the fluctuations of water levels are a major disturbance that results from an increase in impervious surface, it can be hypothesized that the decline in the Northwest is a result of this disturbance. Information from other parts of the United States seems to confirm this hypothesis.

The densities of some invertebrate species can be decimated by rapid water level fluctuations, especially when the fluctuations are more frequent and severe than historically encountered in the wetland. For example, Missouri floodplain pools that experience large fluctuations in water level during major floods tend to have lower invertebrate density (Magee et al. 1993). Repeated exposure to desiccation in a short period of time can lead to a marked reduction in the density of invertebrates. In an Arizona stream that experienced 12 flash floods between August and December of a single year, densities of all invertebrates were reduced by 75% to 100% (Boulton et al. 1992). In particular, the numbers of water spiders, midges, and some caddisflies, mayflies, and snails declined.

A number of studies have found that reducing fluctuations in streams by maintaining minimum water levels (such as in reservoirs) can increase invertebrate densities in the part of an adjacent wetland that is not permanently inundated (Weisberg et al. 1990, Troelstrup and Hergenrader 1990).

4.5.5 Impacts on Amphibians and Reptiles from Changing the Water Level Fluctuations in the Habitat

In Puget Sound wetlands, amphibian species richness was negatively correlated with the percent of impervious cover in a contributing basin. The primary cause is increased water level fluctuation (Richter and Azous 2001a). The richness of amphibians declined to less than three species when water level fluctuations increased to over 8 inches (20 cm) (Richter and Azous 2001a, Thom et al. 2001). Chin (1996) concluded that the reduced richness of amphibians was correlated with a reduction in the diversity of wetland plants that resulted from increases in water level fluctuations.

Increases in fluctuation of water levels also affect amphibians by (1) stranding egg masses when water levels drop, and (2) reducing the thin-stemmed emergent plant species on which amphibians lay their eggs. Unpublished work by Richter (K. Richter, King County, personal communication 2002) in western Washington found that amphibians preferred thin-stemmed vegetation on which to lay their egg masses. Greater water level fluctuation directly affects amphibian egg survival and causes changes in plant species, reducing the thin-stemmed emergent species used by amphibians for egg laying (Chin 1996).

No correlations were found between the richness of amphibian species and a variety of other factors including wetland size, distance to breeding habitats, presence of predators, and number of vegetation classes (Richter and Azous 2001a). The most significant factor affecting species richness was mean water level fluctuation, with 8 inches (20 cm) mean annual fluctuation being a threshold for lentic breeding species (those that breed in stagnant or slow-moving waters such as ponds and wetlands). Lentic breeding amphibians appear to be affected by increases in the duration and frequency of flooding and increased discharge rates resulting from the greater frequency and magnitude of storm peaks in urban watersheds (Richter and Azous 2001a).

Amphibian populations in western Washington generally experience impacts in contributing basins with increasing amount of impervious surface (Booth and Reinelt 1993). A more recent study documented that watersheds with less than 15% total impervious area had three or more amphibian species, whereas most watersheds with more than 25% impervious area had less than three species (Chin 1996). Chin (1996) concludes that changes in water level fluctuations and maximum water levels during spring breeding and embryo development are the primary adverse effects of increased impervious surface.

4.5.6 Impacts on Fish from Changing the Water Level Fluctuations in the Habitat

No specific information was found on how changing fluctuations in water levels impact the ability of wetlands to provide habitat for fish. It is not possible to hypothesize either positive or negative impacts on habitat for fish because no logical deductions could be made from the available information.

4.5.7 Impacts on Birds from Changing the Water Level Fluctuations in the Habitat

General observations have indicated a decline in bird richness for wetlands located in a contributing basin that is developed or developing. Richness was not reduced in contributing basins that remained rural or relatively undeveloped over the course of the Puget Sound Wetlands and Stormwater Management Research Program (Richter and Azous 2001b, Thom et al. 2001). These observations have not specifically been correlated with changes in the fluctuation of water levels, although it can be hypothesized that some of the changes observed are a result of changes in water level fluctuations because this is one of the major disturbances caused by impervious surface (see Chapter 3).

4.5.8 Impacts on Mammals of Changing the Water Level Fluctuations in the Habitat

No explicit information on how changing fluctuations in water levels will impact mammal populations in wetlands was presented in the literature. It is not possible to hypothesize either positive or negative impacts on mammal populations because no logical deductions could be made from the available information.

4.5.9 Summary of Key Points

- No information was found on the impacts to the hydrologic and water quality functions of wetlands resulting from altered fluctuations in water levels.
- Impacts on habitat for invertebrates and amphibians resulting from changes in how water levels fluctuate in wetlands have been documented. Both groups of wildlife exhibit reduced species richness and abundance when wetlands are subject to increased fluctuations in water levels. Impacts to the suitability of wetlands as habitat for mammals, fish, and birds have not been documented.
- Increasing and decreasing fluctuations in water levels also reduce plant richness in wetlands.

4.6 Impacts from Changing the Amount of Sediment Coming into a Wetland

The sporadic movement of sediment in and out of wetlands is a disturbance that also occurs in the absence of human activities. For example, the persistence of some wetlands (i.e., certain riverine and lakeshore wetlands) depends on a sporadic deposition of sediment (Mistch and Gosslink 2000). On the other hand, depressional wetlands are natural sinks for sediments because they are the low points in the topography (Brinson 1993b), and this is a function they perform with or without the presence of human activities. Negative impacts to wetlands occur when the amount of sediment coming into a wetland either increases or decreases from the levels that are present in the absence of human activities (see Mistch and Gosslink 2000 for general references to this process).

4.6.1 Impacts on Hydrologic Functions from Changing the Amount of Sediment

Despite a lack of explicit information on impacts that sedimentation may have on hydrologic functions, it is possible to hypothesize that increases in sediment load to a wetland will reduce the amount of water it can store. For every cubic yard of sediment deposited in a wetland and not transported further, the storage capacity of water is reduced by a similar amount. This means that depressional wetlands along stream corridors with high inputs of sediment may lose much of their ability to store surface waters during floods. A similar hypothesis can be made for depressional wetlands with no surface outflow. Increases in sediment load to such wetlands can reduce the storage capacity.

4.6.2 Impacts on Functions that Improve Water Quality from Changing the Amount of Sediment

No information was found on how changing the sediment load to a wetland might change the water quality functions in wetlands. It is not possible to hypothesize either positive or negative impacts on the water quality functions because no logical deductions could be made from the available information.

4.6.3 Impacts on Plants from Changing the Amount of Sediment

Accelerated sediment deposition or erosion can tax the ability of plant communities to adapt (Kantrud et al. 1989, Jurik et al. 1994, Wang et al. 1994). Sediments have been found to impact plant communities in wetlands in several general ways:

- **Burying seeds, leaves, or plants.** Sedimentation can bury established vegetation and seed banks (Adamus et al. 2001). The burial of leaves prevents photosynthesis and restricts gas exchange through foliage (Ewing 1996). Buried plants expend energy elongating their shoots in an attempt to outpace sedimentation, seeking oxygen and light, and consequently may be less robust.

- **Changing the depth of habitats.** Over the long term, sedimentation can shrink shallow wetlands or reduce the depth of ponds that previously were too deep to support many wetland plants. Such long-term changes in water depth or relative elevation also result in shifts in species composition, as has been documented in the Mississippi River floodplain (Adamus et al. 2001).

- **Inhibiting germination.** Seeds of the most sensitive species often fail to germinate when buried (Dittmar and Neely 1999). The addition of sediment has been found to reduce germination rates of herb species in wetlands by 34% (Neely and Wiler 1993), 80% (Jurik et al. 1994), and 90% (Wang et al. 1994) depending on the species involved. In general, the species with larger seeds appear to be better able to survive burial (Dittmar and Neely 1999, Jurik et al. 1994, Wang et al. 1994).

  Less than 0.5 inch (1 cm) of sediment can inhibit germination of cattails (*Typha* sp.), barnyard grass (*Echinocola crusgalli*), rice cutgrass (*Leersia oryzoides*), and sedges (*Carex* sp.) (Jurik et al. 1994). Sedimentation inhibits the germination of cattail (*Typha latifolia*) seeds more than seeds of bur-reed (*Sparganium eurycarpum*) (Neely and Wiler 1993). Germination of cattail (*Typha* x *glauca*) seeds decreased by 60% to 90% when sediment loads of less than 0.5 inch (0.2 to 0.4 cm) were applied to the surface of the soil (Wang et al. 1994).

  In contrast, burial by 1 inch (2 cm) of sediment does not interfere with germination of several non-native plant species (Blackshaw 1992, Reddy and Singh 1992).

- **Reducing survival of seedlings.** Excessive sedimentation can reduce the survival of seedlings (Jurik et al. 1994). For example, the density of cattail seedlings and their biomass decreased as sediment loads increased from 0.08 to 0.5 inch (0.2 to 1.0 cm). One study found a fourfold greater density of annuals (vs. perennials) in some heavily sedimented sites (Neely and Wiler 1993). Older and larger seedlings were more tolerant of burial (Wang et al. 1994).

- **Favoring species more tolerant of sediment.** Sedimentation impacts individual wetland species in different ways. The composition of the plant community will therefore change as the most sensitive species are suppressed by the sediment while the more tolerant ones thrive. Effects of sedimentation on particular wetland plant species are not well documented (van der Valk and Jolly 1992) but findings relevant to wetland species found in Washington are discussed here.

  Many mature plants, and especially woody species, apparently are not harmed by a small amount of sedimentation (Wang et al. 1994). Adult plants of wild celery (*Vallisneria americana*) tolerated burial to depths of up to 4 inches (10 cm) but none survived burial under sediment depths of 10 inches (25 cm) (Rybicki and Carter 1986). Among woody plants, saplings of red alder (*Alnus rubra*) tolerated burial less well than those of Oregon ash (*Fraxinus latifolia*) (Ewing 1996).

Growth of the invasive reed *Phragmites australis,* however, typically keeps pace with moderate rates of sedimentation (Pyke and Havens 1999). However, seeds, seedlings, and plants that have evolved in wetland types in which sedimentation is rare (such as bogs) may be highly sensitive to burial. The size of particles that are being deposited, not just their amount, may also influence plant survival (Dittmar and Neely 1999).

A recent study by Mahaney et al. (2004) found that the response of plants to increases in sedimentation depends on the hydrogeomorphic class of the wetland. Increases in sedimentation reduced the emergence of four species found in riparian depressions but only affected one species in slope wetlands and none in headwater floodplains.

4.6.4 Impacts on Invertebrates from Changing the Amount of Sediment in the Habitat

In general, increased amounts of sediment can reduce the richness and density of invertebrates and alter their species composition. Excessive sedimentation affects invertebrates through several mechanisms (reviewed in Adamus et al. 2001):

- Burial of detritus and algae, which are important food sources
- Increase in the time required for invertebrates to move through deposited sediment and collect scarce food items
- Reduced flow of water through soil particles, which is necessary to supplying invertebrates with adequate dissolved oxygen
- Mortality of plants that otherwise provide attachment structures and shelter to invertebrates

Some studies have linked changes in invertebrate communities to the development of watersheds (e.g., Hogg and Norris 1991, Ludwa 1994, Carlisle et al. 1998, Ludwa and Richter 2001a). Development often is accompanied by increased export of sediment to water bodies.

Many invertebrate communities in wetlands are adapted to occasional deposition of small amounts of sediment, whereas constant or severe deposition causes major changes. The following bullets summarize some of the studies that have documented impacts of sediment on individual invertebrate species, as well as groups of species, many of which are found in Washington.

- Once deposited, sediments can further damage wetland invertebrate communities if they are re-suspended by wind mixing or fish, making the water turbid. For example, bottom-feeding carp (*Cyprinus carpio*) noticeably increase turbidity, both directly (as they move along the bottom) and by consuming aquatic plants that otherwise would stabilize and trap sediments (Lougheed et al. 1998). The biomass of planktonic invertebrates declined in Utah ponds after introduction of carp (Huener and Kadlec 1992).

- In some instances, invertebrate density and perhaps richness can increase over the long term if sedimentation replaces coarser substrates with finer substrates that better support establishment of rooted plants. In temporarily flooded prairie pothole wetlands, only caddisflies seemed relatively unaffected by surrounding land use that generated sediments. Ostracods (seed shrimp), cladocerans (water fleas), and some snails (planorbiids, lymnaeids, physids) were diminished, presumably in part because of sedimentation (Euliss and Mushet 1999).

- Burrowing, tube-forming worms and midges commonly predominate where sediments accumulate (Magee et al. 1993). Filter-feeding species and those that graze on the bottom are most sensitive (Lougheed and Chow-Fraser 1998). However, invertebrate size and behavior also influence their tolerance to sediments (McClelland and Brusven 1980). On the other hand, substrates newly created by sedimentation may attract tolerant individuals and species that are poor competitors on older, more crowded substrates (Soster and McCall 1990).

- Severe and rapid sedimentation is inevitably lethal to nearly all aquatic invertebrates. In North Dakota, wetlands surrounded by cropland were virtually devoid of the resting eggs of zooplankton, whereas such eggs were abundant in wetlands surrounded by mostly natural grassland, which presumably minimized erosion and sedimentation (Euliss and Mushet 1999).

- Unionid mussels (mussels in the family Unionidae) are sensitive to increased sedimentation (Goudreau et al. 1993, Box and Mossa 1999). Numbers of the swamp fingernail clam (*Musculium partumeium*) and amphipods were reduced in willow wetlands in northeastern Missouri where 2 to 4 inches (5 to 10 cm) of sediment had been recently deposited (Magee et al. 1993).

- Sediments may clog the filter feeding mechanisms of some species and limit light penetration. This would adversely impact phytoplankton and other primary producers, with a subsequent adverse impact on food chains (Euliss and Mushet 1999).

- Sedimentation also potentially buries invertebrate eggs deposited in the substrates of wetlands (Euliss and Mushet 1999).

4.6.5 Impacts on Amphibians and Reptiles from Changing the Amount of Sediment in the Habitat

Few studies of the impacts of increases in the deposition of sediment on amphibians and reptiles have been conducted in wetlands. On one hand, some species require soft sediments as hibernation sites. For example, painted turtles (*Chrysemys picta*) used sediments 1.6 to 3 feet (0.50 to 0.95 m) thick in an Ontario pond (Taylor and Nol 1989). On the other hand, excessive sediments, when stirred, impair light penetration of the water column and thus can inhibit growth of algae and especially submersed aquatic plants, which provide cover and attachment sites for amphibian eggs.

4.6.6 Impacts on Fish from Changing the Amount of Sediment in the Habitat

No recent studies on the impacts of sediment on habitat for fish in North American wetlands or lakes were found. Most of the studies on the impacts of sediment on fish populations have been done in streams, especially as it concerns the growth and reproduction of salmonids in the Pacific Northwest. This information was reviewed and synthesized in Knutson and Naef (1997). The conclusion reached by Knutson and Naef quoted below can also apply to wetlands because streams are often considered a part of wetlands:

> *Sedimentation in fish-bearing waters affects habitat quality and fish survival in a number of ways. Stream bottoms covered with fine sediments are no longer suitable for spawning. Sediments cover and suffocate fish eggs and fry. High sediment deposits also block fish passage to upper spawning reaches. Suspended sediments clog the gills of fish, decrease dissolved oxygen levels, inhibit fish feeding and growth, and suppress macro-invertebrate food sources.*

4.6.7 Impacts on Birds from Changing the Amount of Sediment in the Habitat

Little information was found on how sedimentation impacts the habitat that a wetland provides for bird communities. One can hypothesize, however, that sedimentation can impact birds by altering structure of vegetation (see Section 4.6.3) that provide food for herbivorous birds or those that prey on invertebrates (see Section 4.6.4). In one case, the densities of breeding dabbling ducks were positively correlated with wetland turbidity in ponds in the interior of British Columbia (Savard et al. 1994).

4.6.8 Impacts on Mammals from Changing the Amount of Sediment in the Habitat

No information was found on how sedimentation might change the habitat that a wetland provides for mammals. As with birds, however, one can hypothesize that sedimentation can impact mammals by altering habitat structure or changing the abundance or availability of prey items.

4.6.9 Summary of Key Points

- No information was found on possible impacts of sedimentation on the functions of wetlands that improve water quality.
- Increasing sedimentation will decrease plant richness and tends to favor the more invasive types that tolerate disturbance.

- Impacts of increased amounts of sediment on the habitat functions of wetlands have been documented for invertebrates, amphibians, and fish. All of these groups generally have reduced species richness and abundance when wetlands are subject to increased sedimentation. In some cases, however, where the sediments coming into a wetland are finer than existing sediments, the number of invertebrate species may increase. Impacts from sedimentation on the suitability of wetlands as habitat for mammals and birds have not been documented.

4.7 Impacts from Increasing the Amounts of Nutrients Coming into a Wetland

The major nutrients for plant growth, phosphates, nitrates, and ammonium, can be transported into aquatic systems and impact the functions performed by wetlands. These nutrients are carried in water in dissolved forms or adsorbed onto sediment. The element phosphorus is usually the limiting nutrient for plant growth in freshwater aquatic systems (Newton 1989, Mitsch and Gosselink 2000). Because it is the limiting factor, phosphorus in the presence of the other critical element, nitrogen, allows expansive growth of phytoplankton, algae, and larger plants in aquatic systems when it is available in higher quantities.

Excessive algal growth is unsustainable, and when the algae blooms die, their decomposition causes the available dissolved oxygen to be consumed. The undesirable growth of vegetation caused by high concentrations of plant nutrients in bodies of water is called *eutrophication*. Eutrophication is defined as the process by which a body of water becomes enriched in dissolved nutrients (as phosphates) that stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen (Merriam Webster online http://www.m-w.com/cgi-bin/dictionary?book=Dictionary&va=eutrophication accessed October 14, 2004).

Excess phosphorous and nitrogen, therefore, often leads to eutrophication with subsequent mortality of the aquatic organisms that require oxygen (Newton 1989, Mitsch and Gosselink 2000). Wetlands with areas of water on the surface can therefore become eutrophic if they receive excessive amounts of phosphorus and/or nitrogen.

4.7.1 Impacts on Hydrologic Functions from Increasing the Amounts of Nutrients

It is possible that the stimulation of plant growth by excess nutrients could increase the density of plants in the wetland. A thicker stand of vegetation can be expected to provide more resistance to flood flows than a thinner one (Adamus et al. 1991, Hruby et al. 1999). Therefore, excess nutrients might indirectly improve the reduction in velocity that a wetland provides during floods. The literature did not provide any other information on how nutrients might affect the hydrologic function of wetlands.

4.7.2 Impacts on Functions that Improve Water Quality from Increasing the Amounts of Nutrients

Some research indicates that excessive nutrients from agricultural operations may reduce the normal ability of wetland microbes to detoxify particular pesticides (Kazumi and Capone 1995, Chung et al. 1996, Entry and Emmingham 1996). Adding nitrogen to riparian wetlands may potentially compromise the long-term ability of the system to remove nitrogen via denitrification (Ettema et al. 1998). Other information on this topic was not documented in the literature.

However, several avenues of research could be combined to make some hypotheses about impacts. The addition of nutrients to acidic bogs results in changes in plant communities. The plant community that maintains the high acidity in the bog may change to one that maintains a more neutral pH. These changes might then alter several aspects of chemistry in the wetland that affect its ability to improve water quality. The rate of nitrification will probably increase because, as noted by Mitch and Gosselink (2000), low pH inhibits denitrifying bacteria. The change in pH will also probably change the ability of the wetland to bind different toxic metals and other compounds. (See the discussion in Chapter 2 on how pH is linked to the ability of a wetland to bind different pollutants.)

4.7.3 Impacts on Plants from Increasing the Amounts of Nutrients

Excessive nutrients can affect wetland plants in a variety of ways including:

- Shifting the species composition away from species that take up nutrients slowly, to those that are able to exploit nutrient pulses more rapidly or which have high nutrient requirements (Hough et al. 1989, Arts et al. 1990, Gopal and Chamanlal 1991, Wetzel and van der Valk 1998)
- Triggering algal blooms that can shade out many submersed herbaceous plants (Crowder and Painter 1991, Stevenson et al. 1993, Srivastava et al. 1995, Short and Burdick 1995)
- Causing dead plant material to accumulate faster than it can decompose completely, thus altering understory and soil structure (Neill 1990b, Craft and Richardson 1993)

Such changes usually result in long-term changes in the distribution and richness of plants within the wetland. Over the long term, nutrient additions to most wetlands tend to reduce species richness and increase the dominance of a few species. Often, non-native species are most capable of invading rapidly changing environments. Consequently they frequently come to dominate some nutrient-enriched wetlands (Adamus et al. 2001).

Increases in plant litter can smother other plants when the fast growing species die, thus helping maintain the dominance of species that exploit nutrients the most (Adamus et al. 2001). For example, the addition of nitrogen and phosphorus fertilizers to a marsh dominated by cattail (*Typha glauca)* and the grass *Scolochloa festucacea* during two growing seasons resulted in increased biomass of both species. However, the biomass of *S. festucacea* declined in the second year due to accumulated litter of *T. glauca* (Neill 1990b).

The plants in bogs and other nutrient-poor wetlands are logically the most sensitive to nutrient additions (Moore et al. 1989). The increased availability of nutrients allows grasses and common opportunistic plants to out-compete rare plants (such as sundews, orchids, and pitcher plants) that are adapted to nutrient-poor conditions. For example, in Appalachian peat bogs, the spatial dominance of bristly dewberry (*Rubus hispidus*) was positively related to nutrient levels, but dominance of the Ericaceae shrubs was negatively related (Stewart and Nilsen 1993).

Many aquatic plant species respond to nutrient additions with increased growth, biomass, and productivity. Growth responses to enrichment have been documented for about 80 wetland-associated species in North America. Of these, most have tolerated enrichment or responded to enrichment with increased biomass or growth (Adamus and Gonyaw 2000).

> Information on the response of many individual plant species to nutrients can be found in the National Database of Wetland Plant Tolerances at:
> http://www.epa.gov/owow/wetlands/bawwg/publicat.html#database1

4.7.4 Impacts on Invertebrates from Increasing the Amounts of Nutrients in the Habitat

Excessive nutrients can cause long-term and short-term shifts in invertebrate communities. The information available suggests that excess nutrients can result in both decreases and increases in species richness as well as changes in the groups of invertebrates found. The direction of the change depends on how the nutrients impact the vegetation and soils that are the main habitat for invertebrates. Findings from the literature include:

- **Increased richness of invertebrates.** Up to some point, nutrient inputs to wetlands can lead to increased invertebrate richness, as more food sources become available to predatory invertebrates (Rader and Richardson 1992, Campeau et al. 1994, Cieminski and Flake 1995, Gernes and Helgen 1999).

- **Reduced richness of invertebrates.** Invertebrate richness in a series of highly enriched wastewater wetlands was found to be lower than in a less enriched reference wetland (Nelson et al. 2000).

- **Changes in the types of invertebrates.** In some cases excess nutrients result in the increased dominance of certain kinds of algae. Invertebrates that specialize in feeding on these algae, or that characteristically find shelter and attachment sites in the aquatic plants, then have an advantage and can become dominant (Murkin et al. 1991, Campeau et al. 1994). Exposure to organic enrichment and eutrophication frequently causes an increase in grazers (such as Tanypodinae midges), as well as other herbivores, species that feed on detritus, predators, and “miners” that burrow into plants. These are groups that typically increase with increasing growth of algae growing on the bottom and emergent aquatic plants (Campeau et al. 1994). A study of four lacustrine wetlands bordering Lake Michigan also found that midge communities shifted across nutrient gradients (Murkin et al. 1992, Campeau et al. 1994).

- **Increased density of invertebrates.** Total invertebrate density increases with increased nutrients, as algal production becomes less of a limiting factor in the invertebrate community (Murkin et al. 1992, Campeau et al. 1994).

- **Changes in the bioaccumulation of metals by invertebrates.** Nutrients appear to influence the tendency of aquatic invertebrates to accumulate heavy metals and the type of metals that are accumulated. For instance, zinc, iron, and manganese concentrations were higher in midges from nutrient-rich wetlands, whereas high copper concentrations were found in midges from nutrient-poor wetlands (Bendell-Young et al. 2000). This may be due at least partly to the bioavailability of various metals being influenced by oxygen conditions in the sediment, which in turn are partly the result of decomposition of algal blooms triggered by high concentrations of nutrients (Adamus et al. 2001).

Information on the response of many individual invertebrate species to enrichment can be found in the National Database of Invertebrate Tolerances at: http://www.epa.gov/owow/wetlands/bawwg/publicat.html#database1

4.7.5 Impacts on Amphibians and Reptiles from Increasing the Amounts of Nutrients in the Habitat

The review of the literature indicates that amphibians can be impacted by the input of nutrients. No studies were found on impacts on reptiles.

Amphibians in the Northwest can be directly impacted by the input of nitrates. Five amphibian species in Oregon showed both sublethal responses and mortality following laboratory applications of nitrate. These studies indicated that the EPA nitrate criteria for drinking water of 10 milligrams per liter (mg/l) and/or for protection of warmwater fish are inadequate to protect these amphibians (Marco et al. 1999). In Texas, playa wetlands receiving nutrient-laden effluent from feedlots were devoid of amphibians found in natural playas (Chavez et al. 1999). Experiments indicated that effluent had to be diluted to less than 3% strength in order to minimize adverse effects on the leopard frog (*Rana pipiens*).

Indirect impacts of excessive nutrients can also be important to amphibians. Shifts in seasonal timing and amount of nutrients that enter a wetland can, over a period of years, increase the relative dominance of algae and/or emergent plants at the expense of submersed plants. This in turn can reduce the availability of submersed plants as attachment substrates for amphibian eggs and as cover for larvae (Beebee 1996).

Excess nutrients can also diminish dissolved oxygen levels (Tattersall and Boutilier 1999), alter the abundance of aquatic predators, and shift the algal and invertebrate foods available to amphibians (Horne and Dunson 1995). As a result, species composition and sometimes species richness of amphibian communities can decline as eutrophication becomes severe. However, well designed studies of such effects are few.

4.7.6 Impacts on Fish from Increasing the Amounts of Nutrients in the Habitat

No information was found documenting direct impacts of excess nutrients on fish in wetlands. However, the secondary impacts of eutrophication such as oxygen depletion do affect fish. Much of the literature deals with impacts of low oxygen in streams (for a review see Knutson and Naef 1997), and it can be assumed that the impacts of low oxygen in wetlands will be similar.

As mentioned previously, the increased plant production that results from added nutrients often results in low oxygen levels when the plant material dies and starts to decompose. Many fish species suffer from reduced levels of dissolved oxygen, and feeding habits also may shift. To some degree, fish families can be grouped according to their susceptibility to oxygen deficiencies. Salmonids and coregonids (whitefish) require high levels of dissolved oxygen, whereas cyprinids (a large family that includes carp and goldfish) often tolerate low dissolved oxygen levels (Harper 1992). Thus the species composition and richness may change depending on the initial state of the wetland and the duration and magnitude of the eutrophication.

4.7.7 Impacts on Birds from Increasing the Amounts of Nutrients in the Habitat

Eutrophication can indirectly impact the composition of the wetland bird community by altering the vegetation structure and availability of prey. In general, moderately elevated nutrient levels also spur the growth of submersed plants that provide food for ducks, as well as supporting more aquatic insects that are especially important as food for ducklings and aerial foragers like swallows. However, excessive nutrients cause algal blooms that can kill fish eaten by birds, reduce the growth of plants growing on the bottom by blocking light, and reduce visibility of other food items under the water surface.

Studies that have documented changes in the bird community related to excess nutrients are summarized below:

- Excessive nitrates have been implicated in deaths of some frogs (see Section 4.7.5). Frogs are a significant prey item for some wetland birds (Adamus et al. 2001).

- Northern shoveler (*Anas clypeata*) and eared grebe (*Podiceps nigricollis*) were positively associated with phosphorus in a survey of wetlands in interior British Columbia (Savard et al. 1994).

- The abundance and biomass of water-birds were positively correlated in 46 Florida lakes with levels of phosphorus, nitrogen, and chlorophyll. There also was a positive correlation of water-bird richness with phosphorus, after accounting for nutrients contributed to the lakes by the birds themselves (Hoyer and Canfield 1994).

- Total density of dabbling ducks was correlated positively with total dissolved nitrogen (Savard et al. 1994).

- The parasitic nematode *Eustrongylides ignotus,* which has only been found in disturbed and enriched wetlands (Spaulding and Forester 1993), negatively affects the health of adult wading birds and the survival of their nestlings (Spaulding et al. 1993).

4.7.8 Impacts on Mammals from Increasing the Amounts of Nutrients in the Habitat

No information was found on impacts from increases in nutrients on the habitat of mammals in wetlands. It can be hypothesized, however, that, if eutrophication results in anoxic conditions that are lethal to the prey of mammals (e.g., fish and some amphibians), the community composition may shift from predator species (such as otter or mink) to vegetarian or invertebrate-eating species and opportunists (such as muskrat).

4.7.9 Summary of Key Points

- Some impacts to the hydrologic functions from increased nutrients can be hypothesized because the increased growth of plants resulting from increased nutrients may provide better resistance to the movement of flood waters.

- Some impacts to the functions of improving water quality have been reported. These include a potential reduction in the ability of wetlands to detoxify pesticides and to remove nitrogen as a pollutant. Impacts from increased nutrients can also be hypothesized for bogs. The ability of bogs to bind toxic metals may be reduced but their ability to remove nitrogen may be increased.

- Increasing nutrients will stimulate plant growth and may change the composition of the species present.

- Impacts of increased amounts of nutrients on the habitat wetlands provide have been documented for invertebrates, amphibians, and birds. Excess nutrients can result in both an improvement in the habitat through the production of food and a reduction in habitat through eutrophication. The actual impacts depend on local conditions in the wetland. Impacts to the habitat for fish and mammals can be inferred because eutrophication causes reductions in the levels of oxygen in the water with resultant impacts to both water quality and the food sources for these two groups.

4.8 Impacts from Introducing Toxic Contaminants to a Wetland

4.8.1 Impacts on Hydrologic Functions from Toxic Contaminants

Contaminants are chemical compounds, solutions, or particles introduced into the environment that change how the environment or the organisms living there function. Toxic contaminants are poisons that specifically impact the growth and reproduction of living organisms.

No explicit information was found in the literature on the possible impacts of toxicity from contaminants on the hydrologic functions provided by wetlands (storing flood waters, reducing erosion, and recharging groundwater). It is not possible at this stage to hypothesize either positive or negative impacts on hydrologic functions because no logical deductions could be made from the available information.

4.8.2 Impacts on Functions that Improve Water Quality from Toxic Contaminants

Information on how toxic compounds affect the function of wetlands to remove pollutants is sparse. It can be hypothesized, however, that an input of low levels of toxic compounds may stimulate the ability of a wetland to detoxify pollutants. Some microbial species biodegrade particular contaminants and their abundance is increased in the presence of low levels of the contaminants. These species can flourish in some wetlands that are only mildly or moderately contaminated.

Contaminants that can be processed by microbes when concentrations are low to moderate include copper (Farago and Mehra 1993), mercury (Marvin-Dipasquale and Oremland 1998), selenium (Steinberg and Oremland 1990, Azaizah et al. 1997), cadmium (Sharma et al. 2000), manganese (Sikora et al. 2000), and petroleum (Nyman 1999, Megharaj et al. 2000).

4.8.3 Impacts on Plants from Toxic Contaminants

Most plant species are relatively tolerant to toxic contaminants. Impacts usually result from the effects of contaminants on plant metabolic pathways, enzymatic reactions, and growth (Fitter and Hay 1987). Symptoms of toxicity can include reduced growth; small, discolored, or dying leaves; early leaf fall; and stunted or suppressed growth of roots (Pahlsson 1989, Rhoads et al. 1989, Vasquez et al. 1989).

Shifts in the composition of the plant community in response to contaminants have not been widely documented. Relevant studies include:

- Arsenic, cadmium, copper, lead, and zinc inhibited growth in hybrid poplar (*Populus*) and several other tree species (Lejeune et al. 1996).
- Iron and manganese, although not usually toxic to wetland plants, do affect species in some wetland types. For example, laboratory experiments revealed differences among 44 fen species with regard to the influence of iron on growth (Snowden and Wheeler 1993).
- Oil spills can have long-lasting effects on wetland plant communities (Obot et al. 1992). In a greenhouse experiment, oil and a detergent used to clean up oil spills were applied to broadleaf arrowhead (*Sagittaria lancifolia)*, salt marsh sedge (*Scirpus olneyi)*, and common cattail (*Typha latifolia)*. The leaves on all of the study plants died following oiling, but new leaves soon developed on those plants subjected to oil and subsequent cleaning with the detergent. *S. olneyi* was the least sensitive of the three species, whereas *T. latifolia* appeared to be the most sensitive (Pezeshki et al. 1998).
- The herbicides Rodeo® and Garlan 3A®, applied to control purple loosestrife (*Lythrum salicaria*), also reduced the growth rates of non-target species such as duckweed (*Lemna gibba)* (Gardner and Grue 1996).

4.8.4 Impacts on Invertebrates from Toxic Contaminants in the Habitat

General studies on the impacts to invertebrates in wetlands of Puget Sound found that increased levels of contaminants and changes in the water regime correlated with declines in species richness among the scraper and shredder functional feeding groups and the Chironomidae family (small, mosquito-like flies) (Ludwa 1994). These authors found declines in richness and abundance of invertebrate groups whose presence is seen as an indicator of the general health or quality of a water body. Another study in Massachusetts also showed a direct and negative correlation between urbanization and the abundance and richness of macro-invertebrates (Hicks 1995) primarily through impacts to water quality.

The following sections first review the effects of metals on invertebrates and then describe the effects of organic and synthetic compounds such as pesticides. Much of the information on the impacts on invertebrates is based on studies in streams. These studies are probably applicable to wetlands because some of the species and many of the invertebrate families reported in the studies are also found in wetlands.

4.8.4.1 Impacts of Heavy Metals on Invertebrates

Heavy metals such as mercury, lead, zinc, copper, and cadmium can be directly toxic to wetland invertebrates. Metals can also impact invertebrate communities by altering the species composition and abundance of algae and aquatic plants upon which invertebrates depend for food and shelter. Growth, larval development, and reproduction of invertebrates can also be harmed by long-term exposure to sublethal concentrations of trace metals (Timmermans 1993). Relatively little, however, is known about the sublethal effects of metal pollutants in freshwater wetlands or how metals are metabolized or accumulated.

The extent to which heavy metals are toxic to wetland invertebrates depends largely on the acidity of the wetland and the particular form of the metal involved. Acidic conditions can mobilize and increase the toxicity of some metals, such as cadmium (Wright and Welbourn 1994), and decrease the toxicity of others, such as aluminum (Wren and Stephenson 1991). On the other hand, some metals, such as iron and aluminum, can to some degree protect invertebrates from otherwise toxic effects of heavy metals in acid mine drainage (Whipple and Dunson 1992).

Specific studies documenting the impact of heavy metals on invertebrates are summarized below:

- Moderate recovery of invertebrates from metal contamination was demonstrated in the Coeur D'Alene River in Idaho. Over 22 years after contamination by zinc and other metals ceased, the number of species grew from zero to 18, while the proportion of mayflies, stoneflies, and caddisflies relative to the proportion of midges rose (Hoiland and Rabe 1992, Hoiland et al. 1994).
- Some studies show herbivores and detritivores as the most sensitive to additions of metals (Kiffney and Clements 1994a, Leland et al. 1989), whereas others have reported scrapers being the most sensitive group (Clements 1994).
- Mayflies and some stoneflies of western streams are sensitive to metals, whereas caddisflies and midges are relatively tolerant (Clements 1994, Kiffney and Clements 1994b, Leland et al. 1989).
- Agricultural drainage water containing arsenic, boron, lithium, and molybdenum entering the Stillwater Wildlife Management Area in Nevada proved acutely toxic to many wetland invertebrates (Hallock and Hallock 1993).
- Copper and some other heavy metals appear to be more damaging to aquatic communities in the spring and summer rather than in the fall (Leland et al. 1989). Summer exposure to metals may coincide more closely with hatching of many macro-invertebrates, and early periods in the development of the invertebrates may be more susceptible.

4.8.4.2 Impacts of Pesticides, Oil, and Other Contaminants on Invertebrates

Pesticides, oil, and other toxic contaminants represent a wide range of pollutants. In general, however, most have been shown to change the community structure (abundance, distribution, and richness) of invertebrates. Contaminants cause these effects through several mechanisms, including:

- Causing acute or chronic toxicity to invertebrates
- Altering algal communities and aquatic plants upon which some invertebrates depend for food and shelter
- Altering predation on invertebrates by decimating numbers of other crustaceans, fish, and amphibians
- Reducing rates of oxygen diffusion
- Changing the effects of other potential disturbances, such as acidity

The range of pesticides and organic pollutants used today is very large and it is not possible to generalize the impacts of this group of pollutants on invertebrates. Table 4-1 summarizes numerous studies that demonstrate the wide range of responses of invertebrates to contaminants.

Table 4-1. Summary of studies on effects of contaminants on invertebrates.

Reference	Contaminant Studied	Results
Eisler (1992)	diflubenzuron (insecticide)	In laboratory tests diflubenzuron was most toxic to crustaceans, followed by mayflies, midges, caddisflies. Larvae of corixids, dragonfly adults and larvae, spiders, dytiscids, and ostracods had moderate sensitivity
Eisler (1992)	paraquat, cyanide, fenvalerate, acrolein	These substances were lethal to invertebrates
Dieter et al. (1996)	phorate (pesticide)	In Prairie Pothole Region, macro-invertebrates that were particularly sensitive to phorate included hemipterans, mosquitoes, flies, mayflies, water mites, and water beetles. Less sensitive were leeches, snails, aquatic worms, ostracods
Lieffers (1990)	3-trifluoromethyl-4-nitrophenol (TFM) (lampricide)	TFM had a significant effect on invertebrates in a small stream
Fairchild and Eidt (1993)	fenithrothion (insecticide for forest insects)	Fenithrothion reduced emergence of aquatic insects for 6 to 12 weeks. Densities of most invertebrates (especially predatory species, midges, some other dipterans) were reduced by as much as 50% for more than one month after treatment. Wetland sediments became dominated by aquatic worms and water mites. Although in many streams and large lakes fenithrothion has transitory effects, residual toxicity remained in bog wetlands during winter and into the next year
Hachmoller et al. (1991)	various organic pollutants	Mayflies, stoneflies, caddisflies decreased in abundance in stream contaminated by various organic pollutants

Reference	Contaminant Studied	Results
Keller (1993), Metcalfe and Charlton (1990)	various contaminants	Mussels are especially sensitive to combined effects of pesticides, organic compounds, excessive nutrients
Kemp and Spotila (1996)	industrial pollutants, PCBs	Isopods, oligochaetes, craneflies were main survivors in a Pennsylvania stream with industrial pollution (including PCBs) compared with non-urbanized control segments
Crunkilton and Duchrow (1990)	oil	After 25 days, an oil spill in a Missouri stream reduced macro-invertebrate population to less than 0.1% of normal densities. Recovery of some species of stoneflies, mayflies, and caddisflies did not occur for at least nine months
Henry et al. (1994)	surfactant	In laboratory tests, a surfactant was approximately 100 times more toxic than the herbicide glyphosate, with which it is commonly applied
Wipfli and Merritt (1994), Kreutzweiser et al. (1994), Jackson et al. (1994), Waalwijk et al. (1992)	*Bacillus thuringiensis* var. *israelensis* (Bti) (biological control agent)	Bti appears to have minimal adverse effects on non-target insects in streams although mortality has been observed in Lepidoptera, some midges, craneflies, caddisflies, mayflies
Euliss and Mushet (1999)	agricultural contaminants	Direct adverse correlation found between aquatic invertebrate species richness and agricultural practices for seasonally inundated wetlands in prairie pothole region of North Dakota. Adverse effects on invertebrates could result from agrichemicals (shown to cause increased mortality of aquatic invertebrates in other studies). Tilling around wetlands could increase erosion, leading to suspended sediments and adsorbed metals that are toxic to some zooplankton and thus affect the food chain

4.8.5 Impacts on Amphibians and Reptiles from Toxic Contaminants in the Habitat

Studies of the effects of heavy metals, pesticides, and other toxins on amphibians and reptiles have been conducted mainly on species, not communities. A review of relevant literature was published by Sparling et al. (2000). Schuytema and Nebeker (1996) have compiled a database of toxicity information from published literature for 58 amphibian species as related to 135 chemicals.

Many different pollutants have been documented as toxic to species of amphibians and reptiles found in Washington's wetlands. The following references document the impact of toxic compounds on some species found in the Pacific Northwest:

- Toxic effects of aluminum and other metals on the embryos and tadpoles of the northern leopard frog (*Rana pipiens*) were found by Freda (1991), Freda and McDonald (1990), and Freda et al. (1990).

- Many synthetic organic compounds affect amphibians and aquatic reptiles. Northwestern salamander (*Ambystoma gracile*) egg mortality corresponded with levels of total petroleum hydrocarbons in western Washington (Platin 1994, Platin and Richter 1995).

- The pesticide esfenvalerate caused damaging sublethal effects on tadpoles of the northern leopard frog (Materna et al. 1995).

- Tests of three forest insecticides (fenitrothion, triclopyr, and hexazinone) on the northern leopard frog in Ontario suggested that tadpoles were sensitive to triclopyr and fenitrothion (Berrill et al. 1991).

4.8.6 Impacts on Fish from Toxic Contaminants in the Habitat

The response of fish communities and individual species to toxic compounds is varied and complicated by many environmental factors. Smaller fish may be the first to respond to contaminants (Matuszek et al. 1990).

The toxicity of copper and zinc to some fish species depends on other chemical characteristics of the water (Munkittrick and Dixon 1992, Welsh et al. 1993), as well as fish behavior (Pourang 1995). For example, dissolved organic matter from a marsh at a level of 5 mg carbon per liter kept copper from binding to the gills of small steelhead (*Oncorhynchus mykiss*), thereby reducing its toxicity. This occurred because copper formed a complex with dissolved organic carbon, making the copper unavailable (Hollis et al. 1997). In addition, some fish species may acclimate to moderately elevated levels of some metals (Klerks and Lentz 1998).

Selenium is not directly toxic to fish at concentrations usually found in soils but can become toxic once concentrated in fish food chains. This is especially true in some wetlands that receive effluents from irrigated fields or power plant reservoirs in some regions (Zilberman 1991, Lemly 1996).

Synthetic organics, including pesticides, can accumulate in wetland fish (Cooper 1993), often with adverse effects. In a Canadian wetland receiving effluent containing oily sand, fish had altered blood chemistry and died within fourteen days (Bendell-Young et al. 2000).

4.8.7 Impacts on Birds from Toxic Contaminants in the Habitat

The response of individual bird species and bird communities to toxic compounds is varied. Individual species are directly affected by many pollutants. Many pesticides, however, are more likely to impact bird populations by altering their habitat and foods rather than by direct toxicity. Studies that document such impacts are summarized below:

- Several instances have been documented of wetland birds being directly poisoned by insecticides applied at recommended rates (e.g., parathion, as documented by Flickinger et al. 1991).

- Herbicides have been applied to wetlands to change the structure of vegetation and the composition of plant species, with consequent shifts in the composition of bird species (Solberg and Higgins 1993, Linz et al. 1996). Information on pesticides in prairie wetlands has been compiled by Facemire (1992).

- Detrimental reproductive effects from dioxins have been documented for great blue herons (*Ardea herodias*) (Hart et al. 1991); for dioxins and furans for wood ducks (*Aix sponsa*) (White and Seginack 1994); for PCBs (polychlorinated biphenyls) in American kestrels (*Falco sparverius*); and for petroleum in mallards (*Anas platyrhynchos*) (Holmes and Cavannaugh 1990).

- Research has continued to focus on the effects of selenium on waterfowl in western states. Biogeochemical conditions favoring the release of selenium into wetlands are found throughout the arid regions of the western states and threaten bird communities in many wetlands along the Pacific and Central Flyways (Paveglio et al. 1992). Agricultural drainage, irrigation, and natural waters can leach selenium from many western soils. Subsurface irrigation is the most widespread and biologically important source of selenium toxicity for waterfowl, including the waterfowl in six national refuges (Ohlendorf et al. 1990, Feltz et al. 1991). Selenium is often accompanied by boron, which is toxic to ducklings (Stanley et al. 1996).

Lead shot as a source of toxic metal

The use of lead shot for hunting is banned in Washington State but its use is still allowed for target shooting. If target ranges are adjacent to wetlands the potential exists of lead entering these wetlands. The pathways for uptake of lead shot by aquatic birds would be the same whether the source is from active hunting or from target shooting.

Lead is toxic to aquatic biota (Eisler 1988). Waterborne lead is the most toxic form. The introduction of lead into the aquatic food chain via aquatic plants has been found in the roots and foliage of the pond weed *Potamogeton foliosus* and in the exoskeleton of crayfish (Eisler 1988, Knowlton et al. 1983). Elemental lead (lead shot), however, has been shown to be significantly less bioavailable to rooted aquatics than powdered lead (Behan et al. 1979).

Waterfowl are at risk from ingesting lead shot as they forage in wetlands. Because of the proximity of wetlands to shooting ranges, other aquatic organisms, including amphibians, and some bird species may be at risk from the spent lead. For example, Eisler (1988) found that lead in tadpoles might contribute to the lead levels reported in wildlife that eats tadpoles. Predatory animals that feed on amphibians include reptiles (such as the garter snake), birds such as the great blue heron and the marsh hawk, and mammals such as raccoons (Martin et al. 1951).

4.8.8 Impacts on Mammals from Toxic Contaminants in the Habitat

No explicit information was found in the literature on the possible impacts of toxicity from contaminants in wetlands on mammals using wetlands. It is not possible at this stage to hypothesize either positive or negative impacts on mammals because no logical deductions could be made from the available information.

4.8.9 Summary of Key Points

- No information was found on the impacts of contaminants on the hydrologic functions of wetlands, but it can be hypothesized that increases in sediment can reduce the storage of water in depressional wetlands.
- The rates at which wetlands remove toxic compounds may actually be increased under low levels of contamination because the specific microbes that detoxify the pollutants are stimulated.
- The impact of contaminants on plants has not been studied as extensively, but the information suggests that toxicity from contaminants can change the composition of the plant community.
- Impacts of increased contaminants on the habitat provided by wetlands have been documented for invertebrates, amphibians, fish, and birds. Many contaminants are toxic to these species and their presence in wetlands reduces the suitability of a wetland as habitat. Wetland-associated mammals are the only group of vertebrates for which no information was found.

4.9 Impacts from Changing the Acidity (pH) of Soils or Water in a Wetland

4.9.1 Impacts on Hydrologic Functions from Changing the Acidity

No information was found on the impacts that increasing acidity might have on the hydrologic functions performed by wetlands. In the absence of any information to the contrary, however, it is possible to hypothesize that decreasing pH will probably not change how wetlands perform these functions. Changes in the acidity of water are not expected to change how well wetlands store water, how well they slow it down during peak flows, or how well they recharge groundwater.

4.9.2 Impacts on Functions that Improve Water Quality from Changing the Acidity

Increased acidity (reduced pH) could change aspects of wetland chemistry that affect the ability to improve water quality. It can be hypothesized that the rate of nitrification will probably decrease because, as noted by Mitch and Gosselink (2000), low pH inhibits denitrifying bacteria. Changes in pH will also change the ability of the wetland to bind different toxic metals and other contaminants in the soils (Kadlec and Knight 1996). Each contaminant, however, has different chemical properties. Some are released when pH decreases (acidity increases) and some are more tightly bound when pH decreases. The impacts of changing the pH, will, therefore, depend on the contaminants coming into the wetland.

4.9.3 Impacts on Plants from Changing the Acidity

The pH is critical in determining the distribution of plants in wetlands. Changes in pH that result from human activities can, therefore, have major impacts. Studies described below have documented changes in plant populations that resulted from both decreases in pH (more acidic conditions) and increases in pH (less acidic conditions). However, the effects of acidification (or its reversal by liming) on the species composition of plants are not consistent among wetland types or even within individual wetlands (Farmer 1990, Baker and Christensen 1990, Mackun et al. 1994, Weiher et al. 1994).

For example, many plant species that inhabit bogs are adapted to acidity levels that would kill most wetland plants. Species whose decline or disappearance from a lacustrine wetland coincided with acidification include water lobelia (*Lobelia dortmanna),* shore quillwort (*Isoetes riparia*), water milfoil (*Myriophyllum tenellum),* yellow pond lily (*Nuphar* sp.), common bladderwort (*Utricularia vulgaris),* and ribbon leaf pondweed (*Potamogeton epihydris)* (Farmer 1990). Species whose relative abundance increased included *Leptodictium riparium,* needle spike rush (*Eleocharis acicularis),* sphagnum moss *(Sphagnum* sp.), and pipe wort (*Eriocaulon septangulare)* (Farmer 1990).

In general, making wetlands more acidic can directly impact plants by limiting the availability of some inorganic nutrients and carbon (Farmer 1990). Acidic conditions also promote the conversion of nitrates into ammonium.

Acidic conditions can impact plants indirectly by reducing the densities of invertebrates that graze or process detritus. Acidic conditions in wetland soils increase the toxicity of aluminum and manganese (Rendig and Taylor 1989, Crowder and Painter 1991).

4.9.4 Impacts on Invertebrates from Changing Acidity in the Habitat

In general, changing the acidity in a wetland can alter the community structure of invertebrates by:

- Causing acute or chronic damage to tissues of invertebrates; the species that easily lose sodium ions when pH is reduced tend to be most sensitive (Steinberg and Wright 1992)
- Altering algal communities and aquatic plants upon which some invertebrates depend for food and shelter (see discussion in Section 4.9.3)
- Altering the populations that are predators of invertebrates such as other crustaceans, amphibian, and fish (see Sections 4.9.5, 4.9.6)

The impacts of acidification on aquatic invertebrate communities have been researched extensively. Table 4-2 categorizes invertebrate species as more or less tolerant of acidification based mainly on the North American literature. The list is included here because many of these species are probably found in Washington's wetlands. Few local studies, however, document the distribution of invertebrates in the state so it is not possible to identify the tolerance of species that are found here.

Some invertebrates are sensitive to pH increases (decreased acidity). For example, stormwater input to a Florida freshwater marsh increased phosphorus levels, lowered oxygen levels, and raised pH and hardness. This resulted in a shift of the macro-invertebrate population toward species that otherwise are intolerant of the acidic, nutrient-poor conditions typically found in the studied wetland (Graves et al. 1998).

Acidity often reduces the richness of macro-invertebrates in aquatic habitats (Schell and Kerekes 1989, Hall 1994). One study showed that with increased acidity, many aquatic invertebrates declined in numbers and biomass, especially in wetlands with pH below 5.0 (Parker and Wright 1992). Reductions in acid emissions from some Canadian smelters were followed by significant increases in richness of invertebrates in water bodies downwind of the smelters (Griffiths and Keller 1992).

Table 4-2. Summary of studies describing relative tolerance of invertebrates to acidification.

Taxonomic Group and Study Reference	More Tolerant to low pH (Less Sensitive)	Less Tolerant to low pH (More Sensitive)
Dragonflies and Damselflies (Odonata)		
Damselflies (Parker and Wright 1992, Baker and Christensen 1990)	X	
Beetles (Coleoptera)		
Some water beetles (Parker and Wright 1992), especially hydrophilid and dystiscid beetles (Baker and Christensen 1990)	X	
True Bugs (Hemiptera, Homoptera)		
Some water bugs, at least Notonectidae, Gerridae, Corixidae (Baker and Christensen 1990)	X	
Some water bugs (Parker and Wright 1992)		X

Taxonomic Group and Study Reference	**More Tolerant to low pH (Less Sensitive)**	**Less Tolerant to low pH (More Sensitive)**
Caddisflies (Trichoptera)		
Some caddisflies: *Cheumatopsyche pettiti* (Camargo and Ward 1992).	X	
Some caddisflies (Parker and Wright 1992) and some in the scraper and predator guilds (Williams 1991)		X
Flies, Midges, Mosquitoes (Diptera)		
Midges (Havens 1994a, Baker and Christensen 1990, Tuchman 1993)	X	
Some midges, such as *Tanytarsus, Microtendipes*, and *Nilothauma* (Griffiths and Keller 1992)		X
Stoneflies (Plecoptera)		
Some stoneflies (Tuchman 1993) such as *Amphinemura* and *Leuctra* (Griffith et al. 1995)	X	
Many stoneflies, e.g., *Peltoperla arcuata* (Griffith et al. 1995)		X
Mayflies (Ephemeroptera)		
The mayfly *Eurylophella funeralis* (Griffith et al. 1995)	X	
Some mayflies (Balding 1992)		X
Other Macro-invertebrates		
Planarian *Dugesia dorotocephala* (Camargo and Ward 1992)		X
Some water mites (Havens 1994a)	X	
Molluscs (Grapentine and Rosenberg 1992, Gibbons and Mackie 1991, Balding 1992), including clams (Schell and Kerekes 1989)		X
Mussels, snails, leeches (pH >5.0, Schell and Kerekes 1989)		X
The amphipod *Hyalella azteca* (Havens 1994a); pH must remain above 5.8 (Grapentine and Rosenberg 1992)		X
The amphipod *Gammarus minus* (Griffith et al. 1995)		X
Zooplankton		
Some zooplankters, such as *Daphnia galeata mendotae, D. retrocurva, Skistodiaptomus oregonensis* (Havens 1993)	X	
The rotifers *Gastropus stylifer, Keratella taurocephala, Polyarthra renata, Symchaeta* sp. (Fore et al. 1996)	X	
The water flea *Bosmina longirostris* (Havens 1993)		X

Taxonomic Group and Study Reference	More Tolerant to low pH (Less Sensitive)	Less Tolerant to low pH (More Sensitive)
The rotifers *Asplanchna priodonta, Collotheca mutabilis, Conochiloides* sp., *Conochilus unicornis, Gastropus hyptopus, Kellicota longispina, Keratella cochlearis, Keratella crassa, Polyarthra dolichoptera, Trichocera cylindrica* (Fore et al. 1996)		X
Functional Feeding Groups		
Scrapers and collectors (Smith et al. 1990)	X	
Shredders (Tuchman 1993)		X
Deposit feeders (Smith et al. 1990)		X

4.9.5 Impacts on Amphibians and Reptiles from Changing the Acidity in the Habitat

Increased acidity (lower pH) damages amphibians directly (Horne and Dunson 1994b). Acidity may also have direct impacts as a result of its capacity to mobilize toxic metals and perhaps by making sodium less available in some soil types (Wyman and Jancola 1991).

No studies were found describing the impact of increased acidity on amphibians and reptiles in Washington. Studies from other states, however, document these impacts. The information below summarizes some of the information for amphibian and reptile species that are found in the state, even if the studies were done elsewhere.

In Ontario, the acid-neutralizing capacity (alkalinity) of 38 wetlands positively influenced the probability of the northern leopard frog (*Rana pipiens*) being present (Glooschenko et al. 1992).

Embryos of the tiger salamander (*Ambystoma tigrinum*) had more than 70% survival at pH 4.5 and above but suffered much greater mortality at lower pH levels (Whiteman et al. 1995).

Concerns have been raised regarding the vulnerability to acidification of Montane wetlands in the West. Acidification makes aluminum and cadmium more mobile and increases their concentration in surface waters. Amphibians (e.g., Jefferson's and spotted salamanders) are known to be sensitive to acidity and elevated concentrations of aluminum found in some acidic ponds (Blancher 1991, Ireland 1991, Horne and Dunson 1995).

Aluminum released into Montane pools as a result of acidification sometimes has harmed embryos, reduced growth rates, and/or caused deformities and premature hatching of native amphibians (Bradford et al. 1991, Corn and Vertucci 1992).

4.9.6 Impacts on Fish from Changing the Acidity in the Habitat

No information was found on the impacts of acidity on fish in Washington's wetlands. In their review of the literature, Adamus et al. (2001) found that acidity can be directly toxic to fish, inhibit reproductive maturation, inhibit spawning behavior, induce emigration, and alter food availability. Furthermore, in areas where acid rain may be a problem, the increase in acidity induces aluminum toxicity in fish in many lakes and wetlands (Keller and Crisman 1990). Surveys of literature on effects of acidification on fish in lakes (and therefore potentially in wetlands along lake fringes) are provided by Baker and Christensen (1990) and Minns et al. (1990).

4.9.7 Impacts on Birds from Changing the Acidity in the Habitat

Acidification of wetlands affects birds primarily because it reduces the availability of calcium, which is important for egg development; potentially increases the availability of toxic metals; and alters the species composition and abundance of aquatic insects, submersed plants, amphibians, and fish that are important foods for waterfowl (see previous discussions in Sections 4.9.3, 4.9.4, 4.9.5, 4.9.6).

Changes in the types of available food, especially those rich in calcium, can diminish egg shell thickness and generally reduce the reproductive success of waterbirds in wetlands (Sparling 1990, 1991, Blancher and McNicol 1991, St. Louis et al. 1990, Albers and Camardese 1993). Overall, calcium deficiency appears to affect birds in acidified wetlands more than metal toxicity (Albers and Camardese 1993). Breeding pairs of 15 waterfowl species were more abundant in Ontario wetlands with over 40 parts per million (ppm) of total alkalinity than in less alkaline wetlands (Dennis et al. 1989, Merendino et al. 1992). In British Columbia as well, densities of several breeding duck species were greater in ponds with higher levels of conductivity and calcium (Savard et al. 1994).

4.9.8 Impacts on Mammals from Changing the Acidity in the Habitat

No information on the effects of acidification on the overall community structure of wetland mammals was located. It can be hypothesized, however, that where acidification becomes severe, community composition may shift from fish-eating species (e.g., otter) to vegetarian or invertebrate-eating species and opportunists (e.g., muskrat) (Adamus and Brandt 1990).

4.9.9 Summary of Key Points

- No information was found on the impacts of acidity on the hydrologic functions of wetlands, but it is possible to hypothesize that impacts, if any, are minor.
- The rates at which wetlands remove nitrogen are impacted by increasing acidity because denitrification is reduced.
- The rates at which toxic metals and other contaminants are removed by soils can change with acidity, but the actual changes depend on the chemical properties of the contaminant.
- Increasing the acidity in wetlands can also change the composition of the plant community.
- Impacts of increasing acidity on the habitat provided by wetlands have been documented for invertebrates, amphibians, fish, and birds. In general, increased acidity reduces the richness of invertebrates in wetlands and impacts amphibians either directly or by changing the chemistry of the water in the wetland, making it less suitable as a habitat. Acidic wetlands also become a less suitable habitat for birds because the amounts of calcium rich foods are reduced. Mammals are the only group of vertebrates for which no information exists.

4.10 Impacts from Increasing the Concentrations of Salt in a Wetland

Salt concentration in wetlands can increase as a result of (from Adamus et al. 2001):

- Isolating wetlands from some types of groundwater inflow
- Increasing water lost through evaporation
- Discharging effluents that contain salts (especially irrigation return water)
- Routing runoff that has relatively high conductivity into wetlands

Increased concentrations of salt (salinization) impact the functions of wetlands as described below.

4.10.1 Impacts on Hydrologic Functions from Increasing Concentrations of Salt

No information was found on how changes in salt content might affect the hydrologic functions of flood storage and flood desynchronization [the process by which peak flows are delayed in their downstream movement (Adamus et al. 1991)]. However, it is possible to hypothesize that salinization will probably not change how wetlands in Washington perform these functions. Changes in the salt content of water coming into a wetland are not expected to change the physical structure of the wetland on which the hydrologic functions are based. Increasing salt concentrations are not expected to change how well wetlands store water, how well they slow it down during peak flows, or how well they recharge groundwater.

4.10.2 Impacts on Functions that Improve Water Quality from Increasing Concentrations of Salt

One relevant study found that salinities greater than about 300 grams per liter can inhibit the ability of microbes to detoxify toxic forms of selenium (Steinberg and Oremland 1990). This was the only literature found on how salinization might impact the ability of wetlands to remove pollutants.

As noted below, salinization has some impacts on plants, and thus it may affect nutrient uptake and transformation in a wetland. However, it is not possible to predict or hypothesize how such changes in these species might change other functions that improve water quality.

4.10.3 Impacts on Plants from Increasing Concentrations of Salt

In general, high concentrations of soluble salts are lethal to freshwater plants, and lower concentrations may impair growth (Rendig and Taylor 1989). Woody plants tend to be less tolerant than herbaceous plants because they do not have mechanisms for removing salt, other than accumulating salts in leaves and subsequently dropping them (Adamus et al. 2001).

Many plant species that inhabit inland saline wetlands are, of course, adapted to tolerating salt levels that would kill most other freshwater wetland plant species. A survey of inland lakes in western Canada which spanned a salinity gradient identified relative tolerance to salinity and specific salinity tolerance thresholds of many wetland species (Hammer and Heseltine 1988).

Individual plant species have different tolerances and reactions to increasing salinity. It can be expected that the plant community in a wetland will change to one dominated by salt-tolerant plants when additional salts are introduced. For example, wetlands in which salt has been present for some time, such as alkali wetlands, have a completely different plant community than that found in non-alkali wetlands. In eastern Washington a major change in plant communities was found when the conductivity (a measure of the amount of salts present in the water) increased to 2.0 milliSiemens and higher (Hruby et al. 2000).

A study by Hutchinson (1991) describes the tolerance of many wetland plants found in Washington. It can be used to predict how the plant species might change in Washington's wetlands as salt concentrations increase.

It can also be expected that wetlands subject to increases in salinity through agricultural practices or discharges of salt will also be subject to a change in plant populations. One wetland undergoing such a change was observed in the Richland area by the technical team calibrating the Washington State wetland rating systems in the summer of 2002. The conductivity of the wetland was measured at about 6.5 milliSiemens. About one-quarter of the area was still dominated by cattails (*Typha latifolia*), a wetland plant with a relatively low tolerance to salt (Hutchinson 1991), but this species was dying. Dead stalks of this species covered almost half the area of the wetland.

4.10.4 Impacts on Invertebrates from Increasing Concentrations of Salt in the Habitat

The review of the literature indicates that high levels of salinity can alter the structure of freshwater invertebrate communities in many ways. Adamus et al. (2001) have identified the following mechanisms by which the invertebrate community can be altered:

- Acute and chronic damage to tissues of invertebrates
- Changes in the species composition and structure of algal communities and aquatic plants upon which some invertebrates depend for food and shelter
- Changes in predation on invertebrates by decimating numbers of other crustaceans, fish, and amphibians
- Changes in the bioavailability of some other substances, such as heavy metals and nutrients

Even at low concentrations, increases in chloride (a correlate of salinity, and often associated with road salt applications) among twenty-seven Minnesota wetlands were significantly correlated with declines in species richness among the wetlands (Gernes and Helgen 1999). In Wyoming wetlands of fairly low salinity (0.8 to 30 milliSiemens per centimeter), the dominant macro-invertebrates were amphipods and epiphytic snails. Other recent species-specific data on the impacts of salinity in wetland invertebrates are presented in Parker and Wright (1992), and Lovvorn et al. (1999).

4.10.5 Impacts on Amphibians and Reptiles of Increasing Concentrations from Salt in the Habitat

In general, relatively little is known about amphibian tolerance to salinity in Washington. Three studies have reported a statistically significant negative correlation between conductivity of the water and amphibian species richness (Azous 1991, Platin 1994, Platin and Richter 1995). However, the implications of these studies for understanding impacts on existing populations of amphibians in a wetland that is undergoing an increase in salt concentrations is not clear.

4.10.6 Impacts on Fish from Increasing Concentrations of Salt in the Habitat

No information was found on the tolerance of native fishes in Washington to salinity. Adamus et al. (2001) reported the following information relative to some of the introduced game fish that now are found in Washington's wetlands.

Laboratory trials consisting of 120-day exposure of freshwater largemouth bass (*Micropterus salmoides*) to four salinity levels (0, 4, 8, and 12 ppm) indicated a significant decrease in growth rate with increasing salinity up to 8 ppm.

In another experiment, juvenile bluegill (*Lepomis macrochirus*) from a freshwater pond in northeastern Mississippi and a brackish bayou in coastal Mississippi were held in a chamber with zero salinity but given access to chambers containing 0, 2, 4, 6, 8, and 10 ppm salinity (Peterson et al. 1993). Fish from neither habitat showed a clear preference for any of the salinity options. These data and data from previous studies suggest bluegills are better able to physiologically and behaviorally tolerate elevated salinity relative to other centrarchids (the family of fish containing bluegills, bass, crappies, etc.), particularly bass (Peterson et al. 1993).

4.10.7 Impacts on Birds from Increasing Concentrations of Salt in the Habitat

The impacts of increasing salinity on birds are highly dependent on the species in question. The following summarizes relevant studies:

- Highly saline or alkali conditions are detrimental to some invertebrate and plant foods used by many duck species. High salinity is directly toxic or impairs the growth of young ducklings (Clark and Nudds 1991, Moorman et al. 1991).
- Breeding densities of most duck and grebe species in interior British Columbia were greater in ponds with higher conductivity (higher salt content), but marsh nesting species were unaffected (Savard et al. 1994).
- Some species of water birds are very tolerant of high salt concentrations. They occur regularly at very high densities in alkali wetlands during the breeding season and/or migration. Examples include the American avocet (*Recurvirostra americana*), snowy plover (*Charadrius alexandrinus*), phalaropes, killdeer (*Charadrius vociferus*), horned grebe (*Podiceps auritus*), tundra swan (*Cygnus columbianus*), and white-rumped, semipalmated, and Baird's sandpipers (*Calidris* spp.) (Jehl 1994, Savard et al. 1994, Oring and Reed 1997, Rubega and Robinson 1997, Warnock 1997).

4.10.8 Impacts on Mammals from Increasing Concentrations of Salt in the Habitat

No information was found on the impacts of salinization on the overall structure of mammal communities in wetlands and changes in the suitability of wetlands as habitat for mammals.

4.10.9 Summary of Key Points

- No information was found on the impacts of salinization on the hydrologic functions of wetlands, but it is possible to hypothesize that impacts, if any, are minor.
- Only one study was found that documents any impacts of salinization on the ability of wetlands to improve water quality. Very high salt concentrations inhibit the microbes that detoxify selenium.
- Increasing the salt concentrations in wetlands can change the composition of the plant community because specific species are more tolerant of saline conditions than others.
- Impacts of increased salt concentrations on the habitat provided by wetlands have been documented for invertebrates, fish, and birds. In general, increased salinity changes the composition of the invertebrate community in wetlands. Largemouth bass seem to be especially sensitive to increased salinity relative to other species. The young of some waterbird species may also be sensitive, but other species seem to prefer high salinities. No information exists on the impact of salinization on mammals and amphibians.

4.11 Impacts from Fragmenting Wetland Habitats

Fragmentation results directly from human conversion of land to other uses. As described in Chapter 3 fragmentation is a result of both the direct loss of wetland area that isolate populations of wildlife and from changes to the spatial configuration of the wetlands in the landscape. Wetland loss and isolation is seen as a major factor contributing to the loss of biological diversity in vertebrate populations that use wetlands (Harris 1988, Gibbs 2000).

In general, fragmentation of habitats affects biological diversity through (Harris 1988):

- Loss of the species less tolerant to disturbance or those that inhabit the interior parts of wetlands
- Loss of large species with broad ranges
- Loss of genetic integrity within populations
- Increase in numbers of habitat generalists that thrive in disturbed environments, such as parasites

Occasional migration between wetlands is vital in sustaining local populations of wetland-dependent organisms. Limiting the movements of these species reduces the exchange of genetic material among local populations and can result in population extinctions (Gibbs 2000). Three factors that impede movement among wetlands and other habitats include (Gibbs 2000):

- Greater distances between wetlands
- Degradation of upland habitats
- Increased road density

The effects of fragmentation on wildlife that use wetlands are most extensively documented for amphibians and birds. Little information is available for effects on macro-invertebrates, reptiles, and mammals. Several studies done in the Pacific Northwest are cited in the following discussion of how fragmentation impacts wetland functions.

4.11.1 Impacts on Hydrologic Functions from Fragmentation

No information was found on how fragmentation may impact the flood storage, flood desynchronization, and groundwater recharge performed by individual wetlands. It is possible, however, to hypothesize that fragmentation will probably not change how individual wetlands still remaining in the landscape perform these functions. Fragmentation at a landscape level is not expected to change how well the remaining individual wetlands store water or how well they slow it down during peak flows. On the other hand, fragmentation probably does impact the delivery and routing of water to wetlands as described in Chapter 3. This may change how much water gets to a wetland for storage but not how well the wetland can store it.

4.11.2 Impacts on Functions that Improve Water Quality from Fragmentation

No information was found on how fragmentation may impact the ability of wetlands to improve water quality. It is not possible to hypothesize precisely how such changes might affect these functions because related information was also not found.

4.11.3 Impacts on Plants from Fragmentation

The only information found on the response of wetland plant communities to fragmentation are the series of studies carried out by J. Lienert in fens of Switzerland (Lienert, Diemer and Schmid 2002; Lienert, Fischer et al. 2002; Lienert, Fischer, and Diemer 2002; Lienert and Fischer 2003). These studies on the populations of individual obligate wetland plants show that fragmentation can have the following impacts:

- Fragmentation can reduce the genetic variability in a population (Lienert, Fisher, et al. 2002)
- Fragmentation reduces the densities and size of a plant population (Lienert and Fischer 2003)
- Fragmentation reduces the viability of a plant population (Lienert, Diemer and Schmid 2002)
- Fragmentation can lead to the local extinction of a wetland species (Lienert, Fischer, and Diemer 2002)

4.11.4 Impacts on Invertebrates from Fragmentation

Few studies were found that documented the impact of decreasing connections on the suitability of wetlands as habitat for invertebrates. One study found that wetland isolation combined with the harshness of the surrounding upland landscape in more arid environments (such as much of eastern Washington) limit dispersal and colonization by aquatic invertebrates (Myers and Resh 1999).

Another study in New York comparing macro-invertebrate populations at restored wetlands and reference wetlands showed that less mobile invertebrates colonized new wetland sites very slowly or not at all, whereas insects that disperse aerially colonized the new sites rapidly (Brown et al. 1997). Therefore, wetland isolation may have greater effects on less mobile invertebrate species.

4.11.5 Impacts on Amphibians and Reptiles from Fragmentation

4.11.5.1 Amphibians

As early as the mid-1960s, researchers in various parts of the country documented the effects of fragmentation on amphibians. One author notes the disappearance of a number of species of frogs, toads, turtles, and snakes in an urbanizing area in the Midwest that he studied from 1949 to 1964 (Minton 1968).

The effects of increased wetland isolation have been extensively studied for amphibians since then. This is probably because amphibians:

- Are restricted to movement on the ground
- Do not typically have large migration ranges
- Often move between terrestrial and aquatic habitats
- Have experienced significant population declines throughout the world

The causes of declines in the populations of amphibians have been extensively studied and most researchers conclude that the problem is very complex and multiple factors are likely at work (Hayes and Jennings 1986, Pechmann et al. 1991, Pechmann and Wilbur 1994, Delis et al. 1996, Adams 1999a). Among these factors, there is evidence that increasing isolation of wetlands due to wetland loss may play a significant role in declining amphibian populations (Ostergaard 2000, Adams 1999a, Lehtinen et al. 1999, Semlitsch and Bodie 1998). This has significant implications for amphibians in Washington State because about 97% of amphibian species that occur here commonly use wetlands for at least one life cycle stage (Leonard et al. 1993).

Amphibians are not randomly distributed within acceptable habitats—they occur in higher abundance and species richness in habitats that are better connected to other desirable habitats (Lehtinen et al. 1999, Lehtinen and Galtowitsch 2001). A Minnesota study of 21 marshes noted that the two most important predictors of decreases in amphibian species richness in agricultural areas are the degree of wetland isolation and the road density (Lehtinen et al. 1999). The marshes in this study were located in both prairie and hardwood forest ecoregions in two primary land-use settings: urban and agricultural. The study noted some differences between ecoregions and land-use effects. In the agricultural prairie ecoregion, the amphibian assemblages observed appeared to be most influenced by:

- Road density
- Wetland isolation
- Biological interactions (presence of predators)

In deciduous forest areas that are urbanizing, amphibian richness was most closely related to upland land use and associated habitat fragmentation.

Other landscape-based studies also conclude that the distances between wetlands, as well as the suitability of terrestrial habitats, are key factors in amphibian distribution. Amphibian recolonization patterns are species and spatially dependent because not all species have the capacity to move beyond fragmented, isolated habitats (Lehtinen and Galatowitsch 2001).

Declines in the richness of amphibian species have also been documented as urban land use increases (Lehtinen et al. 1999, Knutson et al. 1999, Richter and Azous 2001a). A landscape analysis of habitats for anurans (frogs and toads) in Wisconsin and Iowa showed that anurans were positively associated with uplands, wetland forests, and emergent wetlands and negatively associated with urban land (Knutson et al. 1999). A positive association, in this study, means higher abundance and species richness. The negative association with urban land is attributed by the authors to:

- Conversion of habitat
- Roads acting as barriers
- Presence of exotic predators
- Chemical contamination
- Other factors

A study of the distribution of frogs in the Netherlands found that the likelihood of a pond being used by frogs depended on the density of ponds and the amount of suitable terrestrial habitat in the surrounding area (Vos and Stumpel 1995). A similar study in the Netherlands showed that frog use of ponds was negatively correlated with the degree of wetland isolation and road density in the surrounding landscape (Vos and Chardon 1998). Distances between breeding ponds and other life stage habitats, as well as the condition of the terrestrial habitats, were primary factors in determining frog distribution. Open fields were avoided by adults and newly metamorphosed juveniles. Roads increased the mortality of frogs and acted as barriers between wetlands, thus effectively increasing wetland isolation (Vos and Chardon 1998).

Similarly, an Indiana study concluded that amphibian distribution was influenced by (Kolozsvary and Swihart 1999):

- Forest area and proximity
- Density of ponds
- Duration of ponding
- Density of vegetation

The importance of each factor varied for each species.

Using a simulation model, one author concluded that the amount of breeding habitat had a significantly greater effect on the likelihood of population extinction than the extent of habitat fragmentation (Fahrig 1997). Her model showed that if breeding habitat covers more than 20% of the landscape, population extinction is very unlikely no matter how fragmented the habitat. However, this work was based on a generalized model that made a number of assumptions that cannot be verified without targeting a selected species, as do the more empirical studies of amphibian distribution.

Other studies indicate that there is a threshold for wetland isolation or distance between wetlands for the movement of each amphibian species. Several studies of maximum distances of amphibian movement to breeding habitats indicate that amphibian reproductive success is affected by wetland isolation and terrestrial habitat condition:

- Richter and Azous (1995) suggest that upland forest habitat must lie within 3,280 feet (1,000 m) of breeding wetland habitat for it to be useful to lentic (pond) breeding amphibian species in the Pacific Northwest.
- Baker and Halliday (1999) found limits on the distance that species of newts, frogs, and toads would move to colonize new ponds in England (1,312 feet [400 m] for newts, 3,117 feet [950 m] for frogs and toads). The authors also found that, in contrast to other studies, the condition and nature of the adjacent upland habitats did not have a strong correlation to pond colonization. The study may not have been sensitive enough, or the mixed land uses within the agricultural settings may have actually supported amphibian populations.

- The ability of juveniles to move from one wetland to the next depends on the spacing between wetlands and the habitat conditions within the buffers. Distances between ponds directly affect the probability of recolonization and the chance to prevent extinction of amphibian populations. Most individual amphibians cannot migrate long distances and adults return to their home ponds, usually after migrating no more than 656 to 984 feet (200 to 300 m) (Semlitsch 2000).
- A similar study in the Netherlands showed that amphibians would colonize new ponds up to 3,280 feet (1,000 m) away (Laan and Verboom 1990). The authors concluded, however, that the probability of a species colonizing a wetland increases with proximity to the source wetland and increased connectivity by upland forest habitats between the wetlands.

4.11.5.2 Reptiles

No studies were found that specifically addressed the effects of fragmentation on reptiles. In one study in North Carolina, researchers evaluated the adequacy of federal and state wetland regulations in protecting the habitats that freshwater turtles need to complete their life cycles (Burke and Gibbons 1995). They determined that the area protected as wetland under federal guidelines did not include the area in which two critical life-cycle stages occurred: nesting and terrestrial hibernation. This means that some of the habitats needed for turtle success are vulnerable to loss due to conversion to other land uses. However, this study focused not on the effects of wetland loss but the effects of eliminating upland habitats adjacent to wetlands.

A study that modeled the effects of wetland loss in Maine showed that local populations of freshwater turtles faced a statistically significant risk of extinction following the loss of small wetlands (Gibbs 1993).

As with amphibians, the limited dispersal distances of reptiles, in comparison to birds and mammals, would logically make reptiles particularly vulnerable to habitat fragmentation. However, documentation of the effects of habitat fragmentation on reptiles that use wetlands is very sparse, and it appears to be completely lacking for Washington State. With the exception of the western pond turtle (*Clemmys marmorata*) and the painted turtle (*Chrysemys picta*), no reptile species in Washington are primarily dependent on aquatic habitats. The terrestrial western and common garter snakes (*Thamnophis* spp.), however, are both common near water bodies, including wetlands.

4.11.6 Impacts on Fish from Fragmentation

No information was found on the impacts of fragmentation on the suitability of wetlands as habitat for fish. Also, not enough related information was found to make any hypotheses.

4.11.7 Impacts on Birds from Fragmentation

The impacts of fragmentation have generally been studied in two types of fragmented landscapes: one fragmented by growing urbanization and one fragmented by agricultural practices. In general there are no studies or conclusions in the literature that would suggest the fragmentation from these two types of land use has significantly different impacts on populations of birds, and so both types of studies are reported below.

The extent of wetland isolation is known to be an important factor that influences bird use of wetland habitats:

- In a study of Puget Sound wetlands, researchers documented a positive association between bird species richness and the proximity of lakes and open water habitats, as well as the structural complexity of the vegetation in the wetlands (Richter and Azous 2001b). This implies that fragmentation results in a reduction in species richness.
- In northern prairie marshes, bird species richness declined with increased isolation of the wetland (Brown and Dinsmore 1986). Marshes that were part of wetland complexes showed higher species richness than isolated wetlands. Smaller marshes had occurrences of certain bird species only when the marshes were part of a wetland complex.
- These findings are supported by a more recent study of wetland complexes in prairie marshes in Iowa (Fairbairn and Dinsmore 2001). This study related bird species richness and densities of individual species to habitat variables within the wetland complexes and to area of wetland habitat in the surrounding landscape. For some bird species, presence and abundance in a wetland complex were clearly related to the amount of wetland habitat in a 1.9 mile (3 km) area surrounding the complex. A similar study also determined that unfragmented landscapes with prairie marsh supported more waterfowl species than isolated wetlands (Naugle et al. 2001).

The pattern of habitat use in, and around, wetlands varies between different bird species that depend on wetlands (Naugle et al. 1999):

- Some species are sedentary and rarely use resources beyond the nest vicinity
- Some use only larger wetlands regardless of the surrounding landscape
- Others require a mosaic of wetlands on the landscape

Therefore, the entire landscape must be assessed, rather than just individual wetlands in order to determine the habitat suitability of an area for many species.

A correlation has been found between the degree of urban development in an area (and the resultant fragmentation) and the extent of declines in native bird species richness. One study in Santa Clara County, California, looked at six sites representing a gradient of development ranging from biological preserve to business district (Blair 1996). Increasing proportions of invasive and exotic bird species were found in the more highly developed areas. The moderately developed sites were highest in species richness and bird biomass. They were, however, lower in native bird diversity than the lesser disturbed sites. The shift in species was related to changes in total available habitat and in habitat structure across the gradient. This study concluded that even relatively minor habitat alterations resulted in loss of species.

Wetlands in the Puget Sound area showed a similar response to urbanization. Researchers found no correlation between total bird species richness and amount of impervious surface, but there was a correlation with native species richness (Richter and Azous 2001b). The rarer, more sensitive birds, all of which are native, tended to decrease with urbanization. The more adaptive species, including a higher percentage of non-natives (e.g., European starlings [*Sturnus vulgaris*]), tended to increase in urbanizing watersheds. Again, these changes are most likely due to loss of habitat, and therefore reduced connections between habitats, as well as habitat degradation.

One study conducted in eastern Canada examined the role that habitat heterogeneity plays in the use of wetlands by ducks (Patterson 1976). It concluded that breeding duck pairs spaced themselves based on the physical size of the wetland. The authors also observed that breeding can occur in relatively less productive wetlands. However, duck broods hatched in less productive wetlands often moved to more biologically productive wetlands where there was a greater food source and more refuge/escape habitat. These preferable wetlands were close to the breeding wetlands because young waterfowl cannot fly. This would suggest that heterogeneity in the types of wetlands in an area are important in maintaining populations of ducks.

As with amphibians, the presence of terrestrial habitats between wetlands can be an important factor in waterfowl distribution. A study conducted in an area of intensive wheat farming demonstrates the importance of maintaining connections among habitats for birds (Saunders and DeRebeira 1991). These researchers found that native bird species used corridors as narrow as 13 feet (4 m) to move between patches of preferred habitat. Corridor width was positively correlated with species richness.

A study of bird populations in forest interiors found that habitat fragmentation impairs reproduction and can result in population declines and extinctions (Temple and Cary 1988). Though not focused on wetlands, the study can reasonably be applied to forested wetlands. The authors modeled the effects of habitat fragmentation. They predicted that success rates for nests for forest-interior birds would drop from 70% when nests are greater than 656 feet (200 m) from the forest edge, to only 18% when nests are less than 328 feet (100 m) from the edge. This indicates that fragmentation of forested wetlands through such activities as logging could have significant effects on species that are not tolerant of edge habitats.

In Minnesota, Mensing et al. (1998) assessed the implications of fragmentation at various landscape scales for birds. They found that:

- Diversity and richness of bird species increased with an increase in the extent of forest and wetland within the surrounding landscape.
- Habitats that were in good condition in the areas surrounding wetlands strongly influenced the biotic diversity, with positive correlations shown for birds within 1,640 feet (500 m) of the wetland edge.

4.11.8 Impacts on Mammals from Fragmentation

Information on the effects of fragmentation on mammals that depend on wetlands is sparse, even though many of the mammal species in Washington State are known to commonly use wetlands (beaver, muskrat, mink, otter, water vole, deer mouse, and others). Most of the literature on mammals in wetlands addresses the effects of beaver dams on wetland systems.

One study from the Pacific Northwest documented that fragmentation of wetlands and the elimination of surrounding upland habitats can have significant effects on small mammals that use wetlands (many of which are not, however, closely associated with wetlands). Richter and Azous (2001c) found that the total area of undeveloped land adjacent to a wetland (including forest, shrub, agricultural fields, and meadows) was weakly associated with mammal richness. A stronger correlation, however, was found between the percent of adjacent forest land (within 1,640 feet [500 m] of a wetland) and mammal richness. The highest small-mammal richness was observed in wetlands with at least 60% of the first 1,640 feet (500 m) surrounding the wetland in forest. The authors noted that richness of mammal species in Puget Sound wetlands has no correlation with area of impervious surface in the watershed.

Roads are an important factor in habitat fragmentation for mammals. For example, a major highway in Massachusetts increased wetland isolation and blocked major travel corridors between suitable habitat patches for mammals (Forman 1998). See Section 4.12.2 for additional discussion of effects of roads on wildlife.

4.11.9 Summary of Key Points

- No information was found on the impacts of fragmentation on the hydrologic functions or the functions that improve water quality.
- Increased isolation of wetlands appears to be a major factor in reducing species richness and abundance for most taxonomic groups. One author states that “modifications to the environment that preclude movement between component subsystems may be as devastating to vertebrates in the long run as are forces that actually destroy the wetland” (Harris 1988).
- Impacts of fragmentation on the habitat provided by wetlands have been documented for plants, invertebrates, amphibians, reptiles, birds, and mammals. No information was found on impacts to fish in wetlands.
- The impacts of habitat fragmentation are not as well documented for birds and mammals as they are for other taxonomic groups. There are different patterns of habitat use between groups of birds and mammals that can influence how they respond to fragmentation (Johnson and O’Neil 2001).

4.12 Impacts from Other Human Disturbances

There are many different human activities on the land which create disturbances that can impact wetland functions and values. The previous discussion addressed only impacts from disturbances caused by activities that have been extensively studied. The following sections review some of the impacts of other types of activities and disturbances that have been documented to a lesser extent. The discussions in these sections are not separated by wetland function because all of the impacts address either plants or wildlife, and the information is not extensive enough to warrant subdividing by functions.

4.12.1 Impacts on Plant Communities from Altering Soils

Physically disturbing wetland soils during the dry season, through tillage, compaction, excavation, or other means, can allow invasion by non-native plant species (Morin et al. 1989, Sutton 1996, David 1999, Galatowitsch et al. 1999). It can also destroy much of the viable seed bank (Lee 1991). Tilling the soil often reduces diversity, including both richness and evenness, as documented in a Carolina bay wetland (Kirkman and Sharitz 1994). The tillage treatment disrupted the roots of perennials more than burning, and it encouraged germination of annuals in the seed bank and colonization by several invasive species.

Invasive plants, especially non-native plants, significantly alter the species composition of many wetlands, sometimes even forming nearly monotypic stands. Among the most widespread invaders in North America are cattail (*Typha*), reed canarygrass (*Phalaris* sp.), purple loosestrife (*Lythrum salicaria*), giant reed (*Phragmites* sp.), milfoil (*Myriophyllum spicatum*), and hydrilla (*Hydrilla verticillata*). Their increased dominance is frequently attributed in part to the physical disturbance of soils or water levels within a wetland and/or the surrounding landscape, including accelerated sedimentation, eutrophication, and the construction of mitigation wetlands (Confer and Niering 1992, Magee et al. 1999).

Continuously disturbing the soil, for example through compaction and road building, can alter species composition. These disturbed conditions can lead to a decline in both the biomass of native species and a change in the soil conditions that support them (Ehrenfeld and Schneider 1991). Use of all-terrain vehicles also impacted wetlands on the Atlantic coastal plain, reducing the density of seed in wetland seed banks and allowing common rushes to displace rare species (Wisheu and Keddy 1991). Excavation and clearing of gas pipeline rights-of-way through forested wetlands in Florida resulted in increased species richness within the wetland clearings but an increased percent cover of non-native species (Van Dyke et al. 1993).

4.12.2 Impacts on Wildlife from Roads

Roads have been found to contribute to lower species richness for a variety of wildlife groups through the factors listed below. While most of the studies cited in this section were conducted in other regions of the country, much of the information is likely to pertain to effects on Pacific Northwest wildlife because the types of impacts described are inherent to roads regardless of region, and many of the species impacted are also found in the Northwest. Furthermore, Findlay and Bourdages (2000) note that there may be long time lags between road construction and the time when effects on wildlife are perceptible. Impacts may be undetectable in some species for decades.

It is theorized that roads cause the loss of biodiversity by (Findlay and Bourdages 2000):

- Restricting movement between populations of wildlife
- Increasing mortality from road kills
- Fragmenting habitat
- Increasing edge habitat that increase the habitat for "generalist" species
- Facilitating invasion by exotic species
- Increasing human access to wildlife habitats

The following studies have documented the impacts of roads on different species of wildlife.

- In wetlands of southeast Ontario, the species richness of mammals, amphibians, reptiles, and birds was seen to decline with increased road density and forest removal (Findlay and Houlahan 1997).
- The numbers of frog and toads decreased with increasing traffic in a study by Fahrig et al. (1995). This study concluded that increased road density can contribute to a decline in the abundance of amphibians in urbanizing areas.
- A study of amphibians using small isolated wetlands in Florida found high mortality during migration between upland terrestrial habitats and temporary pond breeding habitats (Means 1996). The author attributes much of this to direct road mortality.
- A study of the "road-effect zone" of a four-lane suburban highway in Massachusetts was undertaken to determine the distance from a road that impacts can be measured (Forman 1998). This study concluded that the road blocks migration routes for salamanders up to several hundred meters from wetlands. The study also showed that the effect of the road on blocking major travel corridors between suitable habitat patches for small mammals could be measured to several kilometers from the road. The effects of traffic noise on birds could be measured up to 2,132 feet (650 m) from the road in forested areas and 3,051 feet (930 m) in open areas.
- A related study of the same Massachusetts highway showed that impacts on populations extended out at least 328 feet (100 m) from the highway. Forman and Deblinger (2000) studied nine ecological factors relating to, among other things, wetlands, streams, and amphibians. Assessing all factors, this study concluded that the "road-effect zone" averaged approximately 1,969 feet (600 m) wide, though it was quite variable in width at specific locations.
- In a study within the Columbia Basin, roads were found to increase human access and disturbance to fish and wildlife habitats, and this may reduce the number of waterfowl

using easily-accessed wetlands by an order of magnitude during the late-fall and winter months (Foster et al. 1984).

4.12.3 Impacts on Wildlife from Noise

The impacts of noise on wildlife are a topic of growing concern. The frequency of the sound waves and the duration of the sounds influence how noise affects wildlife species. Although many of the studies discussed below do not address wetlands specifically, the impacts of noise are not expected to change whether the species in question is in a wetland or another type of habitat.

Frequency is the pitch of a sound, and different animals show different sensitivities to the same range of frequencies. Generally, smaller mammals such as rodents, shrews, and bats have a greater sensitivity to higher frequencies—often within ranges exceeding 20,000 Hertz (Hz), the upper limit of human sound perception. Larger mammals show sensitivity to low frequencies and may be able to detect sound at or below 10 Hz. While most birds show a sensitivity to sound that is similar to humans (20 to 20,000 Hz), certain birds (such as rock doves) can also perceive low-frequency sounds, often with much greater sensitivity than their larger mammalian counterparts (Kreithen and Quine 1979). Some frogs and toads also show low-frequency sensitivity and even some small mammals are capable of discerning sounds of only a few Hertz (Plassman and Kadel 1991).

Sound duration may be divided into two classifications: continuous sounds which last for a long time with little or no interruption, and impulse sounds lasting for only short durations (Larkin et al. 1996). Impulse sound and continuous sound appear to have different physiological and behavioral effects. Generally, impulse noise appears to be more stressful to wildlife, at least in part due to the unpredictability of such noise (Larkin et al. 1996).

Overall, the literature suggests that species differ widely in their physiological response to various types, durations, and sources of noise (Manci et al. 1988). However, noise effects on wildlife may be broadly classified as primary, secondary, and tertiary:

- **Primary effects.** Are direct, physiological changes, such as stress and hypertension, to the auditory system and may be considered to include the “masking” of auditory signals. Masking is the inability of an individual to hear important environmental signals such as calls from mates or noises of predators or prey.

- **Secondary effects**. May include behavioral modifications that include interference with mating or reproduction and impaired ability to obtain adequate food, cover, or water.

- **Tertiary effects.** Are the direct result of primary and secondary effects at a population level and include population decline and habitat degradation. Most of the effects of noise are mild enough that they may never be detectable as variables of change in population size or population growth against the background of normal variation (Bowles 1995).

The behavioral responses of wildlife to noise show a high degree of variation depending on the species, the type of noise, and the habituation of the individuals to the source of noise. For example, some bald eagles can be very tolerant of auditory stimuli when the sources are screened from view (Stalmaster 1987), but other raptor species such as prairie falcons flush from perches and nests at sudden loud noises (Harmata et al. 1978).

Animals may become tolerant of repeated noises. Krausman et al. (1986) studied desert ungulates exposed to aircraft noise and noted that short-term habituation to aircraft noise occurred with repeated exposure. Sandhill cranes nesting meters away from a Florida highway showed no response to passing traffic (Dwyer and Tanner 1992). The effects of noise vary not only with the type of noise in question, but with an individual animal's experience, time of day (Herbold et al. 1992, Gese et al. 1989), and reproductive cycle (Platt 1977).

Research on the effects of traffic noise on breeding birds was conducted by Reijnen et al. (1995, 1996) who studied woodland and grassland bird populations in the vicinity of roadways. Ambient noise up to a given level resulted in no reduction in the density of bird populations. However, once an ambient noise threshold level was exceeded, densities decreased exponentially with increased noise. Threshold levels were found to range from 36 to 58 decibels, depending upon species, and the zones of decreased breeding densities surrounding the roadways ranged up to 2,670 feet (810 m) for particularly sensitive species near busy roadways. They found habitat avoidance by individual birds in habitat that would otherwise have been suitable for breeding.

One study also found evidence that reproductive output may be diminished in frogs breeding near highways because of acoustic interference (Barass 1985 in Larkin et al. 1996).

4.12.4 Impacts on Wildlife and Plant Communities from Recreational Activities

Little information was found on the impacts of recreational activities in wetlands. Most of the available information is anecdotal and focused on the more evident impacts such as loss of vegetation from the use of off-road vehicles. There is less information on the effects on wildlife of such disturbances as noise, light, glare, and human presence caused by recreational activities, particularly with respect to wetlands. None of the studies described in this section were located in the Pacific Northwest.

A synthesis paper on management of amphibians in Montana notes that among the many factors that are likely to contribute to a decline in amphibian populations are trail development, on- and off-road vehicles use, and development and management of recreational facilities (Maxell 2000). Citing a number of studies from the 1980s, Klein (1993) notes that recreational uses in natural areas can disrupt:

- Wildlife foraging and social behavior
- Animals that are feeding

- Parent-offspring bonds
- Pair bonds

The author also cites several studies stating that increased predation of nests and decreased densities of wildlife result from greater human recreational use of natural areas.

A study of flooded gravel pits in Britain examined the abundance and distribution of one species of wintering waterfowl with regard to recreational disturbance (Fox et al. 1994). The authors found that water-based recreational activity, such as boating, reduced the number of birds on the ponds to the greatest extent of all the observed activities. Ponds where fishing, walking, or other bank-side activities were allowed also showed reduced numbers of birds in comparison to the ponds that were designated reserves with restricted access. They were, however, not as reduced in abundance as those ponds that also allowed water-based activities.

The effects of recreational use on waterfowl were also studied in areas near the shore on Lake Erie (Knapton et al. 2000). Excessive human disturbance reduced the foraging efficiency and body fat acquisition for waterfowl and can result in decreased bird densities. Diving ducks appeared to be the most sensitive to disturbance.

In another study on recreation impacts on birds, Klein (1993) studied the specific behaviors of humans that disturb wildlife on a subtropical barrier island that is a National Wildlife Refuge off the coast of Florida. Her study sites were primarily in mudflat and mangrove wetland habitats. She tested a variety of treatments such as driving by without stopping, stopping the vehicle with and without getting out, approaching the birds on foot, and playing noise tapes. The author found that most of the bird species present were disturbed by the noise tape. Some species such as great blue heron consistently flew away when approached by a person, whereas other species tolerated human presence until closely approached.

Klein (1993) concludes that car traffic is less disruptive to wildlife than out-of-vehicle activity. Frequent human approaches may cause some bird species to forage in areas with fewer intrusions. Wildlife photographers were the most likely visitors to approach birds. Visitors who spoke with refuge staff and volunteers were the least likely to disturb birds, possibly due to an increased awareness of the habitat needs of wildlife. While this study involved a very different ecosystem, it is useful because it generated data on the Great Blue Heron, a bird species that also occurs in Washington. It also is one of the few studies that examined the effects of specific human behaviors on wildlife.

Recreational activity is believed to be one of the main factors in lakeshore deterioration and decline in reed-dominated wetlands in a study of Central European lakes (Ostendorp et al. 1995). It is likely that trampling of bank-side vegetation by recreational users is causing bank erosion and excessive siltation in wetlands near the shore.

Although recreation often occurs in more rural habitats, urbanization also brings increased intensity of recreational uses within remaining greenbelts and open spaces. A study in Western Australia examined the trend in smaller lot size relative to the owners' use of nearby open spaces (Syme et al. 2001). Smaller lot size resulted in an increase in recreational visits by the homeowners to nearby wetlands. Increased access to and recreational use of wetlands is clearly one of the impacts that accompany urban development.

4.12.5 Introduction of Invasive and Exotic Species in Wetlands

Human activities increase the likelihood of introducing exotic animal and plant species to wetlands because they cause disturbances that favor the establishment of exotic species (Mack et al. 2000). The following factors have been found to favor the establishment of exotic species (Houck 1996, Dale et al. 2000, Mack et al. 2000, Gelbard and Belnap 2003, Maurer et al. 2003):

- Increased movement of seed and animals through higher road densities
- Greater fragmentation of the landscape that limit re-colonization of native species
- Higher densities of human land use
- Alterations of water regimes
- Direct disturbance of soils

The studies cited in the following discussion implicate disease, predation, and competition as major factors in limiting the success of native species when exotic, invasive species come in. Many of the relationships between invasive species and native species are not well understood because many environmental and biological factors play a role (Mack et al. 2000).

In Washington and Oregon, about 42 exotic vertebrate species have established populations (Witmer and Lewis 2001). These include species of 18 birds, 19 mammals, three reptiles, and two amphibians. The birds were mainly introduced for hunting or aesthetic purposes, while the mammals mostly escaped from commercial or domestic settings. The amphibians and reptiles were released pets or were introduced for food or aesthetic purposes. About 30% of these exotic species are restricted to freshwater and riparian systems, although others among this group will commonly use these habitats (Witmer and Lewis 2001). No information, however, was found on the number of exotic plant species found in wetlands.

4.12.5.1 Impacts on Wetlands from Exotic and Invasive Plants

Invasive plants, especially non-native invaders, significantly alter the composition of plant communities in many wetlands, sometimes even forming nearly monotypic stands (Adamus et al. 2001). Changes in the plant community can be expected to result in changes to all the invertebrates and microscopic organisms that are associated with specific plant species.

Among the most geographically widespread invaders in Washington's wetlands are reed canarygrass (*Phalaris arundinaceae*), purple loosestrife (*Lythrum salicaria*), giant reed (*Phragmites* sp.), and European milfoil (*Myriophyllum spicatum*). Their increased dominance is frequently considered to be a result of human disturbances such as the following:

- Changes in soils or water levels within a wetland and/or the surrounding landscape, including accelerated sedimentation, eutrophication, and the construction of mitigation wetlands (Confer and Niering 1992, Magee et al. 1999)
- Changes in hydroperiod following urbanization (Cooke and Azous 2001)
- Increased human access and mechanical disturbance of wetlands (e.g., a study in southern Australia showed that vegetation removal and site disturbance are major factors in plant invasions; Detenbeck et al. 1999)
- Increases in sediment and nutrients resulting from agriculture or urbanization (Maurer et al. 2003).

4.12.5.2 Impacts on Species Using Wetlands from Domestic Pets

No information on the impacts of domestic pets on specific wetland-associated species was found. However, general information on predation by pets, specifically cats, indicate they can impact populations of many different small species living adjacent to residential areas. Residential development typically brings increased access to wetlands by domestic pets, primarily cats and dogs because wetlands are not fenced off.

Several studies of predation by house cats indicate that small mammals and birds were the preferred prey of house cats, but cats also killed reptiles and amphibians (Barratt 1997, Lepczyk et al. 2003). Many of the mice and rats captured by the cats are exotic species themselves. The results, however, suggest that house cats may have significant impacts on native populations as well, particularly along the fringes of suburban expansion where native mammals and birds are more common.

A study of predation by house cats in Virginia determined that individual cats caught an average of 26 animals in urban areas and 83 animals in rural areas over an 11-month period (Mitchell and Beck 1992). In another study in Michigan, Lepczyk et al. (2003) found that cats preyed on about 1 bird per week. Extrapolating these numbers of prey to the total number of cats in a specific urban or suburban area would give an astonishingly high toll attributable to house cats.

4.12.5.3 Impacts on Species Using Wetlands from Exotic Mammals and Birds

Many introduced birds are known to usurp nests of native birds or to compete with them for nest sites. European starlings (*Sturnus vulgaris*) are known to displace wood ducks, woodpeckers, and other species from their nests, often destroying the eggs and young (Witmer and Lewis 2001). Starlings also out-compete many native species for nest cavities, overwhelming them with their large numbers and aggressive behavior. Transmission of disease, particularly from exotic birds and rodents from Europe, is also a major problem that threatens native wildlife (Witmer and Lewis 2001).

Introduced mammals affect native wildlife and plants through predation and herbivory (Witmer and Lewis 2001). For example, nutria (*Myocaster coypus*), which were introduced from South America for fur production, have tremendous impacts on wetland vegetation, uprooting plants as they dig for rhizomes and denuding vast areas (Mitsch and Gosselink 2000, Witmer and Lewis 2001). Nutria may be implicated in population declines of muskrats (*Ondatra zibethicus*), probably due to competitive exclusion (Witmer and Lewis 2001).

4.12.5.4 Impacts on Native Invertebrates from Exotic Invertebrates in Wetlands

Humans have introduced a number of non-native invertebrates to wetlands. Native invertebrate communities seem ill-adapted to compete with or avoid these alien species, but data on long-term effects to wetland communities are mostly lacking.

The zebra mussel (*Dreissena polymorpha*) has invaded many aquatic systems throughout North America. Although the zebra mussel has not yet been found in Washington, some local populations of mussels that live in wetlands may be highly susceptible if an invasion occurs. Some mussels (of the family Unionidae which is found in Washington streams and rivers) are particularly susceptible to disruptions from introduced mussels because they are relatively immobile and have long life spans, often over 10 years (Mehlhop and Vaughn 1994). Furthermore, riverine wetlands with higher alkalinity tend to be more susceptible to invasions by zebra mussels (Whittier et al. 1995).

In areas in other parts of the country that have been invaded by Zebra mussels substrates can become totally carpeted, displacing native mussels (Tucker and Atwood 1995). Some midges, snails, and caddisflies can be outcompeted as well. The mussel has minimal or positive effects on amphipods and flatworms (Wisenden and Bailey 1995). They may also concentrate contaminants, making them more available to invertebrate food chains (Bruner et al. 1994).

The rapid spread of zebra mussels may have been made more possible by the preceding decline of native mussels as a result of pollution and changes in habitat (Roberts 1990, Nalepa and Schloesser 1993, Mackie 1991, Haag et al. 1993, Whittier et al. 1995).

4.12.5.5 Impacts on Native Amphibians from Exotic Species in Wetlands

The effects of exotic species of amphibians on native amphibians that use wetlands are particularly well studied, but not well understood. Predation and competition from introduced amphibians has been suggested as one cause of population declines for native amphibian species (Witmer and Lewis 2001), but as described below the effects are complex.

Bullfrogs (*Rana catesbeiana*) are often cited as a factor in declining amphibian populations (Hecnar and M'Closkey 1996, Kiesecker and Blaustein 1998, Adams 1999a). Native to eastern North America, bullfrogs were introduced to the Pacific Northwest in the early 1900s for hunting and food. Bullfrogs are suspected of causing amphibian declines because they prey on frogs and salamanders and are often so numerous in wetlands that they are thought to out-compete native species for space (Witmer and Lewis 2001). Studies of the role that bullfrogs play in declines of amphibian populations are, however, somewhat contradictory in their findings (Hecnar and M'Closkey 1996, Kiesecker and Blaustein 1998, Adams 1999a, Witmer and Lewis 2001). It is possible that the effects of bullfrogs may differ for various species, or their influence may be quite subtle and complex.

Several studies conducted in the Pacific Northwest have found either weak or no correlation between bullfrog presence and amphibian richness and abundance (Adams 1999a, Richter and Ostergaard 1999, Richter and Azous 1995). Data from a monitoring program of amphibians in wetlands in King County showed that bullfrogs are not causing competitive exclusion of native species (Richter and Ostergaard 1999). Native amphibian richness was not negatively correlated with bullfrog presence or with the presence of permanent water in the wetlands (Richter and Ostergaard 1999). Richter and Azous (1995) noted relatively high species richness for native amphibians in permanently ponded wetlands, the preferred habitat for bullfrogs.

Focusing on red-legged frogs (*Rana aurora*) in Puget Lowland wetlands, Adams (1999a) concluded that this species is not excluded from wetlands that also support bullfrogs. The study showed little to no negative correlation between red-legged frogs and bullfrogs. It noted that exotic fishes such as sunfish, yellow perch (*Perca flavescens*), and smallmouth bass (*Micropterus dolomieui*) had greater effect on amphibian richness in the wetlands studied. In a companion study Adams (1999b) found that habitat gradients or indirect effects of exotic vertebrates on native amphibians play major roles.

A study of red-legged frogs in the Willamette Valley in Oregon, however, stated their development was affected by both bullfrogs and exotic fishes (Kiesecker and Blaustein 1998). In this study, tadpoles showed decreased mass at metamorphosis and increased time to metamorphosis in the presence of larval and adult bullfrogs. Smallmouth bass alone had little effect on tadpole development, but red-legged frog tadpoles altered their use of microhabitats when both bullfrogs and smallmouth bass were present. Survival of tadpoles was affected only when both bullfrog adults and larvae were present, or when both bullfrog larvae and smallmouth bass were present.

4.12.5.6 Impacts on Wetland-associated Species from Exotic Fish

Non-native fish have been widely introduced into waters of the United States and Washington, both intentionally and by accident. Adamus et al. (2001) cite research showing that the effects of invading species on native fish communities are usually adverse (Baltz and Moyle 1993), especially when coupled with simultaneous impacts from other factors (Larimore and Bayley 1996, Marschall and Crowder 1996).

The presence of exotic fish has been implicated in reduced abundances and species richness of amphibians. A study in the Okanogan Highlands in northeast Washington showed that richness of pond-breeding amphibian and abundance were diminished by the presence of exotic fish (Aker 1998). The non-native fish species observed in this study included largemouth bass, tench (*Tinca tinca*), brook trout (*Salvelinus fontinalis*), and perch. While there was lower amphibian richness in ponds with native fish than those with no fish, the data indicate that non-native fish had a greater impact on amphibian numbers and richness. Adams (1999a, 1999b) found that exotic, non-native, fish reduced survival of native amphibians to almost zero in the Puget Lowlands. Further studies by Adams (Adams et al. 2003) found that non-native fish facilitated the invasion of wetlands in Oregon by bullfrogs because they fed on invertebrate predators of bullfrog larvae.

Leonard et al. (1993) surveyed populations of the northern leopard frog (*Rana pipiens*) in Washington State. They found that the species had been extirpated from most of its historic range, with only small populations remaining in parts of eastern Washington. These authors noted that areas once inhabited by the northern leopard frog support exotic species such as largemouth bass (*Micropterus salmoides*), black crappie (*Pomoxis nigromaculatus*), yellow perch (*Perca flavescens*), and brown bullhead (*Ameiurus nebulosus*). They hypothesized that these species may be implicated in the decline of the northern leopard frog but have no definitive data to support this hypothesis.

The introduction of carp has resulted in significant impacts on wetlands in eastern Washington. Large, herbivorous fish such as carp compete directly with birds for submerged aquatic plants (Bouffard and Hanson 1997). The fish also resuspend the sediments on the bottom of lakes and ponds. This has a significant impact on invertebrates as well as the submerged aquatic plants. Parkos et al. (2003) found that the presence of the common carp was positively correlated with increases of phosphorus (a nutrient that causes eutrophication), turbidity, suspended solids, and zooplankton biomass. Their presence was negatively correlated with the abundance of aquatic plants and invertebrates.

4.12.6 Summary of Key Points

- Alteration of soils can change the plant community in a wetland and allow invasion by exotic species.
- Noise creates stress for wildlife, but the impacts are very specific to individual species and to the type of noise generated.
- Recreational use of wetlands impacts the normal behavior of wildlife and reduces densities.
- Invasions by exotic species can alter the distributions of both plant and animal species in wetlands. The impacts of bullfrogs on other amphibians, however, seem to be ambiguous even though this question has been studied extensively.

4.13 Chapter Summary and Conclusions

Humans create many different types of disturbances that can affect the performance of wetland functions. The disturbances were reviewed in Chapter 3. Chapter 4 has reviewed the information available on how each type of human disturbance impacts wetlands and their functions. The disturbances that impact wetlands the most include:

- Direct changes to the physical structure of wetlands via filling, vegetation removal, tilling of soils, and compaction of soils
- Changes in the amount of water in wetlands
- Changes in how water levels fluctuate (frequency, amplitude, direction of flows)
- Changes in the amount of sediment
- Increases in the amount of nutrients
- Increases in the amount of toxic contaminants
- Changes in the amount of acidity
- Increasing the concentration of salts
- Increasing the fragmentation of habitat
- Other disturbances that are not as well documented including alteration of soils, construction of roads, noise, recreational use, and invasion by exotic species.

Table 4-3 reviews how various land-use practices create disturbances that can change the environmental factors that control wetland functions. Table 4-4 summarizes the effects of each of these disturbances in terms of the wetland functions they may impact. The rating of the impacts in the table represents a synthesis by the authors of all the information presented in this chapter. By combining the information in these two tables, it is possible to associate changes in functions of wetlands with general types of human land use, as shown in Table 4-5. The human land uses create various disturbances in the environment, and those disturbances in turn affect the factors that control wetland functions, ultimately leading to changes in those functions.

For example, Table 4-3 shows that urbanization creates significant disturbances that change the amount of water, the fluctuations of water levels, and input of sediments, nutrients, and contaminants to wetlands. Table 4-4 shows that these disturbances have a major impact on the wetland functions of providing habitat for plants, invertebrates and reptiles/amphibians. Table 4-5 synthesizes this information to show that urbanization impacts the habitat for plants, invertebrates, reptiles, and amphibians in wetlands.

The scientific information available indicates that human activities and uses of the land can have significant impacts on the functions in wetlands at both the larger, landscape scale and at the scale of the individual wetland itself. As a result many different approaches have been developed to try to minimize these impacts. These include regulations to control human activities near wetlands, methods to replace the functions lost or altered including restoration, ways to protect the wetland resource through non-regulatory measures and incentives. The effectiveness of some of these tools at actually protecting wetland functions are discussed in Chapters 5 and 6.

Table 4-3. Summary of types of environmental disturbances created by some types of land use.

Disturbance	Scale of Disturbance	Agriculture	Urbanization	Mining
Changing the physical structure within wetlands (filling, vegetation removal, tilling of soils, compaction of soils)	Site scale	xx	xx	h
Changing the amounts of water	Landscape scale Site scale	xx xx	xx xx	? h
Changing fluctuations of water levels (frequency, amplitude, direction of flows)	Landscape scale Site scale	xx xx	xx xx	? h
Changing the amounts of sediment	Landscape scale Site scale	xx xx	xx xx	h h
Increasing the amount of nutrients	Landscape scale Site scale	xx xx	xx xx	nm nm
Increasing the amount of toxic contaminants	Landscape scale Site scale	xx xx	xx xx	x xx
Changing the acidity	Landscape scale Site scale	nm nm	nm nm	x xx
Increasing the concentrations of salt	Landscape scale Site scale	x x	nm nm	nm nm
Fragmentation	Landscape scale	xx	xx	h
Other disturbances	Site scale	xx	xx	h

Key to symbols used in table:

(xx) Land use creates a major disturbance of environmental factors

(x) Land use creates a disturbance

(nm) Studies on impacts of this land use do not mention this disturbance

(h) Literature is lacking but disturbances can be hypothesized based on authors' experience

(?) Information lacking

Table 4-4. Synthesis of the information reported in the literature on the negative impacts of different human disturbances on wetland functions.

Disturbance Type	Functions: Hydrologic	Water Quality	Plants	Habitat for Invertebrates	Habitat for Amphibians and Reptiles	Habitat for Fish	Habitat for Birds	Habitat for Mammals
Changing the physical structure of wetlands	+	+	++	++	+	+	++	+
Changing the amount of water	+	+	++	++	++	+	+	?
Changing fluctuations of water levels	?	?	++	+	++	+	?	?
Changing amounts of sediment	+	?	++	++	?	?	?	?
Increasing amounts of nutrients	+	+	++	++	++	+	+	+
Increasing amounts of toxic contaminants	?	+	++	++	++	++	++	?
Changing acidity	0	+	+	++	++	+	+	+
Increasing concentrations of salt	0	?	++	++	?	?	+	?
Fragmentation	0	?	?	?	++	?	++	+
Other disturbances	?	?	++	+	++	++	++	++

Key to symbols used in table:

++ Major negative impacts on specific functions have been documented
+ Some data suggest impacts or impacts could be hypothesized
0 Data indicate that impacts are minimal
? Information is lacking

Table 4-5. Synthesis of the negative impacts of some land uses on wetland functions.

Land Use	Functions							
	Hydrologic	Water Quality Improvement	Plants	Habitat for Invertebrates	Habitat for Reptiles and Amphibians	Habitat for Fish	Habitat for Birds	Habitat for Mammals
Agriculture	+	+	++	++	++	++	++	+?
Urbanization	+	+	++	++	++	++	++	+?
Mining	?	?	+	++	++	+	+	+?

Key to symbols used in table:

++ Major negative impacts on specific functions have been documented

\+ Some data suggest impacts or impacts could be hypothesized

? Information is lacking

+? Some impacts have been documented but more information is needed

Chapter 5

The Science and Effectiveness of Wetland Management Tools

5.1 Reader's Guide to this Chapter

This chapter builds on the previous discussion of how wetlands function (Chapter 2), how human activities and changes in land use cause disturbances (across the landscape and at specific sites) that influence the factors that control wetland functions (Chapter 3), and how wetland functions are impacted by these disturbances (Chapter 4).

Chapter 5 presents a synthesis of what the current literature reports on four tools currently used to identify wetlands and to address impacts to wetlands and their functions: wetland definitions, wetland delineation methods, wetland ratings, and buffers. This chapter does not provide language or recommendations for regulatory or policy language—those will be provided in a separate volume on management options and recommendations (Volume 2).

5.1.1 Chapter Contents

Major sections of this chapter and the topics they cover include:

Section 5.2, Introduction and Background on Regulatory Tools introduces the key wetland management tools that are discussed in this chapter.

Section 5.3, How Wetlands Are Defined and Delineated describes similarities and differences in the way various agencies define *wetland*. It explains the critical difference between "biological wetlands" and "regulated wetlands." It also discusses certain types of wetlands that are frequently exempted from regulation, such as isolated wetlands, small wetlands, or those designated as Prior Converted Croplands. The various manuals that have been developed to guide the delineation of wetland boundaries are also briefly discussed.

Section 5.4, Wetland Rating Systems discusses how rating systems have been developed to rapidly assess wetland characteristics in the field. These characterizations allow wetlands to be rated for regulatory or management purposes. This section introduces the reader to the Washington State wetland rating systems, which were briefly mentioned previously in a number of places in the document. It also includes discussion of certain wetland types that require particular attention under the Washington State wetland rating systems.

Section 5.5, Buffers comprises the bulk of this chapter. This section provides a synthesis of the literature on how buffers protect and maintain wetland functions. The section concludes by summarizing recommendations from the literature for establishing effective buffer widths.

Section 5.6, Chapter Summary and Conclusions ties together the major concepts presented in the chapter.

5.1.2 Where to Find Summary Information and Conclusions

Each major section of this chapter concludes with a brief summary of the major points resulting from the literature review on that topic in a bulleted list. The reader is encouraged to remember that a review of the entire section preceding the summary is necessary for an in-depth understanding of the topic.

For summaries of the information presented in this chapter, see the following sections:

- Section 5.3.6
- Section 5.4.2
- Section 5.5.3.5
- Section 5.5.4.4
- Section 5.5.5.4
- Section 5.5.6.1

In addition, Section 5.6 provides a summary and conclusions about the overarching themes gleaned from the literature and presented in this chapter.

5.1.3 Data Sources and Data Gaps

No literature review was conducted for the section on wetland definitions or delineations. Both of these management tools are currently established by state and federal statutes. It was determined that review of the previous discourse on these topics was not relevant to the current state of the science for Washington State.

Considerable research was published prior to 2000 on the role of small wetlands relative to wildlife in a landscape context. Since then, several synthesis documents on small and isolated wetlands have been published.

Papers on the adequacy or effectiveness of wetland rating systems were not found; instead, the literature concentrates on function assessment methods. This chapter does not attempt to assess the science on wetland function assessment because the Washington State Department of Ecology (Ecology) has evaluated and described different function assessment methods previously (see Volume 2, Appendix 5-B for more information). Additionally, Ecology completed function assessment methods for several different wetland hydrogeomorphic types on both sides of the state within the last five years (see Chapter 2 for further information).

The subject of buffers is well documented in the scientific literature. Numerous studies from across the U.S. have been conducted for wetland and stream buffers. The results of buffer studies, completed here in the Pacific Northwest as well as other areas of the country, provide remarkably consistent findings related to the factors that are important in determining appropriate buffer widths. This consistency is particularly striking in the numerous buffer synthesis documents. Additionally, the results of many studies conducted in other parts of the U.S. have been replicated in studies in the Pacific Northwest.

Determining relevance to Washington, however, can be challenging, since the physical settings of the studies vary widely. Some, however, obviously do relate to Washington; for example, literature related to agricultural practices and vegetated filter strips from the north-central United States and south-central Canada is relevant to some agricultural practices in Washington, especially in areas east of the Cascades.

The majority of research on buffers tends to focus on how buffers influence water quality. Far fewer studies examine the influence of a buffer's physical characteristics on attenuating rates of surface water flow.

Most studies on buffers related to wildlife document the needs of a particular species or guild related to how far they travel from aquatic habitats to fulfill their life-needs. While there is substantial literature on the implications of habitat fragmentation, this literature does not specifically address the role of buffers in reducing fragmentation between wetlands and other parts of the landscape.

Numerous compilations and syntheses of the literature concerning buffers have been completed since 1990. These synthesis documents are used in this document as direct sources when no more recent research was found. This chapter also cites literature related to stream buffers and riparian areas when the findings are relevant to the functions or processes these areas provide to the adjacent aquatic resource.

A more detailed description of the types of literature used and any recognized gaps in the scientific literature are provided within each section on buffers as appropriate.

5.2 Introduction and Background on Regulatory Tools

The regulatory tools discussed in this chapter are components of "typical" wetland protection programs. The intent is not to analyze all elements of protection programs and their regulations but to focus on the key science-based elements relating directly to wetland protection and management. Therefore, this chapter focuses on the following four elements:

- Wetland definitions
- Wetland delineation methods
- Wetland ratings
- Buffers

The topic of compensatory mitigation, another key regulatory tool, is discussed separately in Chapter 6 because of the volume of information and literature available on this subject.

5.3 How Wetlands are Defined and Delineated

5.3.1 How Agencies Define Wetlands

Several definitions of wetlands have been developed and used by various federal, state, and local agencies and jurisdictions. The effectiveness of current federal or state wetland definitions was not evaluated as part of this synthesis. However, definitions are included here because how a wetland is defined is critical to determining what areas are subject to the provisions of a law or regulation.

For the purposes of most laws and regulations, wetlands are usually defined using one of the following two definitions:

> *Those areas that are saturated or inundated by surface or groundwater at a frequency and duration sufficient to support, and under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.* (U.S. Army Corps of Engineers 1987);
>
> or
>
> *"Wetlands" or "wetland areas" means areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas. Wetlands do not include those artificial wetlands intentionally created from non-wetland sites, including, but not limited to, irrigation and drainage ditches, grass-lined swales, canals, detention facilities, wastewater treatment facilities, farm ponds, and landscape amenities, or those wetlands created after July 1, 1990, that were unintentionally created as a result of the construction of a road, street, or highway. Wetlands may include those artificial wetlands intentionally created from nonwetland areas to mitigate the conversion of wetlands.* (Washington Administrative Code 173-22-030.)

The Washington State definition is derived from the U.S. Army Corps of Engineers (Corps) definition, but it also includes clarifying language that identifies which common human-made or -induced features are not meant to be defined as wetland. The state definition is required by the Growth Management Act (RCW 36.70A.030 (20)) to be used in all local critical area regulations.

In addition, for the National Wetland Inventory, the U.S. Fish and Wildlife Service (USFWS) defined wetlands as follows:

> *Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For the purpose of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes, (2) the substrate is predominantly undrained hydric soil, and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year.* (Cowardin et al. 1979)

Note that the definition used by the USFWS allows the use of a single parameter to determine if an area is a wetland. The definition also includes areas that may not be vegetated, such as gravel bars and mudflats. In most cases, the Corps and Ecology definitions require the presence of all three parameters (vegetation, soil, and hydrology) for an area to be considered a wetland, and they both assume that wetlands generally are vegetated.

5.3.2 Biological vs. Regulated Wetlands

In some jurisdictions, all lands that meet the definition of *wetland* are regulated. However, it is not unusual for a jurisdiction to differentiate within its regulations between "wetlands" (i.e., biological wetlands) and "regulated wetlands" (i.e., wetlands that they intend to regulate). The definition of what constitutes a regulated wetland may vary from jurisdiction to jurisdiction.

In reviewing regulatory language from local wetland regulations, the three primary criteria used to differentiate between "wetland" and "regulated wetland" were:

- The category or rating of the wetland
- The size of the wetland
- The type of wetland (such as isolated wetlands and those designated as Prior Converted Croplands)

In general, a category or rating system has been used historically in regulatory language to differentiate between wetlands that need different degrees of protection. Rating systems are used by local jurisdictions to group wetlands based on physical characteristics and/or functions that the wetlands may provide and how those characteristics or functions are valued. Section 5.4 of this document describes the current state of the science on wetland ratings and the wetland rating systems developed for eastern and western Washington.

The criterion of wetland size is usually a minimum below which the jurisdiction will not regulate a wetland. For example, the jurisdiction may allow no fill in wetlands larger than 10,000 square feet, or they may include language such as "Category 2 wetlands larger than 0.25 acre cannot be altered." The historical rationale for the use of size as a regulatory criterion was the perception that "bigger is better," and the belief that small wetlands were less important and did not provide significant functions. The scientific literature of the last 10 years has made it clear that size does matter but not in the way previously believed. In multiple studies, small wetlands have been shown to contain a significant diversity of plant and animal species (See Section 5.3.3 for more information).

Additionally, two other wetland types may be exempted from regulation: isolated wetlands and wetlands designated as Prior Converted Croplands.

In 2001, the U.S. Supreme Court determined that isolated wetlands are not subject to regulation under Section 404 of the federal Clean Water Act if the only basis for their regulation is their use by migratory birds. However, the Court did not define "isolated," and the federal government has not issued any new guidance or regulations to clarify the situation. In general practice, the U.S. Army Corps of Engineers (Corps), the federal agency that administers the Clean Water Act, considers isolated wetlands to be those of any size that are not adjacent to or have no direct surface water connection to any navigable waters. However, recent lower court decisions have interpreted Corps jurisdiction over isolated waters differently, and the situation is in flux.

Washington State has determined that isolated wetlands are regulated by the Department of Ecology under the state Water Pollution Control Act (RCW 90.48). Since some local jurisdictions in Washington fashion their wetland regulations on the federal or state standards, it is important to consider the implications of not regulating isolated wetlands. Thus, scientific information on isolated wetlands is discussed in Section 5.3.4.

Wetlands that are designated as Prior Converted Croplands (PCC) are another type of wetland that are exempt from regulation by the federal government. PCC are those wetlands that were drained or otherwise manipulated prior to December 23, 1985, for the production of commodity crops. They are wetlands in which inundation (ponding) does not occur for more than 14 consecutive days during the growing season. These sites must produce an agricultural commodity that requires planting a crop that needs annual tilling. These areas are considered waters of the U.S. if they are abandoned (i.e., tilling and planting has not occurred for five consecutive years), and hydrophytic vegetation and wetland hydrology returns. However, even if they are not abandoned, many of the PCCs in Washington still meet the three criteria required for biological wetlands. As with isolated wetlands, the Department of Ecology regulates PCCs that are wetlands under state law.

No information on wetland areas meeting the definition of PCC was found in the scientific literature. However, many wetlands meeting the criteria for PCC would still be expected to provide important functions, given that the criteria for being designated “Prior Converted” require only that the wetland has been manipulated for production of commodity crops since 1985 and does not pond for more than 14 consecutive days during the growing season. The authors of Volume I have observed widespread flooding in PCC areas during the winter and have observed use of these areas by several species of overwintering waterfowl. One published study of waterfowl in Puget Sound documented significant use of farmlands by several duck species for feeding during the winter (Lovvorn and Baldwin 1996). This study found greater use by waterfowl of farm fields that were flooded in winter, but made no distinction between upland farm fields, farmed wetlands, and Prior Converted Croplands. In addition, the authors of Volume I have documented significant water quality and quantity functions provided by PCCs in projects reviewed and permitted by the Department of Ecology (This data has not been published).

If the agricultural activities were abandoned, PCCs could revert to a plant community characteristic of wetland; and, without maintenance of the hydrologic modifications, the wetland’s water regime may revert to a condition more like that which existed prior to the alteration. Further analysis of the functions of wetland areas designated as PCC is needed.

No literature was found that discussed the ecological consequences of the legal bifurcation between biological wetlands and regulated wetlands. However, literature was found that discusses the functions and values provided by small wetlands and isolated wetlands, as discussed below.

5.3.3 Small Wetlands

The elimination of small wetlands is an issue that has gained attention over the past 10 years. Many regulations have preferentially allowed filling of small wetlands. Many regulations completely exempt wetlands under a certain threshold. Also, size is one of the most common characteristics used in determining wetland ratings at the local level, and smaller wetlands typically receive lower levels of protection. Yet, the loss of small wetlands is one of the most common cumulative impacts on wetlands and wildlife (Weller 1988, Tiner et al. 2002).

No definition of *small* is provided here because what constitutes "small" varies between jurisdictions and scientific studies (see also Section 5.3.2). In some contexts, small is determined exclusively by size. Small may mean less than 0.10 acre; in others, it may mean less than 10 acres.

Some jurisdictions, however, also differentiate small wetlands using criteria that reflect function and values. Small wetlands can have outlets, be in a floodplain, or be otherwise associated with a larger aquatic system. These characteristics are often used in rating systems and, combined with size, determine what is considered a small wetland. For example, a jurisdiction may include language in their regulations such as “Category 2 wetlands larger than 0.25 acre cannot be altered.” For each of the studies below, we have included the authors' definition of small.

In addition to the obvious loss of habitat for wildlife, fragmentation of habitat increases as small wetlands are eliminated, resulting in greater distances between wetland patches in the landscape. Semlitsch and Bodie (1998) found that creating greater distances between wetlands of 0.5 to 10 acres in size can have a significant effect on the ability of a landscape to support viable populations of amphibians, as juveniles dispersing from a source wetland may not be able to travel far enough to recolonize other surrounding (now distant) wetlands. Management priorities have focused on larger, semi-permanent wetlands, with the least emphasis on protecting the smaller, seasonal wetlands (< 1.2 acres) that are critical components of wetland complexes (Naugle et al. 2001).

The following sections describe studies of the use of small wetlands by wildlife, and the role that small wetlands play in maintaining connections between habitats. For each of these studies, the authors' definition of small is described.

Studies of the relationship between wetland size and wildlife distribution have mostly focused on amphibians and birds. Few studies have examined how use of wetlands by mammals relates to wetland size, and no studies of this relationship were found for macroinvertebrates or reptiles. No studies were found that documented the role that small wetlands play in providing water quality or hydrologic functions. However, the degree to which small wetlands perform water quality or hydrologic functions is likely to be determined by site-specific characteristics (see Chapter 2) and can be estimated on a per-acre basis using some of the available function assessment methods.

5.3.3.1 Amphibians and Small Wetlands

Snodgrass et al. (2000) undertook a study of amphibian use of wetlands to address three commonly held beliefs about small wetlands (0.7 acres - 3 acres):

- They have short hydroperiods
- They support few species
- They support species that are also found in larger wetlands

Snodgrass et al. (2000) determined that amphibian species richness increases with length of hydroperiod. They also concluded that short-hydroperiod wetlands (smaller temporarily ponded wetlands) are also important in maintaining biological diversity in that they support species not found in larger wetlands with longer hydroperiods. The species they found in small wetlands were not a subset of those in larger wetlands but rather a unique group of species.

Similarly, amphibian richness in Puget Sound wetlands was found to have no correlation with wetland size (1 - 30 acres). High richness occurred in some of the smallest wetlands (Richter and Azous 1995). The study indicates that small wetlands that are vegetatively simple can serve adequately as breeding habitats as long as favorable nonbreeding habitat is present nearby. Species richness also was not related to persistence of ponding.

Gibbs (1993) conducted a simulation model in Maine from which he theorized that small wetlands may be most important for wetland organisms with low population growth rates and low densities. The model demonstrated that the loss of small freshwater wetlands (less than approximately 5 acres [2 ha]) would result in a decline of total wetland area by 19% and total wetland number by 62%, while the average distance between wetlands would increase by 67% (Gibbs 1993). The model showed that the loss of small wetlands would result in a change (from 90% to 54%) of the area that would lie within the maximum migration distance of terrestrial-dwelling and aquatic-breeding amphibians. The risk of extinction would significantly increase for local populations of turtles, small birds, and small mammals that are currently stable even though the model showed no change in the risk of metapopulation extinction for salamanders or frogs. Amphibian populations in the study were buffered from the risk of extinction due to high rates of population increase. The model demonstrated that dispersal ability for amphibians is a predictor of population growth rate and density, not sensitivity of a population to loss of small wetlands.

5.3.3.2 Birds and Small Wetlands

Bird use of wetlands appears to have a stronger relationship to wetland size than that of amphibians. Bird richness was positively correlated with larger wetland size in a Puget Sound study of palustrine wetlands (Richter and Azous 2001b). This is attributed to the fact that larger wetlands in the study generally had greater structural complexity and a greater number of habitat types.

Martin-Yanny (1992) also found that bird species richness and abundance in wetlands of the Pacific Northwest are positively correlated with wetland size. However, Martin-Yanny noted that habitat heterogeneity was a more important determining factor than wetland area in influencing bird species richness. Wetlands in highly urbanized watersheds had fewer neotropical migrant species, fewer ground-nesting birds, and more edge-tolerant (habitat generalist) species. This is because urbanizing watersheds tend to have smaller wetlands (less than 10 acres [4 ha]) with more edge habitat, making birds more susceptible to competition, predation, and nest parasitism. The author recommends preserving large wetlands or complexes of smaller wetlands that are connected by extensive upland buffers.

In northern prairie marshes, bird species richness was also seen to increase with marsh size and to decrease as the wetland became more isolated (Brown and Dinsmore 1986). Marshes that were part of wetland complexes showed higher species richness than isolated wetlands. Certain bird species used smaller marshes only when the marshes were part of a wetland complex. Large isolated marshes in the study often had lower species richness than smaller marshes that were part of wetland complexes. While bird species richness increased, the rate of increase slowed as the marshes became larger. In other words, they concluded that prairie marshes in the size range of 49 to 74 acres (20 to 30 ha) were more efficient in preserving bird species than larger marshes.

A study of agriculturally disturbed wetlands in western Oregon reached similar conclusions in finding that larger wetlands support more bird species (Budeau and Snow 1992). These authors also showed that wetlands of all sizes were important to water-birds.

However, in eastern Washington, Foster et al. (1984) found that waterfowl breeding use of wetlands in the Columbia Basin was greatest in smaller wetlands (less than 1 acre [0.4 ha]).

5.3.3.3 Mammals and Small Wetlands

The study that modeled the effects of the loss of small wetlands in Maine showed that local populations of small mammals faced a significant risk of extinction following the loss of small wetlands (<5 acres) (Gibbs 1993). However, in a study of Puget Sound wetlands, Richter and Azous (2001c) concluded that wetland size alone was not a significant factor in determining mammal richness or abundance. They noted that small-mammal richness was most closely affected by the combined factors of:

- Wetland size
- Extent of retention of forest adjacent to the wetland
- Quantity of large woody debris within wetland buffers

In conclusion, the literature suggests that size is not a significant factor in contributing to most wetland habitat functions. Rather, habitat structure, connectivity, and wetland hydroperiod are much more significant factors in determining habitat functions than size alone. The literature emphasizes that small wetlands are critically important to amphibians, particularly when connectivity between wetlands and with adjacent uplands is maintained. However, none of the studies evaluated the role of wetlands less than 0.5 acre, so the implications of exempting wetlands less than 0.25 acre, as is commonly done in local wetland regulations, are unknown.

The next section deals specifically with isolated wetlands. The following excerpt from Moler and Franz (1987) describes small, isolated wetlands and sheds some light on the attributes of both size and isolation.

> *To a great extent, the unique values and functions of small, isolated wetlands have been overlooked. This oversight derives from several factors, perhaps foremost being the general tendency to think of small wetlands as being little more than subsets of larger wetlands. So long as the uniqueness of small wetlands is unrecognized, then it is intuitive to think of wetlands as declining in value directly as function of size. Similarly, so long as the unique values of isolated wetlands are unrecognized, it is understandable that connected wetlands might be considered of greater value. In reality, small isolated wetlands are biologically unique systems. Because of their isolation and small size, they support a very different assemblage of species than that found in*

larger, more permanently wet situations. The ephemeral nature of many small wetlands makes them unsuitable for species which require permanent water.

5.3.4 Isolated Wetlands

Isolated wetlands are being addressed in this document because of the recent Supreme Court decision to exclude many isolated wetlands from federal regulation. The Supreme Court decision regarding isolated wetlands was made based on a legal interpretation of jurisdiction under the federal Clean Water Act (Solid Waste of Northern Cook County v. United States Army Corps of Engineers). The key factor was the language in the Act that relates to navigable waters. The Court did not rule that isolated wetlands are less important than non-isolated wetlands, only that the intent of Congress in passing the Clean Water Act was to relate the protection of waters of the United States to navigability. The Court also did not provide any definition of what constitutes "isolation" for purposes of jurisdiction.

The Seattle District of the U.S. Army Corps of Engineers (Corps) does not have any national or regional guidance for making isolated wetland determinations. As of November 2004, if a wetland meets the test of "adjacency" (neighboring, bordering or contiguous) with any navigable water, or if the wetland has a surface outlet that drains to a navigable water, then the Corps does not consider it isolated (T.J. Stetz, U.S. Army Corps of Engineers, Seattle, personal communication 2004). Future court or administrative decisions may change how isolated wetlands are determined.

Much confusion has resulted from this decision, and some in the public have assumed that isolated wetlands are less important or less worthy of protection. Therefore, it is important to summarize some of the basic science on isolated wetlands, which is presented in the paragraphs that follow.

Much of the information comes from the work of Tiner et al. (2002) and a recent issue of *Wetlands* (Volume 23, #3, 2003) that includes numerous articles on isolated wetlands. Readers are directed to this work for more detailed information. Additionally, the work of Hruby et al. (1999, 2000) in developing assessment methods for wetland functions in Washington provides important scientific information on depressional wetlands in Washington, a wetland type that contains the majority of isolated wetlands in Washington.

Wetlands can be defined as isolated based on their geographic isolation, ecological isolation, or hydrologic isolation (Tiner et al. 2002). For this discussion, isolated wetlands are defined by a very specific type of hydrologic isolation—they do not have a surface outlet by which water leaves the wetland, even seasonally, to another water body. Although frequently described as closed depressions (Tiner et al. 2002, Winter and LaBaugh 2003), isolated wetlands can also be sloped wetlands where surface water, if present, re-enters the shallow groundwater zone at the base of the wetland and is not linked via surface flows to a downstream water body. Isolated wetlands are not necessarily small. They can be large systems with substantial heterogeneity and diverse habitat types (Tiner et al. 2002, Leibowitz 2003).

Generally, isolated wetlands provide most of the same functions as non-isolated wetlands and do so for the same reasons: position in the landscape, hydrologic regime, and type of soils and vegetation present (Leibowitz 2003, Whigam and Jordan 2003, Liebowitz and Nadeau 2003). Basic functions of isolated wetlands as described by Hruby et al. (1999), Tiner et al. (2002), Leibowitz (2003), and Whigam and Jordan (2003) are presented below.

- **Water quantity (hydrologic functions).** Isolated wetlands have no surface outlet. Precipitation and local runoff entering the wetland must either return to the atmosphere by evapotranspiration or infiltrate into groundwater (Leibowitz 2003). As a result, their ability to retain surface water may be significant, depending upon the surrounding topography. This provides potential flood storage because no surface water leaves the wetland to cause potential flooding or erosion downgradient.

- **Water quality.** Because they lack an outlet, isolated wetlands function as sediment traps for contaminants that move into them. Isolated wetlands function as sinks for most dissolved and all sediment-associated nutrients and toxics because they have no outlets that allow materials to be transported downgradient (Hruby et al. 1999). A review of the literature by Whigam and Jordan (2003) concludes that isolated, depressional wetlands have been shown to improve water quality and to efficiently retain nutrients.

- **Wildlife habitat.** Isolated wetlands provide wildlife habitat functions similar to those of non-isolated wetlands (Liebowitz 2003), except in regard to habitat for migrating fish in Washington (Hruby et al. 1999). The habitat value of isolated wetlands is governed by the same factors as non-isolated wetlands (hydrologic regime, vegetation, habitat structure, connectivity to other habitats, etc.) (Liebowitz 2003, Gibbons 2003). Tiner et al. (2002) found that isolated wetlands provide essential habitat for a wide range of guilds and may be vital to maintaining viable, genetically diverse metapopulations. They state:

  > *From an ecological standpoint, isolated wetlands are among the country's most significant biological resources. In some areas, isolation has led to the evolution of endemic species vital for the conservation of biodiversity. In other cases, their isolation and sheer numbers in a given locality have made these wetlands crucial habitats for amphibian breeding and survival (e.g., woodland vernal pools and cypress domes) or for waterfowl and waterbird breeding (e.g., potholes). In arid and semi-arid regions, many isolated wetlands are veritable oases – watering places and habitats vital to many wildlife that use them for breeding, feeding, and resting, or for their primary residence.*

5.3.5 Delineation Methods

In addition to the definition of what constitutes a wetland, the U.S. Army Corps of Engineers (Corps) and Washington State Department of Ecology (Ecology) have provided guidance on how to determine the edge of a wetland (i.e., how to delineate the wetland boundary). Delineating a wetland's boundary is a necessary step in the regulatory process because it factors into calculations of potential wetland impacts and determines the starting point for buffers and setbacks.

The Corps published a federal manual to delineate wetlands in 1987 and another manual in 1989, jointly with the U.S. Environmental Protection Agency (EPA), Soil Conservation Service, and U.S. Fish and Wildlife Service. In subsequent years (1991, 1992, and with EPA in 1994) the Corps released updates to clarify questions and provide regional guidance.

In the early 1990s, there was substantial controversy over proposals to change the 1987 and 1989 federal delineation manuals. A substantial amount of literature was produced analyzing the effectiveness of the various delineation manuals for determining a wetland edge. In subsequent years, the use of the 1987 Federal Manual for Delineation of Wetland Areas became the required legal standard for the Corps.

As required by state legislation, Ecology issued the *Washington State Wetlands Identification and Delineation Manual* in 1996 (WAC 173-22-080, Ecology publication #96-94). Ecology's manual uses the original 1987 Corps of Engineers manual and incorporates changes in the manual made by the federal government since 1987. The state manual includes national guidance issued by the Corps in 1991 and 1992 (which is not present in the 1987 Corps manual), as well as regional guidance issued by the Corps and EPA in 1994. In addition, the state manual eliminated references and examples that were not relevant to Washington State and added examples and situations relevant to Washington. The 1996 state manual is required by statute (RCW 36.70A.175) to be used by local jurisdictions in implementing the Growth Management Act. Since the two manuals rely upon the same criteria and indicators for hydrology, soils, and vegetation, proper use of either manual should result in the same boundary.

5.3.6 Summary of Key Points

- Regulatory agencies define the term *wetland* in slightly different ways.
- Local jurisdictions often differentiate between "biological wetlands" and "regulated wetlands". The distinction is often based on the wetland rating and/or wetland size.
- The studies of the correlation of wetland size to wildlife use conflict somewhat in their findings, but most generally conclude that small wetlands are important habitats (particularly where adjacent buffer habitats are available) and that elimination of small wetlands can negatively impact local populations.

- Small wetlands provide habitat for a range of species that are not a subset of the species found in larger, more permanently inundated wetlands. Small wetlands do not just provide a smaller area for the same array of amphibian species found in larger wetlands.
- Small wetlands are very important in reducing isolation among wetland habitat patches. Smaller wetlands provide significant habitat for wildlife and affect the habitat suitability of larger wetlands by reducing isolation on the landscape.
- The presence of small wetlands reduces the distance between wetlands and thus increases the probability of successful dispersal of organisms. This, in turn, likely increases the number of individuals dispersing among patches in a wetland mosaic, thereby reducing the chance of population extinction.
- Isolated wetlands provide the same range of wetland functions as non-isolated wetlands. Isolated wetlands provide important water quantity, water quality, and habitat functions.
- The U.S. Army Corps of Engineers 1987 wetland delineation manual and the 1996 *Washington State Wetlands Identification and Delineation Manual* are the current standards to be used in determining the boundary of a wetland. Correct use of these two manuals should result in the same wetland boundary.

5.4 Wetland Rating Systems

Wetland rating systems (or categorizations) are one of the numerous procedures that have been developed to analyze wetlands, providing ways to identify, characterize, or rate wetland characteristics, functions, and social benefits (values). Categorizations, as well as other procedures such as function assessment, are used by natural resource managers and regulators in a variety of contexts for regulating, planning, and managing the wetland resource (Bartoldus 1999). In the context of local regulations, rating systems are used to categorize wetlands based on different needs for protection. However, rating systems can often be used as one means to analyze wetlands.

Many different procedures to analyze wetlands have been developed in the last three decades. These range from detailed scientific evaluations that may require many years to complete, to the judgments of individual experts during one visit to a wetland. For example, Bartoldus (1999) summarized 40 different tools that were developed up to 1998, and that are used to meet the needs of regulating and managing wetlands.

Although many different rating-type tools have been developed, the literature search for this document did not uncover any analyses of the effectiveness of rating systems at protecting the wetland resource. It is assumed that better protection for wetlands is provided with improved understanding of wetland functions and values (e.g., Roth et al. 1993, National Research Council 1995).

Scientific rigor is often time consuming and costly. For regulatory use, tools are needed that provide some information on the functions and values of wetlands in a time- and cost-effective way. One way to accomplish this is with an analytical tool that categorizes wetlands by their important attributes or characteristics based on the collective judgment of regional experts. Categorization methods, such as rating systems, are relatively rapid but can still provide some scientific rigor (Hruby 1999).

The rapid method most commonly used for analyzing wetlands in eastern and western Washington has been Ecology's wetland rating systems (Ecology 1991, 1993, Hruby 2004a,b). This rating system or some modification of it has been incorporated in the wetland regulations of at least 20 counties in the state and many cities and towns as well (Chris Parsons, Washington State Department of Community, Trade and Economic Development (CTED), personal communications and survey 1999, data are available on request from CTED).

> In the first editions of the Washington State wetland rating systems, the term *rating* was not used in a manner that is consistent with its definition in the dictionary, and this has caused some confusion. The method does not rate the wetland and generate a relative estimate of value (e.g., high, medium, low). Rather, it is a categorization of wetlands based on specific criteria, such as sensitivity to disturbance and rarity in the landscape.

The rating systems were designed to differentiate between wetlands based on their sensitivity to disturbance, their significance, their rarity, our ability to replace them, and the functions they provide. However, the rating systems were not intended to replace a full assessment that may be necessary to determine the levels of performance for numerous functions or to plan and monitor a compensatory mitigation project. As noted in the wetland rating system for eastern Washington:

> *The rating categories are intended to be used as the basis for developing standards for protecting and managing the wetlands to minimize further loss of their resource value. The management decisions that can be made based on the rating include the width of buffers necessary to protect the wetland from adjacent development, the ratios needed to compensate for impacts to the wetland, and permitted uses in the wetland.* (Hruby 2004a)

The rating systems for both eastern and western Washington have been revised by Ecology in conjunction with teams of wetland experts and local planners in each region who provided technical input and field testing. The goal of the revisions is to reflect the best and most current science on wetlands and how they function (using three broad groups of functions—hydrologic, water quality, and habitat) while maintaining rapidity and ease of use. You can access the rating systems for eastern and western Washington at the following web site: http://www.ecy.wa.gov/programs/sea/wetlan.html.

Wetland rating systems used in other parts of the nation

Categorization systems have also been used in other parts of the United States to manage wetlands. Other states have wetland categorizations as part of their wetland laws and rules, and other jurisdictions have used them to help manage wetlands for specific projects. For example:

Vermont adopted a law (10 VSA Chapter 37, Section (a) (7-9)) mandating that rules be adopted to identify Vermont's significant wetlands. The rules categorize wetlands into three classes of which the first two are considered "significant" (Vermont Department of Environmental Conservation 1999).

New Jersey has a wetland categorization included directly in its law (NJAC 7:7A). Criteria are provided for categorizing wetlands into (1) freshwater wetlands of exceptional resource value, (2) wetlands of ordinary resource value, and (3) wetlands of intermediate resource value.

New York has adopted rules that categorize wetlands into four categories based on ecological associations, hydrologic features, pollution control features, cover types, and distribution and location (6 NYCRR Part 664.5).

West Eugene, Oregon developed a method for a plan based on "needs for protection" (City of Eugene 2002).

North Carolina created a GIS-based system that characterizes the "significance" of wetlands based on several landscape and function-based criteria (Gainey and Roise 1998).

5.4.1 Other Characteristics Used for Rating

Some wetlands in Washington are categorized in the Washington State wetland rating systems based on important characteristics that are not specifically related to functions. These characteristics include rarity on the landscape, sensitivity to disturbance, and difficulty in restoring or creating such wetlands through mitigation efforts (Ecology 1991, Hruby 2004a,b). The wetland types that have been defined for eastern and western Washington are listed below. Some of the types are unique to either eastern or western Washington (e.g., Wetlands in coastal lagoons are unique to western Washington):

- Bogs
- Alkali wetlands
- Mature and old-growth forested wetlands
- Vernal pools
- Wetlands identified by the Washington State Department of Natural Resources as "Natural Heritage" wetlands

- Wetlands in coastal lagoons
- Interdunal wetlands
- Estuarine wetlands

Each of these types is described in more detail below.

5.4.1.1 Bogs

Many of the scientific studies of bogs have been published in Europe and the northern parts of the United States, such as Minnesota and Maine. There has not been extensive research on bogs in Washington State. This summary of the literature is not intended to be a thorough synthesis but provides basic background information regarding characteristics of bogs requiring special consideration for management.

Predominance of Organic Soils

Bogs are peatlands (wetlands with organic soils) that have been classified according to their shape, chemistry, plant species, and vegetation structure (Gore 1983). The common factor in bogs is the presence of organic soils or peat, which result from the accumulation of poorly decomposed plant material. The optimum conditions for peat formation occur in cool, humid climates in a location with poorly drained soil.

The rate of peat accumulation is generally quite low, although it can vary with site-specific factors. Heathewaite and Gottlich (1993) report rates of accumulation ranging from 2 to 4 inches (5 to 10 cm) every 100 years. Durno (1961) lists a range of 0.5 to 4.3 inches (1.2 to 11 cm) accumulation every 100 years. In Washington, Rigg (1958) reports peat accumulation of 1 inch (2.5 cm) in 40 years for the west side of the Cascades and 1 inch in 50 years on the east side. Peat can be as little as 8 inches (20 cm) deep to over 45 feet (15 m) deep (Heathewaite and Gottlich 1993).

The three ways that peat is formed, described below, illustrate the lengthy process of peat and bog formation and help explain why bogs are almost impossible to recreate through compensatory mitigation (see below and in Chapter 6).

- In a **filled-lake sequence**, open water progresses to a sedge or moss community that gradually builds a mat over the water, evolving into a bog, bog forest, and then climax community (Conway 1949).
- **Paludification** occurs when bogs invade the surrounding forest. Sphagnum species cause a rise in the water table as peat layers compress and impede drainage (Heathewaite and Gottlich 1993).
- A **flow-through succession** occurs when surface flows are modified. Organic matter builds up to the point where surface flows are diverted around the peat mound. As it builds, the mound becomes isolated from groundwater, relying solely on precipitation as its water source (Klinger 1996).

Studies have shown, on the other hand, that many bogs remain very stable for thousands of years as a sphagnum moss/shrub community, even though succession to a forested community can occur (Klinger 1996).

Acidity and Poor Nutrients

Bogs have unusual hydrodynamics and chemistry for wetlands. They typically only receive precipitation and very localized surface runoff as their sources of water. As a result, many essential nutrients, such as nitrogen, occur in low concentrations. The upper layers of peat, formed by slowly decomposing sphagnum, are often strongly acidic, usually with a pH of 4 or less.

Bogs typically support plant species that are specially adapted to these harsh growing conditions. Sphagnum moss, as well as other mosses, usually dominate the vegetation near the ground. Ericaceous shrubs, such as Labrador tea (*Ledum gladulosum*), are also common in bogs.

Trees can grow in bogs but at a very slow rate due to the poor growing conditions. In studies in the Pacific Northwest, Rigg (1918) found tree growth in sphagnum peat soils was slow. Rigg determined that hemlock (*Tsuga heterophylla*) grew in sphagnum soils at a rate that was only 27% of its growth rate in productive upland soils, and that Douglas-fir (*Pseudotsuga menziesii*) grew in sphagnum at only 16% of its growth rate in upland soils. He measured the annual growth of western red cedar (*Thuja plicata*) as only 0.02 inches (0.6 mm).

Although persistent wet conditions, low soil oxygen, and high acidity are important factors, it is actually the lack of available nutrients, or the inability of plants to absorb nutrients because of acidity (Moore and Bellamy 1974), that most influences the flora of bogs. Most bog species have developed special adaptations to these conditions and out-compete more common wetland plants (Mitsch and Gosselink 2000). Therefore, this makes bog species susceptible to nutrient loading and changes in acidity (as well as alterations in water source that can precipitate these changes) that would enable other species to establish and dominate.

Bogs in Western and Eastern Washington

In western Washington, Kunze (1994) characterized numerous types of peatlands, including bogs and fens. She identified 10 types of sphagnum bog communities in the Puget Trough region and 14 in the Olympic Peninsula/southwest Washington. They occur in the lowlands of the Puget Trough in depressions, oxbows, and old lake beds. These typically have a raised center with a moat around the edge. Bogs and fens also occur on the Olympic Peninsula and in southwest Washington where they can occupy basins, slopes, and flat to rolling ground, as well as forming along low-gradient streams. Bogs in the foothills of the Cascades include sloping bogs, which are influenced by both mineral soil water and precipitation.

Peatlands in eastern Washington have not been classified to the extent of those in western Washington. However, 50 peatlands were identified by Rigg (1958). Forty-four of those identified were located in the northeastern corner of the state. They included fens associated with flowing water, and bogs formed in depressions or along lake margins. Six peat systems were found in scabland channels and depressions on the Columbia Plateau.

Difficulty in Restoring Bogs

Researchers in Northern Europe and Canada have found that restoring bogs is difficult, specifically in regard to plant communities (Bolscher 1995, Grosvermier et al. 1995, Schouwenaars 1995, Schrautzer et al. 1996), water regime (Grootjans and van Diggelen 1995, Schouwenaars 1995), and/or water chemistry (Wind-Mulder and Vitt 2000). In fact, restoration may be impossible because of changes to the biotic and abiotic properties (Shouwenaars 1995, Schrautzer et al. 1996).

It is apparent that true restoration of a raised bog ecosystem is a long-term process. In *Restoration of Temperate Wetlands*, Joosten (1995) states:

> *Long term studies in bog regeneration indicate that restoration of bogs as self-regulating landscapes after severe anthropogenic damage is impossible within human time perspective, because the necessary massive re-establishment of bog key species and renewed accumulation of peat require centuries.*

Refer to Chapter 6 for more information on the challenges in restoring bogs.

5.4.1.2 Alkali Wetlands

Alkali wetlands are characterized by the occurrence of non-tidal, shallow saline water. In eastern Washington, these wetlands contain surface water with specific conductance (a measure of salinity) that exceeds 3,000 micromhos per centimeter. These wetlands provide the primary habitat for several species of migratory shorebirds and are also heavily used by migrating waterfowl. They also have unique plants and animals that are not found anywhere else in eastern Washington. For example, the small alkali bee that is used to pollinate alfalfa and onion for seed production lives in alkali systems. This bee is a valuable natural resource for agriculture in the western United States and especially in eastern Washington (Delaplane and Mayer 2000). The “regular” bees which pollinate fruits and vegetables are generally too large to pollinate the small flowers of these commercially important plants.

The salt concentrations in alkali wetlands have resulted from a relatively long-term process of groundwater surfacing and evaporating. These conditions cannot be easily reproduced through compensatory mitigation because the balance of salts, evaporation, and water inflows is hard to reproduce, and no references were found suggesting this has ever been attempted. Alkali wetlands are also rare in the landscape of eastern Washington. Of several hundred wetlands that were surveyed and visited by wetland scientists during field work for the state’s function assessment methods and the rating system for eastern Washington (Hruby et al. 2000, Hruby 2004a), only nine could be classified as alkali.

5.4.1.3 Mature and Old-Growth Forested Wetlands

No mature or old-growth forested wetlands have ever been successfully created or restored through compensatory mitigation. A mature forested wetland may require 80 years or more to develop, and the full range of functions performed by these wetlands may take even longer (Stanturf et al. 2001). The actual time required to reconstruct old-growth forests and their soil properties (in contrast to mature forests) is unknown (Zedler and Callaway 1999). These forested wetlands provide important functions associated with wetlands as well as habitat functions associated with mature and old-growth forests. (Washington State Department of Fish and Wildlife 1999a).

5.4.1.4 Vernal Pools

Vernal pool wetlands occur in eastern Washington and are formed when small depressions in bedrock or in shallow soils fill with snowmelt or spring rains. They retain water until the late spring when reduced precipitation and increased evapotranspiration lead to a complete drying out. The wetlands hold water long enough throughout the year to allow some strictly aquatic organisms to flourish but not long enough for the development of a typical wetland environment (Zedler 1987). Vernal pools often contain upland species during the summer after they dry out and may be difficult to identify as jurisdictional wetlands during part of the year.

Vernal pools in the scablands are the first to melt in the early spring. This open water provides areas where migrating waterfowl can find food while other, larger bodies of water are still frozen. Furthermore, the open water provides areas for pair bonding of waterfowl (R. Friesz, Washington State Department of Fish and Wildlife, personal communications 2000-2004). Thus, vernal pools in a landscape with other wetlands provide a critical habitat function for waterfowl (Hruby 2004a).

5.4.1.5 "Natural Heritage" Wetlands

"Natural Heritage" wetlands are those that have been identified by scientists of the Washington State Natural Heritage Program as high-quality, relatively undisturbed wetlands, and wetlands that support state threatened, endangered, or sensitive plant species.

The Natural Heritage Program has identified important natural plant communities and species that are very sensitive to disturbance or threatened by human activities and maintains a database of these sites. The program's web site states:

> *Some natural systems and species will survive in Washington only if we give them special attention. By focusing on species at risk and maintaining the diversity of natural ecosystems and native species, we can help assure our state's continued environmental and economic health.* (Washington State Department of Natural Resources No Date, http://www.dnr.wa.gov/nhp/about.html)

5.4.1.6 Estuarine Wetlands

Estuaries, the areas where freshwater and salt water mix, are among the most highly productive and complex ecosystems. Here, tremendous quantities of sediments, nutrients, and organic matter are exchanged between terrestrial, freshwater, and marine communities. A large number of plants and animals benefit from estuarine wetlands. Fish, shellfish, birds, and plants are the most visible organisms that live in estuarine wetlands. However, a huge variety of other life forms also live in an estuarine wetland, including many kinds of diatoms, algae and invertebrates.

Estuaries, of which estuarine wetlands are a part, are a "priority habitat" as defined by the state Department of Fish and Wildlife. Estuaries have a high fish and wildlife density and species richness, important breeding habitat, important fish and wildlife seasonal ranges and movement corridors, limited availability, and high vulnerability to alteration of their habitat (Washington State Department of Fish and Wildlife, http://www.wa.gov/wdfw/hab/phslist.htm , accessed October 15, 2003).

Estuarine wetlands are not freshwater wetlands, and therefore, information about them was not reviewed in Volume 1. They are included in this compilation of wetlands with special characteristics because they are included in the wetland rating System for western Washington (Hruby 2004b). They are often found adjacent to freshwater wetlands and should be managed in conjunction with freshwater wetlands. The methods for identifying estuarine wetlands and the rationale for protecting them are described in more detail in the rating system (Hruby 2004b).

5.4.1.7 Wetlands in Coastal Lagoons

Coastal lagoons are shallow bodies of water, like a pond, partly or completely separated from the sea by a barrier beach. They may, or may not, be connected to the sea by an inlet, but they all receive periodic influxes of salt water. This can be either through storm surges overtopping the barrier beach or by flow through the porous sediments of the beach. Coastal lagoons often contain vegetated areas that are jurisdictional wetlands. The wetlands associated with coastal lagoons are, therefore, included in the rating system as wetlands with special characteristics.

Wetlands in coastal lagoons probably cannot be reproduced through compensatory mitigation, and they are relatively rare in the landscape. No information was found on any attempts to create or restore wetlands in coastal lagoons in Washington that would suggest this type of compensatory mitigation is possible. Any impacts to lagoons will, therefore, probably result in a net loss of their functions and values.

In addition, coastal lagoons and their associated wetlands are proving to be very important habitat for salmonids. Unpublished reports of ongoing research in the Puget Sound (Hirschi et al. 2003, Beamer et al. 2003) suggest coastal lagoons are heavily used by juvenile salmonids.

5.4.1.8 Interdunal Wetlands

As defined in the western Washington rating system (Hruby 2004b), any wetlands that are located to the west of the Boundary Line of Upland Ownership as determined in 1889 are considered interdunal. The boundary line is a legally defined line along the Pacific Coast. Interdunal wetlands form in the "deflation plains" and "swales" that are geomorphic features in areas of coastal dunes. These dunes are the result of the interaction between sand, wind, water, and plants. The dune system immediately behind the ocean beach (the primary dune system) and its associated wetlands is very dynamic and can change from storm to storm (Wiedemann 1984). This means that the location of the wetlands is not fixed and may change from year to year.

Interdunal wetlands provide critical habitat for many species in this ecosystem (Wiedemann 1984). Although important, these wetlands constitute only a small part of the total dune system (Wiedemann 1984). No methods have been developed to characterize how well interdunal wetlands function so these wetlands cannot be rated by a score for their functions. In the absence of direct methods for characterizing their functions, the rating of interdunal wetlands is based on their documented importance as habitat in the coastal dune ecosystem.

5.4.2 Summary of Key Points

- Wetland rating systems provide a rapid method to identify, characterize, categorize, or estimate relative wetland functions and values. This information is used in regulating and managing wetlands.
- The rapid method most commonly used for analyzing wetlands in eastern and western Washington has been the Washington State wetland rating systems. The rating system was designed to differentiate between wetlands based on a broad grouping of functions that they provide (hydrologic, water quality, and habitat), as well as other characteristics (listed in the next bullet). However, this rating system does not replace the more robust function assessment methods developed for Washington State. The latter may be necessary to determine the level of performance for specific functions (such as the potential to remove sediment) or to plan and monitor a compensatory mitigation project.
- In the rating system, some wetlands are categorized because of their rarity on the landscape, sensitivity to disturbance, or difficulty in restoration or creation through mitigation efforts, and not because of the functions these wetlands perform. The wetland types in Washington that are included in the rating system because they have these other characteristics include bogs, alkali wetlands, mature and old-growth forested wetlands, vernal pools, estuarine wetlands, wetlands in coastal lagoons, interdunal wetlands, and "Natural Heritage" wetlands.

5.5 Buffers

Buffers are another common element of wetland regulations. Buffers are vegetated areas adjacent to an aquatic resource that can, through various physical, chemical, and/or biological processes, reduce impacts from adjacent land uses. Buffers also provide the terrestrial habitats necessary for wildlife that use wetlands to meet their life-history needs. In this document, we collectively call these processes that buffers provide the *functions* of buffers. Buffers and other adjacent upland areas provide habitat for other wildlife species that do not commonly use wetlands. This document does not address those functions of upland habitats.

The primary purpose of buffers is to protect and maintain the wide variety of functions and values provided by wetlands (or other aquatic areas). The physical characteristics of buffers—slope, soils, vegetation, and width—determine how well buffers reduce the adverse impacts of human development and provide the habitat needed by wildlife species that use wetlands. These characteristics are discussed in detail in this section.

The subject of buffers is well documented in the scientific literature. The research on buffers has occurred worldwide, and this section includes literature from a variety of regions when it was found to be relevant. In particular, a variety of literature related to agricultural practices and vegetated filter strips from the north-central United States and south-central Canada is directly relevant to some agricultural practices in Washington State, especially east of the Cascades. In addition, studies on buffers in urban and suburban settings conducted in the Pacific Northwest region are clearly relevant. However, many of the buffer studies conducted elsewhere in the U.S. and the world, as well as the many buffer synthesis documents, provide information relevant to the state of Washington.

The majority of research on buffers tends to focus on the processes that buffers provide to filter sediment or take up nutrients (i.e., their influence on water quality). Far fewer studies look at the influence of a buffer's physical characteristics on attenuating surface water flow rates, except as it relates to water quality. The long-term effectiveness of buffers in providing such mechanical and biological processes is not well documented in the literature and may represent a critical need for future research.

The literature on buffers related to wildlife is, in general, less focused. Most studies document the needs of a particular species or guild relative to distances for breeding or other life-history needs within a radius from aquatic habitats. There is substantial literature on the implications of habitat fragmentation and connectivity, some of it related specifically to agricultural practices, forestry practices, or the impacts of urbanization. This literature does not specifically address the role of buffers in providing connectivity between wetlands and other parts of the landscape. It does, however, unequivocally support maintaining connectivity between wetlands in order to maintain viable populations of species that are closely associated with wetlands. The reader is referred to Section 4.11 in Chapter 4, which discussed the effects of habitat loss and fragmentation as well as Section 5.5.4.3.

Older research studied the tolerance limits of wetland wildlife for disturbance—how closely a disturbance can approach animals before they are flushed from wetlands—with particular emphasis on waterfowl. These studies tend to be older than 1990 and focus on the prairie pothole region of North America. Where the findings are germane and where they have not been superceded by more recent work, they are included.

In addition to papers on specific research studies, multiple compilations and syntheses of literature on buffers have been completed since 1990. Synthesis papers were compiled by Castelle and other authors (1992b, 1994, and 2000) and another was compiled by McMillan (2000) as a master's thesis. These compilations include literature that was published prior to 1990, but much of the work they rely on is considered seminal to the effectiveness of buffers in protecting wetlands and contributing to habitat. Therefore these synthesis documents are used in this document as direct sources when no more recent research was found to supercede the earlier findings.

This section also cites literature related to stream buffers and riparian areas when the findings are relevant to the influence these areas have on the adjacent aquatic resource. The literature on stream buffers related to microclimate, water quality influences, and some habitat characteristics is particularly relevant because the ways buffers protect and maintain these functions is similar whether they are adjacent to streams or wetlands.

5.5.1 Terms Used to Describe Buffers

The scientific literature varies widely on the terms used to denote the area that serves to reduce impacts to wetlands from adjacent land uses and provide habitat for parts of the life-cycle of many species. Common terms include:

- Buffer
- Wetland setback
- Vegetated filter strip
- Buffer strip
- Riparian area
- Riparian zone
- Riparian corridor

These terms can be differentiated as those that are a product of regulations or policy language and those that define or describe an ecological condition or location (Castelle et al. 1994). Terms such as *buffer, wetland setback*, or *vegetated filter strip* are most commonly applied in an administrative context to denote the landscape immediately adjacent to an aquatic resource, the dimensions of which are legally determined. The terms *buffer strip* or *vegetated filter strip* may imply a relatively undisturbed, vegetated area that helps attenuate the adverse effects of land uses adjacent to a wetland. For example, Norman (1996) provides this definition:

> *Buffer strips are strips of vegetated land composed in many cases of natural ecotonal and upland plant communities which separate development from environmentally sensitive areas and lessen these adverse impacts of human disturbance.*

The terms *riparian areas* or *riparian zones* are defined by many to denote ecologically discernable ecotones (transition zones) along aquatic resources where the presence or action of surface waters, or the presence and duration of shallow groundwater, influences the structure and composition of the vegetation community (Lowrance et al. 1995, Harper and MacDonald 2001). The term *riparian corridor* is defined by Naiman et al. (1993) as "encompass(ing) the stream channel and that portion of the terrestrial landscape from the high water mark towards the uplands where vegetation may be influenced by elevated water tables or flooding, and by the ability of the soils to hold water."

5.5.2 Functions Provided by Buffers

The literature is broadly consistent on the ways in which buffers can provide for the protection and maintenance of wetland functions. These include:

- Removing sediment
- Removing excess nutrients (phosphorous and nitrogen)
- Removing toxics (bacteria, metals, pesticides)
- Influencing the microclimate
- Maintaining adjacent habitat critical for the life needs of many species that use wetlands
- Screening adjacent disturbances (noise, light, etc.)
- Maintaining habitat connectivity

As noted by Castelle and Johnson (2000), buffers can be both ecological sources and sinks. They can control or limit the effects of land uses upslope of the aquatic resource (act as a sink), and they can contribute biological benefits to the aquatic resource (act as a source). Naimen et al. (1992) summarize the range of functions provided by buffers along streams as follows:

> *It is well known that riparian vegetation regulates light and temperature regimes, provides nourishment to aquatic as well as terrestrial biota, acts as a source of large woody debris,…regulates the flow of water and nutrients from uplands to the stream, and maintains biodiversity by providing an unusually diverse array of habitat and ecological services.*

These same functions can be attributed to wetland buffers (Castelle et al. 1992b, Desbonnet et al. 1994, McMillan 2000).

The literature also describes the physical, chemical, and/or biological characteristics of a buffer that determine the functions it provides. The most frequently cited physical characteristics that influence the effectiveness of a buffer are:

- Vegetation characteristics (composition, density, and roughness—for example, downed material)
- Percent slope
- Soils
- Buffer width and length (adjacent to the source of impacts)

Only two of the physical characteristics noted above can be easily managed (vegetation characteristics and buffer width/length), while the others are characteristics that do not lend themselves to manipulation.

By far the issue of greatest interest with respect to buffers is the question of how wide a buffer needs to be in order to be effective in protecting a wetland (or other aquatic resource). While the literature is unanimous that buffers provide important functions that protect wetlands and provide essential habitat for many species, there is wide-ranging discussion about how much buffer is necessary to be effective in providing a particular level of function (Young et al. 1980, Booth 1991, Castelle et al. 1994, Norman 1996, Dosskey 2000, McMillan 2000, Rickerl et al. 2000).

For ease of discussion as to the effective widths of buffers, the functions of buffers listed above are grouped into two major categories:

- Water quality (discussed in Section 5.5.3)
- Wildlife habitat (discussed in Section 5.5.4)

Buffers and their influence on wetland hydroperiod, as described in the few studies found on this subject, are summarized in the shaded box on the next page.

> The following literature sources are generally consistent in describing what functions buffers provide to aquatic resources as well as the physical parameters that influence a buffer's ability to provide these functions: Budd et al. (1987), Phillips (1989), Castelle et al. (1992, 1994), Naiman et al. (1992), Belt and O'Laughlin (1994), Desbonnet et al. (1994), Norman (1996), Dillaha and Inamdar (1997), Dosskey (2000), Van der Kamp and Hayashi (1998), Liquori (2000), McMillan (2000), Todd (2000), Townsend and Robinson (2001), Dosskey (2001).

Buffers alone have limited influence on wetland hydroperiod

As described in detail in Chapter 3, human land uses, such as agricultural practices, clearing, and land development, alter the movement and storage of surface water and groundwater within a wetland's contributing basin. These changes can significantly affect the hydroperiod of wetlands and other aquatic resources, causing an adverse effect on many wetland functions (Azous and Horner 2001). There is little published literature on the effectiveness of buffers in ameliorating the effect of changes in land use within the contributing basin on wetland hydroperiod. Some of the literature indicates that wetland buffers are far less effective at maintaining wetland hydroperiod than other mechanisms, such as controlling impervious surfaces and utilizing effective stormwater management practices (Herson-Jones et al. 1995).

Research in the Puget Sound Basin has agreed that changes in the land cover type in the contributing basin have a stronger influence on the resulting hydroperiod of the wetland than the buffer does (Booth 1991, Azous and Horner 2001). An exception may be for wetlands that have a very small contributing basin. However, the rate and manner in which stormwater enters the wetland following land-use changes in the contributing basin will most often shift from sheet flow and interflow to one or more point sources, resulting in a potential change in hydroperiod. Based on hydroperiod models using the U.S. Environmental Protection Agency's Hydrologic Simulation Program Fortran (HSPF model) for areas west of the Cascades, the wetland will tend to receive more water more quickly in the fall and will receive less water for a shorter period in the spring, resulting in a shift in the seasonal hydroperiod.

Buffer width is usually not sufficient to counteract the influence of land-use changes and stormwater management facilities within the wetland's contributing basin.

5.5.3 Buffers and Protection of Water Quality

Buffers protect the water quality of wetlands through four basic mechanisms:

- They remove sediment (and attached pollutants) from surface water flowing across the buffer
- They biologically "treat" surface and shallow groundwater through plant uptake or by biological conversion of nutrients and bacteria into less harmful forms
- They bind dissolved pollutants by adsorption onto clay and humus particles in the soil
- They help maintain the water temperatures in the wetland through shading and blocking wind

Literature describing the different ways that buffers maintain and improve water quality in wetlands and other aquatic areas is abundant. There is also considerable research on the effective widths that provide a relative percentage of removal of sediments, nutrients, and some toxics emanating from various sources. Four categories of water quality improvement are discussed below:

- Removing sediment
- Removing nutrients
- Removing toxics and pathogens
- Maintaining microclimate

For each of these categories, a summary is provided on what the literature says about the relationship between buffer width (or other characteristics) and the buffer's effectiveness in providing that type of water quality improvement. A summary table is included that lists the range of buffer widths for each category and the literature references that substantiate those findings. However, the literature does not address the issue of "how much pollutant removal is acceptable." For each pollutant, there may be a maximum amount that a buffer can process before its ability to do so is overwhelmed. The literature does not provide any specific thresholds (See section 5.5.5.3 for more on this issue).

5.5.3.1 Removing Sediment

Characteristics that Influence a Buffer's Ability to Remove Sediment

A buffer's ability to remove sediment from surface water flows depends upon several physical characteristics of the buffer. Sediment removal occurs when (Castelle et al. 1992b, Dillaha and Inamdar 1997, Phillips 1989):

- Flows are slowed sufficiently to allow particles to settle out
- Physical filtering by vegetation and roots mechanically removes sediments from the water column
- The slope of the buffer is of a low enough gradient to preclude formation of rills and scouring
- There is large woody debris on the ground to create roughness
- The infiltration rate of the soils allows water to move through the soils rather than on the surface

The way sediment-laden water enters a buffer influences the ability of the buffer to slow the flows sufficiently to allow sediment deposition. Several studies noted that vegetated buffers are only effective at removing sediments if sediment-laden waters enter the buffer as sheet flow, rather than in channels or rivulets (Phillips 1989, Booth 1991, Castelle et al. 1992b, Desbonnet et al. 1994, Belt and O'Laughlin 1994, Sheridan et al. 1999). Norman (1996) cites work conducted by Schueler in 1987 that found buffers in urban settings were most effective at removing sediments where slopes were less than 5%, and waters entered the buffer in shallow, dispersed sheet flow. Norman surmised that, "The rate of removal of pollutants appears to be a function of the width, slope, and soil permeability of the (buffer) strip, the size of the contributing runoff area, and the runoff velocity."

In other research, Sheridan et al. (1999) found that the greatest reduction in sediment loading occurs in the initial "treatment" stages using a vegetated filter strip that is managed and mowed. Their research found the greatest removal of sediments (56 to 72%) and reduction in flow rates occurs in the outer portion of a vegetated filter strip (the strip closest to the source of sediment). Grass filter strips provided removal ranging from 78 to 83% of suspended sediments.

The ability of a buffer to provide physical filtering of sediments also depends on the condition of the vegetation and the surface roughness. Belt and O'Laughlin (1994) noted that when vegetation, rocks, or other obstructions were eliminated from the buffer surface, sediment-laden waters flowed further into (or through) a buffer. Buffers were found to be effective in removing sediments only if flows were shallow and broad, not narrow and incised. The presence of woody debris and vegetative obstructions on the ground surface (roughness) was found to slow flows, inhibit the formation of rills, and facilitate sediment deposition.

In contrast, hydrologic models created by Phillips (1989) estimated that surface roughness would be of minor concern, and buffer width was not critical, as long as a minimum 49-foot (15 m) buffer was maintained. This study was based on estimated models, whereas Belt and O'Laughlin's work was based on field measurements.

Phillips (1989) also emphasized the importance of slope. He states, "Results show that where solid-phase pollutants transported as suspended or bed-load in overland flow are the major concern, slope gradient is the most critical factor, followed by soil hydraulic conductivity." Slope gradient is critical because, on slopes greater than 5%, sheet flow can start to become channelized. Channelized flows have faster rates, more erosive powers, and less contact with vegetation (Norman 1996). Faster moving water has the capacity to carry fine sediment particles farther than slower flows, even moving through dense vegetation.

In his research in urbanizing settings, Booth (1991) notes that buffers adjacent to aquatic resources may have limited ability to filter and slow flows caused by stormwater. He found that (1) in some instances the buffers no longer existed in a natural vegetated condition, (2) once development occurred, and the buffer was subdivided into multiple private ownerships, maintaining an intact buffer was not possible, or (3) the increased volumes and rates of flows were too significant to be controlled by conditions within a vegetated buffer.

Buffers were found to facilitate reduction of sediment from active agricultural fields in several studies:

- Welsch (1991) found that a three-tiered buffer system on a shallow slope, with the first tier (closest to the source of sediment) composed of dense herbaceous vegetation, maximized sediment removal (See Section 5.5.6 for a discussion of the three-tiered system).
- Dosskey (2001) noted in agricultural settings that vegetated buffers retain pollutants by reducing the flow rates and filtering surface runoff from fields.
- Assessing management options to control non-point-source pollution (sediment, nitrogen, and phosphorus) in agricultural settings, Yocom et al. (1989) recommended the use of vegetated filter strips between actively cropped land and adjacent wetlands.

Buffer Width and Effectiveness in Removing Sediment

As noted above, the ability of a buffer to remove sediment is based on the condition of the buffer and its slope, as well as the characteristics of the incoming sediment. The following variables all contribute to the sediment removal effectiveness of a buffer:

- The velocity of sediment transport (in surface water)
- The size of sediment particles from the source materials
- The density of the vegetation present
- The presence and extent of large woody debris
- Surface roughness within the buffer

However, the relationship between the width of the buffer and its effectiveness is non-linear. The largest particles and the greatest percentage of particles are dropped in the outer portions of the buffer (closest to the source of sediment). In these outer areas, the rate of surface flow begins to diminish as the water is slowed by vegetation and woody debris. Slower water movement allows particles to drop out of the water column.

This is graphically illustrated in the graph below (Figure 5-1). This table is included here for illustrative purposes only, to depict the non-linear nature of buffers in removing sediments. This graph is based on data from the buffer synthesis by Desbonnet et al. (1994).

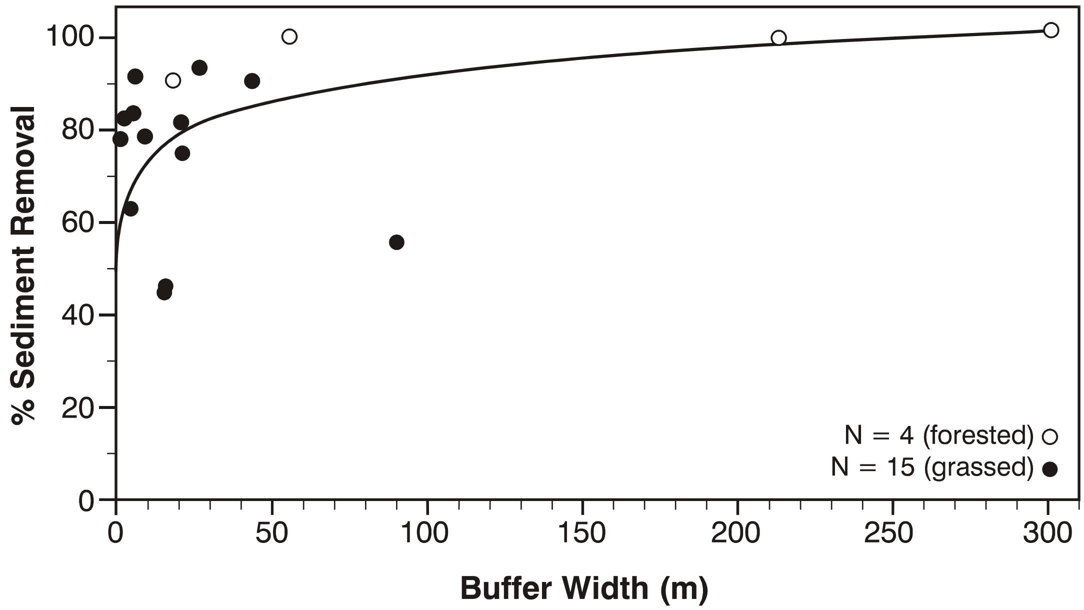

Figure 5-1. Relationship of percent removal to buffer width for the treatment of sediments contained in surface water runoff (Desbonnet et al. 1994).

In 1982, Wong and McCuen derived a formula to model a buffer's ability to remove sediments based on sediment particle size, the slope within the buffer, the rate of surface runoff, and the amount of vegetation and woody debris (roughness) in the buffer (Castelle et al. 1994). The model predicted that there would be a point of relative diminishing returns for function vs. width. For example, "If the sediment removal design criteria were increased from 90 to 95% on a 2% slope, then the buffer widths would have to be doubled from 30.5 to 61 m (100 to 200 ft)." In other words, the model predicted that the width of the buffer would have to double to achieve an additional 5% removal of sediment after 90% of it had already been removed from the water column. Desbonnet et al. (1994) determined that a small buffer (7 feet [2 m]) could effectively remove up to 60% of suspended sediment, while a buffer of up to 82 feet (25 m) would be needed to remove 80%.

These findings are consistent with others who have found that progressively larger buffer dimensions are required to filter out finer particles (Norman 1996). These and other studies are summarized in Table 5-1.

See Section 5.5.5 for discussion of the ability of buffers to continue providing sediment removal over the long term.

Table 5-1. Summary of studies on sediment control provided by buffers of various widths.

Author(s)	Date	Buffer Width	Comments
Broderson	1973	200 feet (61 m)	Effective sediment control "even on steep slopes"
Desbonnet et al.	1994	6.6 – 82 feet (2 – 25 m)	60% removal in 6.6 feet (2 m); 80% removal required 80 feet (25 m)
Desbonnet et al.	1994	16 – 49 feet (5 – 15 m)	On grassy buffers on slopes with less than 5% slope, removed all but the finest particles
Ghaffarzadeh et al.	1992	16 – 49 feet (5 – 15 m)	Found 85% removal in 30-foot (9.1 m) buffers
Horner and Mar	1982	200 feet (61 m)	80% of sediments. As cited by Castelle and Johnson (2000)
Lynch et al.	1985	98 feet (30 m)	75 to 80% removal of sediment from logging activities into wetlands
Norman	1996	9.8 feet (3 m): sands 49.9 feet (15.2 m): silts 400 feet (122 m): clays	Distances required for effective removal of progressively smaller particle sizes
Wong and McCuen	1982	100 – 200 feet (30.5 – 61 m)	90% at 100 feet (30 m), need 200 feet (61 m) to obtain 95% removal effectiveness
Young et al.	1980	80 feet (24.4 m)	92% sediment removal rate from feedlot through vegetated buffer strip

5.5.3.2 Removing Nutrients

Characteristics that Influence a Buffer's Ability to Remove Nutrients

Nutrients are transported into wetlands via sediment-laden water or dissolved in surface or shallow subsurface flows. The primary nutrients of concern are nitrogen and phosphorous. Buffers remove nitrogen and phosphorous through a variety of mechanisms that are similar to the mechanisms present within the wetland itself, as described in Chapter 2.

As much as 85% of phosphorous in surface waters is bound to sediments (Karr and Schlosser 1977) and thus can be removed via sediment removal in buffers. Phosphorus and other nutrients may be effectively reduced in surface waters by filtering and uptake; however, dissolved forms of nitrogen are not affected by surface processes and can be more effectively removed in the buffer through subsurface contact with fine roots (Muscutt et al. 1993, Townsend and Robinson 2001). Lowrance et al. (1995) confirm that the areas where improvements in water quality are the most effective are where precipitation moves across, through, or near the rooting zone of a forested buffer. These findings are similar to those of Phillips (1989), who found that longer contact of dissolved pollutants through wider vegetated buffers was the most important factor for effective removal.

Buffer Width and Effectiveness in Removing Nutrients

It is difficult to compare studies of buffer width and effectiveness at removing nutrients because the basic parameters of the studies differ greatly. Some studies were conducted in field settings while others occurred in experimentally designed plots. There were differences in the loading rate of nutrients, the types of soils, and the vegetation in the buffers. Some studies examined only nitrogen or phosphorous removal, whereas others combined different nutrients. The result is that reported effectiveness of buffer widths for removing nutrients ranges from a few meters to hundreds of meters. Studies are listed in Table 5-2.

In a synthesis of research on nitrogen removal, McMillan (2000) found nitrogen can be effectively removed in buffer strips ranging from 20 to 98 feet (6 to 30 m) wide. He cites work by two research groups (Patty et al. 1997, Daniels and Gilliam 1996) that 47 to 99% removal of nitrogen can be achieved in buffers ranging from 20 to 66 feet (6 to 20 m) wide. This is not totally consistent with synthesis results presented by Desbonnet et al. (1994) that “well configured” buffers (with ideal slope, soils, and vegetation) as small as 30 feet (9 m) could reduce as much as 60% of nitrogen, while 197-foot (60 m) buffers would be necessary for 80% nitrogen removal.

A recent study from Oregon documented the role of red alder forests in exporting nitrogen to streams (Compton et al. 2003). They found that the percent of alder forest in a watershed was positively correlated with nitrate concentrations in surface water. This has implications for assuming that buffers with alder forests will help reduce the input of nitrogen from adjacent land uses into wetlands and other surface water.

The literature also describes a range of buffer widths necessary for phosphorus removal. Studies of buffer widths as small as 13 feet (4 m) and as large as 279 feet (85 m) found phosphorus removal rates of 50% to over 90% (see Table 5-2).

Overall, a consistent pattern emerges from the literature. The largest relative percent removal of phosphorus occurs within the outer portions of the buffer (closest to the source), while larger buffers are required to remove increasingly more of the nutrients. This consistency substantiates the conclusions of many that initial contact causes sediment-associated nutrients to be deposited, while dissolved nutrients require longer residence time and prolonged contact with vegetation for effective uptake (removal from the water column) to occur.

Castelle and Johnson (2000) surmised in their literature review that nutrient removal may have a similar non-linear relationship to buffer width as sediment removal. However, Phillips (1989) found that buffer width was a more critical element for dissolved nutrients (especially nitrogen), because wider buffers provided more prolonged contact with the rooting zone and time for uptake and conversion. Phillips did not report widths of buffers related to a certain percent of removal or effectiveness.

Limited research has been done on the long-term effectiveness of buffers for nutrient removal when there is an ongoing nutrient source present on the outside edge of the buffer. See Section 5.5.5.3 for a discussion.

Table 5-2. Summary of studies on nutrient removal provided by buffers of various widths.

Author(s)	Date	Width	Comments
Daniels and Gilliam	1996	20 – 66 feet (6 – 20 m)	47-99% removal of nitrogen
Desbonnet et al.	1994	30 feet (9 m): 60% removal 197 feet (60 m): 80% removal	Small buffers could have effective removal rates for nitrogen; much larger buffers are necessary for a significant increase in effectiveness
Desbonnet et al.	1994	Averages: 39 feet (12 m): 60% 279 feet (85 m): 80%	When all the findings from the literature synthesis were averaged, the average removal efficiencies were non-linear: larger buffers were needed for increases in effectiveness
Dillaha	1993	15 feet (4.6 m): 70% 30 feet (9.1 m): 84 %	Percent removal of suspended solids and their associated nutrients with vegetated filter strips. As cited in Todd (2000)
Dillaha	1993	15 feet (4.6 m): 61 % 30 feet (9.1 m): 79 %	Removal of phosphorus with vegetated filter strips. As cited by Todd (2000)
Dillaha	1993	15 feet (4.6 m): 54% 30 feet (9.1 m): 73%	Removal of nitrogen with vegetated filter strips. As cited by Todd (2000)
Doyle et al.	1977	12.5 feet (3.8 m) forested 13.1 feet (4 m) grass	Reduced nitrogen, phosphorus, and potassium levels
Edwards et al.	1983	98 feet (30 m)	50% removal rate of phosphorus
Lowrance	1992	23 feet (7 m)	Forested buffer zones were effective at removing nitrate through plant uptake and microbial denitrification
Lynch et al.	1985	98 feet (30 m)	Forested buffers reduced soluble nutrient levels from logging activities to “appropriate” levels
Patty et al.	1997	20 – 66 feet (6 – 20 m)	47 - 99% removal of nitrogen
Shisler et al.	1987	62 feet (19 m)	Forested riparian buffers effectively removed up to 80% and 89% of phosphorus and nitrogen, respectively
Thompson et al.	1978	39 – 118 feet (12 – 36 m)	Found a range of removal effectiveness of 44 to 70%

Author(s)	Date	Width	Comments
Vanderholm and Dickey	1978	> 853 feet (260 m)	Removal of 80% of nutrients, solids, and BOD from feedlot runoff with shallow (<0.5%) buffer slopes. Cited in Castelle et al. (1992b)
Young et al.	1980	69 feet (21 m): 67% removal 89 feet (27 m): 88% removal	Removal of phosphorus
Xu et al.	1992	33 feet (10 m)	Significant reductions in nitrate through a mixed herbaceous and forested buffer strip (as cited by Castelle and Johnson 2000)

5.5.3.3 Removing Toxics and Pathogens

Characteristics that Influence a Buffer's Ability to Remove Toxics and Pathogens

A buffer's ability to remove toxicants and pathogens is one of the least thoroughly studied. At this time, it represents a significant data gap. Castelle and Johnson (2000) note the lack of research on pathogens, toxicants and fecal coliform bacteria (an indicator of the possible presence of pathogens). Many of the studies they examined are quite old, but little recent research was found to supplement these older studies. Therefore, the conclusions presented from the synthesis of the previous work are provided here.

Gilliam (1994) also confirms in his work that little to no research is available on the effective removal of fecal coliforms or various pesticides. Much of the work assessed the effectiveness of removal of nutrients and toxics, without identifying a dimension of width necessary to provide that removal.

Toxics (pesticides and metals) can be removed by buffers through sedimentation, biological uptake by vegetation, adsorption onto clay or humus particles in the soil of the buffer, or degradation of the toxics through biochemical processes (McMillan 2000, Patty et al. 1997).

As mentioned in the discussion of sediment removal, Welsch (1991) described the use of a three-tier buffering system for the most effective removal of sediments and their associated toxics. The outermost tier (closest to the source of impacts) was a densely vegetated filter strip, managed to ensure no erosion or rill formation. He found the most effective removal of sediments and the toxics adhered to sediment particles was through surface sheet flows through the vegetated filter strip. The middle tier was subject to some management activities (limited agriculture or limited tree harvest), while the innermost tier was undisturbed natural vegetation. Dissolved nutrients and some toxics were not affected by physical filtering unless there was prolonged contact with the rooting zone through the shallow groundwater table. See Section 5.5.6 for further discussion.

Castelle and Johnson (2000) note that the apparent effectiveness of small buffers in removing toxics is due to the adsorption of many toxics to sediment particles. When vegetated buffers are effective at filtering sediments, they will also be effective at filtering those toxics and nutrients adhered to the sediments.

One study in Saskatchewan (Donald et al. 1999) found that the concentrations of agricultural pesticides and herbicides in wetlands were influenced by the timing of precipitation relative to the applications of the chemicals. They noted that buffer width may influence exposure of the wetland to these chemicals, but they did not quantify what buffer widths related to the effectiveness of removing chemicals.

Neary et al. (1993) reviewed studies in the Southeastern U.S. on the use of buffers in reducing contamination of water by pesticides. They found that cases of high concentrations of pesticides in water only occurred when no buffer was present or when pesticides were applied within the buffer. Regular use of buffer strips kept concentrations of pesticide residue within water-quality standards. Neary concluded that, generally speaking, buffer strips of 15 m (49 ft) or larger are effective in minimizing contamination of streams by pesticide residue.

Table 5-3 summarizes studies on the effectiveness of toxicant and pathogen removal provided by buffers of various widths.

Table 5-3. Summary of studies on pathogen control provided by buffers of various widths.

Author(s)	Date	Width	Comments
Doyle et al.	1977	12.5-foot (3.8 m) forested buffers 13.1-foot (4 m) grass buffers	Reduction in fecal coliform bacteria levels.
Grismer	1981	98-foot (30 m) grass filter strip	Removal of 60% of fecal coliform bacteria.
Young et al.	1980	115-foot (35 m) grass buffer	Reduced microorganisms to acceptable levels.

5.5.3.4 Maintaining Microclimate

The influence of buffers on microclimate is most often thought of in the context of shading for maintaining water temperature. This is well documented in the literature in relation to the effects on streams (Lynch et al. 1985, Johnson and Stypula 1993, Belt and O'Laughlin 1994, Castelle and Johnson 2000,). In those documents, literature focused on streams and their buffers is almost exclusively relied upon to discuss the influences of buffers on water temperature. No literature was found that specifically examined the influence of buffers on the water temperatures and microclimates within wetlands.

It may be tempting to deduce that the benefit of forested shade in moderating water temperatures is the same in wetlands as in streams. However, it is not reasonable to apply to wetlands the findings on the widths used for stream buffers for the purpose of shading. As with streams, there are many variables that can influence how shading affects the water temperature in a wetland. These variables relate to differences in water budgets (e.g., the relative influence of groundwater on a seasonal basis, whether the wetland has an inlet/outlet, etc.). In addition, the physical configurations of a large open-water wetland, a small fully vegetated wetland, and a linear stream corridor may not provide reasonable parallels. With these limitations in mind, some relevant findings are provided below.

Forests can create shade and also block the wind, which can help moderate temperatures in adjacent aquatic systems (Oke 1987). Stable water temperature helps maintain water quality because cooler water can carry higher loads of dissolved oxygen, which is important for many aquatic biota. Warmer water can also result in a looser bond between sediment particles and nutrients, which could result in an increase in nutrient loading in warmer aquatic systems (Karr and Schlosser 1977).

Microclimate influences can also extend from large wetlands into the adjacent forests. Harper and MacDonald (2001) conducted research on boreal forests near lakes and found a “distinct lake edge community” of about 131 feet (40 m) width. The lake edge community tended to have greater structural diversity, less canopy cover, fewer snags, greater amounts of coarse woody debris, and greater number of saplings and mid-canopy trees than the interior forest. Changes in the distribution of vegetation species were along a shade tolerance gradient, but the authors postulated that moisture gradient or water table depth also had an influence. Their research was conducted within forests adjacent to open water lakes, but it would be valid to extrapolate their findings to forested communities adjacent to permanent, large open wetlands that would create the same “light and shade” effect. The findings imply that large open aquatic systems influence the adjoining upland community for approximately 131 feet (40 m) distance into the interior of the forested buffer. Thus, buffers not only influence temperatures and wind effects in a wetland, but research identifies that large aquatic systems may have a reverse positive influence on the vegetation structure and species diversity of the buffer. This can thereby affect some of the habitat discussed later in this chapter.

Table 5-4. Summary of a study on the influence of microclimate provided by buffers of various widths.

Author(s)	Date	Width	Comments
Harper and MacDonald	2001	Approx. 131 feet (40 m)	Influence of large aquatic systems on adjacent upland forest composition and structural complexity

5.5.3.5 Summary of Key Points

- The use of buffers to protect and maintain water quality in wetlands (removing sediments, nutrients, and toxicants) is best accomplished by ensuring sheet flow across a well vegetated buffer with a flat slope (less than 5%).

- Significant reductions in some pollutants, especially coarse sediments and the pollutants adhered to them, can be accomplished in a relatively narrow buffer of 16 to 66 feet (5 to 20 m), but removal of fine sediments requires substantially wider buffers of 66 to 328 feet (20 to 100 m).

- Removal of dissolved nutrients requires long retention times (dense vegetation and/or very low slope) and, more importantly, contact with fine roots in the upper soil profile (i.e., soils that are permeable and not compacted). Distances for dissolved nutrient removal are quite variable, ranging in the literature from approximately 16 to 131 feet (5 to 40 m).

- The literature is consistent in finding that it takes a proportionally larger buffer to remove significantly more pollutants because coarse sediments and the pollutants associated with them drop out in the initial (outer) portions of a buffer. It takes a longer time for settling, filtering, and contact with biologically active root zones to remove fine particles and dissolved nutrients.

- The role of buffers in protecting the microclimate of streams is well documented and may be applicable to wetlands, but no specific data on buffers and wetland microclimate maintenance were found.

5.5.4 Buffers and Wildlife Habitat

Wetland buffers are essential to maintaining viable wildlife habitat because they perform three overlapping functions:

- Buffers can provide an ecologically rich and diverse transition zone between aquatic and terrestrial habitats. This includes necessary terrestrial habitats for many wildlife species that use and/or need wetlands but also need terrestrial habitats to meet critical life requirements.

- Buffers can screen wetland habitat from the disturbances of adjacent human development

- Buffers may provide connectivity between otherwise isolated habitat areas

In regard to wildlife, most of the scientific research is not directly focused on the effectiveness of buffers for maintaining individuals or populations of species that use wetlands. Some of the research simply documents use of upland habitats adjacent to wetlands by wildlife to meet their life-history needs. For example, a substantial body of research identifies the distances that amphibians may be found away from a wetland edge. However, the implications to amphibian populations of providing buffers that are smaller than those identified ranges are not well documented.

The following discussion summarizes the literature on buffers related to wildlife that use wetlands for the three essential functions listed above. Several documents are cited that represent a synthesis of scientific literature on the effectiveness of buffers for protecting wildlife-related functions of wetlands. Even though these documents include some research conducted prior to 1990, they have been included where relevant.

There is substantial literature on the implications to wildlife populations from fragmenting habitats as a result of human activities. However, this research was not necessarily conducted to address the effectiveness of various buffer widths. The literature on this topic is mentioned because of the management implications for the long-term viability of species that are closely associated with wetlands. The reader is referred to Section 4.11 in Chapter 4 and Section 5.5.4.3 for a detailed discussion of habitat fragmentation.

5.5.4.1 Maintaining Terrestrial Habitat Adjacent to Wetlands

Buffers provide a transition between aquatic and terrestrial environments and are a critical component of the habitat of wildlife that use wetlands. The specific habitat functions provided by wetland buffers include:

- Sites for wildlife for foraging, breeding, and nesting
- Cover for escape from predators or adverse weather
- Source of woody debris and organic matter that provides habitat structure and food, as well as moderation of water temperatures within adjacent wetlands to support species that are sensitive to temperature (e.g., fish, amphibians).
- Areas for dispersal and migration related to both individuals and populations; buffers may connect or be part of corridors

As defined previously, buffers are predominantly upland habitat communities that lie adjacent to aquatic habitats. They are a different habitat type than the wetland and their presence increases habitat heterogeneity by providing niches for more species. First described by Leopold (1933) as the “edge effect,” and later by Odum (1959) as an “ecotone,” this phenomenon features higher use of transition zones by wildlife, particularly between aquatic and terrestrial habitats. It has been demonstrated in studies of birds (Beecher 1942, McElveen 1977), mammals (Bider 1968), and amphibians (Bury 1988). The same pattern has been demonstrated in the Pacific Northwest in studies by Oakley et al. (1985), Knight (1988), and Cross (1988). Recent research conducted in the Puget Sound lowlands found that the greatest species richness of birds and small mammals in 50 foot wetland buffers was found when an additional 1,640 feet (500 m) of relatively undisturbed habitat was adjacent to the wetland buffer (Richter and Azous 2001b, 2001c).

Protection of upland areas adjacent to wetlands is critical to helping ensure that wildlife populations that are closely associated with wetlands have access to the habitat features necessary to meet their survival requirements. Species that are closely associated with wetlands, such as many amphibians, aquatic invertebrates, waterfowl, and some mammals, require access to wetlands for critical stages of their life-history. Many more species use wetlands, as well as other aquatic systems such as streams, lakes, or rivers, to meet various life-history needs. Research shows that species that were assumed to be dependent upon wetlands also depend upon adequate and appropriate upland habitats to maintain viable populations (Foster et al. 1984, Bury 1988, Washington Department of Wildlife in Castelle et al. 1992b, Semlitsch 1998, Semlitsch 2000).

In addition, vegetated buffers protect habitat in wetlands by maintaining the microclimate (through temperature moderation), as discussed previously, and by providing a source of organic matter to aquatic systems. This includes both large organic debris (e.g., logs, root wads, limbs), which provides habitat structure in aquatic environments, and particulate and dissolved organic matter, which provides a source of food for invertebrates (Brown 1985, Groffman et al. 1991a).

In coastal wetlands in South Carolina, Braccia and Batzer (2001) found that large woody debris within wetlands was critical for both aquatic and terrestrial invertebrate populations. They identified that the source of the large woody debris within the wetlands was from the adjacent uplands. The forest conditions in adjacent uplands, therefore, can have a significant influence on wetland biota because the aquatic invertebrates form the foundation of many food chains in aquatic settings (Castelle et al. 1994).

Buffer Width and Effectiveness in Protecting Wetland Habitat and Providing Habitat in Adjacent Uplands

This section summarizes the literature that identified ranges of widths of uplands that protect wetland habitat and/or that provide adjacent upland habitat for wildlife species that use wetlands. The literature presents findings in a variety of ways. Some studies identify the distance that target species range from a wetland source, while other researchers identified the distances that species travel between wetlands. Synthesis documents outlined recommendations for buffer widths based on a review of research findings. Some of the literature identified use of habitats by broad categories of wildlife guilds, while other studies focused on limited guilds or even individual species.

It is important to understand that the range of buffer widths identified and discussed in the literature is a reflection of many variables including the objectives of the research, the species/guilds studied and their varied life-history needs, and the methods of the research. Thus, it is not appropriate to choose a single study or buffer dimension to justify a buffer dimension, whether large or small. It is critical to incorporate the life-history requirements of the range of targeted species when considering buffer dimensions. Synthesis documents clarify that a range of upland habitat buffer dimensions may be appropriate depending upon site considerations, landscape context, and targeted species.

For example, in summarizing the literature he reviewed on buffer effectiveness, McMillan (2000) concluded, "An appropriate buffer to maintain wildlife habitat functions for all but the most highly degraded wetlands would be comprised of native tree and/or shrub vegetation and range from 30 to 100 meters [98 to 328 feet]." Other authors have reached similar conclusions, with their buffer recommendations varying depending on the type of wildlife, life-history stage, intensity of adjacent land use, and surrounding landscape (Groffman et al. 1991a, Castelle et al. 1992b, Desbonnet et al. 1994, Semlitsch 1998). Because there is often substantial information on the needs for some specific wildlife groups, the research findings that are relevant for birds, amphibians, reptiles, and mammals are provided below. Following this discussion, Table 5-5 provides a summary of literature on general habitat needs in relation to buffer sizes.

One consideration not found for this synthesis was the implication of the condition of the upland buffer relative to its provision of wildlife habitat. In several studies on the use of upland buffers by native species, the study identified that the buffer was upland forest. However, no studies were reviewed for this synthesis that compared wildlife use of mature forested buffers with buffers composed of meadow, shrubland, harvest forest, or younger forests. Some research has identified the importance of intact forest habitat to wetland-related species (Azous and Horner 2001, Richter 1997), but a comparison study was not found for this synthesis.

Generally, wildlife-species have varying needs for different types of adjacent habitat for different life needs, such as breeding, foraging, and resting (Brown 1985). This makes it difficult to prescribe one particular type of habitat as best for wildlife. Habitat is very species specific. However, as a general rule, most researchers have recommended that buffers be maintained or restored to a forested condition if only for the screening function they provide. (Obviously, this has little relevance to the shrub-steppe ecoregion in Eastern Washington, where trees are rarely found.)

Birds

The research on birds ranges from studies in individual species to summaries on bird species richness. A tremendous amount of research on waterfowl exists, with the majority being conducted in the prairie pothole region of the United States. This section focuses on studies or syntheses that are relevant to the Pacific Northwest.

The Puget Sound Stormwater Management Research Program found that a distance of 1,640 feet (500 m) from a wetland edge was necessary to account for total species richness of birds (Richter and Azous 2001b). In a study of bird use of freshwater wetlands in urban King County, Washington, Milligan (1985) determined that bird species diversity was strongly correlated with the percentage of the wetland boundary that was buffered by at least 49 feet (15 m) of trees and shrubs.

In eastern Washington, Foster et al. (1984) determined that 68% of waterfowl nests were in upland areas within 98 feet (30 m) of the wetland edge, whereas it would take a 312-foot (95 m) buffer to encompass 95% of the nesting sites.

Temple and Cary (1988) created a computer model whose results may relate to the breeding success of forest birds using wetland buffers. Estimating the effects of habitat fragmentation on birds breeding in the interior of forests in Wisconsin, their model predicted that nesting success was strongly correlated to distance to the edge of a forest. The computer model predicted a success rate of 70% for nests greater than 656 feet (200 m) from the forest edge, 58% for a distance of 328 to 656 feet (100 to 200 m), and only 18% for nests less than 328 feet (100 m) from the forest edge. Applying these findings to wetland buffers, those less than 100 feet (30 m) in width might not be expected to support bird species that nest in forest interiors. The authors concluded that, without "recruits" (birds moving into appropriate habitat niches from farther afield), the continued fragmentation of forest habitats could lead to local extinction of populations of birds that use the interior of forests.

Amphibians

The research on amphibians and buffers in relation to their habitat needs comes both from studies in the Pacific Northwest and literature summaries from around the United States. Findings are rather consistent in that amphibians range substantial distances from breeding locations in a wetland to fulfill their life-history needs. On the west side of the Cascades, there appears to be a preference for forested habitats adjacent to breeding sites. Urban land uses near breeding sites seem to have a negative influence on amphibian abundance.

Detailed findings include:

- A study in the Puget Sound lowlands documented a decline in amphibian richness in wetlands where forest in the contributing watershed was diminishing. Results were not linked to buffer dimensions (Richter and Azous 2001a).

- In a study in King County by Ostergaard (2000), the greatest use of stormwater ponds by native breeding amphibians was found when 3,280 feet (1,000 m) of forested habitat was available adjacent to the pond.

- A study of pond-breeding salamanders in the eastern U.S. found that a buffer of 534 feet (164 m) would be needed to encompass 95% of adult and juvenile salamanders. This buffer range may apply to other similarly mobile species (Semlitsch 1998). Buffers of 98 to 328 feet (30 to 100 m) were recommended along riparian zones, depending upon slope, stream width, and adjacent use (Semlitsch 1998).

- Salamanders use upland habitats over 1,969 feet (600 m) from the edge of wetlands for non-breeding life-history stages. Sustaining viable amphibian species closely associated with wetlands requires maintaining the connection between wetlands and terrestrial habitats (Semlitsch 1998).

See Table 5-5 for further information on these studies.

In addition, in the Midwestern U.S., Knutson et al. (1999) found a positive correlation between the presence of forest around the perimeter of the wetland and amphibian abundance, and a negative correlation to urban land uses on the perimeter.

Reptiles

Western pond turtles are associated with a variety of aquatic habitats, including wetlands, streams, and rivers. In a California study, western pond turtles were found to overwinter as far as 1,650 feet (500m) from water (Reese and Welsh 1997). An unpublished study done in Washington for the Washington Department of Wildlife found nest sites as far as 615 feet (187m) from water, usually in open areas with good sun exposure (Holland 1991).

Research on freshwater turtles in North Carolina found that turtles used a wide area for nesting and terrestrial hibernation in uplands surrounding the ponds where breeding occurred (Burke and Gibbons 1995). They found that a 902-foot (275 m) buffer was required to protect 100% of the nest and hibernation sites. Protecting 90% of the sites required a 240-foot (73 m) buffer. The authors concluded that most buffer requirements are inadequate to protect turtle habitat for all stages of their life-history.

Mammals

Use of wetlands by mammals depends upon adjacent uplands. The literature indicates that even a mammal that is closely associated with wetlands, such as a beaver, uses upland habitats an average of 100 feet (30 m) from the wetland edge in eastern Washington and over 300 feet (100 m) distant in western Washington (Castelle et al. 1992b). Research on small mammals found the greatest concentration of species near riparian corridors, with some species found within that riparian corridor that were not found farther away in upland habitats (Cross 1985).

Dimensions of effective buffers for mammals are more difficult to discern from the literature because they depend upon the species' life-history. Also, as discussed in Section 4.11 of Chapter 4, habitat linkages and fragmentation may be more critical for the sustainability of some populations.

As part of the Puget Sound Stormwater Management Research Program, Richter and Azous (2001c) found that the highest richness of small mammals was in wetlands with at least 60% of the first 1,640 feet (500 m) of buffer in forest cover. Other findings of this program include:

- The preservation of large woody debris within the wetland and adjacent upland forest is important for maintaining small-mammal habitat.
- Small-mammal richness was best associated with the combined factors of wetland size, adjacent forest, and the quantity of large, coarse woody debris within the wetland and its buffer.

- In southwestern Oregon, Cross (1985) conducted research on small mammals in "leave-strips" adjacent to streams within zones of forest that had been harvested. He found that the richness of small-mammal species was highest in the riparian zone closest to the stream, intermediate in the transition zone, and lowest in the upland zone. (The zones were defined by vegetation composition, not by dimension.) Because riparian habitats provide more niches for species, it is expected that such habitats would maintain greater species richness (Cross 1985).

Cross also found no species in the upland zone that were not found in the riparian zone, but he found five species present in the riparian zone that were not present in the upland or transition zones. A strip averaging 220 feet (67 m) wide supports mammal communities at similar numbers and richness to the nearby undisturbed riparian corridor. This study focused on small mammals which, relative to large mammals, have small home ranges. Therefore, the study is not broadly applicable to appropriate leave-strip dimensions for larger species.

Table 5-5 presents a summary of literature on wildlife and buffer/upland habitat use that was relevant to this synthesis. As noted previously, some of the research is specific to individual species, some is focused on a particular guild or group of similar species, some looks at life-history patterns (nesting distances), and some sources represent synthesis documents of buffer effectiveness. These distances do not necessarily reflect the literature relative to human disturbance and/or habitat fragmentation, which are discussed in the next sections.

It is difficult to synthesize the findings of the research on wildlife and the width of buffers into simple generalizations that can be readily applied. When looking at life-history needs (e.g., nesting sites, foraging ranges, etc.), the distances presented in the literature range from 98 feet (30 m) (Foster et al. 1984, Castelle et al. 1992b) to 3,280 feet (1,000 m) (Richter 1997). These distances, measured in the field, represent the distance that species ranged, nested, or foraged from a wetland edge.

Other authors have presented their own synthesis or recommendations of effective buffer ranges based on review of the literature. These range from 49 feet (15 m) (Desbonnet et al. 1994) to 328 feet (100 m) (Groffman et al. 1991a, Castelle et al. 1992b, Desbonnet et al. 1994, McMillan 2000). Note that Desbonnet et al. (1994) recommends a range of buffer dimensions based on site conditions, species of interest, and proposed adjacent land uses; hence, their studies are cited at both ends of the distance spectrum.

Table 5-5. Summary of studies on wildlife habitat provided by buffers.

Author(s)	Date	Width	Comments
Allen	1982	328 – 590 feet (100 – 180 m)	Mink use: generally concentrated within 330 feet (100 m) of water but will use upland habitats up to 590 feet (180 m) distant
Burke and Gibbons	1995	240 feet (73 m): 90% 902 feet (275 m): 100%	Buffer to encompass % nesting and hibernation of turtles in North Carolina

Author(s)	Date	Width	Comments
Castelle et al.	1992b	197 – 295 feet (60 – 90 m): Western Washington 98 – 197 feet (30 – 60 m): Eastern Washington	Range for all species they noted Range for all species they noted
Castelle et al.	1992b	263 feet (80 m) avg. - 590 feet (180 m)	Wood duck nesting locations from wetland edge (non-Washington data)
Castelle et al.	1992b	98 feet (30 m): Eastern Washington 328 feet (100 m): Western Washington	Distance of beaver use of upland habitats from water edge
Chase et al.	1995	98 feet (30 m) or more	100 feet (30 m) would be "adequate"; buffers larger than 100 feet needed to meet habitat needs, including breeding for birds and some mammals
Cross	1985	220 feet (67 m)	Forested "leave-strips" for small mammal richness adjacent to streams in SW Oregon
Desbonnet et al.	1994	49 – 98 feet (15 – 30 m): low intensity 98 – 328 feet (30 – 100 m): high intensity	Variable buffer widths using adjacent land uses as decision-making criteria
Fischer et al.	2000	98 feet (30 m) minimum	Literature review; majority of literature cited recommends buffer widths of 330 feet (100 m) for reptiles, amphibians, birds, and mammals
Foster et al.	1984	98 feet (30 m): 68% of nests) 312 feet (95 m): 95% of nests	Waterfowl breeding use of wetlands in the Columbia Basin greatest in smaller (<1 acre [0.4 ha]) wetlands; 68% of waterfowl nests within 100 feet (30 m) of wetland edge; to encompass 95% of waterfowl nests would require 310 feet (95 m) of buffer
Groffman et al.	1991a	197 - 328 feet (60 - 100 m)	For most wildlife needs
Groffman et al.	1991a	328 feet (100 m)	Neotropical migratory bird species
Howard and Allen	1989	197 feet (60 m)	For most wildlife needs
McMillan	2000	98 – 328 feet (30 – 100 m)	Based on a synthesis of literature
Milligan	1985	49 feet (15 m)	Bird species diversity strongly correlated with the percentage of the wetland boundary buffered by at least 50 feet (15 m) of tree and shrub vegetation
Norman	1996	164 feet (50 m)	To protect wetland functions; more buffer may be required for "sensitive wildlife species"

Author(s)	Date	Width	Comments
Ostergaard	2001	3,280 feet (1,000 m)	Forested habitat surrounding stormwater ponds, related to native amphibian richness
Richter	1996	3,280 feet (1,000 m)	Literature review and synthesis
Richter	1996	3,280 feet (1,000 m)	Native amphibian use
Richter and Azous	2001b	1,680 feet (512 m)	Distance from wetland edge necessary to include all bird richness in Puget Sound lowland wetlands
Richter and Azous	2001c	1,640 feet (500 m): 60%	Highest small-mammal richness when 60% of first 1,640 feet (500 m) of buffer was forest habitat
Semlitsch	1998	1,969 feet (600 m)	Salamanders
Semlitsch	1998	228 – 411 feet (69.6 - 125.3 m) 539 feet (164.3 m) for 95% of all species	Six species of adult salamanders and two species of juveniles; mean distance from wetland edge was 228 feet (juveniles) – 411 feet (adults). To incorporate 95% of all species, buffer mean would have to be 539 feet
Short and Cooper	1985	164 – 328 feet (50 – 100 m)	164 feet (50 m) for foraging
Temple and Cary	1988	> 656 feet (200 m): 70% success 328 – 656 feet (100 – 200 m): 58% success < 328 feet (100 m): 18% success	Nesting success rates for interior-dwelling forest birds related to distance into the interior of a forest from the forest edge

5.5.4.2 Screening Adjacent Disturbances

Wetland buffers screen wildlife from human activities. Disturbance from humans can come in the form of noise and light (indirect effects) or from human presence/movement (direct effects). Noise and light can disrupt feeding, breeding, and sleeping habits of wildlife. Many wildlife species in wetlands are disturbed by unscreened human activity within 200 feet (61 m) (Washington Department of Wildlife in Castelle et al. 1992b). Dense shrubs and trees in a wetland buffer can limit intrusion and screen out noise, light, and movement from adjacent human development (Castelle et al. 1992b).

In addition, domestic pets such as dogs and cats can adversely affect wetland wildlife by preying on some wildlife species and are particularly damaging to ground-nesting species (Churcher 1989). See Section 4.12.5 in Chapter 4 for further discussion.

The effect of noise on wildlife is a topic of growing concern. Little research exists on the effective buffer widths required to filter sounds for wildlife. See Section 4.12.3 in Chapter 4 for a discussion of current literature on the effects of noise on wildlife.

Groffman et al. (1991a) determined that 105 feet (32 m) of dense, forested buffer was necessary to reduce noise from commercial areas to background noise levels. Shisler et al. (1987) differentiated between the impacts of low-intensity land uses (agricultural, recreational, low-density housing) and high-intensity land uses (high-density residential, commercial/industrial). They found that low-intensity land uses could be effectively screened with vegetated buffers of 49 to 98 feet (15 to 30 m), while high-intensity land uses required buffers of 98 to 164 feet (30 to 50 m).

Direct sighting of humans approaching was found to disrupt birds (i.e., change their behavior or cause flushing) between 46 and 164 feet (14 to 50 m) (Shisler et al. 1987, Josselyn et al. 1989, Rodgers and Smith 1997). Looking specifically at great blue herons, Short and Cooper (1985) documented that they would flush from their nests if humans approached within 328 feet (100 m). Buffers between 46 and 164 feet (14 to 50 m) may be required to screen wildlife from direct observation of humans, while larger buffers (328 feet or 100 m) were documented as necessary to screen nesting herons.

Other researchers differentiated between the types of activities humans are engaged in and their effects on wildlife. Humans walking toward birds were studied to see how closely they could approach before birds flushed from perches or stopped foraging. In Florida, Rodgers and Smith (1997) found that humans could approach 46 to 112 feet (14 to 34 m) before flushing, but automobiles flushed birds at 61 to 78 feet (18.5 to 24 m). Interestingly, they found that bird-watching (as opposed to humans who were simply walking) had the greatest adverse impacts on birds. They surmised this was due to the human behavior of stopping and standing with binoculars at one point for a prolonged time.

Cooke (in Castelle et al. 1992b) analyzed 21 wetland sites in western Washington and concluded that buffers smaller than 50 feet (15 m) were generally ineffective in screening human disturbance from alterations such as noise, debris, and altered use of the buffer.

Table 5-6 summarizes the findings of the literature related to the disturbance limits or screening effects of a buffer for various wildlife species.

Table 5-6. Summary of studies on screening provided by buffers.

Author(s)	**Date**	**Width**	**Comments**
Castelle et al.	1992b	200 feet (61 m)	General wildlife considerations
Cooke	1992	50 feet (15 m)	Analyzed 21 sites in King County. Buffers less than 50 feet were often disturbed by human activities and were not effective at screening “human effects.” Found in Castelle et al. (1992b)
Groffman et al.	1991a	105 feet (32 m)	Dense forest to filter sound from commercial land uses to natural background levels
Josselyn et al.	1989	49 – 164 feet (15 – 50 m)	Unscreened human activity within 50 – 164 feet was disruptive to waterbirds in San Francisco Bay area

Author(s)	Date	Width	Comments
Rodgers and Smith	1997	46 to 112 feet (14 –34 m) 61 to 78 feet (18.5 – 24 m)	Waterbirds in Florida: flushing distance from walkers 46 – 112 feet; flushing distance from autos 61 – 78 feet. Nature observation had greatest impact if involving walking activities. Nesting birds tolerated closer human approach than birds that were perching/foraging
Shisler et al.	1987	50 - 100 feet (15 – 30 m) 100 – 164 feet (30 – 50 m)	Low-intensity land uses (agriculture, recreation, and low density residential): 50 - 100 feet High-density residential housing and commercial/industrial: 100 - 164 feet Most effective buffers had steep slopes, dense shrubs
Short and Cooper	1985	328 feet (100 m)	328 feet to buffer nesting great blue herons from human disturbance

5.5.4.3 Maintaining Habitat Connections

Converting habitats to other uses directly increases the isolation of wetlands and the fragmentation of habitats (See Section 4.11 in Chapter 4 for further discussion of the impacts of fragmentation). Buffers can play a role in reducing habitat fragmentation by serving as upland habitat directly adjacent to a wetland. They can also provide an area that can connect, or be part of a corridor that connects, wetlands with upland habitats or other water bodies (National Research Council 2001). However, buffers, as applied in a regulatory context, are rarely designed to provide these connections. Typical buffer widths generally are insufficient to link wetlands to other habitats. In addition, maintaining linkages from one habitat type to another on individual parcels is often not a consideration when properties are reviewed case by case. The authors of Volume I believe that maintaining habitat connectivity is best accomplished through landscape-scale planning and protection measures.

In general, the literature states that for terrestrial species with wide-ranging habits, it is important to maintain connections between sites used for breeding, feeding, and refuge. This is critical for maintaining population viability (Bedford and Preston 1988, Gibbs 1993, Semlitsch and Bodie 1998, National Research Council 2001). One may assume that this applies only to large terrestrial mammals. However, research has shown that many native amphibians on the west side of the Cascades can range 3,280 feet (1,000 m) from source wetlands into other wetlands or surrounding upland habitats (Richter 1997). Ostergaard (2001) found the greatest amphibian richness in sites that had upland forest habitat surrounding the site by 3,280 feet (1,000 m). Richter and Azous (2001b) found that a radius of 1,680 feet (512 m) surrounding a wetland was necessary to include all the bird richness of species utilizing the source wetland.

5.5.4.4 Summary of Key Points

- There is no simple, general answer for what constitutes an effective buffer width for wildlife considerations. The width of the buffer is dependent upon the species in question and its life-history needs, whether the goal is to maintain connectivity of habitats across a landscape, or whether one is simply trying to screen wildlife from human interactions.

- The majority of wildlife species in Washington use wetland habitats for some portion of their life-history needs. Many species that are closely associated with wetlands (those that depend upon wetlands for breeding, brood-raising, or feeding) depend upon surrounding upland habitats as well for some life-history stages.

- Many terrestrial species that are dependent upon wetlands have broad-ranging habits, some over 3,280 feet (1,000 m) from the source wetland. Although this might be expected for large mammals such as deer or black bears, it is also true for smaller species, such as salamanders and other amphibians.

- Human access and land uses adjacent to wetlands influence the use and habits of wildlife through noise and light intrusions, as well as elimination or degradation of appropriate upland habitats. Even “passive” activities, such as bird/nature-watching, have been shown to have effects on roosting and foraging birds.

- Synthesis documents that evaluated many studies discussing the protection of habitat provided by wetland buffers generally recommend buffer widths between 50 and 300 feet (15 to 100 m), depending on specific factors. These factors include the quality of the wetland habitat, the species needing protection, the quality of the buffer, and the surrounding land uses.

5.5.5 Buffer Maintenance and Effectiveness over Time

Buffers can help to protect wetlands for as long as the buffers themselves remain intact. Buffer areas can be altered over time by human disturbance and natural events, such as windstorms. In addition, some researchers have raised the issue of whether buffers have a long-term, carrying capacity with regard to filtration and binding of pollutants. In other words, is there a maximum amount that can be processed before the buffer’s ability is overwhelmed?

5.5.5.1 Human Alteration to Buffers

Human activities are the most common mechanism for altering buffers over time. Buffer functions can be reduced if vegetation is cut or trampled, soils are compacted, sediment loading surpasses the filtering capability of the vegetation, or surface-water flows create channels and subsequent erosion.

Cooke (in Castelle et al. 1992b) analyzed 21 wetland sites in western Washington and concluded that buffers less than 50 feet (15 m) wide were more susceptible to being reduced over time by human disturbance. Nearly all of the buffers they studied that were less than 50 feet (15 m) in width were significantly reduced in the few years the buffers had been present on the back of private lots. Some of the buffers were found to have been eliminated through complete clearing of native vegetation. Of the buffers wider than 50 feet (15 m), most still had some portion intact and, overall, showed fewer signs of human disturbance. Cooke also found that fencing buffers (without a gate allowing access) was effective at reducing the alteration of buffers by humans.

In a study in the Monterey Bay area of California, Dyste (1995) examined 15 wetlands with buffers. All of the buffers suffered from human alteration including cutting of vegetation, soil compaction, and dumping of garbage.

5.5.5.2 Loss of Trees to Blowdown

In the Pacific Northwest, forested buffers are often leave-strips around wetlands or along streams when the surrounding forest is cleared for land development. These forested strips are then exposed to winter windstorms, which are common, often resulting in substantial loss of large trees due to blowdown.

Pollock and Kennard (1998) concluded that trees in narrow forested buffers (less than 76 feet [23 m] wide) have a much higher probability of suffering significant mortality from windthrow and blowdown than trees in wider buffers. They conclude that buffers in the range of 76 to 115 feet (23 to 35 m), created when the surrounding forest is cut, are the minimum width that can be expected to withstand the effects of wind in the long term.

5.5.5.3 Reduced Capacity for Sediment/Nutrient Removal

Many of the studies described earlier assessed the effectiveness of buffers in removing sediments and nutrients for short durations (on the order of one to two years, if the time period was discernable in the methods sections of the literature). One study that assessed water quality improvement over longer periods found that effectiveness diminished as the outer margins of the buffers became saturated with sediment (Dillaha and Inamdar 1997). Their findings suggest that buffers have a limited carrying capacity for sediment removal (a maximum amount of sediment that can be removed) and that larger buffers and other methods may be required to ensure long-term control of sediment.

Similarly, Todd (2000) cites work by Dillaha in 1993 that found less than 10% of grass filter strips were effective after three to five years. The grass filter strips became channelized and surface flows were no longer passing through as sheet flow that would allow contact with vegetation to remove sediments and nutrients. Todd emphasizes that, for buffers to be effective, they have to be sustainable over time, and this must be a factor when determining buffer widths.

5.5.5.4 Summary of Key Points

- Human actions can reduce the effectiveness of buffers in the long term through removal of buffer vegetation, soil compaction, sediment loading, and dumping of garbage.
- Buffers may lose their effectiveness to disperse surface flows over time as flows create rills and channels, causing erosion within the buffer.
- Leaving narrow strips of trees can result in tree loss due to blowdown.
- Buffers may become saturated with sediment over time and become less effective at removing pollutants. The literature indicates that this should be considered when determining buffer widths.

5.5.6 Summary of Buffer Ranges and Characteristics from the Literature

The following discussion summarizes the many suggestions and recommendations in the literature for how buffer widths can be established. Many of these were found in synthesis documents that summarize scientific literature on buffers and then draw general conclusions. The recommendations in most of these syntheses are remarkably consistent. Taken together with the great number of site-specific studies cited in the syntheses, they present what should be considered "fundamental principles" for buffers.

At its most basic level, the science on wetland buffers identifies four criteria that should be considered in determining the width of a buffer (Castelle et al. 1992b, Desbonnet et al. 1994, Norman 1996, McMillan 2000, Todd 2000):

- The functions and values of the aquatic resource to be protected by the buffer
- The characteristics of the buffer itself and of the watershed contributing to the aquatic resource
- The intensity of the adjacent land use (or proposed land use) and the expected impacts that result from that land use
- The specific functions that the buffer is supposed to provide; for habitat functions this includes the targeted species to be managed and an understanding of its habitat requirements

The feasibility or possibility of incorporating those four considerations into determining buffer dimensions is dependent upon the jurisdiction in question. Ideally, buffer widths should be tailored to these four factors. However, the authors that recommend considering these factors also acknowledge that the scientific basis for determining the width of a buffer is often superseded by political expediency. Buffers are more often determined administratively as standard or fixed dimensions that may, or may not, be correlated with the criteria listed above.

Table 5-7 presents a summary of the buffer ranges recommended by the authors who conducted literature reviews or syntheses on buffer effectiveness. Minimums ranged from 25 feet (8 m) to 197 feet (60 m). Maximums ranged from 98 feet (30 m) for some land uses to 350 feet (107 m).

Table 5-7. Summary of recommendations for buffer dimensions from the literature.

Author(s)	Date	Minimum Buffer	Maximum Buffer	Comments
Castelle et al.	1994	50 to 100 feet (15 - 30m)		"Minimum buffers necessary to protect wetlands and streams under most circumstances"
Fischer et al.	2000	98 feet (30 m)	328 feet (100 m)	Larger buffer for reptiles, amphibians, birds and mammals
Groffman et al.	1991a	197 feet (60 m)	328 feet (100 m)	For most wildlife needs
Howard and Allen	1989	197 feet (60 m)		For most wildlife needs
McMillan	2000	25 feet (8 m)	350 feet (107 m)	Case by case, using a rating system and the intensity of proposed or existing land use for protecting most wetland functions
Norman	1996	164 feet (50 m)		To protect wetland functions; more may be required to protect more "sensitive wildlife species"

Table 5-8 is taken from one of the most comprehensive buffer syntheses published (Desbonnet et al. 1994). The authors of the synthesis looked at several hundred articles and reports on buffers. This table presents the information in a format that outlines the general effectiveness of different buffer widths at removing pollutants and providing habitat.

Table 5-8. A summary of the effectiveness of pollutant removal and the value of the wildlife habitat of vegetated buffers according to buffer width (Desbonnet et al. 1994).

Buffer Width in Feet (Meters)	Pollutant Removal Effectiveness	Wildlife Habitat Value
16 feet (5 m)	Approximately 50% or greater sediment and pollutant removal	Poor habitat value; useful for temporary activities of wildlife
32 feet (10 m)	Approximately 60% or greater sediment and pollutant removal	Minimally protects stream habitat; poor habitat value; useful for temporary activities of wildlife
49 feet (15 m)	Greater than 60% sediment and pollutant removal	Minimal general wildlife and avian habitat value
66 feet (20 m)	Greater than 70% sediment and pollutant removal	Minimal wildlife habitat value; some value as avian habitat
98 feet (30 m)	Approximately 70% or greater sediment and pollutant removal	May have use as a wildlife travel corridor as well as general avian habitat
164 feet (50 m)	Approximately 75% or greater sediment and pollutant removal	Minimal general wildlife habitat value
246 feet (75 m)	Approximately 80% or greater sediment and pollutant removal	Fair to good general wildlife and avian habitat value
328 feet (100 m)	Approximately 80% or greater sediment and pollutant removal	Good general wildlife habitat value; may protect significant wildlife habitat
656 feet (200 m)	Approximately 90% or greater sediment and pollutant removal	Excellent general wildlife value; likely to support a diverse community
1,968 feet (600 m)	Approximately 99% or greater sediment and pollutant removal	Excellent general wildlife value; supports a diverse community; protection of significant species

Castelle et al. (1994), summarizing research conducted primarily before 1990, concluded "buffers necessary to protect wetlands and streams should be a minimum of 49 to 98 feet (15 to 30 m) in width under most circumstances." They note that the lower end of the spectrum is the minimum necessary to maintain physical and chemical processes, while the upper end of the spectrum may be the minimum necessary to maintain biological processes. The Castelle et al. report of 1994 does not identify appropriate maximums. McMillan (2000) recommends an approach to determining buffers that attempts to balance predictability with flexibility by setting standard buffer widths that can be altered on a case-by-case basis to adapt to site-specific factors. This approach for determining buffer width incorporates a rating system for wetlands, plus an assessment of the intensity of proposed or existing adjacent land use, to establish buffer widths ranging from 25 to 350 feet (8 to 107 m). It is perhaps the method that is closest to fitting the four bulleted criteria outlined at the beginning of this section. It incorporates an understanding of the condition of the wetland, the buffer, and the proposed adjacent land use.

Several other authors also suggest that considering site-specific factors enhances the effectiveness of buffer strips over using fixed-width buffers (Steinblums et al. 1984, Norman 1996, Todd 2000). Belt and O'Laughlin (1994) note that, "The fixed minimum-width approach enjoys the virtue of simplicity in application, but has the potential for providing either not enough or too much protection."

Liquori (2000) also cautions against using fixed buffer widths to protect long-term ecological functioning of buffers and their associated aquatic resources. He notes that many of the functions that buffers provide are directly related to physical characteristics and biological processes within the buffers. Informed with site-specific information, a case-by-case argument could be made for establishing buffer widths. "The nature of the [functions a buffer provides] may significantly depend upon riparian structure both locally and as a mosaic over the watershed scale."

In urban settings, larger buffer widths are often prescribed in anticipation of future impacts from adjacent land use and activity upstream in the watershed. The most important criterion for determining buffer width is identification of the various functions the buffer is expected to provide (Todd 2000).

In agricultural lands, Welsch (1991) identifies a three-zone approach for establishing buffers:

- **Zone 1** consists of riparian-type trees and shrubs immediately adjacent to the stream, water body, or wetland. It should be a minimum 13 feet (4 m) wide, or adjusted to include the entire riparian area (the area with year-long or seasonal soil-moisture regime influenced by the stream or water body). Minimum length should be the length of the proposed disturbance outside the riparian management zones, or "the longest distance possible."

- **Zone 2** extends upslope from Zone 1 and consists of vegetation that may be periodically harvested as it matures. A minimum distance of 20 feet (6 m) should be allowed for this zone for small streams or water bodies; for larger streams or water bodies the total of Zones 1 and 2 can be increased up to 98 feet (30 m) or 30% of the geomorphic floodplain (whichever is less). Minimum length should match that of Zone 1. Zone 2 can be an active harvest zone, but trees and vegetation need to be left to provide soil holding and filtering capacity.

- **Zone 3** is added upslope of Zone 2 if adjacent land (away from the aquatic resource) is cultivated cropland or another land use with the potential for erosion or sediment production. Zone 3 is a vegetated filter strip and should be wide enough to control "concentrated flow erosion from cultivated cropland." Zone 3 vegetation should be established prior to the establishment of Zones 1 and 2.

This zonal approach is recommended for active agricultural activities, which implies the regular creation of conditions with high erosion potential (grazing or tilling). It also allows more active use of the central portion of the buffer and active management of the outer area of the buffer.

Townsend and Robinson (2001) build on this zonal approach and recommend guidance on maintenance of canopy coverage and closure. They suggest using species that readily resprout from stumps or roots in the areas nearest the stream channels (to allow the vegetation to respond to flood damage and/or beaver activity). They stress the need for ongoing maintenance, especially in Zone 3, to ensure that erosive flows are not causing rills or channelized flows into Zone 2. They also note that, while most of these buffers will be applied on an ownership basis, greater benefit would be realized if the concept of zoned buffers were applied on a watershed basis.

Other recommendations are based on wildlife species of particular interest. Based on their study of waterbirds in Florida, Rodgers and Smith (1997) recommend a buffer width of 328 feet (100 m) to ensure that birds will not be triggered into an “approach” response, a state which occurs prior to actual flushing. They derived this figure by analyzing the flushing distance from human approach for 16 species, then adding 131 feet (40 m) to that distance. The 131-foot (40 m) distance was derived from previous work which found that birds became alert (stopped their ongoing behavior and focused on the approaching human) in a range of 82 to 131 feet (25 to 40 m).

5.5.6.1 Summary of Key Points

- Many researchers have recommended using four basic criteria to determine the width of a buffer:
  - the functions and values of the aquatic resource to be protected by the buffer
  - the characteristics of the buffer itself and of the watershed contributing to the aquatic resource
  - the intensity of the adjacent land use (or proposed land use) and the expected impacts that result from that land use
  - the specific functions that the buffer is supposed to provide including the targeted species to be managed and an understanding of their habitat needs
- Protecting wildlife habitat functions of wetlands generally requires larger buffers than protecting water quality functions of wetlands
- Effective buffer widths should be based on the above factors. They generally should range from:

  25 to 75 feet (8 to 23 m) for wetlands with minimal habitat functions and low-intensity land uses adjacent to the wetland

  75 to 150 feet (15 to 46 m) for wetlands with moderate habitat functions and moderate or high-intensity land uses adjacent to the wetland

  150 to 300+ feet (46 to 92+ m) for wetlands with high habitat functions, regardless of the intensity of the land uses adjacent to the wetland
- Fixed-width buffers may not adequately address the issues of habitat fragmentation and population dynamics. Several researchers have recommended

a more flexible approach that allows buffer widths to be varied depending on site-specific conditions.

5.6 Chapter Summary and Conclusions

Wetlands are defined using well established language that is generally consistent between federal and state laws. However, certain wetland types are sometimes excluded from regulation. These include small wetlands, isolated wetlands, and wetlands that are designated as Prior Converted Croplands (PCC). The scientific literature makes clear that small wetlands and isolated wetlands provide important functions and does not provide any rationale for excluding these wetlands from regulation. Little scientific information is available on PCC, but there is no evidence to suggest that they are unimportant in providing wetland functions. They retain many of the characteristics necessary to provide multiple wetland functions.

Wetland delineation is conducted according to either the federal or state delineation manual. These manuals are consistent and, when applied correctly, will result in the same wetland boundary. Wetland rating systems are a useful tool for grouping wetlands based on their needs for protection. The most widely used method in Washington is the state's rating system which places wetlands in categories based on their rarity, sensitivity, irreplaceability, and functions.

Wetland buffers are a critical tool for protecting wetland functions. Findings regarding buffer functions and effectiveness are consistent in recommending that the width of a buffer should be related to the wetland functions that need protection, the land-use activities from which the wetland is being buffered, and the characteristics of the buffer itself. These factors, derived from the many studies of wetland buffers and other aquatic resources, can be thought of as the "fundamental principles" that are recommended to determine the widths and characteristics of buffers.

The literature confirms that for water quality improvement (e.g., sediment removal and nutrient uptake) there is a non-linear relationship between buffer width and increased effectiveness. Sediment removal and nutrient uptake are provided at the greatest rates within the immediate outer portions of a buffer (nearest the source of sediment/nutrient), with increasingly larger widths of buffers required to obtain measurable increases in those functions. Additionally, the long-term effectiveness of buffers in providing such mechanical and biological processes is not well documented in the literature. However, the literature suggests that buffers may have a carrying capacity or limit to their ability to remove pollutants. Future research on this topic is needed.

Compared to the widths needed for sediment removal and nutrient uptake, the literature has documented the need for significantly wider buffers to protect or maintain habitat functions for wildlife species that are closely associated with wetlands, as well as for populations that use wetlands. Research confirms that many wildlife species and guilds are dependent upon wetlands for only portions of their life cycles, and that they require upland habitats adjacent to the wetland to meet all their life needs. Without adequate upland habitat adjacent to wetlands, these habitat functions are lost. Some species use upland habitats that are far from the source wetland. The literature documents that, without access to appropriate upland habitat and the opportunity to move between wetlands and other habitats across a landscape, it is not possible to maintain viable populations of many species. Beyond simply providing adequate upland habitat adjacent to a single wetland, the literature on the maintenance of wildlife populations finds that it is necessary to link habitat types, including wetlands and uplands, across a landscape in order to maintain genetically viable populations.

Several authors who suggested recommendations for buffer widths based on their own synthesis of the literature have recommended variable widths based on the conditions of the wetland, the conditions of the buffer, the proposed land uses adjacent to the buffer, and what functions are intended to be managed. For protection and maintenance of wildlife habitat functions of wetlands, these studies suggest that effective buffer widths should be based on the above factors and generally should range from: 25 to 75 feet (8 to 23 m) for wetlands with minimal habitat functions and low-intensity land uses adjacent to wetlands; 50 to 150 feet (15 to 46 m) for wetlands with moderate habitat functions and moderate or high-intensity land use that is adjacent; and 150 to 300+ feet (46 to 92+ m) for wetlands with high habitat functions depending on the intensity of the adjacent land use. However, several authors noted that protection and maintenance of viable wildlife populations for many species requires habitat connections via corridors and large habitat patches.

Chapter 6 continues the discussion of regulatory tools used to manage wetlands by discussing wetland compensatory mitigation and its effectiveness.

Chapter 6

The Science and Effectiveness of Wetland Mitigation

6.1 Reader's Guide to this Chapter

This chapter synthesizes the scientific literature regarding compensatory mitigation and its effectiveness at reducing the severity of activities that detrimentally affect wetlands. It also reports the suggestions made by various authors regarding ways to improve compensatory mitigation.

6.1.1 Chapter Contents

Major sections of this chapter and the topics they cover include:

Section 6.2, Introduction and Background to Wetland Mitigation describes wetland mitigation sequencing, which encompasses a series of actions that requires addressing each action, or step, in a particular order. Compensation for wetland impacts is just one of these steps.

Section 6.3, Success of Compensatory Mitigation Wetlands synthesizes the literature on the biological, ecological, or functional success of compensatory mitigation projects. This section does not specifically evaluate the successful compensation for wetland area; that is discussed in Section 6.7.

Section 6.4, Compliance with Permit Requirements describes studies that evaluated several aspects of how well compensatory mitigation projects met legal or permit requirements. These included whether projects were completed or installed according to plan, whether they attained the required wetland acreage, whether performance standards were achieved, whether the project was monitored or maintained, and whether the regulatory agencies followed-up on the project.

Section 6.5, Types of Compensatory Mitigation discusses the use and effectiveness of restoration, creation, enhancement/exchange, preservation, mixed compensatory mitigation, mitigation banking, and in-lieu fees.

Section 6.6, Replacement Ratios describes the rationale for the use of ratios in determining the acreage required as compensation for a given area of wetland impact. It synthesizes the literature on the ratios that were required and those actually achieved for numerous projects. This section also discusses approaches proposed in the literature to more effectively determine compensatory mitigation ratios.

Section 6.7, Replacement of Wetland Acreage summarizes the results of studies examining whether compensatory wetland mitigation is actually replacing the acreage of wetland losses authorized. This includes both evaluations of overall permitting programs and of specific compensation projects in compensating for wetland acreage.

Section 6.8, Functions and Characteristics Provided by Created, Restored, or Enhanced Wetlands describes the ability of mitigation wetlands to provide wildlife habitat, plant communities, adequate soil conditions, and water quality/quantity functions. Compensation wetlands were often compared with pre-existing or reference wetlands in these studies.

Section 6.9, Reproducibility of Particular Wetland Types summarizes the literature regarding whether and how easily certain wetland types, such as bogs, fens, vernal pools, alkali wetlands, and mature forested wetlands, can be reproduced or restored.

Section 6.10, Suggestions from the Literature for Improving Compensatory Mitigation summarizes numerous recommendations made by researchers to improve the success of compensation projects—ranging from improvements to regulations and site selection, to better performance standards, to a broader landscape approach, to mitigation banking.

Section 6.11, Chapter Summary and Conclusions ties together the major concepts presented in the chapter.

6.1.2 Where to Find Summary Information and Conclusions

Each major section of this chapter concludes with a brief summary of the key points resulting from the literature review on that topic in a bullet list format. The reader is encouraged to remember that a review of the entire section preceding the summary is necessary for an in-depth understanding of the topic.

For summaries of the information presented in this chapter, see the following sections:

- Section 6.3.2
- Section 6.4.9
- Section 6.5.8
- Section 6.6.4
- Section 6.7.3
- Section 6.8.6
- Section 6.9.5
- Section 6.10.7

In addition, Section 6.11 provides a summary of the chapter and conclusions about the overarching themes gleaned from the literature and presented in this chapter.

6.1.3 Sources and Gaps in Information

The synthesis in this chapter is based on more than 50 articles, government reports, and conference proceedings that have been published since about 1990 on the topic of compensatory mitigation. (The literature did not address the other types of mitigation listed in Section 6.2.1.)

The information resulted from studies conducted in various states and countries, including several studies from the Pacific Northwest. Environmental conditions may vary in other states and countries. However, the information resulting from these studies is relevant to compensatory wetland mitigation in Washington State for the following reasons:

- The general principals and techniques used to restore, create, and enhance wetlands are similar
- The regulatory approaches and requirements are similar
- Most importantly, the studies provide similar and consistent results

Geographic location of the studies cited in this chapter

The articles and reports that evaluated the effectiveness of individual compensatory mitigation projects focused on a variety of locations, including Washington, Oregon, California, Louisiana, Michigan, Indiana, Ohio, New Jersey, Massachusetts, Maryland, Tennessee, and Florida.

Studies that assessed specific functions performed by wetlands that were sites for compensatory mitigation and non-regulatory restoration were located in: Washington, Oregon, Wyoming, Iowa, Minnesota, Wisconsin, Illinois, Ohio, New York, Pennsylvania, Connecticut, West Virginia, South Carolina, Florida, Canada, Sweden, Spain, Austria, and central Europe.

The information synthesized in this chapter covers a range of topics and issues relating to compensatory wetland mitigation (refer to Chapter Contents, Section 6.1.1). Yet there are some topics and issues for which no scientific information was found. For example, studies were found that examined whether compensation projects had performance standards and whether the performance standards were met. However, no studies were found that explored why performance standards were not met. Other examples of data gaps include studies that:

- Determined the effectiveness of local critical area ordinances at replacing permitted wetland losses
- Examined the effect of construction inspections, monitoring, maintenance, or performance bonding on the success or level of compliance of projects
- Compared the level of success of newly installed versus more established compensation sites

- Looked specifically at the quality and effectiveness of preservation sites
- Focused specifically on wildlife habitat provided by restored, created, or enhanced wetlands in urban settings
- Examined the effects of mitigation decisions on a watershed scale
- Looked at the reproducibility of alkali wetlands

The articles and reports reviewed used a variety of terms to define what they were assessing or evaluating. For the purposes of this synthesis, *effectiveness* is used as a general term referring to how compensatory wetland mitigation was doing overall, including evaluations of success, compliance, and functions and characteristics. These terms will be defined more precisely in subsequent sections.

6.2 Introduction and Background to Wetland Mitigation

6.2.1 Wetland Mitigation Sequence

Mitigation is a series of actions that requires addressing each action, or step, in a particular order. This sequence of steps is used to reduce the severity of negative impacts from activities that potentially affect wetlands. When a change in land use has the potential to adversely affect a wetland, regulatory agencies require the applicant to illustrate how the project has considered the six sequential steps of mitigation. According to the rules implementing the Washington State Environmental Policy Act (Chapter 197.11 WAC), mitigation involves the following:

1. *Avoiding the impact altogether by not taking a certain action or parts of an action;*
2. *Minimizing impacts by limiting the degree or magnitude of the action and its implementation, by using appropriate technology, or by taking affirmative steps to avoid or reduce impacts;*
3. *Rectifying the impact by repairing, rehabilitating, or restoring the affected environment;*
4. *Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action;*
5. *Compensating for the impact by replacing, enhancing, or providing substitute resources or environments; and/or*
6. *Monitoring the impact and taking appropriate corrective measures* (WAC 197.11.768).

The authors of Volume 1 provide a brief explanation and examples of the steps in the mitigation sequence in the following paragraphs.

Avoidance is the first step in the mitigation sequence. Avoidance of impacts means that there is no direct loss of wetland area and functions. Avoidance does not, however, eliminate indirect losses of wetland function. For example, consider a hypothetical proposal to develop a 5-acre parcel of land. The parcel contains 2 acres of wetland. The development is designed around the wetland and will therefore avoid any direct loss. Avoidance has occurred. Yet if buildings and parking lots surround the wetland, indirect impacts to wildlife habitat and hydrology may occur in the form of fragmentation and altered hydroperiod.

Minimization of adverse impacts is the second step. It can reduce the extent of wetland impacts when a project is redesigned to lessen wetland alteration. However, it does not eliminate the direct or indirect loss of area and/or functions.

Rectification, the third step, assumes that losses in wetland area and/or function at the impact site are temporary and can be restored. For example, projects such as installing or maintaining an underground pipeline that passes through a wetland typically use rectification as a mitigation measure. In the example of the underground pipeline, vegetation, soil, and water movement may be disturbed and altered. The wetland area and/or functions are temporarily changed or lost. Rectification would entail replacing the soil, restoring the water movement, and restoring the vegetation.

The fourth step of the mitigation sequence is not generally relevant to wetlands, and therefore, no examples of its application are provided.

Compensation for unavoidable adverse impacts, the fifth step, involves restoring, creating, enhancing, or preserving wetland area to replace or make-up for the wetland area and functions that were lost or altered. It is discussed in much greater detail in the following sections.

Monitoring, step 6, is used to address the potential impact to wetlands that may result from a project when specific impacts are not known. If impacts are observed during or after project completion, actions should be taken to address the loss of wetland functions. For example, if a bridge is built over a river fringed by wetlands, the bridge may shade portions of the wetlands. Though no wetlands would be filled during construction, the shading could alter the performance of functions, thereby resulting in impacts to wetlands. To address the potential risk of impacts to wetlands, the project could be monitored to determine the effect of shading on the riverine wetlands. If monitoring reveals that the functions of the riverine wetlands were adversely altered, then compensation might be required.

The scientific literature reviewed for this synthesis did not contain information on the use or effectiveness of any of the mitigation measures defined above, except compensatory mitigation, which is the focus of the remainder of this chapter.

6.2.2 The Emergence of Compensatory Wetland Mitigation

The term *compensatory mitigation* refers to the compensation stage of the mitigation sequence (number 5 in the list of steps described earlier). Compensatory wetland mitigation generally entails performing one or more of the following types of compensation:

- Restoring wetland conditions (and functions) to an area
- Creating new wetland area and functions
- Enhancing functions at an existing wetland
- Preserving an existing high-quality wetland to protect it from future development

> The term **compensatory mitigation** refers to the compensation stage of the mitigation sequence (number 5 in the list of steps on the previous page). Because the regulatory requirements and policies tend to focus on the compensation stage, the term “mitigation” is often used to refer to compensation, which is just one part of the overall mitigation sequence.

The use of compensatory mitigation for wetland loss emerged in the 1980s (Roberts 1993, National Research Council 2001). The U.S. Army Corps of Engineers considered the process of mitigation as part of the National Environmental Policy Act of 1969. However, it wasn’t until 1980 when the U.S. Environmental Protection Agency (EPA) issued new guidelines for Section 404(b)(1) of the Clean Water Act that mitigating for wetland losses by creating or restoring another wetland as compensation became widely acceptable (National Research Council 2001). Compensatory mitigation was seen as a way to speed up an arduous process of documenting avoidance and minimization efforts, while satisfying concerns about the loss of ecosystems and functions (Roberts 1993). Creating or restoring wetland area to compensate for permitted wetland losses was viewed and publicized as a way to allow development while preventing a net loss of wetland areas.

By the late 1980s, studies of the effectiveness of compensatory mitigation were emerging, with mixed results. The primary indication was that replacing or replicating an existing wetland was difficult, if not impossible (Kusler and Kentula 1990, National Research Council 2001). However, some wetland types and functions could be approximated given the proper conditions (Kusler and Kentula 1990, National Research Council 2001). This chapter focuses on studies published since 1990 that examined the effectiveness of compensatory mitigation.

6.3 Success of Compensatory Mitigation Wetlands

Compensatory mitigation “success” is poorly defined and often contentious (Kentula 2000). The literature refers to legal success, biological success, ecosystem success (Wilson and Mitsch 1996), functional success (Mockler et al. 1998), or some combination of these.

Compliance generally means the same as “legal success.” It is evaluated by comparing the actual on-the-ground, or as-built, conditions against what was required in the permit. Studies describing legal success are referred to as compliance in this document, and they are discussed in Section 6.4.

This section will focus on “biological, ecological, or functional success.” Therefore, when the term *success* is used in this chapter, it refers exclusively to biological, ecological, or functional success. Success involves an evaluation of the factors that characterize a wetland (e.g., hydroperiod, vegetation, soils), the performance of functions, or both. Best professional judgment and/or one of a variety of function assessment methods have been used by researchers to evaluate success.

The authors of Volume 1 have observed two main problems with evaluating the success of compensatory mitigation projects. First, success is often confused with compliance, and it is assumed that they must go hand in hand. In some cases, compliance and success may be separate considerations. For example, a compensation site may be in compliance with its permit requirements and not be considered a success because it does not replace the functions of the wetland that was lost. On the other hand, a site may fall short of meeting its permit requirements, perhaps because performance standards were unrealistic. The site is therefore not in compliance, yet it may still be determined a success because it compensates for the wetland functions lost.

The second problem involves time; when should a project be evaluated for success? For example, two years after installation a compensation site may not be meeting its performance standards, perhaps because the site has too much bare ground, percent aerial cover of native vegetation is too low, or cover by invasive plant species is too high. The site is, therefore, neither in compliance nor a success. However, looking at the same site five or six years after installation, the site may have experienced rapid growth of native shrubs and trees, native volunteer species may have colonized the bare ground, and maintenance activities may have controlled invasive plants. At this time, the site could be evaluated as a success and considered to be in compliance.

Rather than judging the success or failure of a compensatory wetland mitigation project at a single point in time, Zedler and Callaway (2000) proposed evaluating how a project progresses over time. The authors suggest that a focus on progress would encourage proponents to acknowledge problems occurring at a site and look for solutions. Zedler (2000) proposes that more compensation projects should be viewed as experiments without a specific desired outcome. In lieu of attaining a specific level of performance, projects would be monitored as experiments for at least 25 years. The regulatory framework currently in place, however, does not support this method of evaluation due to the relatively short timeframe allowed for monitoring and assessing the compliance of compensation projects (Breaux and Serefiddin 1999, Zedler 2000).

Refer to Section 6.10.4 for more information on performance standards. Specifically, Section 6.10.4.1 discusses shortcomings of existing performance standards, and Section 6.10.4.3 discusses the need for longer monitoring periods.

6.3.1 Results of Literature Studies

Several studies determined the level of success of compensatory mitigation projects (Table 6-1). Though the data indicated that some projects were successful and some projects were unsuccessful, most compensation projects had an intermediate level of success, meaning they were neither fully successful nor completely unsuccessful.

- 25 to 66% of projects were determined to have an intermediate level of success
- 3 to 43% of projects achieved full success
- 7 to 97% of projects were unsuccessful, though half of the studies found that at least 20% of projects were unsuccessful (Johnson et al. 2002, Michigan Department of Environmental Quality 2000, Mockler et al. 1998, Sudol and Ambrose 2002)

The methods used to evaluate the success of compensatory wetland mitigation projects varied from best professional judgment (Storm and Stellini 1994) to function assessments (Wilson and Mitsch 1996, Balzano et al. 2002), to quantitative measures of vegetation cover and survival (Allen and Feddema 1996), or some combination (Michigan Department of Environmental Quality 2000, Johnson et al. 2002). Though the methods of evaluation differed, most studies considered similar variables such as wetland area, hydrologic conditions, wildlife suitability, vegetation, and soils.

Table 6-1. Results of studies examining the success of compensatory mitigation.

Location of Study	No. of Projects Evaluated	Level of Success	Evaluation Criteria
Washington State (Johnson et al. 2002)	24	13% fully successful 33% moderately successful 33% minimally successful 21% not successful	Wetland acreage, performance standards, goals/objectives, contribution to functions, comparison with wetland lost
Washington/ King County (Mockler et al. 1998)	38	3% successful 97% not successful	Replacing the functions of the wetland lost. Examined vegetation survival and areal coverage, hydrology, soil, wetland and buffer condition assessment, wildlife habitat, and invasive species
Western Washington (Storm and Stellini 1994)	17	23% functioned well ecologically 65% functioned poorly 12% were not completed	Vegetation diversity, non-native plant dominance, structural diversity, wildlife use, adjacent land uses, vegetation cover vs. open water

Location of Study	No. of Projects Evaluated	Level of Success	Evaluation Criteria
Southern California (Allen and Feddema 1996)	75	32 successful 9 mostly successful 10 half successful 5 unsuccessful 8 under construction 5 not initiated 6 did not require mitigation	Project installed according to plan; percent cover of vegetation (dead, living, and invasive)
California/ Orange County (Sudol and Ambrose 2002)	55	16% successful 58% partially successful 26% failures	Qualitative evaluation based on habitat quality (e.g., vegetation density and diversity, invasive species, tree height)
Ohio (Wilson and Mitsch 1996)	5	1 high 2 medium to high 1 medium 1 medium to low	WETII evaluation (Adamus et al. 1989) - hydrology, soils, vegetation, wildlife, water quality
New Jersey (Balzano et al. 2002)	74	Wetland Mitigation Quality Assessment scores were indexed from 0 (low) to 1 (high). The average score was 0.51, and the range was 0.25 to 0.83	Hydrology, soils, vegetation, wildlife suitability, site characteristics, and landscape features
Michigan (Michigan Department of Environmental Quality 2000)	69	22% successful overall 78% unsuccessful overall	Project's legal rating (permit compliance) and biological rating (wetland acreage). Does not include enhancement

6.3.2 Summary of Key Points

- Success is defined as meeting biological or ecological criteria, which may include an assessment of functions.
- The majority of compensatory wetland mitigation projects were found to be neither fully successful nor completely unsuccessful, meaning that most projects had an intermediate level of success, relative to biological or ecological functions.
- Though the methods used to evaluate project success differed, the studies considered similar criteria, such as vegetation, soils, and hydrologic conditions.

6.4 Compliance with Permit Requirements

Regulatory agencies typically require wetland compensation for authorized, unavoidable wetland impacts. A wetland mitigation plan is reviewed and approved as part of the permit approval process. It outlines how wetland impacts will be compensated for. The mitigation plan identifies how the project will be designed. It addresses wetland acreage, hydroperiod, vegetation, goals, objectives, performance standards, monitoring, maintenance, contingency actions, and long-term protection. These are the parameters by which regulators often measure compliance.

According to the Merriam-Webster dictionary, compliance means "conformity in fulfilling official requirements." Regarding compensatory wetland mitigation, compliance means that a project has satisfied or is satisfying the legal requirements and obligations identified in a permit.

Most studies that examined compliance investigated how well a compensatory wetland mitigation project complied overall (i.e., with all applicable permit requirements). Several of these studies only reported the results of the overall evaluations. Other studies evaluated how well projects complied with individual requirements, such as:

- Installation – whether the project was installed
- Installation according to plan – whether the project was constructed according to the approved mitigation plan and design
- Wetland area establishment – whether the project obtained the acreage of wetland that was required
- Performance standards/goals/objectives attainment – whether the project performed as anticipated
- Monitoring – whether the project was monitored as required (or was required to be monitored)
- Maintenance – whether project maintenance was performed (or required)

Studies also reviewed regulatory follow-up - whether any regulatory agencies made an attempt to track an individual project after the permit was issued.

Each of these types of evaluations is discussed in subsequent sections.

6.4.1 Compliance Overall

Several studies attempted to determine how well a project complied with several or all of its permit requirements. Because permit requirements vary by state and over time, not all compliance evaluations considered the same criteria or requirements. Where specified, the requirements evaluated by a given study are identified in Table 6-2.

Twelve studies evaluated overall compliance with regulatory requirements for compensatory wetland mitigation projects (Table 6-2). In Washington State four studies that evaluated compliance were conducted in the past decade (Storm and Stellini 1994, Mockler et al. 1998, Johnson et al. 2000, Johnson et al. 2002), and two studies were conducted in Oregon (Gwin and Kentula 1990, Shaich and Franklin 1995).

The studies in Washington found that 29% of compensation projects complied with their regulatory requirements. In Oregon, studies revealed that compliance of projects ranged from zero to 36%.

Studies from other states demonstrated more variability in levels of compliance. Results ranged from less than 20% to about 80% of projects in compliance (Holland and Bossert 1994, De Weese 1998, Morgan and Roberts 1999, Michigan Department of Environmental Quality 2000, Brown and Veneman 2001, Balzano et al. 2002, Sudol and Ambrose 2002).

More recent studies (published in 2000 or after) did not report higher levels of compliance than studies conducted in the 1990s. One might therefore assume that compensation projects have not improved over the years. However, it is important to realize that as knowledge of wetland science and compensatory mitigation has improved and evolved, permit requirements have likewise evolved (Kentula 2000). More recent studies may have been evaluating compensation projects that were being held to a higher standard than projects permitted and evaluated in the 1990s (Sudol and Ambrose 2002). However, a study by Cole and Shafer (2002) in Pennsylvania observed that permit requirements had not changed noticeably over the 14-year range of permits they evaluated (1986-1999).

Table 6-2. Level of overall compliance of compensation projects.

Location of Study	No. of Projects Evaluated	% of Projects in Compliance with all Requirements	Evaluation Criteria
Washington (Johnson et al. 2000)	45	29%	• Project installed • Installed according to plan • Meet performance standards
Washington (Johnson et al. 2002)	24	29%	• Establish required wetland acreage • Meet performance standards • Meet goals/objectives
Washington/western (Storm and Stellini 1994) [a]	17	18%	• Installation of both development and compensatory mitigation projects as required

Location of Study	No. of Projects Evaluated	% of Projects in Compliance with all Requirements	Evaluation Criteria
Washington/King County (Mockler et al. 1998)[b]	29 (38)	21% (16%)	• Meet performance standards - vegetation survival, areal cover, invasive species • Design - hydrology, slopes • Installation - soil • Maintenance - mowing, weeding
Oregon/Portland metro area (Shaich and Franklin 1995) [c]	72	36%	• Project installed • Upland buffer area/vegetation requirements • Requirements for timing of project construction • Wetland vegetation requirements • Hydrology requirements • Requirements for water control structures • Fencing requirements
Oregon/Portland metro area (Gwin and Kentula 1990)	11	0%	• Construction plans match permit specs • As-built matches permit specs: wetland area/shape • Actual slopes match planned slopes • Vegetation established as planned
California/ Orange County (Sudol and Ambrose 2002) [d]	57	53%	• Project installed • Meet performance standards/ permit conditions
California/ vernal pools (De Weese 1998)	25	83%	• Attaining performance standards required by Corps
Massachusetts (Brown and Veneman 2001) [e]	109 (7)	43% (100%)	• Project installed • Compensation project of required size • Water inputs sufficient for wetland conditions • At least 75% cover wetland plants (FAC or wetter)
Tennessee (Morgan and Roberts 1999)	50	12%	• Establish required acreage of wetland • Meet performance standards

Location of Study	No. of Projects Evaluated	% of Projects in Compliance with all Requirements	Evaluation Criteria
Michigan (Michigan Department of Environmental Quality 2000) [f]	74	18%	• Mitigation acreage requirement • Implementation of approved mitigation plan • Conservation easement • Submittal of as-built plans • Monitoring • Placement of elevated wildlife structures • Construction schedule with specified completion date • Prohibited actions • Corrective measures identified • Financial assurances
Louisiana (Holland and Bossert 1994)	9	78%	• Meet Corps of Engineers permit conditions
New Jersey (Balzano et al. 2002)[g]	88	48% weighted average	• Grading (56% concurrence) • Hydrology (47% concurrence) • Soil (51% concurrence) • Vegetation cover (39% concurrence) • Vegetation survival (28% concurrence) • Design (56% concurrence)

[a] Compliance not determined for 53% of projects due to lack of information.

[b] 38 projects examined; 9 not completed. Compliance information for 38 projects is in parentheses.

[c] Not all projects had requirements for all criteria (e.g., only 8% had a requirement for fencing).

[d] Calculated from data provided.

[e] 5 projects did not result in wetland impact and were subtracted from the project total. Results were recalculated from the data provided. Parentheses = data for variance projects (received more oversight).

[f] Permit conditions from the criteria list were considered if specified in permit.

[g] Evaluated concurrence with applicable criteria. Percent = average concurrence score for 88 projects. Average concurrence score for each criterion provided in parentheses.

6.4.2 Project Installation

A number of studies investigated whether mitigation projects had even been constructed or installed. In these studies, mitigation projects were either randomly selected from a database or a complete inventory of all projects permitted during a specific timeframe was conducted. Four studies were conducted in Washington. Studies in seven other states, including Oregon, also investigated whether mitigation projects had been installed.

Results indicated that most projects were installed (Table 6-3). The four studies from Washington found that 74 to 93% of compensatory mitigation projects had been installed. Studies from most of the other states showed similar results (64 to 99%). However, studies performed in Florida and Tennessee revealed that less than half of the compensatory wetland mitigation projects had been installed (Erwin 1991, Morgan and Roberts 1999).

Due to the relatively high percentage of projects that were installed, one could assume that the low levels of overall compliance result from inadequate design, installation, maintenance, follow-up, or some combination.

Table 6-3. Percent of compensatory mitigation projects that were installed.

Location of Study	No. of Projects Evaluated	Percent of Projects Installed
Washington (Johnson et al. 2000)	45	93%
Washington/ King County (Mockler et al. 1998)	38	76%
Washington/ western (Storm and Stellini 1994)	17	88%[a]
Washington (Kunz et al. 1988)	35	74%
Oregon/ Portland metro area (Shaich and Franklin 1995)	90	99%
California/ southern (Allen and Feddema 1996)	75	93%
California/ Orange County (Sudol and Ambrose 2002)	57	96%[a]
Michigan (Michigan Department of Environmental Quality 2000)	159	85%
Indiana (Robb 2002)	333	64%
Massachusetts (Brown and Veneman 2001)[b]	109	77%
Tennessee (Morgan and Roberts 1999)	100	47%
Florida (Erwin 1991)	NA	~40% [c]

[a] Calculated from data provided.

[b] Five projects did not result in wetland impact and were subtracted from the project total. Results were recalculated from the data provided.

[c] "Out of more than 100 permitted projects requiring wetland mitigation only 40 had undertaken any mitigation activity."

6.4.3 Installation According to Plan

Another aspect of determining mitigation compliance is evaluating whether a mitigation project has been installed according to its approved plan. When compensatory wetland mitigation is necessary to offset proposed wetland losses, regulatory staff generally require a wetland mitigation plan. The mitigation plan should provide specific information about project construction, including detailed design drawings. Approval of a permit for wetland loss is often contingent upon approval or acceptance of the wetland mitigation plan.

It is commonly assumed that a project will be built exactly as it is designed. However, many factors during construction and installation can influence what is actually built on the ground. Therefore, permit requirements often require (or recommend) submittal of an as-built plan or report that documents the final installed conditions of a site after construction is complete. When available, as-built drawings are used to document the baseline conditions for monitoring of a site.

Three studies evaluated whether compensation projects were installed according to approved plans (Table 6-4). Results from both Washington and New Jersey indicate that more than half of the compensatory mitigation projects were installed according to requirements (Johnson et al. 2000, Balzano et al. 2002). Johnson et al. (2000) found that 55% of the projects were installed to plan. For those that submitted an as-built plan or report, 88% of the projects were installed according to plan. A study in Oregon, however, determined that none of the projects were implemented according to plan (Gwin and Kentula 1990). All three studies mentioned grading and vegetation as the elements of the plan that were not implemented according to the approved plan.

It can be hypothesized that the divergent results noted in the studies above might be the result of an increase of knowledge and expertise over time. For instance, the projects reviewed by Gwin and Kentula (1990) were designed, permitted, and constructed in the early 1980s. Since that time much has been learned by those who design, construct, and regulate compensatory mitigation projects. It is possible that improved designs, experience and skill in implementing the designs, and improved regulatory follow-up have resulted in a higher percentage of projects being installed according to plan by the mid- to late 1990s. The current scientific literature does not address this possibility.

Table 6-4. Percent of compensatory mitigation projects installed according to plan.

Location of Study and Reference No.	No. of Projects Evaluated	Percent Installed to Plan	Aspects Not Installed to Plan
Washington (Johnson et al. 2000)	42	55%	Mainly vegetation, also grading, misc. plan elements (e.g., fences, signs)
Oregon/ Portland metro area (Gwin and Kentula 1990)	11	0%	Size, shape, slopes, and vegetation
New Jersey (Balzano et al. 2002)	88	56%	Incorrect elevations, sizes, and/or shapes

6.4.4 Establishment of Wetland Acreage

Compensatory wetland mitigation projects are intended to compensate for the loss of wetland area and functions. Hence, permits and mitigation plans often identify a specific acreage of compensation required to offset those losses. Establishing the required acreage is therefore an important criterion of regulatory compliance. (Functions provided by compensatory mitigation projects are discussed in Section 6.8.)

Thirteen studies examined compensatory wetland mitigation sites to determine if the acreage of wetlands required by the permits had been established (Table 6-5). The studies presented the data from these investigations in two ways.

- **The percentage of projects establishing the required wetland acreage.** Researchers determined if each project met its required wetland acreage, then reported how many projects actually met the wetland acreage requirement as a percentage of the total number of projects considered. A few studies mentioned a specific threshold, such that a project had to be smaller than required by a specific acreage or percentage in order to fail to meet its wetland area (Brown and Veneman 2001, Johnson et al. 2002, Morgan and Roberts 2003).
- **The percentage of compensatory wetland acreage established.** Researchers determined the total acreage of compensatory mitigation that was verified as wetland for all the projects considered. The study then reported the total acreage of wetland compensation that was established as a percentage of the total acreage that was required for all the projects considered.

Over half of projects achieved the required wetland area in Washington and Oregon (Shaich and Franklin 1995, Johnson et al. 2002). In fact, the majority of studies determined that about half of the compensation projects established the required acreage of wetland. However, three studies found that less than 30% of projects met their acreage requirements (McKinstry and Anderson 1994, Balzano et al. 2002, Morgan and Roberts 2003). In New Jersey only 7% of projects achieved the wetland acreage requirements (Balzano et al. 2002).

For the total acreage of wetland achieved versus required, a study from Washington determined that 84% of the required acreage of compensatory wetlands was established (Johnson et al. 2002), while a study in Oregon found about 70% of the required wetland acreage was established (Gwin and Kentula 1990). Results from other states indicated between 44 and 74% of the required wetland acreage had been established.

Why is there a discrepancy between the percent of projects achieving acreage and the percentage of total acreage established? New Jersey, for example, found that only 7% of compensation projects achieved the required wetland acreage, yet 63% of the total required wetland acreage was established. It can be hypothesized that this is due to small, individual projects that establish a portion of the required acreage but fall short of the total amount required. For example, a site that was required to provide 1 acre of mitigation but only provided 0.8 acre would not meet the acreage criteria. However, the 0.2-acre difference may represent a very small fraction of the total acreage of compensation evaluated for a large study, thereby affecting the total acreage percentage very little.

Table 6-5. Establishment of required wetland acreage.

Location of Study	No. of Projects Evaluated	% of Projects Achieving Required Wetland Area	% of Required Wetland Area that Was Established
Washington (Johnson et al. 2002)[a]	24	58%	84%
Oregon/Portland metro area (Shaich and Franklin 1995)[b]	72	53% [e]	NA
Oregon/Portland metro area (Gwin and Kentula 1990)	11	NA	71%
California/southern (Allen and Feddema 1996)[c]	75	NA	69%
California/Orange County (Sudol and Ambrose 2002)	55	52%	NA
Wyoming (McKinstry and Anderson 1994)	64	14% [e]	NA
New Jersey (Balzano et al. 2002)	85	7%	63%
Tennessee (Morgan and Roberts 1999)	50	28%	68%
Ohio (Wilson and Mitsch 1996)	5	40%	66%
Indiana (Robb 2002)	31	NA	44%
Michigan (Michigan Department of Environmental Quality 2000)	159	50%	NA
Massachusetts (Brown and Veneman 2001)[d]	109	46%	NA
Florida (Erwin 1991)	NA	NA	74%

NA= information not available

[a] West of the Cascades, projects established 92% of the required acreage; east side projects established 25% of the required acreage.

[b] Compensation wetlands were 16 acres (6.5 ha) short of the 69 acres required.

[c] Projects > 8.5 acres (3.4 ha) resulted in a net gain of 17 acres (6.9 ha) of wetland area, while projects < 8.5 acres resulted in a net loss of almost 25 acres (10 ha).

[d] Five projects did not result in wetland impact and were subtracted from the project total. Results were recalculated from the data provided.

[e] Calculated from data provided.

6.4.5 Attainment of Goals, Objectives, and Performance Standards

Another critical component of compliance for a compensatory wetland mitigation project is determining whether the project has met its goals, objectives, and/or performance standards. Goals, objectives, and performance standards are generally included as part of an approved wetland mitigation plan. Goals and objectives are intended to provide a blueprint for what the project proposes to accomplish in terms of anticipated wetland type, specific habitat, functions, and/or values. The performance standards are intended to provide measurable criteria to determine if the project has accomplished its goals and objectives (Hruby et al. 1994, Ossinger 1999).

Two separate factors were investigated in the studies reviewed:

- Whether a project had goals, objectives, and performance standards
- Whether projects were meeting their goals, objectives, and performance standards

Data in Table 6-6 indicate that at least three-quarters of projects had goals, objectives, or both (Erwin 1991, Storm and Stellini 1994, Johnson et al. 2002). However, fewer projects met the goals/objectives (10 to 38%) according to the two studies that reported this information (Erwin 1991, Johnson et al. 2002).

In general, performance standards were specified less frequently than goals and objectives, though at least half of the projects had them (Erwin 1991, Storm and Stellini 1994, Mockler et al. 1998, Johnson et al. 2000, Cole and Shafer 2002). Two studies conducted in Washington determined that 21% of projects met their performance standards (Mockler et al. 1998, Johnson et al. 2002), while a third study from Washington found that 35% of projects met performance standards (Johnson et al. 2000).

A review of the articles suggests that the percent of projects with performance standards increased with more recent projects. For example, Storm and Stellini (1994) and Cole and Shafer (2002) evaluated compensation projects that were permitted in the mid to late 1980s or early 1990s. Performance standards may not have been as rigorously required (Cole and Shafer 2002) or they may not have been specifically identified as performance standards. For example, of 10 projects that did not contain performance standards, 30% were permitted in the late 1980s and 80% were permitted prior to 1995, while 20% were permitted in the late 1990s (Cole and Shafer 2002).

Data suggest (Table 6-6) that the more recent projects did not appear any more likely to meet performance standards than earlier projects (Mockler et al. 1998, Johnson et al. 2000, Cole and Shafer 2002, Johnson et al. 2002). Some believe that performance standards have become more rigorous overtime, and more recent projects have been held to a higher standard. Cole and Shafer (2002), however, did not find that performance standards noticeably changed in terms of content from projects permitted in the late 1980s to the late 1990s. Therefore, one can conclude that the year of permitting does not appear to be a factor in whether projects met their performance standards.

More information on performance standards is provided in Section 6.10.4.

Table 6-6. Attainment of goals, objectives, and performance standards.

Location of Study	No. of Projects Evaluated	% of Projects w/ Goals or Objectives	% of Projects w/ Performance Standards	% of Projects Meeting Goals or Objectives	% of Projects Meeting Performance Standards
Washington (Johnson et al. 2000)	34	NA	87%[a]	NA	35%
Washington (Johnson et al. 2002)	24	92%	NA	38%	21%
Washington/ King County (Mockler et al. 1998)	29	NA	100%	NA	21%
Washington/ western (Storm and Stellini 1994)	17	76%	53%	NA	NA
Pennsylvania (Cole and Shafer 2002)	23	NA	57%	NA	62%
Florida (Erwin 1991)	40	85%	60%	10%	NA

NA = information not available.

[a] Calculated from data provided.

6.4.6 Monitoring

To determine if a compensatory wetland mitigation project is in compliance, it is necessary to monitor the project over time. Monitoring requirements are typically identified in the wetland mitigation plan. The duration, frequency, and methods of monitoring should depend on the goals, objectives, and performance standards for the project.

Monitoring is the process through which data about site conditions is gathered. Monitoring data is used to determine whether a project is achieving its performance standards, and therefore its goals and objectives, within a predicted timeframe. Monitoring also provides critical information about whether a site requires maintenance or contingency actions. Monitoring is therefore essential for a project to achieve compliance.

The studies investigating whether compensatory wetland mitigation projects were required to be monitored and whether monitoring actually occurred are summarized in Table 6-7. In general, studies conducted more recently found that monitoring was required for a greater percentage of projects. Data from four studies indicate monitoring was required for at least three-fourths of projects (Erwin 1991, Morgan and Roberts 1999, Johnson et al. 2000, Michigan Department of Environmental Quality 2000). The remaining two studies, which examined compensation projects permitted in the late 1980s and early 1990s, found that monitoring was required for a third to half of projects (Holland and Kentula 1992, Storm and Stellini 1994).

Less than half of the projects had monitoring data. However, the studies did not determine whether the monitoring was not conducted or whether there was simply no record of the monitoring reports on file with the regulatory agencies. Since over half of the studies mentioned difficulty finding complete project information from the agency files (Storm and Stellini 1994, Morgan and Roberts 1999, Johnson et al. 2000, Cole and Shaffer 2002), it is possible to conclude that monitoring reports may have been submitted to the appropriate agencies but the reports were lost due to a lack of follow-up and poor file maintenance. If monitoring is not conducted there is no means to trigger maintenance or contingency actions. The consequence of inadequate follow-up by regulatory agencies is discussed in Section 6.4.8.

Table 6-7. Percent of projects requiring monitoring and those actually monitored.

Location of Study	% of Projects Requiring Monitoring	% of Projects Monitored
Washington (Johnson et al. 2000)	71%	33%
Washington/ western (Storm and Stellini 1994)	53%	18%
California (Holland and Kentula 1992)	32%	NA
Michigan (Michigan Department of Environmental Quality 2000)	87%	35%
Pennsylvania (Cole and Shafer 2002)	NA	<10%
Tennessee (Morgan and Roberts 1999)	89%	43%
Florida (Erwin 1991)	98%	38%[a] (62%)[b]

[a] Represents projects that were adequately monitored.

[b] Calculated from Erwin (1991) indicating all projects that received some level of monitoring.

6.4.7 Maintenance

Compensatory wetland mitigation sites require maintenance to help ensure that goals and performance standards will be achieved. Maintenance includes implementing corrective actions to rectify problems, such as an insufficient water supply or inappropriate water regime, invasive species infestation (e.g., reed canarygrass, bull frogs), trash, vandalism, or anything else that may result in non-compliance with permit requirements. Johnson et al. (2002) observed that a lack of maintenance was one of the main reasons for poor success of mitigation projects.

Results revealed that permitting agencies did not require all compensation projects to provide maintenance. Studies discovered that permits required site maintenance for 41 to 78% of projects (Erwin 1991, Storm and Stellini 1994, Michigan Department of Environmental Quality 2000). However, even fewer projects (20 to 60%) complied with their maintenance requirements (Erwin 1991, Michigan Department of Environmental Quality 2000).

The research did not investigate the reasons for low compliance with maintenance provisions. One may assume that it is linked to inadequate monitoring, lack of regulatory follow-up, or a lack of cooperation from the owner of the site.

6.4.8 Regulatory Follow-Up

Once compensatory wetland mitigation is required, it is the responsibility of the regulatory agencies to track the project over time and determine if it complies with permit requirements. A regulatory agency follows up on compensatory mitigation projects by:

- Ensuring that the compensation project is constructed as designed and approved, or that the applicant documents, through "as-built" reports why approved plans were modified during installation
- Ensuring that required monitoring reports are submitted on schedule
- Performing site visits to confirm monitoring results and attainment of performance standards
- Ensuring maintenance actions are undertaken on schedule
- Ensuring that appropriate contingency measures are enacted
- Ensuring the compensation site is protected over the long-term (i.e. through a legal protection mechanism such as a conservation easement)

Studies in Washington and Oregon indicated that about half of compensatory wetland mitigation projects received some regulatory follow-up in the form of site visits, phone calls, or letters (Kentula et al. 1992, Johnson et al. 2002). In Michigan only about a quarter of projects received any kind of follow-up after the permit was issued (Michigan Department of Environmental Quality 2000).

A few studies also examined the effect of regulatory follow-up on project compliance, success, or both. Robb (2002) alluded to the fact that the high number of non-compliant compensation projects resulted from a lack of follow-up and enforcement actions. In Washington a study noted that all of the projects lacking regulatory follow-up were either minimally or not successful, while two-thirds of the projects receiving some kind of follow-up were either fully or moderately successful (Johnson et al. 2002).

One team of researchers observed:

> *The most ecologically successful sites were generally those that had received follow-up work in the form of maintenance, replanting, or improvements to grading or water control structures in accordance with recommendations made by NJDEP [New Jersey Department of Environmental Protection] and other regulatory agencies after initial compliance inspections revealed problems* (Balzano et al. 2002).

Studies indicated that regulatory follow-up can help to ensure the success of compensation sites (Johnson et al. 2002, Balzano et al. 2002). It is assumed that applicants will be more likely to abide by permit requirements and submit monitoring reports if regulatory agencies are actively following up on projects. Since monitoring reports are meant to identify what is working and where there are shortfalls, maintenance actions can be initiated or contingency measures can be triggered to correct the shortfalls and problems as soon as possible. Therefore, one can conclude that agency follow-up improves the compliance and success of compensation projects.

6.4.9 Summary of Key Points

- Most compensatory wetland mitigation projects were installed. However, compliance levels overall were generally low.

- Two out of three studies found that more than half of projects were installed according to plan. Projects not installed to plan most often did not comply with grading and vegetation requirements.

- The majority of studies found that about 50% of projects achieved their required wetland acreage.

- Even if individual projects did not fully achieve their required acreage, most studies found that at least 66% of the overall required acreage of compensation had been established.

- The requirement for monitoring as a regulatory condition seems to be increasing in more recent studies (30 to 50% in the early 1980s; 75% in more recent studies).

- Over 50% of the studies noted that it was difficult to find complete project files, thereby making it difficult to document if monitoring was occurring or being tracked by regulatory staff.

- The research found that 41 to 78% of projects required maintenance; however, only 20 to 60% of projects complied with maintenance requirements.

- Studies in Washington and Oregon found that approximately half of projects received some regulatory follow-up.

- Two studies suggested that follow-up had a positive influence on the level of compliance and success for compensatory wetland mitigation projects.

How is compensatory wetland mitigation doing in Washington?*

Five studies of compensatory wetland mitigation have focused on projects in Washington State during the past decade[1]. The studies examined success, ecological functioning, permit compliance, and achievement of required wetland area, though not all studies looked at the same factors in the same way. The results suggest that compensatory mitigation in Washington is neither fully successful nor completely unsuccessful.

Most studies found that less than half of wetland compensation projects are fully effective. In the most recent and comprehensive evaluation of compensation projects, Johnson et al. (2002) found that 13% of compensatory wetland mitigation projects were fully successful and 33% were moderately successful. In western Washington, Storm and Stellini (1994) determined that 24% of compensation projects functioned well. In King County, Mockler et al. (1998) indicated that 3% of projects replaced lost wetland functions.

In terms of compliance, Johnson et al. (2000) determined that 29% of projects were in full compliance, while for King County Mockler et al. (1998) found that 21% of projects were meeting their required performance standards.

Kentula et al. (1992) examined Section 404 permit decisions for Washington from 1980 through 1986. Data indicated that permit decisions resulted in a wetland loss of 40 acres (16 ha). Johnson et al. (2002) determined that 24 acres (10 ha) of wetland were lost due to projects that did not successfully establish wetland area and the frequent use of existing wetlands for enhancement.

[1]All studies, except Kentula et al. (1992), sampled a sub-set of the applicable mitigation projects.
*Results have been simplified for this summary. Please refer to Sections 6.3 and 6.4 for complete information.

6.5 Types of Compensatory Mitigation

When discussing compensatory mitigation it is important to have a common understanding of the types of compensation that can be used to mitigate for wetland losses. This is difficult because various agencies and organizations often define types of compensation differently (Morgan and Roberts 1999). An added difficulty is that each type of compensation represents a range of activities on a continuum rather than a distinct procedure.

This section describes several types of compensatory mitigation:

- Restoration
- Creation
- Enhancement/exchange
- Preservation
- Mixed compensatory mitigation
- Wetland mitigation banking
- In-lieu fee programs

Definitions given to each of the mitigation types are discussed below, followed by a description of how frequently each type is used and its relative effectiveness.

6.5.1 Restoration

Of the types of compensation, restoration has the widest variety of definitions. The most general is the reestablishment of wetland conditions (i.e., area, functions, and values) at a location where they formerly existed but no longer exist (Johnson et al. 2000, Jones and Boyd 2000). Activities associated with this definition could include removing fill material, plugging ditches, or breaking drain tiles. Other definitions involve returning a site to some historic condition. The following are examples of other definitions.

- Re-establishing historic hydrologic processes (National Research Council 2001) or hydrogeomorphic (HGM) classes (Johnson et al. 2000). Activities associated with this definition typically involve removing a levee or breaching a dike to reconnect an area to the floodplain or to tidal influence.
- "Return of an ecosystem to a close approximation of its condition prior to disturbance (NRC 1992). Restoration requires knowledge of the wetland type prior to disturbance and has the goal of returning the wetland to that type" (Gwin et al. 1999).
- Returning an altered wetland "to a previous, although altered condition (Lewis 1990)" (Gwin et al. 1999).
- "The process, or the result of the process of returning an area or ecosystem to some specific former condition" (Munro 1991).

Perhaps as a result of the numerous definitions, confusion about what constitutes restoration versus other types of compensatory mitigation can occur in regulatory permits and mitigation plans. The last three definitions in the list above could just as easily describe enhancement activities. For example, planting trees in a degraded wet pasture, often considered enhancement, could be an attempt to return an ecosystem (the pasture) to an approximation of its prior condition (forested wetland).

In their study of compensatory wetland mitigation projects in Tennessee, Morgan and Roberts (1999) mentioned that several projects were classified as restoration. Based on the activities specified, however, enhancement would have been a more appropriate term. Similar confusion occurred between restoration and creation. As a result of this confusion, the effectiveness of restoration, as a type of compensation, is difficult to assess.

6.5.1.1 Use of Restoration

For compensatory mitigation, restoration is often cited as the highest priority or most recommended type of compensation "because it offers the highest probability of success (Kruczynski 1990, Kusler and Kentula 1990, USDA-SCS 1992)" (Morgan and Roberts 1999). In addition, the National Academy of Sciences recommended restoration over creation. "Restoration of wetlands has been observed to be more feasible and sustainable than creation of wetlands" (National Research Council 2001).

This emphasis on restoration is not reflected in the number of freshwater, compensatory restoration projects implemented on the ground. Restoration tends to be one of the least utilized types of compensation (Jones and Boyd 2000). In fact, two studies mentioned that none of the projects involved restoration (Shaich and Franklin 1995, Gwin et al. 1999). Most of the studies that specifically mentioned the number or percentage of projects using a particular type of compensation found that 20 to 30% of projects involved some restoration of wetland acreage (Morgan and Roberts 1999, Johnson et al. 2000, Johnson et al. 2002). Projects employing restoration as the sole form of compensation are even fewer (Shaich and Franklin 1995, Johnson et al. 2000, Johnson et al. 2002).

In a departure from the other studies, Holland and Kentula (1992) found that 65% of permits required restoration. However, 42% of the compensatory wetlands they looked at were estuarine or marine. If estuarine and marine projects are subtracted, the percentage of restored, freshwater wetlands is similar to the other studies.

Morgan and Roberts (1999) suggest that the lack of compensatory wetland restoration projects is due to the fact that "most suitable restoration sites are 'prior converted' farmland and because sizable acreages are being restored under the Wetland Reserve Program . . . sites available for compensatory mitigation may be limited." In Washington, however, the authors of Volume 1 believe that restoration is used infrequently because most wetland impacts are relatively small (less than 2 acres [0.8 ha]), and it is very difficult to find restoration opportunities for small sites that are not cost prohibitive. Restoration is typically most feasible and cost effective if done over a large area. In addition, some regulatory requirements, particularly for local governments, direct applicants to provide compensation on-site, which often precludes an opportunity for restoration.

6.5.1.2 Effectiveness of Restoration

While it is widely stated that restoration is the most effective approach, the data to substantiate this claim are sparse. Studies indicate that there is a limited use of restoration for compensatory mitigation in freshwater wetlands. Thus, there is a substantial lack of data with which to evaluate its effectiveness as a type of compensation.

In Washington Johnson et al. (2000) found that one of three restoration projects was in full compliance. Johnson et al. (2002) found that one of two restoration projects established the required acreage of wetland and was fully successful. In Florida, Erwin (1991) found that restoration successfully established 88 acres (36 ha) more wetland area than was required. The limited existing data appear to suggest that when wetlands are restored, they are relatively effective at compensating for permitted losses.

6.5.2 Creation

It is generally agreed that creation involves establishing wetland conditions (area, functions, and values) in a location where wetland conditions previously did not exist (Johnson et al. 2000) or "that was not a wetland in the recent past (within the last 100-200 years) (Kruczynski 1990, Lewis 1990)" (Gwin et al. 1999). "Typically, a wetland is created by excavation of upland soils to elevations that will support the growth of wetland species through the establishment of an appropriate hydroperiod (Kruczynski 1990, Lewis 1990)" (Gwin et al. 1999).

Gwin et al. (1999) made a distinction between creating a wetland that is isolated from existing wetlands (creation) and creating a wetland that is immediately adjacent to an existing wetland, thereby enlarging the existing wetland (expansion). No other studies made this distinction.

> The U.S. Army Corps of Engineers' Regulatory Guidance Letter -02-2 uses the term *establishment* rather than the previously accepted term *creation*. Federal agencies, as well as the Department of Ecology, have started using the term *establishment*. However, this document synthesizes studies and documents written before this regulatory guidance letter was produced. Therefore, this document uses the term *creation* rather than *establishment*.

6.5.2.1 Use of Creation

Seven studies discussed how frequently creation was required as compensation. All noted that at least 30% and in some cases more than half of compensatory wetland projects were created or involved some creation (Holland and Kentula 1992, Shaich and Franklin 1995, Gwin et al. 1999, Morgan and Roberts 1999, Johnson et al. 2000, Jones and Boyd 2000, Johnson et al. 2002).

6.5.2.2 Effectiveness of Creation

In Washington, Johnson et al. (2000) found that 10% of created wetlands were in compliance. Seventy percent of creation projects established the required acreage of wetland, and 60% of created projects were either fully or moderately successful (Johnson et al. 2002).

In other states, however, created wetlands did not perform as well. Creation projects failed to establish 527 acres (213 ha) of required wetland area in Florida (Erwin 1991). In Tennessee, Morgan and Roberts (1999) found, "Most creation projects…were only partially successful because they failed to develop wetland characteristics throughout… Problems with created wetlands were numerous and involved both site design and vegetation establishment."

The results on the effectiveness of creation are mixed. Though projects in Washington have poor compliance, other aspects of effectiveness are relatively good. However, other states found poor effectiveness for created wetlands. The data therefore suggest that further study is warranted.

6.5.3 Enhancement/Exchange

Enhancement involves modifying a specific structural feature of an existing degraded wetland to improve one or more functions or values based on management objectives (Gwin et al. 1999, Johnson et al. 2000). Enhancement typically consists of:

- Planting vegetation
- Controlling non-native, invasive species
- Modifying site elevations or the proportion of open water to influence hydroperiods

Gwin et al. (1999) defined exchange as:

> *Enhancement taken to the extreme (Kruczynski 1990), with most or all of the wetland converted from one type to a different type. For example, resource managers may intend to enhance habitat value for waterfowl by excavating an area of open water within an existing emergent marsh. However, if the open water area replaces the emergent wetland or a large proportion of it, wetland types have been exchanged.*

Because enhancement involves altering an existing wetland to compensate for the loss of other wetlands, the scientific literature mentions three main concerns regarding its use.

- Enhancement fails to replace lost wetland area (Shaich and Franklin 1995, Morgan and Roberts 1999). For this reason, the state of Michigan does not allow the use of enhancement for compensatory mitigation (Michigan Department of Environmental Quality 2000).

- Enhancement may fail to replace wetland functions, since "a positive change in one wetland function may negatively affect other wetland functions (Kruczynski 1990, Lewis 1990)" (Gwin et al. 1999). In addition, "there commonly is disagreement about whether or not the practice implemented actually enhances conditions at a site" (Morgan and Roberts 1999).

- Enhancement may result in a conversion of HGM and/or Cowardin classes, typically producing a compensation wetland without natural analogues (Shaich and Franklin 1995, Gwin et al. 1999, Johnson et al. 2002). When enhancement is used for compensation in such cases:

  A single Section 404 decision results in the destruction of the wetland for which the permit was issued, along with the conversion of a second wetland to a different, often atypical, HGM type. This 'double whammy' means that exchange [enhancement] *explicitly does not fulfill the objective of 'no-net-loss' of wetlands but, instead, ensures loss of wetland area, additional wetland disturbance, and changes in overall ecological function* (Gwin et al. 1999).

6.5.3.1 Use of Enhancement

Studies indicated that more than one-third of compensation projects used enhancement of existing wetlands as compensatory mitigation (Shaich and Franklin 1995, Gwin et al. 1999, Morgan and Roberts 1999, Johnson et al. 2000, Johnson et al. 2002).

6.5.3.2 Effectiveness of Enhancement

The effectiveness of enhanced compensation wetlands was evaluated by only two studies, both conducted in Washington. The researchers found less than 13% of enhanced wetlands were in complete compliance, while 56% of enhanced wetland projects met the requirement for acreage of compensation. (For projects that proposed to enhance existing wetlands, establishing the required acreage of wetland compensation entailed implementing the proposed actions to enhance the mitigation site.) Furthermore, none of the enhanced compensation wetlands were fully successful, while 89% were minimally or not successful (Johnson et al. 2000, 2002). For more information refer to Section 6.3.1 and Table 6-1.

Johnson et al. (2002) suggested two main reasons for the low level of success among enhancement projects.

- The enhancement project did not achieve the proposed vegetative structure, diversity, or both (the planted trees and shrubs did not survive or did not grow). Thus the project did not establish the required acreage of compensation, did not meet performance standards, or both.

- The enhancement project achieved the proposed structure/diversity, but despite this, it did not adequately compensate for the wetlands lost because the contribution of the enhancement to the performance of wetland functions was low.

The enhanced wetlands evaluated by Johnson et al. (2002) were all in the ground for less than eight years. Their study confirmed that for the projects they evaluated, eight years was not sufficient time to achieve the structural and species complexity of shrub and forested habitats. When structurally complex habitats are the goal of a compensatory mitigation design, studies continue to show that longer timeframes are necessary to begin to provide some of the attributes of those functions (National Research Council 2001). If structurally complex habitats are altered, it is possible to conclude that the delay in replicating those functions results in a prolonged temporal loss of functions on the landscape. This is equally true for projects proposing to restore or create wetlands.

Wetland creation vs. enhancement: Which contributes greater functions?

Johnson et al. (2002) determined that created wetlands were significantly more successful than enhanced wetlands. These researchers assessed the potential of compensation wetlands to perform wetland functions. They then determined how much the activities associated with the type of compensation contributed to, or improved, the level of wetland function. For creation/restoration projects it was assumed that if wetland conditions were achieved then the compensation activities were responsible for providing the assessed level of wetland functions. Enhanced wetlands performed some wetland functions prior to implementation of compensation activities. The authors believed it was important to determine how much enhancement activities contributed to, or improved, the level of performance of functions at a compensation wetland. The authors believed this was particularly important since enhancement, as a compensation tool, is based on improvement of wetland functions.

The study compared the contribution of created sites and enhanced sites for three function categories. Results indicated that over half of the created sites provided high or moderate contributions to wildlife habitat, water quality, and water quantity functions. Over half of the enhancement projects provided minimal to no contribution to wetland functions. The vast majority of enhancement actions were targeted at improving wildlife habitat functions. However, the enhanced wetlands were typically surrounded by development and lacked the buffers and connectivity necessary to improve habitat for most wildlife. In addition, most of the wetlands that were enhanced already provided some water quality functions. Thus, creation of wetlands provided a significantly greater contribution to the performance of water quality functions than enhancement of wetlands. Contribution to wetland functions was one element of overall success.

It is important to note that many created wetlands and some enhanced wetlands resulted in Cowardin and hydrogeomorphic (HGM) classes that were not typical for the landscape. This is discussed in more detail in Sections 6.8.2.2 and 6.8.5.1, respectively. Also, because enhancement provides less gain in function per acre than creation or restoration, replacement ratios are generally higher; refer to Section 6.6 for more information.

6.5.4 Preservation

Preservation means "the protection of an existing and well-functioning wetland from prospective future threats" (National Research Council 2001). Preservation, therefore, provides the opportunity to protect wetland areas that might otherwise be in jeopardy. Like enhancement, preservation does not produce any new wetland acreage; for that reason, some concerns have been raised regarding its use as compensation for permitted wetland loss.

- Preservation results in a net loss of wetland acreage.
- Preserved wetlands are generally not large enough to protect ecosystems and biodiversity over the long term (Whigham 1999).
- Preserved areas may not be checked by regulatory agencies to verify that they contain the specified acreage of wetland. For example, Morgan and Roberts (1999) observed that one of the larger preserved wetlands in their study was predominantly upland and "did not meet the criteria for being considered a jurisdictional wetland."

On the other hand, if an area can be verified as wetland, "Preservation of an existing wetland removes the uncertainty of success inherent in a wetland creation or restoration project and requires no construction to complete" (Washington State Department of Transportation 1999). Preservation, therefore, eliminates the risk of failure and temporal loss of wetland functions since the preserved area is already an existing wetland.

6.5.4.1 Use of Preservation

The studies generally found that preservation was required as compensation for less than one-quarter of projects (Holland and Kentula 1992, Morgan and Roberts 1999, Johnson et al. 2000, Jones and Boyd 2000). Preservation generated about 2% of the compensatory wetland acreage in a study from San Francisco, California (Breaux and Serefiddin 1999). A report from the Washington State Department of Transportation (1999) indicated that 76% of state transportation departments in the United States use preservation as at least one component of compensatory mitigation and 38% use it as a stand-alone form of compensation.

6.5.4.2 Effectiveness of Preservation

There is a general lack of information about the effectiveness of preservation. Only one study examined the effectiveness of preservation as a type of compensatory mitigation. In Washington, Johnson et al. (2000) determined that all four of the projects involving preservation as the sole form of compensation were in compliance. Compliance for preservation projects entailed verifying that the area was preserved and free from development and that a deed restriction or conservation easement was in place to legally protect the parcel from future development.

6.5.5 Mixed Compensatory Mitigation

Mixed projects involve more than one type of compensatory mitigation. For example, a common proposal in the Pacific Northwest entails enhancing an existing wetland and creating additional wetland area immediately adjacent to it. Mockler et al. (1998) observed, "most sites consist of creation—a small pool graded for open water and emergents—and enhancement, typically of wetland buffer." Mixed compensation, however, can also occur on separate sites, such as a created wetland adjacent to the development site and a preserved wetland some distance away.

Several studies identified mixed compensation projects (Mockler et al. 1998, Gwin et al. 1999, Johnson et al. 2000, Johnson et al. 2002). For their studies of compensation wetlands, Mockler et al. (1998) and Johnson et al. (2002) classified compensation wetlands according to their dominant type of compensation. However, some projects lacked sufficient information to make this determination, while other projects lacked dominance by any one type of compensation.

6.5.5.1 Use of Mixed Compensation Projects

In the six studies that discussed how frequently mixed compensatory mitigation was required, results ranged from 13% (Johnson et al. 2002) to 43% (Johnson et al. 2000). Most studies found that mixtures were used for less than a third of projects (Holland and Kentula 1992, Shaich and Franklin 1995, Gwin et al. 1999, Morgan and Roberts 1999).

6.5.5.2 Effectiveness of Mixed Compensation Projects

Only two studies, both from Washington, examined the effectiveness of projects utilizing a mixture of compensation types. Johnson et al. (2000) found that 32% of mixed projects were in compliance. Johnson et al. (2002) determined that all of the mixed projects were moderately successful.

6.5.6 Wetland Mitigation Banking

Mitigation banking is defined as "the practice of restoring, creating, enhancing, or preserving off-site wetland areas to provide compensatory mitigation for authorized impacts to wetlands" (Environmental Law Institute 2002). Wetland banking provides an alternative to traditional, concurrent, compensatory wetland mitigation, and its acceptance and use continue to grow.

Typically a public agency, organization, or private entrepreneur establishes a bank on a large area to be used to compensate for a number of smaller wetland impacts. Banks are generally established as compensation in advance of authorized impacts to wetlands at another site. One may conclude that this practice could provide advantages over traditional compensatory mitigation by reducing the temporal loss of wetland functions.

6.5.6.1 Use of Wetland Banking

Mitigation banking was used for about 7% of Section 404 permits in California issued from 1971 to 1987 (Holland and Kentula 1992). For permits issued from 1996 to 1998 which required mitigation, the Corps District of Norfolk, Virginia reported about 10% of projects purchased bank credits for use as compensation (Jones and Boyd 2000).

By the beginning of 1996, Brown and Lant (1999) determined that 68 banks had been established across the country, totaling nearly 41,000 acres (16,590 ha). A recent survey by the Environmental Law Institute (2002) determined that 219 banks had been approved across 40 states, totaling more than 139,000 acres (56,250 ha). Though 22 of the 219 banks have already sold all their eligible compensatory wetland acreage/credits, the remaining 197 banks were active, meaning they had credits/acreage that had not yet been purchased for use as compensation (Environmental Law Institute 2002).

Since wetland bank credits result from one or more of the previously mentioned types of compensation, the Environmental Law Institute (2002) investigated how frequently each type was used in mitigation banking. Results indicated that 78% of banks involved multiple types of compensation and that enhancement and restoration are the most commonly used. Of the banks that relied on a single type of compensation, about a third was restoration; another third was creation, while enhancement and preservation were each used on 16% of the banks.

6.5.6.2 Effectiveness of Wetland Mitigation Banks

Only one study has examined the effectiveness of wetland mitigation banks. Brown and Lant (1999) examined banks that had been established by the beginning of 1996. Overall, they found there would be a net loss of over 21,000 acres (8,450 ha) of wetland due to the use of enhancement and preservation at banks. The authors also discovered that eight banks did not provide the functions required or specified, while four banks used or sold more acreage for compensation of wetland loss than was eligible from the bank (in other words, the bank was overdrawn).

Wetland mitigation banking is increasingly being used to compensate for wetland losses. Yet the only study investigating the effectiveness of banks raises concerns about its use. Further study will therefore be critical to determine the level of compliance and success of mitigation banks in providing functions.

Please refer to Section 6.10.6 Mitigation Banking for more information on wetland banking as it relates to improving compensatory mitigation. In addition, the *Draft Programmatic Environmental Impact Statement: Washington State's Draft Rule on Wetland Mitigation Banking* (Driscoll and Granger 2001) contains a more in-depth discussion of the issues involved in mitigation banking (available at: http://www.ecy.wa.gov/biblio/0106022.html).

6.5.7 In-Lieu Fee Programs

In-lieu fee programs provide an additional option for compensatory mitigation. They allow permit applicants to compensate for wetland losses by paying a fee to a third party such as a government agency or conservation organization (U.S. General Accounting Office 2001, Environmental Law Institute 2002). The fees are intended to be used to restore, create, enhance, or preserve wetlands (U.S. General Accounting Office 2001).

Generally, in-lieu fee contributions are collected in advance of wetland losses. These funds are accumulated until they are sufficient to design and implement a wetland compensation project (Environmental Law Institute 2002).

6.5.7.1 Use of In-Lieu Fee Programs

A recent survey by the Environmental Law Institute (2002) determined there were 87 active in-lieu fee programs across 27 states. "Through fiscal year 2000, developers used the in-lieu-fee option to fulfill mitigation requirements for over 1,440 acres [583 ha] of adversely affected wetlands, and paid over $64.2 million to in-lieu-fee organizations" (U.S. General Accounting Office 2001).

6.5.7.2 Effectiveness of In-Lieu Fee Programs

Two studies discussed the effectiveness of in-lieu fee programs. However, neither study provided information on the level of compliance or ecological success of these programs.

A study by the U.S. General Accounting Office (2001) examined the effectiveness of in-lieu fee programs used by the U.S. Army Corps of Engineers (Corps) to compensate for wetland losses permitted through the Section 404 program. Of the 17 Corps districts using in-lieu fees, 65% did not require a specific timeframe for spending or obligating the fees received, and a few districts had not spent or obligated any funds though they had been collecting fees as compensation for wetland losses for at least three years (U.S. General Accounting Office 2001). The study found that three districts used the fees for research and/or education, rather than on-the-ground activities to compensate for wetland loss. In-lieu fee programs in 30% of the districts restored, created, enhanced, or preserved wetland acreage equal to or greater than the wetland acreage lost. The remaining districts either had used the fees to implement wetland activities that did not compensate for the wetland acreage lost, or they did not have any data (U.S. General Accounting Office 2001).

A study by the Environmental Law Institute found that 45% of in-lieu fee programs lacked the data necessary to determine their effectiveness. In-lieu fees replaced more wetland acreage than was lost in 56 programs, while "thirteen in-lieu-fee programs reported replacing fewer acres than had been impacted" (Environmental Law Institute 2002).

These studies paint a rather grim picture of the effectiveness of in-lieu fee programs as compensation for wetland loss. However, both in-lieu fees and mitigation banking can provide a mechanism to compensate for regulated wetland impacts that are so small they currently do not require compensation, because compensation for such small wetland losses was not considered viable or practical (Shabman et al. 1993). In the year 2000 federal guidance on the use of in-lieu fee arrangements for compensatory mitigation was issued, while prior to this there were no federal requirements for in-lieu fee programs (Environmental Law Institute 2002). Further study will be needed to ensure that abuses of in-lieu fee compensation are not occurring.

6.5.8 Summary of Key Points

- The variety of definitions or criteria associated with types of compensatory mitigation has led to confusion in permitting and evaluating projects. For instance, comparing the effectiveness of one type of compensation with another is impossible when it is not clear if a project involved creation, restoration, enhancement, or some combination thereof.

- Restoration has been recommended as the "highest priority" method for compensation. Research in Washington has found that it is the least used, though one of three projects was in compliance and one of two projects was fully successful.

- Creation was used in one-third to one-half of compensation projects. In Washington, 10% of creation projects were in compliance, 60% were at least moderately successful. Studies from other states indicated that creation projects experienced major problems such as a failure to establish vegetation and produce wetland conditions.

- Enhancement was used for compensation in more than one-third of compensation projects. Research in Washington found that less than 13% of enhancement projects were in compliance. There were no fully successful enhancement projects, while 89% were minimally or not successful.

- The low level of success for enhancement projects was attributed to an inability to achieve the proposed vegetative structure/diversity, a minimal gain in functions, or both. This may partially be a factor of time: There will be continued temporal loss of some functions until young sites mature to more complex structural conditions.

- Two studies from Washington indicated that mixed compensation projects had a higher level of compliance than either creation or enhancement, and all mixed projects were moderately successful.

- Preservation can result in permanent protection of existing wetland resources, but compliance was found to be variable. One study found a large area of preserved wetland was actually predominantly upland habitat. However, a study in Washington found that 100% of preservation sites were in compliance.

- Studies of wetland mitigation banking and in-lieu fee programs focused on whether the goal of preventing the net loss of wetlands had been achieved on paper. The results indicated that a net loss of wetland area was occurring. A few banks were overdrawn, and some of the in-lieu fee programs had not used the money collected to implement compensation activities. No studies determined their effectiveness on the ground.

Does size influence the effectiveness of compensatory wetland mitigation projects?

Studies of the effect of wetland size on compensation projects revealed mixed results.

Two studies indicated that larger projects, which probably involved more planning and regulatory oversight, had a higher level of compliance (Brown and Veneman 2001) or success (Allen and Feddema 1996). Allen and Feddema (1996) noted that large projects (greater than 8.6 acres [3.5 ha]) resulted in a net gain of wetland acreage, while the smaller projects resulted in a net loss of wetland acreage. Though Brown and Veneman (2001) indicated larger projects had a higher level of compliance, larger projects were no more successful at replacing the plant communities or wildlife functions that were lost than the smaller compensation wetlands.

Two other studies determined that no statistically significant correlation existed between wetland size and compliance or success (Balzano et al. 2002, Johnson et al. 2002). Raw data from Johnson et al. (2002) implied that compensatory mitigation projects 5 acres (2 ha) or larger were less successful than smaller projects. Balzano et al. (2002) found that larger compensation wetlands tended to be more successful at establishing the required wetland acreage. However, this trend was attributed to one large site (over 40 acres [16 ha]) that established more wetland acreage than was required.

The Committee on Mitigating Wetland Losses determined that wetland size does affect wetland functions (National Research Council 2001). For example, "for water quality purposes, many small wetlands would be more effective than one large wetland covering the same area." The committee therefore concluded that "replacement area should be proportional to the area required to replace the functions lost" (National Research Council 2001).

6.6 Replacement Ratios

A replacement ratio, or compensation ratio, is an approach used to determine appropriate reparation for permitted wetland losses. Not all regulatory agencies use this approach. For example, the U.S. Army Corps of Engineers, Seattle District considers the needs for compensation on a project-specific basis rather than assigning replacement ratios.

The replacement ratio reflects the acreage of a particular type of compensatory mitigation (creation, restoration, enhancement, or preservation) required to make up for the loss of an acre of wetland (King et al. 1993, McMillan 1998). For example, a permitted loss of one acre may be compensated with two acres of restoration, thus requiring a 2:1 replacement ratio. The rationale for requiring more than 1:1 replacement for wetland impacts is provided in Section 6.6.1.

This section provides the following information:

- The rationale for using replacement ratios
- A summary of the literature regarding what replacement ratios are being required and if they are being achieved
- Some of the methods used to determine appropriate replacement ratios

6.6.1 Rationale for the Use of Replacement Ratios

When compensatory wetland mitigation was first required, the loss of an acre of wetland would simply require an acre of compensation (McMillan 1998). A simple 1:1 replacement ratio generally is no longer considered appropriate (Castelle et al. 1992a, King et al. 1993, National Research Council 2001) for the following reasons:

- **Risk of failure.** It is possible that compensation projects will not perform as proposed (King and Bohlen 1994) and may fail to compensate for wetland losses (Castelle et al. 1992a).
- **Temporal loss.** It may take anywhere from several years to several decades for a compensation project to achieve ecological equivalency (National Research Council 2001) and to develop the proposed/required wetland structures and/or functions (Castelle et al. 1992a).

Because of the risk of failure and temporal loss, "replacement ratios greater than 1:1 are used as a means of equalizing the tradeoff. While the goal is always to replace the lost functions at a 1:1 ratio, it is almost always necessary to increase the replacement acreage in order to accomplish this" (McMillan 1998).

A literature review performed by Castelle et al. (1992a) concluded that:

> *The risks of project failure and the time it takes for a created wetland to represent a fully functioning ecosystem should be factored into replacement ratios which exceed 1:1…*
>
> *Replacement ratios of 2:1 or greater are necessary to compensate for our current rate of failure to achieve permit compliance of basic wetland community structural objectives within attempted mitigation projects, neither of which are accurate measures of functional equivalency.*

An additional consideration is that there are many types of wetlands and various degrees of degradation. As a result, not all wetlands provide the same levels of functions or values. Replacement ratios, therefore, should take into account the type and quality of the wetland and the functions and values that would be lost. For example, the loss of a high-quality forested wetland would require a higher replacement ratio than the loss of a highly degraded wet pasture (Breaux and Serefiddin 1999).

Also, the type of compensation can influence the replacement ratio. Johnson et al. 2002 found that the use of enhancement not only results in a net loss of wetland area but provides a limited increase in wetland functions. Therefore, enhancement typically requires higher replacement ratios than restoration or creation (McMillan 1998).

Higher replacement ratios result in more area for compensatory mitigation, but unfortunately size does not guarantee success or quality. A study conducted by the National Academy of Sciences concluded that attempts to compensate for rare wetland types by requiring high replacement ratios yielded wetlands of a common type at a low ratio. Rather than replicating the rare wetland type, a more common wetland type was substituted. "In effect, the regulatory program may reassemble the landscape with a different habitat mix than the wetlands being lost" (National Research Council 2001).

6.6.2 Replacement Ratios Required and Achieved

Table 6-8 summarizes the overall or average replacement ratios that were required for compensatory wetland mitigation projects. A wide range of replacement ratios was required—from 0.66:1 to 5.9:1 (Kunz et al. 1988, Johnson et al. 2000). These are the extremes. The low end represents projects from the early to mid 1980s, when compensatory mitigation was still a relatively new idea. The higher ratios reflect more recent projects using predominantly enhancement and/or preservation, which typically require higher replacement ratios.

Between these extremes, the remaining studies noted ratios ranging from 1.5:1 to 2.7:1 (Wilson and Mitsch 1996, Morgan and Roberts 1999, Michigan Department of Environmental Quality 2000, Balzano et al. 2002, Johnson et al. 2002, Robb 2002).

Actual replacement ratios that were achieved for the projects studied are also shown in Table 6-8. None of the studies found that the required ratios had been realized. In fact, Balzano et al. (2002) determined that forested compensation wetlands achieved only 1/100th of an acre for every acre lost despite the fact that over 2 acres of forested wetland were required. Achieved ratios ranged from 0.7:1 to 1.9:1 (Wilson and Mitsch 1996, Morgan and Roberts 1999, Balzano et al. 2002, Johnson et al. 2002, Robb 2002).

As mentioned in the previous section, replacement ratios typically require greater than 1:1 replacement to factor in the risk of failure. Table 6-8 demonstrates the utility of this approach since all of the studies indicated that the achieved ratios were smaller than those required. All but one of the studies found the achieved ratios were greater than 1:1, though not by a substantial margin. But two of these studies included enhancement of existing wetlands.

Ratios are a tool to address the temporal loss of wetland functions and the historic failure of replicating wetland acreage and functions. The results indicate an inability of compensation projects to achieve their required replacement ratios. It is assumed that this inability reflects the same problems and shortfalls associated with compensation project success and compliance (see Section 6.4).

Table 6-8. Comparison of replacement ratios that were required and achieved.

Location of Study and Reference No.	No. of Projects Evaluated	Replacement Ratio Required	Replacement Ratio Achieved	Comments
Washington (Johnson et al. 2002)	24	2.2:1[a]	1.87:1 [a]	Enhancement accounted for 65% of the established acreage
Washington (Johnson et al. 2000)	45	5.9:1 [a]	NA	Acreage predominantly preservation and enhancement
Washington (Kunz et al. 1988)	35	0.66:1	NA	Corps and EPA data 1980 to 1986
Michigan (Michigan Department of Environmental Quality 2000)	76	1.82:1 (average)	NA	Required ratios ranged <1:1 to >5:1; study did not include enhancement
Indiana (Robb 2002)	31	2.5:1	1.1:1	Achieved ratios for specific Cowardin classes ranged from 0.48:1 for PFO to 45:1 for POW; study did not include enhancement
Ohio (Wilson and Mitsch 1996)	4 (5)	1.5:1 (1.7:1) [a]	1.4:1 (0.7:1) [a]	Study reviewed 5 projects, results and conclusions focus on 4; parentheses reflect results for all 5
New Jersey (Balzano et al. 2002)	75	1.8:1 (average) 2.04:1 PFO 2.78:1 PSS 1.85:1 PEM 1.07:1 POW	0.78:1 (average) 0.01:1 PFO 0.91:1 PSS 1.29:1 PEM 0.28:1 POW	Sites proposing POW did not achieve the required acreage. However, POW was on sites that did not propose to have open water; thereby resulting in three times more POW acreage than required
Tennessee (Morgan and Roberts 1999)	47	2.7:1	1.9:1	Ratio = 0.88:1when enhancement and preservation are excluded

NA = not available

PFO = palustrine forested; PSS = palustrine scrub-shrub; PEM = palustrine emergent; POW = palustrine open water

[a] Calculated from data provided.

6.6.3 Approaches for Determining Replacement Ratios

King et al. (1993) proposed a framework for calculating replacement ratios, “based on the idea that compensatory mitigation involves trading one form of environmental capital for another and that full compensation requires increases in environmental functions and values from the compensation wetland that are sufficient to make up for the decline in functions and values resulting from the loss of existing wetland.” The authors mentioned five parameters to consider when determining an appropriate replacement ratio.

- The pre-existing level of wetland function per acre at the site proposed for wetland compensation. In the case of enhancement, this ensures that an applicant does not get mitigation credit for functions that were already being provided by a pre-existing wetland.
- The maximum level of function anticipated to be provided by the wetland compensation project.
- The number of years after construction that will be required for the wetland compensation project to reach its anticipated or sustainable level of function.
- The number of years between the loss of the original wetland and the completion of construction of the compensation wetland (temporal loss). Mitigation could be done concurrent with impacts, in advance, or delayed after impacts occur.
- The likelihood that the project will not achieve its anticipated level of function.

King et al. (1993) suggested entering the values for each of the five parameters into an analytic model that then calculates an appropriate compensation ratio for the project-specific information provided. King and Bohlen (1994) provided easy to use tables of replacement ratios that would result from a variety of values for the five parameters identified above. Using parameters comparable to King et al. (1993) for determining appropriate compensation, Rheinhardt et al. (1997) described an approach based on function assessment. The authors proposed the following steps.

1. Develop a function assessment method for the specific regional conditions, including identification of reference wetlands.

2. Assess wetlands proposed to be lost, thereby determining the level of each wetland function that will be lost.

3. Assess potential compensatory mitigation sites to evaluate their current level of function and predict future conditions and levels of function that would result from mitigation activities within the timeframe required for regulatory monitoring.

4. Calculate ratios for compensation for each function “by dividing the degree to which a function is reduced through project alteration by the degree to which a function is increased through restoration” (Rheinhardt et al. 1997).

The ratio "varies among functions and is influenced by (1) the magnitude to which any given function occurs at a project site both before and after the site is altered, (2) the magnitude to which any given function occurs at a compensatory mitigation site both before and after restoration is applied, and (3) the rate at which any given function is restored" (Rheinhardt et al. 1997). The goal of this approach is not just to ensure no net loss of wetland functions but also to restore wetland ecosystems (Rheinhardt et al. 1997).

In contrast, Breaux and Serefiddin (1999) argue that "there has not been any single, universally accepted assessment procedure to determine wetland functions and values (Kusler 1997)." As a result they suggest that "the quantitative measure of area provides a degree of certitude that should be taken advantage of" (Breaux and Serefiddin 1999). In other words, assessing or determining the level of functions provided by a wetland can be time-consuming to near impossible, while acreage provides an easy measurement. The authors mention a few conditions that may require greater than 1:1 replacement ratios (for example 2:1 or 3:1):

1. *If it is determined that the area lost includes functions and values of high quality…*

2. *If… the replacement area is outside the watershed, sub-watershed, or county;*

3. *If the replacement area involves a high risk of failure or uncertain outcome,*

4. *If there are high temporal losses…*

5. *If the habitat loss is likely to be substantially greater than the creation of new habitat; or*

6. *If the connection between two wetland sites is severed or a large site is divided* (Breaux and Serefiddin 1999).

Robb (2002) also proposed using an acreage-based system for determining appropriate replacement ratios. However, where the previous studies did not base ratios on the type of wetland, his system focused on developing replacement ratios for each Cowardin class. This approach resulted from a delineation of 31 compensatory mitigation sites in Indiana. Robb (2002) compared the required acreage of each Cowardin class with the acreage that was established. For example, results indicated that 71% of the required acreage of palustrine forested wetlands was not established (a 71% rate of failure). The ratio recommended to overcome this failure was calculated by dividing the required acreage by the acreage actually established. Using these data, the ratio for palustrine forested wetlands should therefore be 3.5 acres of compensation for every acre of wetland lost. The rationale was that for every 3.5 acres constructed that were intended to be palustrine forested wetland, 1 acre would actually become forested wetland. Proposed ratios for other wetland types included:

- 1.8:1 for scrub-shrub
- 7.6:1 for wet meadow
- 1.2:1 for shallow marsh
- 1:1 for open water

Robb (2002) conceded that his study did not consider the quality of the compensation wetlands or whether they replaced the functions lost. The author mentioned that more regulatory follow-up could result in more successful projects and therefore lower replacement ratios.

6.6.4 Summary of Key Points

- Replacement ratios provide a means of taking into account the potential failure and temporal loss of functions as well as the potential change in acreage or functions to be provided by the compensation project.
- Several methods are available to calculate replacement ratios on a case-by-case basis. Examples of some of the criteria used to determine ratios include the functions proposed to be provided at the compensation site, the functions anticipated to be lost at the impact site, size, landscape position, and relative chance of success.
- Required replacement ratios vary from one state to another, based on the type of compensation proposed, and based on project-specific circumstances.
- Studies found that compensation projects did not achieve their required replacement ratios. In some cases this resulted in less than 1:1 acreage replacement.

6.7 Replacement of Wetland Acreage

This section summarizes the results of studies examining whether compensatory wetland mitigation is replacing the acreage of authorized wetland losses. Replacement of wetland acreage is similar to “no net loss,” which refers to a goal for the nation and Washington State to ensure there will be no overall net loss in acreage and function of the remaining wetland resource base (The Conservation Foundation 1988, McMillan 1998). The no-net-loss goal, however, “does not mean that no further wetlands will be lost; rather, that mitigation and non-regulatory restoration will offset wetland losses” (McMillan 1998). Replacement of wetland acreage, on the other hand, focuses on wetland losses and gains associated with compensatory wetland mitigation.

Replacement of wetland acreage provides a measurable and consistent method for evaluating and comparing the effectiveness of compensatory mitigation programs (Kusler 1988). The scientific literature contained two types of information on this topic.

- Studies that evaluated how well permitting programs (e.g., Section 404) achieved replacement of wetland acreage. Most of these studies used information from permit files and databases.

- Studies that evaluated how well compensation projects achieved the replacement of wetland acreage on the ground. These studies were conducted in the field and typically involved the delineation of wetland boundaries.

6.7.1 Programmatic Evaluations of Acreage Replacement

Programmatic evaluations, in contrast to most of the studies mentioned thus far, are not concerned with the effectiveness of individual compensatory mitigation projects. Instead, programmatic evaluations focus on whether a permitting agency or permit program is requiring sufficient wetland acreage compensation to replace the authorized wetland losses occurring over a specified time.

In a programmatic evaluation, wetland acreage replacement is determined by comparing the acreage of wetlands lost, or adversely altered, with the acreage of wetlands required for compensatory mitigation in a specific geographic area. These evaluations typically rely on information from permit files and databases, rather than verification of on-the-ground, as-built conditions.

Five studies examined the effectiveness of wetland permitting and compensatory mitigation programs (Table 6-9). The earliest study reviewed Section 404 permit data from Washington, 1980 to 1986, and Oregon, 1977 to 1987, "to describe how permit decisions affect the wetland resource" (Kentula et al. 1992). Results indicated that in Washington 39 acres (16 ha) of wetland were not replaced, while in Oregon 79 acres (32 ha) of wetland were not replaced. The authors also observed, "In Washington, approximately 3 percent of the permits issued required compensatory mitigation" (Kentula et al. 1992).

The results of this study should be considered within the context of the Seattle District Corps of Engineers regulatory program in the early 1980s. The authors of Volume 1 observed that in the early 1980s compensatory mitigation, when it was required, was only required for projects that triggered an individual permit. The threshold for wetland fill under a Nationwide Permit 26 (a general permit for headwaters and isolated waters discharges) was 10 acres (4 ha), therefore an individual permit was only required for projects with greater than 10 acres of wetland fill. Fill of 10 acres or less in isolated wetlands was permitted outright. It is therefore possible to conclude that the 40 acres of wetland identified by Kentula et al. (1992) as "not replaced" very likely represents but a fraction of the total acreage of permitted wetland losses that were not compensated for at that time.

A study of Section 404 permitting from southern California noted that 8 acres (3 ha) of wetland were not replaced (Allen and Feddema 1996). The study also determined that "freshwater wetlands are experiencing a disproportionately greater loss of area and that riparian woodland wetlands are most often used in mitigation efforts. The net result of these accumulated actions is an overall substitution of wetland types throughout the region" (Allen and Feddema 1996).

Two of the remaining studies generally found that permitting programs required a net gain from compensatory mitigation (Table 6-9). Gains in acreage ranged from about 47 acres (19 ha) (Torok et al. 1996) to nearly 197 acres (80 ha) (Holland and Kentula 1992). However, the study of the effectiveness of the New Jersey Freshwater Wetlands Protection Act (Torok et al. 1996) mentioned compensatory mitigation acreage only for individual permits. It was not clear from the article if any of the 3,003 general permits, resulting in over 600 acres (243 ha) of wetland loss, required any compensatory mitigation. Furthermore, Holland and Kentula (1992), in their evaluation of Section 404 permitting in California, noted that data on acreage of impacts and compensation were lacking in about 40% of the permit files.

The fifth study focused on the Norfolk Corps District (Jones and Boyd 2000). The authors indicated that new wetland acreage produced by creation or restoration did not fully replace the permitted wetland losses, thereby resulting in a loss of about 260 acres (105 ha) (Jones and Boyd 2000). However, preservation, mitigation bank credits, and substantial in-lieu fee contributions provided additional compensation. If acreages from all types of compensatory mitigation are included, the authors assumed there was a gain of at least 1,500 acres (607 ha). Despite the fact that only 24% of the permits required compensation, the authors concluded that replacement of wetland acreage was achieved, at least on paper (Jones and Boyd 2000).

The results (Table 6-9) indicate that since the early 1980s, permitting programs have required an increasing amount of acreage to compensate for wetland losses. It can be inferred that permits from the mid-1980s did not require the replacement of acreage for wetland losses, whereas permits from the mid- to late 1990s appear to have required replacement of wetland acreage.

Table 6-9. Permitted wetland loss compared to required wetland compensation.

Location of Study	No. of Permits	Wetland Area Lost	Area of Compensation Required	Comments
Washington (Kentula et al. 1992)	35	152 acres (61.4 ha)	112 acres (45.5 ha) created	Section 404 permits 1980-1986
Oregon (Kentula et al. 1992)	58	183 acres (73.9 ha)	103 acres (41.8 ha) created	Section 404 permits 1977-1987
California (Holland and Kentula 1992)	324	2,907 acres (1,176.3) ha	3,103 acres (1,255.9 ha)	Section 404 permits 1971-1987; data on acreages was often lacking

Location of Study	No. of Permits	Wetland Area Lost	Area of Compensation Required	Comments
California/ southern (Allen and Feddema 1996)	75	199 acres (80.5 ha)	191 acres (77.3 ha) completed	Section 404 permits 1987-1989; permits required 276 acres (111.6 ha) of compensatory mitigation
Norfolk Corps District (Jones and Boyd 2000)	1692	863.8 acres (349.6 ha)	538.6 acres created (218.0 ha) 65.5 acres restored (26.5 ha) 1,537.2 acres preserved (622.1 ha) 200.8 bank credits $2,574,966 in lieu fee	Section 404 permits 1996-1998
New Jersey (Torok et al. 1996)	3003 (107)	602 acres (243.8 ha) *164 acres (66.5 ha)*	NA *171 acres (69.2 ha) created;* *41 acres (16.5 ha) restored*	New Jersey Freshwater Wetlands Protection Act permits 1988-1993. *Numbers in italics are individual permits; all other numbers are state general permits.*

6.7.2 Project-Specific Evaluations of Acreage Replacement

Studies that examined the effectiveness of compensation projects often assessed whether the projects achieved replacement of wetland acreage. The assessment generally involved determining how much wetland acreage the compensation projects provided. The wetland compensation acreage produced on the ground was then compared to the acreage of wetland loss associated with those projects. If the compensation acreage was less than the wetland acreage lost, a net loss of wetland occurred. Seven studies analyzed compensatory wetland mitigation project data to determine whether replacement of wetland acreage was achieved.

Four studies either focused on creation or restoration, or they did not mention the type of compensation. The studies noted that the acreage of wetland compensation was less than the acreage of wetland loss by as much as 34%, thereby resulting in a net loss of up to 8 acres (3 ha) (Gwin and Kentula 1990, Allen and Feddema 1996, Wilson and Mitsch 1996). However, a study conducted for the South Florida Water Management District found that creation and restoration activities resulted in 106% of the wetland acreage lost—a net gain of almost 65 acres (26 ha) of wetlands (Erwin 1991).

One issue that emerges when considering replacement of wetland acreage is the use of enhancement and preservation as wetland compensation. Three studies noted that enhanced or preserved wetlands accounted for 45 to 65% of the acreage of compensation (Shaich and Franklin 1995, Morgan and Roberts 1999, Johnson et al. 2002). In Washington nearly two-thirds of the established acreage of compensation involved enhancing existing wetlands, while creation and restoration of wetland area replaced only 65% of the permitted wetland losses (Johnson et al. 2002).

Some authors discounted the acreage provided by enhancement and preservation. Enhancement and preservation are often not included in determining net loss or gain because neither type of compensatory mitigation produces any new wetland acreage (Breaux and Serefiddin 1999). When acreage provided by enhancement and preservation are disregarded, three studies found wetland losses of 22, 11, and 24 acres (9, 4, and 10 ha) respectively (Shaich and Franklin 1995, Morgan and Roberts 1999, Johnson et al. 2002). This equaled 58, 12, and 41% of the authorized wetland losses, respectively (Shaich and Franklin 1995, Morgan and Roberts 1999, Johnson et al. 2002).

6.7.3 Summary of Key Points

- Programmatic evaluations have documented an increase in the acreages of wetland compensation required since the early 1980s. However, the acreage of wetland replacement may include preservation, enhancement, or both.
- Project-specific data revealed that compensation wetlands did not replace the acreage of wetlands that were lost. Even larger losses occurred if the acreages of enhancement and preservation were discounted.

6.8 Functions and Characteristics Provided by Created, Restored, or Enhanced Wetlands

This section describes the functions and characteristics provided by wetlands created, restored, or enhanced for compensatory mitigation and non-regulatory projects.

- The capacity of created and restored wetlands to provide wildlife habitat for invertebrates, amphibians, and birds. Wildlife habitat was evaluated through direct observations or evidence of wildlife use, the presence of structural indicators, or comparison to reference wetlands.
- The ability of created, restored, or enhanced wetlands to develop plant communities and vegetative characteristics. Studies involved comparisons with reference wetlands and investigations of factors affecting vegetation.
- The importance of soil conditions, particularly as they relate to establishing vegetation and improving water quality. Soil properties of created and restored wetlands were compared with reference wetlands.
- The ability of created and restored wetlands to provide water quality functions.
- The importance of water regime and how the creation and enhancement of compensation wetlands can result in atypical water regimes.

The scientific literature indicated that the ability of compensatory wetland mitigation projects to perform wetland functions is not noticeably different from that of non-regulatory restoration or creation projects. Newly implemented wetland sites face similar challenges and develop in similar ways regardless of whether they were legally required or voluntarily initiated.

Refer to Chapter 2 of this document for a discussion of the functions that wetlands provide.

In Section 6.8, use of the terms "**significant**" and "**significantly**" implies statistical significance that was determined by the authors of the specific study being discussed.

6.8.1 Wildlife Habitat

Most articles focused on the ability of a created or restored wetland to provide habitat for one specific guild or group of animals, such as invertebrates, amphibians, or birds. Information on other habitat functions provided by created or restored wetlands was lacking.

6.8.1.1 Invertebrates

Several studies have compared the invertebrate communities of created or restored wetlands with those of reference wetlands. Most of these determined that reference wetlands were more diverse, had greater taxon richness, or had higher density of species than created or restored sites (Brown et al. 1997, McIntosh et al. 1999, Fairchild et al. 2000, Dodson and Lillie 2001). One study, however, found "no convincing differences" in fly (dipteran) densities between created and reference wetlands (Streever et al. 1996). None of these studies were conducted in the Pacific Northwest. However, the results should be broadly applicable to wetlands anywhere.

The age of the wetland, or the amount of time elapsed since restoration occurred, was an important factor influencing invertebrate taxon richness, abundance, and/or diversity (Brown et al. 1997, Fairchild et al. 2000, Dodson and Lillie 2001). For example, "insects with aerial dispersal capability rapidly colonized the restored habitats, but some less mobile forms (non-insects and some hemipterans [true bugs]) either colonized more slowly or not at all" (Brown et al. 1997). Dodson and Lillie (2001) determined that a newly restored site would require 6.4 years for the zooplankton taxon richness to resemble that of a minimally disturbed reference wetland.

The growth and development of vegetation also appears to affect invertebrate communities (Chovanec 1994, Brown et al. 1997, Chovanec and Raab 1997, McIntosh et al. 1999, Fairchild et al. 2000). For example, certain predatory groups of beetles were early colonists at young sites with limited development of vegetation, while herbivorous beetle groups occurred at older sites after specific types of vegetation had developed (Fairchild et al. 2000). McIntosh et al. (1999) concluded, "wetlands at different successional stages may contain very distinct aquatic macroinvertebrate assemblages which may be important to the food web and other functional processes of wetlands."

6.8.1.2 Amphibians

The amphibian habitat present in created or restored wetlands has been compared with that of reference wetlands in several studies. On the east slope of the Cascade Range in the Teanaway and lower Swauk River drainages of Kittitas County, Quinn et al. (2001) found no difference in species richness of amphibians between created and reference wetlands, "although sample sizes may have been too small for differential species-use patterns to emerge." Other authors determined that created and restored wetlands differed from reference wetlands in terms of amphibian community structure, species richness, or stomach content (Bursey 1998, Lehtinen and Galatowitsch 2001, Pechmann et al. 2001).

Though created or restored wetlands provide habitat for some amphibian species, conditions within the wetland and conditions outside the wetland may limit productivity, dispersal, colonization, or all three. Conditions within a wetland that appear to affect amphibian communities include hydroperiod, substrate, presence of emergent vegetation, presence of fish, and the availability of an invertebrate prey source (Bursey 1998, Baker and Halliday 1999, Monellow and Wright 1999, Pechmann et al. 2001).

Conditions outside of a restored or created wetland that affect amphibian communities include distance to other wetlands, connectivity between habitats, and the land use of the surrounding terrestrial habitats (Baker and Halliday 1999, Monellow and Wright 1999, Lehtinen and Galatowitsch 2001, Pechmann et al. 2001). For example, Baker and Halliday (1999) observed that two species of amphibians dispersed to new ponds only if they were within 1,312 feet (400 m) of an existing pond, while two other species colonized new ponds up to 3,117 feet (950 m) from an existing pond.

Monellow and Wright (1999) concluded, "The interconnectiveness of amphibian habitat is an essential element in sustaining amphibian populations because it allows amphibians to overcome large population fluctuations and recolonize areas where populations have been extirpated."

Lehtinen and Galatowitsch (2001) found that the wetlands restored in urban areas had the lowest amphibian species richness. However, authors of a study of wetlands created in a recreational area in an intensively used urban site near Vienna, Austria observed all seven of the amphibian species known to occur in the area. As many as six species were breeding (Chovanec 1994).

6.8.1.3 Birds/Waterfowl

All of the studies that examined the ability of created or restored wetlands to provide habitat for birds focused on non-regulatory projects. Therefore this section does not contain information on the ability of compensatory wetland mitigation projects to provide habitat for birds. However, the information is still relevant based on the similarity of results among compensatory and non-regulatory projects for the other studies of functions. None of the studies cited below were conducted in the Pacific Northwest.

Studies comparing bird use of created or restored wetlands and reference wetlands demonstrated variable results, perhaps indicating that site-specific conditions influence bird use. For example, two studies found no difference in bird abundance between restored and reference wetlands (Brown and Smith 1998, Ratti et al. 2001), while two other studies determined that reference wetlands had greater bird species richness and abundance (Delphey and Dinsmore 1993, Dobkin et al. 1998). Brown and Smith (1998) found no difference in bird abundance or the number of bird species observed. However, they did determine that the bird communities differed by a statistically significant margin and that density was greater at reference wetlands (Brown and Smith 1998). Regardless of the findings for bird populations in general, two studies noted that ducks had similar or greater abundance, species richness, or density at created and restored wetlands (Delphey and Dinsmore 1993, Ratti et al. 2001).

In the literature, the main factors that appeared to affect wetland use by bird populations were:

- The percent cover of emergent vegetation (Belanger and Couture 1988, Hemesath and Dinsmore 1993, VanRees-Siewert and Dinsmore 1996)
- The density and abundance of invertebrates (Belanger and Couture 1988, Cooper and Anderson 1996)

Though the age of the wetland did not directly affect overall bird populations at created and restored wetlands, VanRees-Siewert and Dinsmore (1996) noted that the richness of breeding bird species was significantly greater at older restoration sites. The composition of the bird community changed with age. Both of these effects were associated with an increase in the emergent vegetation in older wetlands.

6.8.2 Plants

6.8.2.1 Comparisons with Reference Wetlands

This section discusses studies that compared the vegetation of created and restored wetlands to that of reference wetlands. The studies examined a variety of parameters in a number of states and found variable results. Only one study determined that there was no difference in vegetation between created/restored and reference wetlands (Brown 1991). Two studies were conducted in the Pacific Northwest.

In the metropolitan area of Portland, Oregon, reference wetlands differed significantly from mitigation wetlands in terms of floristic composition. Mitigation wetlands had higher overall plant species richness, higher average percentage of native species, and significantly higher average occurrence of introduced and invasive/introduced species than reference wetlands (Magee et al. 1999).

Another study was conducted in the northwestern Great Basin on land that had previously been grazed by cattle. The study found that "sedge cover, forb cover, and foliage height diversity of herbs were greater" on reference plots, in which livestock had been excluded for more than 30 years. "[B]are ground, litter cover, shrub cover, and shrub foliage height diversity were greater" on restored plots, in which livestock grazing pressure had been removed prior to commencement of the study (Dobkin et al. 1998). During the four-year study period, restored plots experienced an increase in grass, forb, rush, and cryptogamic cover, but sedge cover did not change. The authors concluded, "the lack of change in sedge and shrub cover on open [restored] plots suggests that restoration to a sedge-dominated meadow will not happen quickly" (Dobkin et al. 1998).

Restored prairie pothole wetlands were found to lack low prairie and wet meadow zones that reference wetlands possessed. Restored wetlands had significantly higher richness of submersed aquatics and greater coverage by mudflat and open water (Delphey and Dinsmore 1993, Galatowitsch and van der Valk 1995, Galatowitsch and van der Valk 1996). The researchers concluded that restored wetlands are not likely to develop the sedge meadow and wet prairie zones present in reference wetlands (Galatowitsch and van der Valk 1995, VanRees-Siewert and Dinsmore 1996).

Other authors determined that reference wetlands exhibited greater percent cover by wetland species. However, created wetlands had species richness that was equal to or greater than reference wetlands (Moore et al. 1999). Restored wetlands had significantly lower wetland index values (indicating that wetland species were providing more of the total vegetative cover) than reference sites (Brown 1999).

One could hypothesize that created and restored wetlands have greater vegetation species richness due to the level of disturbance associated with creation and restoration and the broad range of niches created on a new site. For example, a newly created or restored site is like a *tabula rasa* (a blank slate) upon which species will be planted (installed or seeded), species from the previous habitat on the site will re-emerge, and species adapted to disturbance will colonize.

6.8.2.2 Cowardin Classes Provided by Compensatory Mitigation Wetlands

Cowardin class refers to a method used to categorize wetlands based on the dominant type of vegetation (Cowardin et al. 1979), as well as other factors. The main Cowardin classes used to categorize freshwater wetlands are:

- Emergent
- Scrub-shrub
- Forested
- Aquatic bed
- Open water (though not technically a Cowardin class, open water is often used to map and describe unvegetated areas of inundation)

Several studies evaluated compensatory wetland mitigation sites to determine which Cowardin classes were being established. Nearly all of these studies found that compensatory mitigation resulted in more acreage of open water/aquatic bed/deep marsh than was originally lost or required (Kentula et al. 1992, Shaich and Franklin 1995, Bishel-Machung et al. 1996, Magee et al. 1999, Cole and Brooks 2000, Michigan Department of Environmental Quality 2000, Balzano et al. 2002, Johnson et al. 2002, Robb 2002).

For example, in Washington State over 16 acres (6 ha) of open water/aquatic bed wetlands were gained (Johnson et al. 2002). In the Portland metropolitan area of Oregon, 29 acres (12 ha) of open water were gained (Shaich and Franklin 1995), and Indiana gained over 3 acres (1 ha) of open water/deep marsh/aquatic bed (Robb 2002). Compensatory wetland mitigation projects in New Jersey generated 50 acres (20 ha) more open water than was required (Balzano et al. 2002).

Results for other Cowardin classes were more variable. For example, four studies noted either a loss of forested wetland area (4 to 8 acres [2 to 3 ha]) or an inability to establish this wetland class (Shaich and Franklin 1995, Bishel-Machung et al. 1996, Brown and Veneman 2001, Balzano et al. 2002, Robb 2002). On the other hand, a study from Washington State observed a net gain of over 12 acres (5 ha) in forested/scrub-shrub wetlands (Johnson et al. 2002).

Additional variability occurred in the balance of emergent wetlands. Two studies from the Pacific Northwest noted a loss of 35 to 51 acres (14 to 21 ha) for emergent wetlands due to their conversion to other Cowardin classes (Shaich and Franklin 1995, Johnson et al. 2002). Studies from other states, meanwhile, found that emergent wetlands were established more successfully than other wetland classes (Bishel-Machung et al. 1996, Brown and Veneman 2001, Balzano et al. 2002). Though the studies did not mention whether the emergent wetlands were dominated by native vegetation, Brown and Veneman (2001) noted "plant communities in replicated wetlands differed significantly from those in wetlands they were designed to replace" in terms of the number and percent cover of species in general and the number and percent cover of wetland species.

Compensatory mitigation may often result in a different wetland type compared to what was lost (Shaich and Franklin 1995, Balzano et al. 2002, Johnson et al. 2002, Robb 2002). For example, if an open-water pond was provided as compensation for an authorized impact to a wetland pasture, a change in wetland type occurred. If the compensatory mitigation was enhancement and involved constructing an open water pond in another wetland pasture, a second change in wetland type occurred.

The studies examining changes in Cowardin classes at compensation wetlands found a net increase in open water/aquatic bed habitats (Shaich and Franklin 1995, Balzano et al. 2002, Johnson et al. 2002, Robb 2002). Though the reasons for this change are not clear for all studies, several studies indicated that open water/aquatic bed resulted from an inability to establish the proposed Cowardin class (Balzano et al. 2002, Robb 2002). One could assume that another reason may be that open water is relatively easy to establish given adequate hydrologic conditions. Furthermore, the authors of Volume 1 have observed situations in which the wetland mitigation design was intended to maximize a limited space by providing a variety of habitat niches, and open water is often considered a key habitat niche for waterfowl. Therefore, it is possible to conclude that regulatory decisions may have been biased toward the construction of more open water/aquatic bed/emergent wetland complexes in order to achieve an enhancement of functions in a limited space.

Studies from Washington and Oregon reported a net loss of emergent wetlands (Shaich and Franklin 1995, Johnson et al. 2002). However, many wetlands in the Puget Lowlands of Washington and the Willamette Valley of Oregon that are classified as emergent are wet pastures dominated by non-native grasses. Johnson et al. (2002) noted that 90% of the emergent acreage lost or converted was pasture dominated by non-native species. It can be assumed that much of the current area of emergent pasture may historically have been forested wetland. Therefore, one can conclude that converting pastures into other wetland types with a greater diversity of hydroperiod and more structural complexity, such as forested wetlands, may represent an opportunity for a net increase in wetland functions over time, compared with leaving the wet pastures unchanged.

6.8.2.3 Factors Affecting Plants

Several major factors influencing wetland vegetation have emerged from the literature:

- Soil and soil disturbance
- Age of the wetland
- Competition and non-native vegetation
- Seed or plant source
- Human manipulation

The studies summarized in this section looked at different parameters in different types of wetlands across the country; therefore, the results are highly variable.

Soil and Soil Disturbance

Five studies indicated that soil conditions at the created or restored wetlands influenced vegetation composition (Brown 1991, Ashworth 1997, Brown and Bedford 1997, Stauffer and Brooks 1997, Brown 1999). Three of these studies discussed the positive effects of adding salvaged or donor hydric soil to created or restored wetlands. Benefits included increased species richness (Brown 1991, Stauffer and Brooks 1997) and significantly higher number and percent cover of wetland species (Brown and Bedford 1997). Stauffer and Brooks (1997) concluded that more organic matter in the hydric soil improved the retention of moisture and nutrients, thereby helping to increase plant cover, density, and species richness. Another study, involving dike removal to restore a site, observed that disturbance of the soil resulted in vegetation dominated by cattails (Brown 1999).

Age of the Wetland

The effect of age on the vegetation of created and restored wetlands was noted in various studies (Reinartz and Warne 1993, Magee et al. 1999, Moore et al. 1999). Created and restored wetlands less than three years old differed, in terms of floristic composition, from sites three years and older (Reinartz and Warne 1993, Magee et al. 1999). Older sites had higher mean total plant cover and mean cover of native wetland species (Reinartz and Warne 1993). Moore et al. (1999) found that age, in addition to sedimentation, resulted in:

- A decrease in open water and water depth
- An increase in emergent and woody cover
- An increase in the number of plant species
- An increase in wetland vegetation species richness

In western Washington, Celedonia (2002) investigated the age at which canopy convergence occurs. The study found that "aerial [woody] cover increases with age until year 8 and remains constant into years 10-11." The author noted, "80% cover is generally achieved by year 8, and perhaps as early as year 7." The study found that the most abundant species in terms of frequency and cover were red alder (*Alnus rubra*), willows (*Salix spp*.), black cottonwood (*Populus balsamifera*) and red osier dogwood (*Cornus sericea*). In addition, Celedonia (2002) found that native woody cover was strongly correlated with the density of stems greater than 6.5 feet (2 m) tall, such that percent cover increased as stem density increased up to about 2,100 stems per acre. Sites with densities higher than 2,100 stems per acre generally had greater than 90% woody cover (Celedonia 2002).

Competition and Non-Native Vegetation

The effect of competition on vegetation has been examined in several studies. The studies focused on specific species or treatments used to manage vegetation, factors that affect competition with non-native species, and the presence and extent of non-native species on compensatory wetland mitigation sites.

A few of the studies were conducted outside of the Pacific Northwest, and may have limited applicability to Washington State. For example, in the southeastern United States McLeod et al. (2001) determined that an existing willow canopy did not detrimentally affect the survival of three under-planted tree species. In the Midwest, Budelsky and Galatowitsch (2000) experimented with hairy sedge (*Carex lacustris*). The authors concluded, "*C. lacustris* can produce dense stands under a primarily annual weed community within two to three growing seasons, but that reed canary grass (*Phalaris arundinacea*) can preclude successful establishment of *C. lacustris*" (Budelsky and Galatowitsch 2000).

In the western Washington, Celedonia (2002) found that reed canary grass (*P. arundinacea*) can exist at relatively high densities (as much as 40% aerial cover) under abundant canopy cover (>95%). This study was not able to determine: 1) whether reed canary grass was actually spreading through the understory, or whether it was a remnant, and woody species were establishing 'over' it; or 2) the extent to which reed canary grass inhibits establishment of desirable plant species during the re-initiation of the understory (Celedonia 2002).

Research has identified two factors that affect competition with non-native species.

- **Shrub density.** Celedonia (2002) observed, "greater shrub layer densities were associated with less reed canarygrass." The author suggests that an initial planting of a very dense shrub layer (e.g., more than 3,000 stems per acre) may help to preclude domination of reed canarygrass (*Phalaris arundinacea*).

- **Land use.** Magee et al. (1999) found that "the number of introduced and invasive/introduced species per site increases significantly with more intensive land use."

A few studies investigated how many compensation projects experienced problems with invasive species or how many non-native species occurred on sites. In Washington State, Johnson et al. (2002) noted that 61% of compensatory mitigation sites had at least 25% of the site dominated by non-native species. Celedonia (2002) found that nearly half of the sites visited in Washington had greater than 10% cover of reed canarygrass. In a study conducted by the Michigan Department of Environmental Quality (2000), "8% of mitigation sites were found to have a problem with invasive species" (defined as constituting 10% or more of the vegetation community).

In the Portland metropolitan area of Oregon, a study of vegetation at compensatory mitigation wetlands observed that non-natives composed more than half of the species present and "nine of the 14 most common taxa were invasive introduced species" (Magee et al. 1999).

Seed or Plant Source

The seed or plant source has been identified as important for restored wetlands (Reinartz and Warne 1993, Galatowitsch and van der Valk 1995). Restoration wetlands seeded with native wetland species had higher diversity and richness and less cover by cattails than the unseeded wetlands (Reinartz and Warne 1993). Emergent perennial species rapidly recolonized restoration wetlands possessing a viable refugium of wetland plant species (e.g., present in existing ditches) that spread through vegetative rooting (Galatowitsch and van der Valk 1995). The importance of proximity to a seed source was mentioned by Reinartz and Warne (1993) but discounted by Galatowitsch and van der Valk (1995).

Kellogg and Bridgham (2002), however, found that low density planting "offered no clear advantages over hydrologic restoration." Though seeding of a cover crop appeared to limit the establishment of aggressive species such as *Phalaris arundinacea*, it also appeared to limit establishment of wet prairie and sedge meadow species (Kellogg and Bridgham 2002).

Human Manipulation

A study conducted in the Willamette Valley of Oregon examined the response of wetland vegetation to three techniques for the restoration of wet prairie: burning, hand removal, and mowing (Clark and Wilson 2001). Results indicated that:

- **Burning** significantly reduced the survival and percent cover of woody species and non-native forbs (e.g., common St. John's-wort [*Hypericum perforatum*]), increased flowering of slender rush (*Juncus tenuis*), and increased cover of native forbs (e.g., Spanish-clover [*Lotus purshiana*] and marsh speedwell [*Veronica scutellata*]), but decreased flowering of tufted hairgrass (*Deschampsia cespitosa*), the dominant wetland prairie grass.

- **Hand removal** significantly reduced cover by woody species and non-native forbs, increased cover of native forbs, but increased flowering of non-native grasses (e.g., velvet grass [*Holcus lanatus*] and sweet vernal grass [*Anthoxanthum odoratum*]).

- **Mowing** had no effect on cover of woody species, but it increased the flowering of non-native grasses and significantly increased flowering of slender rush.

The authors concluded that though "no treatment was clearly superior in fulfilling the restoration objectives" mowing with removal of cut material was specifically not recommended (Clark and Wilson 2001).

6.8.3 Soil Characteristics

Soils are a critical component of wetlands. Soil characteristics can influence the growth and development of vegetation as well as the ability of wetlands to perform certain water quality functions. Researchers have investigated several factors related to wetland soil characteristics at compensatory wetland mitigation sites, including:

- Organic matter content
- Bulk density (compaction)
- Particle size
- Nitrogen content

Several authors used the approach of comparing soil conditions of created wetlands with reference wetlands. In these studies, the reference wetlands were either of the same wetland types as the mitigation wetlands, or they were adjacent to the mitigation wetlands. Only one study compared treatment plots to control plots at created wetlands. None of the articles on soil characteristics involved non-regulatory projects. Only one was conducted within the Pacific Northwest.

Results consistently indicated that the soil of created wetlands had a lower content of organic matter than reference wetlands (Brown 1991, Bishel-Machung et al. 1996, Streever et al. 1996, Shaffer and Ernst 1999, Whittecar and Daniels 1999, Stolt et al. 2000). Bishel-Machung et al. (1996) found that created wetlands had less organic matter than reference wetlands regardless of the Cowardin class or hydrogeomorphic class.

In the Portland metropolitan area, Shaffer and Ernst (1999) observed that both reference and mitigation wetlands with a high extent and duration of standing water had a lower concentration of soil organic matter. However, the authors also observed a consistent pattern of lower concentrations of organic matter in the soil of mitigation wetlands compared to reference wetlands within the same soil series, texture classes, and associations. Since many of the mitigation wetlands in this study involved construction of a pond in an existing wetland, the authors hypothesized that organic matter in mitigation wetlands is being lost due to the excavation of upper soil layers during project installation (Shafer and Ernst 1999).

In studies examining created wetlands from one to 11 years old and one to eight years old, the age of the created wetlands did not have an effect on organic matter content of the soil (Shaffer and Ernst 1999, Bishel-Machung et al. 1996). Concentrations of organic matter were relatively uniform between surface and subsurface samples. This indicated that accumulation of organic matter was either not occurring or was occurring so slowly it was not detectable (Bishel-Machung et al. 1996, Shaffer and Ernst 1999).

Stauffer and Brooks (1997) examined the effect of adding organic soil amendments to created wetlands. The authors found that plots treated with “salvaged marsh surface” (hydric topsoil) and leaf litter compost contained more organic matter than untreated, control plots. After two growing seasons, soil organic matter remained higher in plots treated with organic soil amendments.

Studies looking at particle size, bulk density, and nitrogen content found that soils in created wetlands had more sand, higher bulk densities (more compacted), and a lower nitrogen content than reference wetlands (Bishel-Machung et al. 1996, Whittecar and Daniels 1999, Stolt et al. 2000). In combination with low organic content, the soil characteristics of created wetlands may hinder plant establishment and growth (Whittecar and Daniels 1999, Stolt et al. 2000), denitrification and pollutant trapping (Stolt et al. 2000), and redox conditions (Bishel-Machung et al. 1996), thereby influencing microbial activity (Whittecar and Daniels 1999).

In contrast, Gilliam et al. (1999) found that redox levels and nitrogen content (in the form of ammonia) at an eight-month-old created wetland were comparable to a reference wetland after the created wetland was inundated. However, pH, phosphorus, manganese, magnesium, and zinc did not change noticeably at the created site. The authors concluded that eight months was “an insufficient period of time for a complete change toward hydromorphic soils.”

6.8.4 Water Quality

Most of the water quality studies investigated the ability of created or restored wetlands to retain sediment, phosphorus, nitrogen, or some combination. One study compared water quality attributes at created and reference wetlands (Streever et al. 1996). None of the studies were conducted in the Pacific Northwest.

6.8.4.1 Comparison of Water Quality at Created and Reference Wetlands

Streever et al. (1996) determined that created wetlands had higher pH and conductivity than reference wetlands. The authors hypothesized that the amount of organic matter in the soil is related to pH and conductivity: "because decomposition of organic material releases CO2, lower pH values would be expected in natural systems with well-developed organic soils. A well-developed organic substrate may isolate surface water from underlying sand and rock, leading to decreased dissolution of minerals and lower conductivity." (See the previous discussion of soil characteristics in Section 6.8.3.)

6.8.4.2 Sediment Removal

Findings related to retention of sediment by created wetlands include the following:

- Wetlands created adjacent to roads were effective at retaining sediment, such that inflow culverts were clogged by accumulated sediment at a couple of sites (Moore et al. 1999).

- Mitsch (1992) found that a created wetland retained 90% of sediments, while a reference wetland retained 3%. The actual amount of sediment retained depends upon the loading rate.

- Fennessey et al. (1994) investigated the location within a created wetland where sediment was retained. Rates of sediment deposition, in general, were highest near the inflow and decreased as distance from the inflow increased, "except when outflow ceased, in which case the maximum sedimentation often occurred near the outfall." Open water areas also had higher sediment deposition than vegetated areas, which restricted flow. The authors observed that vegetation seems to present a barrier to water and sediment flow and, therefore, the study "did not illustrate the conventional belief that the presence of vegetation enhances sedimentation." The authors concluded, "deeper open water areas are more conducive to sediment accumulation than are shallower open water areas that are more easily subjected to wind-driven and biological sediment disturbances and subsequent re-suspension."

6.8.4.3 Nutrient Removal

In several studies, phosphorus retention at created or restored wetlands ranged from 16 to 96% (Mitsch 1992, Mitsch et al. 1995, Niswander and Mitsch 1995, White et al. 2000). In all but one of these studies, created/restored wetlands retained at least 53% of phosphorus (Mitsch 1992, Mitsch et al. 1995, White et al. 2000). The percent of retention varied depending on:

- Whether the wetland experienced high or low flows (Mitsch 1992, Mitsch et al. 1995)
- The configuration of the outflow
- The amount of time water was retained in the wetland (Niswander and Mitsch 1995)

White et al. (2000) mentioned that a restored wetland's capacity for phosphorus retention is limited. Sediments near the wetland inflow had a limited ability for additional uptake of phosphorus. However, approximately 66% of the marsh sediments still had a high capacity for uptake. The authors concluded, "future treatment efficacy may decrease if the remaining sediments become saturated. Continued high P [phosphorus] loading to the marsh may lead to eutrophication problems and downstream P export from the wetland."

Romero et al. (1999) found that total nitrogen retention was 30 to 91% at four restored wetlands. The authors attributed this to the high retention of dissolved inorganic nitrogen, while the retention efficiencies for particulate and dissolved organic nitrogen were much lower. The authors observed no significant difference between nitrogen retention and the age of the restored wetland.

Woltemade (2000) examined the factors that affect the ability of a created or restored wetland to retain nutrients. The most critical design elements for wetlands constructed to treat agricultural runoff were determined to be the retention time (amount of time that water is retained in the wetland) and the wetland-to-watershed ratio (size of the wetland compared to the size of its contributing basin):

> *If nutrient and sediment concentrations are to be reduced to acceptable levels on a landscape scale, drainage water must be retained for at least one to two weeks within wetlands before being discharged into streams. Monitoring of restored wetlands indicates that the longer the retention time, the greater the water quality benefits. . . Ultimately, the appropriate size of a restored wetland will depend on the contaminant of greatest local concern that requires the longest retention time for its degradation, and on the percent reduction of this contaminant that is required seasonally, annually, or interannually (van der Valk and Jolly 1992).* (Woltemade 2000).

6.8.5 Water Quantity

No studies were found that discussed the ability of created or restored wetlands to perform water quantity functions, such as decreasing downstream erosion or reducing peak flows, or that mentioned factors influencing a wetland's ability to perform water quantity functions.

Two studies compared the water regime of compensatory mitigation wetlands with reference wetlands. Both found that the compensatory wetlands had more standing water for a longer period (Shaffer et al. 1999, Cole and Brooks 2000).

6.8.5.1 Using Hydrogeomorphic (HGM) Classification to Study Water Regime at Mitigation Sites

Differences in the water regime between existing wetlands and mitigation wetlands have been examined by several researchers in the Pacific Northwest and elsewhere. The researchers used the hydrogeomorphic (HGM) classification to compare the water regimes of existing wetlands with those of mitigation wetlands. As described in Chapter 2, the HGM classification is based on the position of the wetland in the landscape (geomorphic setting), the wetland's water source, and the flow and fluctuation of the water once in the wetland. These are some of the major environmental factors that control wetland functions (National Research Council 1995).

Gwin et al. (1999) focused on HGM classifications of wetlands to determine how compensatory mitigation was affecting the wetland resource in and around Portland, Oregon. Classification of reference wetlands resulted in three regional HGM classes that were typical in the Portland metropolitan area: slope, riverine, and depressional. However, classification of mitigation wetlands

> *required development of new, atypical HGM classes to describe the unique combinations of site morphology and landscape setting found in these wetlands:*
>
> - *depression-in-riverine setting,*
> - *in-stream-depression, and*
> - *depression-in-slope setting* (Gwin et al. 1999).

Atypical refers to created or enhanced wetlands that do not match the geomorphic setting, water source, and/or hydroperiod found within the range of existing wetlands in a region. Gwin et al. (1999) characterized atypical classes by:

- Exaggerated depressional morphology with steep banks
- Large areas of open and/or deep water
- A large berm isolating the wetland from an adjacent stream channel
- Excavation within the stream channel producing an open water area wider and deeper than the original stream

In Washington 35% of compensatory mitigation projects resulted in wetlands of an atypical HGM class (Johnson et al. 2002). In Portland, Gwin et al. (1999) found that almost all of the enhanced wetlands and nearly half of the created wetlands resulted in an atypical HGM class.

What are the hydrologic consequences of creating atypical wetlands in the landscape? Shaffer et al. (1999) examined hydrologic conditions in reference and mitigation wetlands in the Portland metropolitan area. The study compared the regional HGM classes identified by Gwin et al. (1999)—slope, riverine, and depressional—with the atypical classes for mitigation wetlands—depression-in-riverine setting, depression-in-slope setting, and in-stream-depression. The results indicated significant differences. For example, slope wetlands had the lowest extent, depth, and duration of inundation, "while depression-in-slope wetlands had the highest water levels and greatest extent/duration of inundation" (Shaffer et al. 1999).

Similarly, Cole and Brooks (2000) noted that created wetlands were dominated by open water, while "most naturally occurring mainstem floodplain wetlands in central Pennsylvania are vegetated with very little open water." The authors concluded, "in the rush to make sure there is some water in mitigation wetlands we have gone too far in keeping sites inundated. In reality, many wetlands are merely saturated, or much drier" (Cole and Brooks 2000).

Schaffer et al. (1999) state:

> *Unless wetlands are restored or created in a manner that reproduces the hydrogeomorphic characteristics of naturally occurring wetlands in a region, management activities are unlikely to maintain or replace hydrologic and other valued functions of wetlands.*

Similarly, Cole and Brooks (2000) conclude:

> *The ecological consequences of a different hydrologic regime are clear. Standing water will promote anaerobic conditions in the soil, and the resulting soil chemistry will be defined by anaerobic pathways (Mitsch and Gosselink 1993). When combined with other common construction effects (e.g. soil compaction), this leads to difficult conditions for plant community establishment.*

In addition, water regimes exhibiting extensive areas of open water in mitigation wetlands hindered the formation of soil organic matter (Shaffer and Ernst 1999).

6.8.6 Summary of Key Points

- Functions performed and characteristics produced by created, restored and enhanced wetlands differed from those performed and produced by reference wetlands, except water quality functions, which appeared to be performed in a similar capacity.

- Most studies determined that reference wetlands provided habitat for a greater diversity or abundance of wildlife than created or restored wetlands. Birds were an exception since half of the studies found no difference between created/restored sites and reference wetlands, particularly for ducks.
- A variety of factors appeared to influence the abundance and diversity of wildlife at created or restored wetlands: development of vegetation communities, particularly emergent vegetation communities; age of the wetlands, which is often associated with the development of vegetation communities; and availability of a food source, often invertebrates, which is also often associated with the development of vegetation communities.
- Amphibian communities were affected by additional factors, such as the hydroperiod of the wetland, the presence of fish, distance to other wetlands, connectivity between terrestrial and wetland habitats, and surrounding land uses.
- Created and restored wetlands have different vegetation characteristics and plant communities than reference wetlands. A few studies found that certain plant communities, such as sedge meadows, may require many years to develop, if they develop at all.
- Compensatory mitigation is producing more acreage of open water wetlands than was lost. The ability of compensatory mitigation to produce other Cowardin classes varied.
- Several major factors were found to affect vegetation and plant communities, including the age of the wetland (older created/restored sites had a higher percent cover of emergent and woody species than younger sites); soil conditions (positive effects on vegetation resulted from adding hydric topsoil); competition (reed canarygrass can be problematic when attempting to establish emergent vegetation); and a source of native seeds or plants (this may speed up recolonization and increase diversity).
- Created, restored, and enhanced wetlands had less organic matter than reference wetlands. In addition, organic matter at compensation wetlands did not appear to accumulate over time. Plant establishment at compensation sites could be hindered by the low organic content in conjunction with soils that were found to be sandier, more compacted, and lower in nitrogen than soils at reference wetlands.
- Created and restored wetlands were comparable to reference wetlands at retaining sediments, phosphorus, and nitrogen. Factors affecting sediment and nutrient retention included the volume of water flowing into the wetland, the length of time water remains in the wetland, and the size of the wetland compared to the size of the basin.
- Some compensatory mitigation wetlands produced different HGM classes than were present in reference wetlands. This has resulted in wetlands that have more inundation for a longer duration than reference wetlands.

6.9 Reproducibility of Particular Wetland Types

This section discusses findings from the literature regarding the ability to restore, create, or enhance certain wetland types, such as bogs and fens, vernal pools, alkali wetlands, and mature forested wetlands.

6.9.1 Bogs and Fens

Bogs and fens are characterized by their highly organic soils, water regimes, and water chemistries. There were no studies of bog or fen restoration conducted in the Pacific Northwest. However, studies of bog and fen restoration in Northern Europe and Canada concluded that restoration may not be possible due to "irreversible changes of the biotic and abiotic properties" (Schouwenaars 1995, Schrautzer et al. 1996). This includes soil compaction and eutrophication (Grootjans and van Diggelen 1995, Schrautzer et al. 1996, Wind-Mulder and Vitt 2000) and other alterations to bogs resulting from drainage, peat harvesting, pollution, and agricultural practices (National Research Council 2001).

The studies mentioned difficulties in restoring bog vegetation communities (Bolscher 1995, Grosvernier et al. 1995, Schouwenaars 1995, Schrautzer et al. 1996), water regime (Grootjans and van Diggelen 1995, Schouwenaars 1995), and/or water chemistry (Wind-Mulder and Vitt 2000). Major conclusions include the following:

- Restore the water regime and the vegetation community will follow (Grootjans and van Diggelen 1995, Grosvernier et al. 1995).
- Prior to any restoration activity, the chemical state of the bog must be assessed. This influences the vegetation community and will, therefore, dictate the development of a restoration plan (Wind-Mulder and Vitt 2000).
- "Hydrological research may be crucial for a correct assessment of perspectives for rewetting" (Schouwenaars 1995). Prior to restoration it is necessary to determine the reason for a low water table because this affects the activities that will be required to restore a suitable water regime for the desired vegetation communities (Schouwenaars 1995).
- Bogs that were restored by rewetting and tree removal "differed from those of natural raised bogs, particularly in having taller and denser vegetation, a smaller range of moisture gradient and a more uniform vegetation physiognomy. Rewetted bogs did not have an undulating surface relief of hummocks and hollows" (Bolscher 1995).
- The best chance for restoration lies with restoring the least disturbed or damaged bogs or fens (Grootjans and van Diggelen 1995, Schrautzer et al. 1996).
- Restoration of bogs or fens will not yield rapid results (Grootjans and van Diggelen 1995).

- “Research has demonstrated that natural recovery of the moss surface following harvesting takes about 20 years (Elling and Knighton 1984)” (National Research Council 2001).

In terms of creation, research indicates that in reference systems organic soil (peat) accumulates at 0.1 to 3.8 mm per year (National Research Council 2001). At this rate it would take from 7 to 250 years for just 1 inch of peat to accumulate.

No information was available on the success or compliance of bogs or fens that were restored or created as wetland compensation. However, the literature suggests that bogs and fens cannot be reproduced within a regulatory timeframe.

6.9.2 Vernal Pools

Vernal pools are characterized by their short duration of inundation (National Research Council 2001). Thus, in order to reproduce a vernal pool, a site with a suitable substrate must be found and the correct depth and hydroperiod must be created or restored (National Research Council 2001). “In a long-term study of California vernal pools that were created by excavating depressions near natural pools, the hydroperiods did not converge with those of the reference systems until year 10 (Zedler et al. 1993)” (National Research Council 2001). If the hydroperiod is too long, the result will be an emergent marsh or an open water or aquatic bed system. If the site has inadequate substrate or is too shallow, the result may be upland with no inundation.

In terms of compliance, De Weese (1998) examined over 1,500 created vernal pools in California. She found that 83% of projects were in permit compliance, 96% met their hydrologic performance standards for depth of inundation, and 69% met vegetation performance standards. Seventy-two percent of projects were compared with reference vernal pools to determine their biological viability, while 35% of projects required some site remediation.

Guidance on construction has helped to transform the steep-sided “bathtubs” into pools that more closely mimic reference pools with gradual, vegetated slopes (De Weese 1998). De Weese (1998) concluded, “The art and science of constructing vernal pools have greatly improved over the past eight years [1987 to 1994].”

The literature suggests that, in California, vernal pools may be reproduced under the right conditions. However, the right conditions typically occur where vernal pools already exist, so creation of new pools merely increases the density of pools in an area (National Research Council 2001).

No information was found on the reproducibility of vernal pools in Washington.

6.9.3 Alkali Wetlands

No information was found that addressed the reproducibility of alkali wetlands.

6.9.4 Mature Forested Wetlands

Though studies have found that forested wetlands can be reproduced in Washington (Celedonia 2002, Johnson et al. 2002), *mature* forested wetlands have not been successfully reproduced simply because of the time necessary for the trees and the structural characteristics of the forest to mature (National Research Council 2001). Enhanced and created sites that have been planted often have a high density of stems to rapidly provide woody cover and shade out invasive species in the understory (Celedonia 2002, National Research Council 2001). Within a regulatory time-frame, compensatory mitigation wetlands may not begin to reproduce some of the attributes of mature forested reference wetlands unless these sites are thinned (National Research Council 2001).

6.9.5 Summary of Key Points

- The reproducibility of some wetland types is generally dependent upon time. For example, bogs, fens, and mature forested wetlands require several decades at a minimum, and possibly centuries, to develop the structural, chemical, biological, and hydrological attributes that characterize these wetland types.

- Studies suggest that vernal pools, at least in California, may be reproducible under the right conditions.

6.10 Suggestions from the Literature for Improving Compensatory Mitigation

A number of reports and articles suggested or recommended changes that could be made to help improve the effectiveness of compensatory wetland mitigation or alleviate problems that were frequently encountered. The recommendations described below are those of the authors of the literature sources cited, not the agencies or staff who have synthesized the information in this volume.

Data from a variety of sources are summarized throughout this section in a series of tables. To simplify the tables and efficiently use space, each literature source listed in the tables is represented by a reference number listed in Table 6-10. This is not a comprehensive list of all references cited in this section; see the references section at the end of Volume 1 for a complete list of literature sources.

Table 6-10. Literature sources and corresponding reference numbers.

Reference No.	Literature Source	Reference No.	Literature Source
1	Allen and Feddema (1996)	19	Shaich and Franklin (1995)
2	Balzano et al. (2002)	20	Storm and Stellini (1994)
3	Brown (1999)	21	Ossinger (1999)
4	Ashworth (1997)	22	Wilson and Mitsch (1996)
5	Erwin (1991)	23	Barry et al. (1996)
6	Gwin and Kentula (1990)	24	Castelle et al. (1992a)
7	Holland and Kentula (1992)	25	Celedonia (2002)
8	Holland and Bossert (1994)	26	Chovanec (1994)
9	Johnson et al. (2000)	27	Hunt et al. (1999)
10	Johnson et al. (2002)	28	Kentula (2000)
11	Stauffer and Brooks (1997)	29	National Research Council (2001)
12	Kentula et al. (1992)	30	Race and Fonseca (1996)
13	Kunz et al. (1988)	31	Sheldon and Dole (1992)
14	Shaffer and Ernst (1999)	32	Whittecar and Daniels (1999)
15	Michigan Department of Environmental Quality (2000)	33	Zedler and Callaway (2000)
16	Mockler et al. (1998)	34	Mitsch and Wilson (1996)
17	Morgan and Roberts (1999)	35	Breaux and Serefiddin (1999)
18	Robb (2002)	36	Kellogg and Bridgham (2002)

The scientific literature contained recommendations that fall into three main categories:

- Recommendations for regulators of compensatory mitigation, including guidance on mitigation plans and monitoring reports, compliance tracking and enforcement, and alternative mitigation options
- Recommendations for site selection and design, including comprehensive wetland planning, baseline monitoring, hydrologic analysis, and considerations for site design
- Recommendations for implementing compensatory mitigation, including having a wetland biologist on-site to oversee construction activities, performing monitoring and maintenance of the site

The scientific literature provided more extensive information on additional topics:

- Performance standards
- Compensatory mitigation using a watershed approach
- Mitigation banking and in-lieu fees

Each of these is discussed below.

6.10.1 Regulatory Improvements

Of the suggestions provided by the scientific literature, the majority focused on elements that regulatory agencies should address (Table 6-11), such as:

- Improving guidance for every step of the mitigation process, from avoidance and minimization to submitting a monitoring report for a compensation wetland. This should help regulators with decision-making and provide applicants and consultants with more predictability
- Adjusting replacement ratios to reflect the risk of failure
- Requiring financial assurances or performance bonding
- Protecting all compensatory mitigation sites in perpetuity with a legal mechanism, such as a deed restriction or conservation easement
- Increasing regulatory follow-up and enforcement of compensatory mitigation projects, including developing and maintaining a database and filing system, allocating staff to perform compliance and enforcement activities, and implementing reviews of regulatory program performance
- Developing and implementing alternative mitigation options, such as advance mitigation, mitigation banking, and in-lieu fees

Table 6-11. Suggestions from the literature for regulatory improvement.

Suggestion	Reference No. [a]
Improve mitigation sequencing (i.e., avoidance and minimization)	5, 19, 29, 2, 10
Improve guidance for compensation projects, focusing on replacing functions as well as area	22, 29, 10
Improve site selection criteria. Site selection should be based on a watershed scale to maintain diversity, connectivity, and a balance of upland and wetland	5, 12, 15, 29, 2, 10
Improve goals, objectives, and performance standards, so that they are measurable, meaningful, achievable, and enforceable	13, 5, 31, 20, 19, 17, 9, 29, 10, 21
Standardize report format and elements for mitigation plans and monitoring reports, including an implementation schedule	13, 7, 8, 20, 17, 15, 2, 10

Suggestion	Reference No. [a]
Adjust (increase) replacement ratios to reflect the risk of failure. This should be based on the level of success of previous projects	1, 2, 18
Require performance bonding/financial assurances	13, 5, 8, 20, 15, 29, 2, 18
Require that compensation wetlands be protected in perpetuity with some kind of legal mechanism, such as a deed restriction or conservation easement	20, 29
Improve regulatory follow-up and enforcement of compensatory mitigation projects	5, 20, 19, 1, 30, 17, 15, 9, 29, 10, 18
Develop and maintain a permit/compensatory mitigation project tracking database and filing system	5, 7, 20, 19, 1, 17, 9, 15, 29, 2
Allocate staff for compliance and enforcement	5, 19, 17
Implement regular reviews of regulatory program performance	7, 19, 2
Implement studies of cumulative wetland loss (beyond what is recorded for regulatory permitting programs)	19, 1
Develop and implement alternative compensatory mitigation options: in-lieu fees, mitigation banking	20, 19, 1, 15, 29
Perform the compensatory mitigation in advance of the wetland loss	30, 29, 10, 18
[a] See Table 6-10 for a listing of literature sources that correspond to each reference number.	

6.10.2 Improving Site Selection and Design

The scientific literature also suggested site selection and design considerations (Table 6-12), including:

- Using a watershed approach to improve site selection
- Prioritizing wetland restoration
- Performing baseline monitoring of the wetland to be lost, identifying the wetland types and functions so that they can be replaced more effectively
- Performing baseline monitoring of the areas proposed for compensation to document the existing conditions and level of function
- Performing a hydrologic analysis for compensation wetlands to identify where the water will come from, how it will get to the site, and what the extent and duration of inundation or saturation will be
- Designing the compensation site to be self-sustaining and incorporating or simulating natural processes and structures, such as hydroperiods, slopes, shorelines, soils, topography, and vegetation

Table 6-12. Suggestions from the literature for improving site selection and design.

Suggestions	Reference No.[a]
Ensure that compensation wetlands will have a suitable source of water and compatible adjacent land uses	5, 28, 17, 29, 2, 10
Use a watershed approach to select compensation sites and support comprehensive wetland planning	19, 1, 28, 17, 29, 10
Prioritize restoration as the first choice for compensatory mitigation	17, 15, 29
Design compensatory mitigation wetlands to be self-sustaining and incorporate natural processes whenever possible	33, 29
Perform baseline monitoring of wetlands to be lost and areas proposed for compensatory wetland mitigation. Monitoring should characterize hydroperiod, soils, water quality, macroinvertebrates, and wetland functions	13, 5, 31, 20, 29, 10
Perform hydrologic analysis: identify hydrologic source, how water will get to the site, the intended depth and duration of inundation, and demonstrate that water source will be reliable and adequate Determine appropriate hydroperiod/hydrologic inputs early in the design stage, so that the water levels of the compensation wetland dictate how to design the building sites and roads, rather than letting the upland development create poor wetland conditions (too wet or too dry)	5, 31, 16, 28, 2
Grade slopes to be as gentle as possible; they should match the slopes of adjacent natural wetlands	6
Provide heterogeneous topography. For example, simulate microtopographic "mound and pool" features (e.g., wind-thrown or toppled trees)	23, 29
Incorporate native upland ecosystems into compensatory mitigation sites	5, 29
Deconsolidate (i.e., break-up) soils to reduce compaction and amend to insure adequate soil organic matter (e.g., 2 inches of coarse sand and 4 inches organic compost, natural hydric muck, or topsoil)	6, 16, 28, 32, 14
Take advantage of native seedbanks, natural recruitment, and salvaged topsoil and plants when available and feasible	29, 3, 4, 11
Minimize human encroachment by planting dense vegetation around the site or installing fences	26, 20, 16
Establish rapid canopy convergence and limit invasive species infestations by planting trees and shrubs at specific densities	25
Indicate the boundaries of the site with signs and markers	20, 16
[a] See Table 6-10 for a listing of literature sources that correspond to each reference number.	

6.10.3 Improving Implementation

Compensatory wetland mitigation projects would be greatly improved if they were implemented as designed (Johnson et al. 2000, Balzano et al. 2002). The scientific literature provides numerous suggestions for improving implementation (Table 6-13), such as:

- Having a wetland biologist on-site during construction
- Monitoring the compensation wetland
- Develop an adaptive management plan that allows potential problems to be detected early and identifies how problems will be addressed
- Maintaining the compensation wetland to avoid problems and manage them early in the development of the site

Table 6-13. Suggestions from the literature for improving implementation.

Suggestion	Reference No.[a]
Wetland biologist on-site to oversee construction or train/educate contractors and to authorize and document any necessary changes	5, 31, 9, 2
Monitoring of mitigation sites should characterize baseline, construction, as-built, and post-construction conditions. Monitoring reports should include a section on lessons learned	13, 6, 5, 24, 7, 31, 8, 20, 19, 15, 9, 2, 10
Monitoring parameters and methods should be specific to a project's goals, objectives, and should include: project size, shape, topography, hydroperiod, water quality, flora, and fauna	5, 17, 33
Monitor compensatory mitigation wetlands. Duration of monitoring may range from 3 to more than 20 years, depending on the size of compensation wetland, the proposed wetland type (e.g., Cowardin class), and the likelihood of success	5, 34, 35, 17, 15, 10, 29, 36
Monitor hydrology during the first growing season to characterize the site's hydroperiod. Develop and implement a planting plan after the hydroperiod has been characterized	27
Perform long-term monitoring after a project has been deemed successful to keep track of it over time, study how it matures, use it as model for other sites	5, 28, 36
Develop an adaptive management program, which includes early monitoring of wetland structure, processes, and functions to detect potential problems and allow for corrective actions	29
Maintain compensatory mitigation sites, including a contingency plan for how to address problems. Maintenance should focus on controlling invasive species, providing irrigation, replacing dead plants, correcting slopes and topography	13, 24, 31, 8, 2, 10, 29

[a] See Table 6-10 for a listing of literature sources that correspond to each reference number.

6.10.4 Performance Standards

Performance standards, performance criteria, success criteria, success measures, standards of success, and other terms all refer to regulatory conditions used to determine how effective a mitigation project is at meeting regulatory requirements, which may or may not include compensating for wetland loss. Ideally performance standards should serve as “measurable benchmarks used to evaluate the development of ecological characteristics associated with specific wetland functions” (Azous et al. 1998). Performance standards allow regulators to determine if a compensatory mitigation project has fulfilled its goals, and also provide a mechanism for regulators to implement enforcement actions against unsuccessful projects (Streever 1999).

As explained in Chapter 2, wetlands differ in how they function, by geomorphology and water regime and other characteristics. Compensatory wetland mitigation projects, likewise, exhibit considerable variability with different types of wetland compensation (creation, restoration, etc.). The variability makes it difficult to develop and require universal performance standards, yet in the absence of some kind of uniformity, performance standards that are approved can lack meaning.

6.10.4.1 Shortcomings of Existing Performance Standards

Sheldon and Dole (1992) performed a study of eight compensatory mitigation projects in King and Snohomish Counties in Washington. The authors observed that “none of the goal statements provided a quantifiable method of determining success, thus they provided no means for an agency to assess success/failure or to require remediation.” The Michigan Department of Environmental Quality (2000) similarly found, “The practice of including no specific performance standards, or only very general performance standards (regarding the size and possibly the type of wetland to be constructed), resulted in many unenforceable permits and contributed to the poor quality mitigation wetlands.”

Johnson et al. (2000), in their study of 45 compensatory mitigation wetlands, noted some problems with performance standards, such as:

- Standards that are too general or “easy to attain” and, therefore, are not indicative of ecological development at a site
- Standards that are not measurable and, therefore, cannot be used to evaluate the success or compliance of projects
- Standards that contain confusing or ambiguous language and, therefore, result in inaccurate assessment or preclude assessment

In addition, Johnson et al. (2002) in their evaluation of 24 compensation projects excluded performance standards that were unrealistic, not feasible, or so rigorous that the standard may never be attained. Such standards were “. . .setting sites up for failure” and therefore “. . .did not reflect how the site was functioning or progressing ecologically”

(Johnson et al. 2002). Ossinger (1999), in a guidance document for the Washington State Department of Transportation, suggests that performance standards should strike a balance between accountability and flexibility. The author recommends that crafting performance standards requires a technical knowledge of the quantitative values that are achievable, or to be expected, for the wetland attributes targeted by the standard.

Approved mitigation projects can also lack performance standards for important wetland functions or conditions. Breaux and Serefiddin (1999) discovered in their review of 110 projects in San Francisco, California, that only 22% had quantitative standards focusing on hydrological parameters. Johnson et al. (2000) reviewed 179 performance standards from 36 projects and observed that 8% of the performance standards related to hydrological conditions. The Michigan Department of Environmental Quality (2000) found that "none of the permits examined contained any specific criteria regarding vegetation or hydrology by which the mitigation wetland could be judged for success or failure." Johnson et al. (2002) noted that most of the projects evaluated in their study of 24 compensation wetlands lacked basic standards for wetland area, water regime, area of Cowardin classes, percent cover of native wetland vegetation, and maximum percent cover of invasive vegetation.

Breaux and Serefiddin (1999) argue, "In seasonal wetlands, hydrology clearly ought to be the reigning criterion given that the successive presence and absence of water is the defining characteristic of a seasonal wetland." However, the authors go on to admit, "there is no agreement as to what the specific hydrological criterion should be."

6.10.4.2 Use of Reference Wetlands in Developing Performance Standards

Brinson and Rheinhardt (1996) state that "the proper use of reference wetlands removes potential bias and provides the foundation for more objective functional-assessment procedures…reference wetlands should be central to the development of standards against which impacts to wetlands and restoration efforts are evaluated."

Azous et al. (1998) also support the use of reference wetlands:

> *By collecting data on the ecological characteristics associated with reference wetlands, and created or restored wetlands, standards of comparison can be established by which to judge the development of wetland characteristics in compensatory mitigation projects. The use of regional reference wetland characteristics provide greater assurance that project performance standards will be reasonable (i.e., attainable) and useful gauges of the development of wetland functions.*

For example, a compensation wetland might have a goal to provide amphibian habitat by the end of the monitoring period. Based on an evaluation of 24 depressional, flow-through, reference wetlands in the Puget Lowlands of western Washington, Azous et al. (1998) proposed performance standards to determine if amphibian habitat had successfully been established. "The standards include specific guidelines for planning and designing mitigation projects to provide preference for the establishment of amphibian breeding, feeding, and refuge habitats." The authors suggested the following standard, "Wetlands created for amphibian habitat should have thin-stemmed emergent plants that comprise at least 30% or more of the total wetland area (Azous et al. 1998)."

However, Whittecar and Daniels (1999) mention a problem with using reference wetlands to develop benchmarks or performance standards for compensatory mitigation:

> *[U]nlike the mitigation site, reference wetlands coexist with landforms that may have required thousands of years to form (Brinson et al. 1995). Each wetland has a history that influences modern functions. Many of these functions will not redevelop in the new wetland within a time span acceptable to regulatory constraints without thoughtful planning and careful attention to construction.*

Ehrenfeld (2000) recommends that reference sites be identified in urban areas and used to develop attainable performance standards for compensatory wetland mitigation projects that are also located in urban areas. The author states: "Measures of restoration success and functional performance must start with an appreciation and assessment of the particular conditions imposed by the urban environment."

6.10.4.3 Longer Period Needed to Evaluate Projects

Part of the problem with developing achievable performance standards is that monitoring periods or regulatory timeframes for the majority of compensatory mitigation projects are relatively short (five to 10 years). The "success" or compliance of compensatory mitigation projects is, therefore, determined or evaluated when the site is still relatively young and immature (Kentula 1995, Mitsch and Wilson 1996). Longer monitoring periods are necessary to allow for secondary succession and natural events (e.g., drought or floods) that may affect or restructure vegetation communities (Kellogg and Bridgham 2002). Long term monitoring would also result in larger data sets upon which realistic performance standards and project goals could be based (Kellogg and Bridgham 2002).

If projects are to be evaluated within five to 20 years, then they should be compared to other compensatory mitigation projects. Kentula (1995) suggests comparing "wetland creation and restoration projects to each other and to similar, naturally occurring wetlands to define standards for project performance over time." She describes an approach for developing performance standards based on monitoring information from previous projects. "In this way, we can be assured that new projects are doing at least as well as past projects."

Celedonia (2002) implemented Kentula's approach by conducting a study of 29 compensatory mitigation projects from six to 11 years old in the lowland wetlands of western Washington. Time series curves were created from the data to determine at what point in time projects could be expected to meet certain vegetative standards, such as percent areal cover of woody vegetation. Based on the data, the author proposed that by year eight a mitigation site could attain 80% cover of native woody vegetation.

6.10.5 Compensatory Mitigation Using a Watershed/Landscape Approach

In the context of compensatory mitigation, a watershed approach means:

> *to recognize that management of wetland types, functions, and locations requires structured consideration of watershed needs and how wetland types and location serve these needs. A watershed approach means that mitigation decisions are made with a regional perspective, involve multiple agencies, citizens, scientists, and nonprofit organizations, and draw upon multiple funding sources (e.g., permittee-responsible, mitigation banks, and in-lieu fees). A watershed approach means that permitting decisions are integrated with other regulatory programs (e.g., storm water management or habitat conservation) and nonregulatory programs (e.g., conservation easement programs)* (National Research Council 2001).

Bedford (1996) explained the need for a watershed/landscape approach as follows:

> *From a policy perspective, the central issue in wetland mitigation is not the effects on a single site but the cumulative effect of numerous mitigation decisions on landscapes. Mitigation must be recognized as a policy that has the potential to re-configure the kinds and spatial distribution of wetland ecosystems over large geographic areas. … The net effect is the loss of wetland diversity in terms of both hydrologic functions and biological communities, and a consequent homogenization of wetland landscapes. One way to avoid such cumulative effects is to make decisions about individual projects within a framework focused at larger scales (Lee and Gosselink 1988).*

This section describes recommendations from the literature for methods to implement a landscape or watershed-scale approach in order to improve the success of mitigation projects. Further discussion of restoration using a landscape approach is included in Chapter 7 in the context of addressing cumulative impacts to wetlands.

6.10.5.1 Methods for Implementing a Landscape Approach

Three types of watershed planning are described in a report by the National Research Council (2001):

- **Management-oriented** wetland planning, which would replace case-by-case permitting. Decisions about permitting, mitigation sequencing, and the acreage, type, and location of compensation would be made in advance using a watershed approach. This type of watershed plan would require regulatory and non-regulatory programs to be coordinated.

- **Protection-oriented** wetland planning, which is focused on avoiding wetland loss and alteration by identifying wetlands and their ecological value. This type of watershed plan would be used during the mitigation sequencing process.

- **Compensation** wetland planning, which "identifies watershed needs for types, functions, and general locations of wetlands in the landscape in order to establish restoration priorities for both regulatory and nonregulatory programs. …This type of planning might link projects undertaken through both regulatory and nonregulatory programs to secure some desired mosaic of wetlands in the landscape."

Hashisaki (1996) discusses the utility of a landscape-level analysis to examine conditions not just at an impact, compensation, or reference site, but also in the surrounding landscape. A landscape-level analysis "considers the effect of historic, current, and proposed land management practices on the individual functional indicators. . . . In addition to identifying constraints on land management practices, it can be useful in identifying critical preservation and restoration opportunities. Understanding the control that human activities exert on the disturbance regimes of an ecosystem allows projections about expected future conditions."

Bedford (1996) recommends developing wetland profiles/templates based on the diversity of wetland types that exist in a region as a result of the unique interaction of hydrogeology and climate. By understanding the current and historic wetland types and their relative abundances in a region, decisions regarding compensatory mitigation can be made to help maintain the diversity and hydrologic equivalence.

In some cases, using a watershed approach may result in a watershed plan that identifies all the wetlands in an area and assesses the functions that they perform. Hruby and Scuderi (1995) used this approach for a watershed near Seattle, Washington, that was experiencing development pressure. The goal of the plan was "to ensure that the performance of wetland functions and their societal values continue to be equal to or greater than those currently existing…" (Hruby and Scuderi 1995). Wetland areas targeted for restoration or enhancement were assessed to quantify how much wetland function could be gained. The proposed/potential gain in function through restoration/enhancement could then be used to determine how much wetland function could be lost to development activities in the watershed.

A report by the National Research Council (2001) proposed that "Functional tradeoffs might be considered in the context of the needs of the watershed." A watershed plan would be developed for an area, such that the functions of wetlands proposed for loss or alteration are understood, as well as the needs of the watershed for wetland functions. Functions that are abundant or a low priority in a watershed could be lost and replaced by other functions that are limited or a higher priority in the watershed.

Race and Fonseca (1996) point out that on a national level, a landscape approach to land use and compensation would require the cooperation/participation of thousands or millions of private landowners:

> *Taking a large-scale, ecosystem approach to wetlands management is a significant change in natural resource management policies, one representing a major paradigm shift that will require radical revision in values, management practices, and institutional structures in order to succeed (Cortner and Moote 1994). …Thus, integrating ecologically relevant concepts such as landscape-scale decision criteria need more than good science; it will also require conscious redesign of the entire permitting infrastructure to avoid legal challenges.*

6.10.6 Mitigation Banking

Compensatory mitigation banking and other third-party compensation approaches (in-lieu fee, market-based mitigation) are believed by some to provide part of a solution and have offered new hope for successful compensation of wetland impacts (Kukoy and Canter 1995).

Currently, even when wetlands have been avoided or established as compensation they often "have diminished ecological functions from polluted runoff, from changes in hydrologic regimes, and from the fragmentation of the landscape which isolates the wetlands from the surrounding uplands, water, and biological resources of the watershed" (Shabman et al. 1993).

In addition, some federal, state, and local permits for wetland loss do not require compensatory mitigation because the individual impact is so small that compensation is considered impractical, despite the fact that cumulative losses are occurring (Shabman et al. 1993, Kukoy and Canter 1995, Weems and Canter 1995). Finally, even when compensatory mitigation is required there is no guarantee that it will be implemented or successful.

Shabman et al. (1993) outlined a market solution to improve compensatory wetland mitigation. Market-based mitigation approaches start with an entrepreneurial restoration firm seeking to make a profit from selling a product—a wetland ecosystem. If the product is not of a particular quality then it will not sell. For example, if the wetland bank is not in compliance, not meeting its performance standards, or not providing the proposed functions then the regulatory agencies will not accept credits from the bank as compensation for wetland losses. The permit applicant, therefore, will not purchase the "product" of the wetland bank. This is the incentive for the restoration firm to establish a functioning wetland ecosystem.

In addition, a restoration firm can take the time to find a suitable location for the wetland that will minimize problems with fragmentation (Kukoy and Canter 1995). Wetland banks can also secure large sites for restoration that would not be feasible on a small project scale (Weems and Canter 1995).

Once the wetland is established, credits or tradable portions of the wetland can be made available for purchase to compensate for wetland losses (Weems and Canter 1995), even wetland losses that were previously too small to require compensation (Kukoy and Canter 1995). It is assumed that the availability of bank credits for compensation can also provide efficient permitting since the applicant would not have to worry about getting a mitigation plan approved, and regulators could more readily assess the effectiveness of the compensation.

Mitigation banking in Washington State has been more thoroughly discussed in the *Draft Programmatic Environmental Impact Statement: Washington State's Draft Rule on Wetland Mitigation Banking* (Driscoll and Granger 2001, available at: http://www.ecy.wa.gov/biblio/0106022.html). For additional information on mitigation banking and in-lieu fee programs refer to *Banks and Fees: The Status of Off-Site Wetland Mitigation in the United States* (Environmental Law Institute 2002).

6.10.7 Summary of Key Points

- The scientific literature provided suggestions for improving virtually every aspect of the mitigation process from regulatory guidance and policies to specifications for controlling invasive vegetation.
- Suggestions included measurable, meaningful, achievable, and enforceable performance standards; better sites that provide increased benefits due to their location within a watershed; better monitoring of compensatory mitigation wetlands; and measures to increase regulatory follow-up of compensation projects.

6.11 Chapter Summary and Conclusions

Wetland compensatory mitigation has been studied in Washington and elsewhere in the United States for the past 15 years. Considerable data are available to evaluate the effectiveness of compensatory mitigation.

The majority of compensatory wetland mitigation projects described in the literature was neither fully successful nor completely unsuccessful. Most projects were found to have an intermediate level of success. While most compensatory mitigation projects were installed, compliance of the projects with permit requirements was generally low. The authors of Volume 1 hypothesized that this was due to shortfalls of wetland acreage, failure to achieve performance standards, and a lack of monitoring and maintenance. The few studies that examined the effect of regulatory follow-up suggested that it had a positive influence on the level of compliance and success for compensatory wetland mitigation projects.

There is a general lack of information about the relative effectiveness of the various types of compensation (e.g., restoration, creation, enhancement, etc.). Creation is generally the most frequently used type of compensation, but studies of its effectiveness produced mixed results. Enhancement of wetlands was also frequently used, but few studies examined its effectiveness. Limited studies from Washington indicated a low level of success among enhanced wetlands, primarily due to a minimal gain in functions. Restoring wetlands was noted as a high priority, but as a type of compensation it is not frequently used.

Preservation and a mixture of compensation types appear to be used occasionally. Studies provided limited information on the effectiveness of these types. Two studies from Washington indicated that mixed compensation projects had a higher level of compliance than creation or enhancement, and all mixed projects were moderately successful. The lack of data regarding the effectiveness of preservation is problematic since one of the only studies to look at its effectiveness determined that one large site was predominantly upland habitat. On the other hand, if a site can be confirmed as wetland, or if a mosaic of wetland and upland is determined to be acceptable, preservation of existing wetlands offers no risk of failure and no temporal loss of wetland functions, which are inherent in the other types of compensation. Preservation does, however, result in a net loss of wetland area and possibly functions.

Replacement ratios attempt to equalize the trade-off between the wetland being lost and the wetland being provided as compensation by accounting for the risk of failure and temporal loss of functions. Required replacement ratios vary from one state to another, based on the type of compensation proposed, and based on project-specific circumstances. Replacement ratios actually achieved through compensation were less than what was required, which is to be expected since the ratios are meant to encompass a certain level of failure. However, in some cases this resulted in less than 1:1 acreage replacement.

Studies relying solely on permit files and databases indicated that permitting programs have improved over time in terms of wetland acreage required for compensation. However, studies which relied on site visits and field analyses indicated that compensatory wetland mitigation has resulted in a loss of wetland acreage.

Functions performed and characteristics produced by created and restored wetlands differed from those performed and produced by reference wetlands, except water quality functions, which appeared to be performed in a similar capacity. None of the studies compared the functions provided by compensation wetlands with the functions provided by the wetlands that were lost.

For the most part, reference wetlands provided habitat for a greater diversity or abundance of wildlife than created or restored wetlands. Birds were an exception since half of the studies found no difference between created/restored sites and reference wetlands, particularly for ducks. Created and restored wetlands have different vegetative characteristics and plant communities than reference wetlands. Certain plant communities, such as sedge meadows, may require many years to develop if at all.

The authors of Volume 1 conclude that the common finding that wetland compensation sites have greater vegetation species richness is linked to the broad range of niches created on a new site. A newly created or restored site is a “blank slate” upon which species will be planted, species from the previous habitat on the site will re-emerge, and species adapted to disturbance will colonize. Over time the site will stabilize and mature and only the species adapted to the resulting conditions will remain. However, research on restored, created, or enhanced sites that have stabilized is currently lacking. One could infer, therefore, that sites are not studied for a long enough time, due either to the relatively short regulatory timeframe or the decades or lifetimes necessary to achieve stabilization and maturity.

Researchers observed that created, restored, and enhanced wetlands had less organic matter than reference wetlands. This could be due to the excavation of surface soil layers during project construction. Studies also indicated that organic matter at compensation wetlands did not appear to accumulate over time. Therefore, plant establishment at compensation wetlands could be hindered by low organic content in conjunction with soils that were found to be sandier, more compacted, and lower in nitrogen.

Compensatory mitigation is producing more acreage of open water wetlands than was lost. The ability of compensatory mitigation projects to produce other Cowardin classes varied. Some compensatory mitigation wetlands have produced different HGM classes than were present in the reference wetlands. This has resulted in wetlands that have more inundation for a longer period than reference systems.

Some unique types of wetlands, such as bogs, fens, and mature forested wetlands, may not be reproducible, especially not within current regulatory timeframes. Other wetland types, such as vernal pools, may be reproducible given the right conditions.

The literature provided numerous suggestions on virtually every aspect of the mitigation process. Key suggestions include:

- Improving regulatory guidance on a variety of topics, such as measurable, meaningful, achievable, and enforceable performance standards for compensatory mitigation
- Finding better sites that provide increased benefits due to their location within a watershed
- Monitoring compensatory mitigation wetlands more effectively
- Implementing measures to increase regulatory follow-up of compensation projects

The literature suggests that some improvements have been made in compensatory mitigation over the past two decades, particularly in terms of what is required. However, overall success and permit compliance have not noticeably improved. Most studies indicate that created and restored wetlands do not provide the same characteristics or level of functions as reference wetlands (water quality functions may be the exception).

Since the effectiveness of compensatory mitigation remains highly variable and somewhat questionable, it is increasingly important to understand the cumulative effects of the continuing loss of wetland acreage and functions. This will be addressed in the next chapter.

Chapter 7

Cumulative Impacts to Wetlands and the Need for a New Approach

"Evidence in increasing that the most devastating environmental effects may result, not from the direct effects of a particular action, but from the combination of individually minor effects of multiple actions over time." (Council of Environmental Quality 1997)

7.1 Reader's Guide to This Chapter

This chapter introduces the concept of "cumulative impacts" to represent the incremental losses and degradation of wetlands that continue in spite of all the existing regulatory and non-regulatory actions we are taking to protect them. The chapter discusses different types of cumulative impacts and the loss of wetland area as the most easily assessed measure of cumulative impacts. It goes on to present some of the causes of cumulative impacts in Washington.

The synthesis of the scientific literature in Chapters 2, 3, and 4 has clearly established that wetlands do not function in isolation from the landscape that surrounds them. A wetland's ability to provide certain functions is influenced by the conditions and land uses within their contributing basins, especially by the patterns of water flow and movement that can be changed by different land uses. Existing wetland regulations usually are structured so decisions are made on an application by application basis. There are no provisions for assessing or considering the implications of individual decisions on the resource in general. The information presented in previous chapters demonstrates that project-by-project decisions cannot adequately address the complexities of wetland systems, and new approaches are needed to reduce the continued impacts to wetlands.

7.1.1 Chapter Contents

Major sections of this chapter and the topics they cover include:

Section 7.2, Loss of Wetlands as an Indicator of Cumulative Impacts describes the total wetland losses in Washington and three studies in the Pacific Northwest that illustrate more recent loss.

Section 7.3, Types of Cumulative Impacts describes how cumulative impacts result from disturbances related to geography and time that are not adequately managed. It lists types of cumulative impacts such as fragmentation and time lags.

Sections 7.4, Causes of Cumulative Impacts in Washington describes how the current approach to wetland management and protection results in cumulative impacts. The causes discussed include case-by-case permitting, lack of consistency between jurisdictions, and implementation of local programs for protecting wetlands through regulations. Different types of cumulative impacts are listed along with examples of possible causes from inadequate protection at the local level.

Section 7.5, Chapter Summary and Conclusions ties together the major concepts presented in the chapter.

7.1.2 Where to Find Summary Information and Conclusions

One summary is provided at the end of the chapter, along with the authors' conclusions. The reader is encouraged to remember that a review of the entire section preceding the summary is necessary for an in-depth understanding of the topic.

7.1.3 Sources and Gaps in Information

Much of the literature published on the topic of cumulative impacts is not specific to wetlands. Most of the research has been focused on environmental processes that affect biodiversity (i.e., habitat loss, fragmentation, metapopulations). The available information is weighted toward the impacts of some types of land use (urbanization and forest practices), with less information available on the impacts from other types of land use (agricultural practices, mining).

The 1997 Council of Environmental Quality report (Executive Office of the President) is a key document on cumulative impacts in general, and it provides a good summary of how land uses can cause cumulative impacts. This document is available on the internet at: http://ceq.eh.doe.gov/nepa/ccenepa/ccenepa.htm . This information can be applied to the protection and management of wetlands in the state.

The information available that specifically addresses wetlands is very general in nature and addresses cumulative impacts to wetlands only in terms of direct loss of wetland area, not the changes in functions that might result from changes in environmental processes at the landscape scale.

There is a significant gap in information regarding the cumulative impacts to wetlands and their functions resulting from the current approaches to managing wetlands at any level of government. The gap regarding the cumulative impacts and local protection programs is especially significant. The legal framework within Washington State (see Chapter 2 in Volume 2), delegates the decisions about land use, including comprehensive planning, designation of zoning, and regulation of critical areas, to local governments. As the information synthesized in Chapters 2-4 of this document has shown, decisions that change land uses can cause impacts to wetlands. However, little research has been conducted on the effectiveness of local efforts in effectively planning for and protecting wetlands, thereby preventing cumulative impacts. Only two studies were found that review the effectiveness of local protection programs for wetlands, and they dealt with specific topics relating to regulations: standards for compensatory mitigation in King County and buffer requirements in the critical area ordinances of local jurisdictions in Washington in 1999 (See section 7.4.3).

Some hypotheses about the effectiveness of local programs, however, can be made by correlating the findings of the relevant literature with different aspects of the regulatory framework for wetlands used by local governments. The scientific information provides ample guidance on what is needed to protect wetland functions (e.g., planning to address and protect landscape processes, providing adequate buffers, modifying current practices of compensatory mitigation). A comparison of this information to the usual standards found in current programs can provide insights about the effectiveness of these programs. If they do not provide the range of measures for protection that are suggested by the scientific literature, it can be hypothesized that those programs may not be providing adequate protection to prevent cumulative impacts and assure long-term sustainability of wetlands.

What are Cumulative Impacts?

Cumulative impact, as defined by the Council on Environmental Quality, "is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time." http://ceq.eh.doe.gov/nepa/regs/ceq/1508.htm#1508.1

Cumulative impacts also have been described by Hemond and Benoit (1988) as follows: "Wetlands are frequently subject to multiple impacts over time and/or space; the effects of such multiple impacts may be simply additive, or the total effect may be more severe than the sum of the effects of the individual impacts alone. Cumulative impact as used here refers to multiple impacts whose effects on the wetland cannot be predicted by simply adding the effects of all the individual impacts."

7.2 Loss of Wetlands as an Indicator of Cumulative Impacts

The loss of wetland area that continues to occur as a result of human activities is a general indicator that cumulative impacts are occurring. A net loss of wetland area and the functions it supports is a measure of the incremental impacts of human activities that are not adequately addressed. At the national level, wetlands continue to be lost, according to a report released by the National Research Council (1995). The U.S. Environmental Protection Agency states that although wetland loss rates are slowing, the United States continues to lose approximately 70,000 to 90,000 acres (28,300 to 36,400 ha) of wetlands on non-federal, rural lands each year (U.S. Environmental Protection Agency 2002).

Here in Washington, the state has lost an estimated 31% of its 1.35 million acres (55 million ha) of wetlands up to the 1980s (Dahl 1990). Recent data on total wetland losses in the state are not available, but three studies in the Pacific Northwest illustrate that the loss of wetlands continues:

- Bell (2002) studied sphagnum-dominated peatlands that were originally mapped by Rigg in the early 1950s in King County. Bell found a 69% loss of these wetlands since 1958. Of 26 sites, six remained relatively undisturbed. Eight showed a decline in acreage and quality of plant communities. Five wetlands are now highly disturbed with no sphagnum moss present. The remaining seven wetlands were either drained or filled. Of the 406 acres (162 ha) present in 1958, only 125 acres (50 ha) remain today. The losses were due to agricultural conversion, development, and peat mining.
- A study of recent losses of wetlands within the Willamette Valley, Oregon, found that from 1981/1982 to 1994 there was a loss of approximately 9,500 acres (3,800 ha) of wetlands, representing approximately a 2.1% loss of wetlands within the Willamette Valley study area. They found that 70% of the loss was attributable to agriculture, 6% was associated with the impacts of urbanization, and 24% was attributable to other unidentified causes (Bernert et al. 1999).
- A study conducted by Holland et al. (1995) in the greater Portland, Oregon, area found that 40% of the wetlands identified in the National Wetland Inventory of 1981/1982 were missing in 1992. They attributed most of the loss to the impacts of urbanization, yet they still attributed 31% of the losses to agricultural conversion. One conclusion of their study was that small, often isolated wetlands were lost due to decisions regarding single-project permits that did not take into account the overall pattern of wetland loss.

In addition to the direct loss of wetlands, alterations have occurred from human activities such as diking, draining, and agricultural practices (Washington State Department of Natural Resources 1998). These changes, even if apparently small on an individual basis, can have a cumulative impact on the functions of wetlands.

7.3 Types of Cumulative Impacts

Cumulative impacts result from the spatial (geographic) and temporal (time) crowding of disturbances that are not adequately managed. The impacts of a disturbance can be compounded when a second disturbance occurs at a site before the ecosystem can fully recover from the effect of the first disturbance (Council of Environmental Quality 1997). The scientific community has not yet agreed on a standard definition or method for assessing cumulative impacts because of the diversity of disturbances, the complexity of environmental processes, and the diversity of impacts possible (Council of Environmental Quality 1997). Nonetheless, the Council was able to identify eight scenarios (types of cumulative impacts) by which cumulative impacts occur (Table 7-1). These types are discussed further in Section 7.4.4 (Table 2) in relation to various causes of cumulative impacts in Washington.

Table 7-1. Types of cumulative impacts (modified from Council of Environmental Quality 1997)

Type of Cumulative Impact	Main Characteristics	Examples of Cumulative Impacts
Time crowding	Frequent and repetitive disturbances before the ecosystem has recovered from previous disturbance	Changes in the water regime that increase the depths of water and duration of flooding that, in turn, drowns vegetation not tolerant to prolonged inundation
Time lags	Impacts of disturbance are delayed from the time the disturbance occurs	Changes in water regime that causes a slow shift in the vegetation to species not suitable as sites for laying amphibian eggs
Space crowding	Impacts are occurring in close physical proximity to each other	Construction of new roads and commercial land uses on opposite sides of a wetland, resulting in increased human disturbances, such as noise, lighting, and less upland habitat
Cross-boundary	Impacts occur away from the source	Eutrophication in wetlands and lakes that results from discharges of nutrients in upper watershed
Fragmentation	Changes in the pattern of ecosystems across the landscape	Construction of a subdivision with roads interrupts the natural pathways used by animals for movement between patches of habitat
Compounding effects	Impacts arising from multiple sources or pathways	A small buffer reduces the upland habitat needed for wildlife that is closely associated with wetlands and that allows intrusion by humans and domestic pets
Indirect effects	Additional disturbances that result from changes in human activities that themselves are a result of the initial disturbance	The additional impacts that result from development after roads or other infrastructure are built. The building of a road has direct impacts but also changes human activities that cause additional ones.
Thresholds and triggers	The accumulation of disturbances causes a fundamental change in the behavior of the ecosystem	Changes in land use result in increased surface runoff that causes streams to become incised. As a result, wetlands become disconnected from the floodplain.

7.4 Causes of Cumulative Impacts in Washington

Some of the causes of cumulative impacts on wetlands stem from how wetlands are regulated in Washington State, and how local governments plan for future land use and development. Local city or county governments generally have the authority to plan for, manage, and otherwise regulate land uses within their jurisdictional boundaries, including those within and adjacent to wetlands. They may regulate what occurs directly in a wetland and, in many cases, they regulate land uses adjacent to a wetland and its buffer (see Volume 2). Federal and state agencies may regulate many direct impacts to wetlands. However, state and federal agencies do not regulate all activities that take place in wetlands and do not regulate land uses in the uplands around a wetland. They also don't provide the comprehensive planning and inter-jurisdictional coordination that affects cumulative impacts. Thus, federal and state agencies that regulate wetlands do not manage, and cannot protect, all wetlands nor many of the landscape processes that influence the functions that wetlands provide.

7.4.1 Case-by-case Permitting as a Cause of Cumulative Impacts

Wetlands in Washington are primarily managed by local jurisdictions through regulations that are implemented on a case-by-case or permit-by-permit basis. Proposed actions are often reviewed and approved without a legal authority or mechanism to assess how previous, relevant decisions may have impacted wetlands and caused cumulative impacts. Each action also is not typically reviewed in the context of impacts to associated landscape processes that may result in cumulative impacts.

On a national level, there is information on the relation between case-by-case decision-making and cumulative impacts. One of the reasons often cited for the failure of site-specific management to adequately protect aquatic resources is the inability of such an approach to address cumulative impacts (Johnston et al. 1990, U.S. Environmental Protection Agency 1999, Dale et al. 2000).

The literature has clearly identified that environmental regulations that are implemented on a permit-by-permit basis have a substantial cumulative impact. This occurs because the permit-by-permit approach fails to identify and account for the landscape processes that create and maintain wetlands (Wissmar and Beschta 1998). In the late 1980s, Bedford and Preston (1988) observed, "The incongruity between the regional scales at which wetland losses are occurring and the project-specific scale at which wetlands are regulated, and also studied, has become obvious." Failure to address the landscape processes results in two types of cumulative impacts (see Table 7-1) that are based on larger, geographic scales - cross-boundary impacts and fragmentation.

Bedford and Preston (1988) note that making decisions on a project-by-project basis fails to evaluate the potential impacts within the spatial and temporal scale within which ecosystems function. They state that, although project-by-project decision-making

> *. . . allows evaluation of the local impacts on resources, it does not allow evaluation of impacts of the project on these resources as a whole, of the total impact on these resources from all anthropogenic disturbances, or of secondary impacts resulting from the interaction of impacts from the project with other anthropogenic disturbances. This is true because the spatial and temporal boundaries of the analysis have not fully enclosed spatial and temporal dynamics of the environmental resources of concern and the anthropogenic activities influencing them.*

These authors recognize that impacts can be generated not only from project-specific actions, but they can also result from actions that occur out of time and outside the vicinity of the activity that may be under scrutiny for a particular project. This results in two types of cumulative impacts described on Table 7-1, time-lags and indirect effects.

Others, such as Everard (1999), are concerned that regulating wetlands and other aquatic resources without considering landscape processes creates the illusion that the resources are being protected by case-by-case management decisions. The ramifications of this misconception include:

- Assumptions by the public that current land-use regulations and management decisions are adequate to protect aquatic systems
- The public perception that protection of aquatic resources is an ongoing financial burden
- The assumption that current regulations are adequate eliminates any incentive or perceived need to assess or modify existing policies and/or regulatory programs

Cumulative effects of decisions made project-by-project: An analogy

Understanding the implication of cumulative impacts from a project-by-project perspective rather than one at a landscape scale may seem abstract given the complexity of how the environment functions in the landscape. The following analogy is offered to provide an alternative description of cumulative effects and the need to manage natural resources using a landscape approach. Credit for the following analogy was given to Gosselink and Lee by Preston and Bedford (1988):

Imagine a Renaissance mosaic of a mother and child, composed of beautiful tiles of various shapes and colors. As it has aged the mosaic has begun to lose tiles. As managers responsible for the mosaic, we have to determine which of the tiles to preserve and reinforce, which to attempt to restore, and which we will allow to be further damaged or even destroyed. Our objective is to attempt to preserve the highest value for the mosaic. Using a tile-by-tile decision method (the project-by-project impacts assessment), each tile would be assessed separately and individually for its intrinsic value. Each decision for a tile would not consider the other nearby tiles, nor even how the tiles fit into the whole image. This strategy would very likely not preserve the image of the mother and child. Yet, it is the image that gives the mosaic its inherent value, not the sum of the individual tiles. If one is to preserve the value of the image, then one needs to be able to determine the relative significance of each individual tile relative to each other tile and to the image as a whole.

7.4.2 Lack of Consistent Plans and Regulations between Jurisdictions as a Possible Cause of Cumulative Impacts

The approach of managing wetlands on a permit-by-permit basis described in the previous section is the best documented cause of cumulative impacts. There are other aspects, however, of the regulatory framework in Washington that can be hypothesized to cause cumulative impacts. A possible source of cumulative impacts is the lack of consistent regulations between jurisdictions to protect and manage landscape processes that occur across jurisdictional boundaries. One jurisdiction may manage water flows from impervious surface, but another one that is further upstream may not manage such flows. Or, one jurisdiction may provide a 200-foot buffer on a reach of riparian wetlands while the adjacent jurisdiction may only provide a 50-foot buffer on the same reach.

In Washington State, most local jurisdictions have development codes that establish the regulatory framework for land use in all areas including wetlands. These codes are based on the objectives developed for each jurisdiction. Adjacent jurisdictions may have quite different objectives for managing the resources and therefore adopt distinctly different codes and regulatory protection. A common inconsistency in regulatory protection is the use of different wetland rating systems that result in variable levels of protection. For example, the city of Tukwila in King County has adopted a rating of wetlands into three categories (Critical Areas Ordinance #2074, December 13, 2004) while King County has adopted a four category rating system (Final Critical Areas Ordinance 15051, Adopted

October 29, 2004). The levels of protection assigned each of the wetland categories is also different. Disparities between rating systems may result in different levels of protection to different portions of the same wetland if it crosses jurisdictional boundaries. It is also quite possible that different buffer widths and different ratios for compensatory mitigation could be required for different parts of the same wetland in adjacent jurisdictions. Such discrepancies therefore can result in cumulative impacts across boundaries.

The failure to address the landscape processes consistently can result in two types of cumulative impacts (see Table 7-1) that are based on larger geographic scales - cross-boundary impacts and fragmentation. The differences in rating systems can result in "cross-boundary" impacts while the example of the different buffers for riparian wetlands would cause impacts from fragmentation.

7.4.3 Implementation of Regulatory Programs at the Local Level as a Possible Cause of Cumulative Impacts

Currently, there is little published information on the possible cumulative impacts that may result from the implementation of regulatory programs by local jurisdictions. For example, there is no documentation on the impacts of:

- Exempting wetlands from protection based on size (e.g., wetlands smaller than ¼ acre are not being regulated at all). Such exemptions can be hypothesized to cause cumulative impacts such as fragmentation and exceeding thresholds of ecosystem viability if there are many small wetlands within a jurisdiction.
- Exempting wetlands based on isolation (e.g., isolated wetlands are those that do not have a surface water connection to other water bodies). Such exemptions can be hypothesized to cause cumulative impacts such as fragmentation and exceeding thresholds of ecosystem viability if there are many isolated wetlands within a jurisdiction.
- Inadequate provisions for protection (e.g., inadequate buffer widths). This can be hypothesized to cause cumulative impacts such as "compounding effect" where an inadequate buffer reduces the habitat for species that need the buffer, as well as by introducing additional disturbances from adjacent development.
- Using standards for compensatory mitigation that are inadequate to ensure replacement of wetland area and/or function. This will result in all types of cumulative impacts because there is a continued loss of wetlands and their functions.

Scientific information synthesized in this document provides guidance on what should be used to effectively protect wetland functions (e.g., landscape approaches, buffers, mitigation standards). See Volume 2 in this two-part series for details regarding specific recommendations. To assess the effectiveness of local programs, we can, therefore, compare the requirements developed by local jurisdictions against what natural resource experts say is needed. The information available suggests that local programs do not provide the level of planning and protection needed to maintain existing functions and address cumulative impacts.

Two studies in Washington provide more direct information regarding this issue. A King County study (Mockler et al. 1998) concluded that standards for compensatory mitigation implemented by the county were significantly less than what was necessary to meet the goal of no net loss of function or area. In addition, data from the Washington State Department of Community, Trade and Economic Development (CTED) addresses the adequacy of buffer requirements by local governments in Washington. The department collects data on the buffer requirements in critical area ordinances of cities and counties in Washington. In the last such survey in 1999 (Chris Parsons, CTED, personal communications 1999, data are available on request from CTED), the buffers for wetlands were considerably narrower than what the scientific information indicates is necessary to protect many functions. Of the 128 jurisdictions in Washington that specify a numeric buffer width, 99 had buffers of 100 ft or less on wetlands that rate high for their habitat functions. The summary of the scientific information provided in Chapter 5 indicates, however, that most habitat functions are not adequately protected by this buffer width.

Additionally, no city or county in Washington has developed and implemented a landscape-based approach to assessing and protecting wetlands. The scientific information summarized by the Ecological Society of America (Dale et al. 2000) and by the Council of Environmental Quality (1997) indicates that a landscape-based approach is necessary to minimize cumulative impacts.

Thus, it is reasonable to hypothesize that existing wetland protection programs, as implemented in Washington, are not adequately protecting wetland functions and values, and cumulative impacts are resulting.

7.4.4 Relating the Types of Cumulative Impacts to Measures Taken by Local Governments

The list of types of cumulative impacts listed in Table 7-1 can be related to inadequacies of the measures taken to protect wetlands at the local level that have been documented or that can be hypothesized. Examples of the different types of cumulative impacts and examples illustrating these inadequacies are provided in Table 7-2. The inadequacies span the realms of planning, coordination, and regulation.

Table 7-2. Types of cumulative impacts and examples of factors at the local level that might cause the impacts.

Type of Cumulative Impact	Main Characteristics	Examples of Cumulative Impacts	Examples at the Local Level That Might Cause This Impact
Time crowding	Frequent and repetitive disturbances before recovery has occurred from previous disturbance	Reoccurring flooding that drowns vegetation that is not adapted to prolonged inundation	Inadequate storm-water regulations that do not address impacts on wetlands of changes in water regime
Time lags	Impacts of disturbance are delayed	Exposure to toxics	No provision for regulating the use of chemicals on residential lawns draining to wetlands
Space crowding	Impacts are occurring in close proximity to each other	Construction of new highways and high-density commercial zones on both sides of a wetland, resulting in increased noise, lighting, and human presence	No provision for planning at the landscape scale that allows the identification and adequate protection of critical landscape linkages between habitats
Cross-boundary	Impacts occur away from the source	Eutrophication in wetlands and lakes that results from nutrient discharges in upper watershed	Lack of coordination among jurisdictions in controlling nutrient inputs to a watershed
Fragmentation	Changes in the pattern of ecosystems across the landscape	Distribution and size of wetlands across the landscape is reduced	No planning at a landscape scale that identifies key landscape processes and incorporates appropriate management options. Permits are issued on a case-by-case basis
Compounding effects	Impacts arising from multiple sources or pathways	Construction of roads, stormwater facilities, and high density commercial development after an approved rezone	The lack of authority to adequately assess potential long-term effects to landscape processes when changing the potential land use of a parcel or area
Thresholds and triggers	The accumulation of disturbances causes a fundamental change in the behavior of the ecosystem	Increased surface runoff causes streams to be incised and wetlands become disconnected from the floodplain	Permit-by-permit decision making precludes the ability to regulate known or anticipated cumulative effects, unless the regulatory framework is in place

7.5 Chapter Summary and Conclusions

Loss of wetland area and alteration of wetland functions due to human activities are indicators that cumulative impacts are occurring. Wetland losses continue to occur on a national level. The few studies done in the Pacific Northwest suggest that losses continue to occur in the region as well.

The Council on Environmental Quality has identified seven types of cumulative impacts: time crowding, time lags, space crowding, cross-boundary, fragmentation, compounding effects, thresholds and triggers.

Some of the causes of cumulative impacts include the following:

- Permit decisions made on a case-by-case basis. The scientific information available has clearly identified that environmental regulations that are implemented on a permit-by-permit basis have substantial cumulative impacts.
- Lack of consistent regulations between jurisdictions. Local governments vary in the protection they provide to wetlands or to different parts of the same wetland if it crosses political boundaries. Therefore, the same wetland may be subject to a variety of policies and regulatory standards. Differing standards can result in cumulative effects and loss of wetland functions across the landscape.
- Insufficient protection at the local level. Most cities and counties in Washington have historically required buffers that are considerably less than what the research indicates are necessary to protect functions.
- The lack of planning at a larger geographic scale. The scientific information shows that a landscape-based approach is needed to effectively manage wetlands. However, no local government in Washington has developed and implemented a landscape-based approach to assessing and protecting wetlands.

Based on the synthesis of the scientific literature, combined with the knowledge of the standards for protection and how land-use decisions are currently made, it can be hypothesized that current protection programs result in cumulative impacts to wetlands.

Improvements in the way wetlands are protected and managed, and therefore how cumulative impacts can be avoided, is the subject of the second volume in this two-part series. It provides guidance in regard to:

- Implementing a four-part framework for protecting and managing wetlands
- Analyzing the landscape and its wetlands
- Using landscape information in developing plans and policies, and incorporating these into comprehensive planning
- Developing and improving tools typically used in local regulations (rating, buffers, compensatory mitigation, etc)

- Developing and improving non-regulatory tools such as preservation, conservation, and restoration
- Identifying the risks from proposed or existing programs
- Implementing programs
- Monitoring wetland protection and management measures that have been implemented, and adapting programs to address the inadequacies identified

The reader is referred to Volume 2 for suggestions regarding solutions to the problem of cumulative impacts.

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The following list of references includes those literature sources obtained, reviewed, and synthesized by the Core Team (See Appendix 1-A) that prepared this document. The list also includes references cited in those portions of “Indicators for Monitoring Biological Integrity of Inland, Freshwater Wetlands” (Adamus et al. 2001) that were adapted for use in this synthesis. The references from the adapted portions of the Adamus et al. (2001) document have not all been obtained and reviewed by the Core Team, but they are included here for the convenience of the reader who wishes to consult the original literature for further information. Not all references listed here are cited in the synthesis. Citations listed as “personal communications” in the text are not listed here since the citation contains the information. The references cited in the appendices are listed here and at the end of each appendix. The authors recognize that the format of the references is not always consistent but that this should not prevent interested persons from locating any of the listed references.

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Glossary

Terms defined in the context of the sentence in which they appear in this document may not be included in the glossary.

Adventitious roots. Additional roots that develop in some plants, such as willows and alders, as an adaptation to saturated or flooded conditions.

Aquatic resources (systems). Refers to ecological systems where the regular or occasional presence of water is the dominant factor determining the characteristics of the site. Aquatic systems are made up of wetlands, rivers, streams, lakes and other deepwater habitats.

Assessment methods. Methods that generate a number representing an estimate of the performance of a wetland function. The number generated is relative to a predetermined standard (e.g., level of function provided by reference wetlands). Numbers do not reflect an actual level of function performance (Hruby 1999). Examples include the Washington State Methods for Assessing Wetland Functions (WFAM) (Hruby et al. 1999 and 2000) and the HGM approach to wetland function assessment (Brinson et al. 1995).

Biological wetland. A biological wetland is a wetland that meets the three parameter criteria of either the 1987 Corps of Engineers Delineation Manual or the 1997 Washington State Wetlands Identification and Delineation Manual (WAC 173-22-035). Compare to jurisdictional wetland.

Bog. A unique type of wetland dominated by mosses that form organic peat. Bogs form in areas where the climate allows the accumulation of peat to exceed its decomposition. Bog hydrology is dominated by precipitation rather than surface inflow. The plant community is specialized to survive in the nutrient-poor and highly acidic conditions typical of bog systems.

Buffers or buffer areas. Vegetated areas adjacent to wetlands, or other aquatic resources, that can reduce impacts from adjacent land uses through various physical, chemical, and/or biological processes.

Canopy cover. The degree to which the foliage of the highest vegetation layer in a plant community blocks sunlight or obscures the sky.

Class. A grouping based on shared characteristics in a classification scheme. In the Cowardin et al. (1979) classification of wetlands a class is the third level in the 'taxonomy' of wetlands whereas in the Hydrogeomorphic Classification (Brinson 1993) it is the highest taxonomic unit.

Compensatory mitigation. The compensation stage of the mitigation sequence where impacts to the functions and values of wetlands are replaced through creation, restoration, or enhancement of other wetlands. Because regulatory requirements and policies tend to focus on the compensation stage, the term "mitigation" is often used to refer to compensation, which is just one part of the overall mitigation sequence. See *mitigation.*

Conductivity. A measure of the amount of dissolved constituents (ions) in water, based on the water's ability to conduct electricity. See *specific conductance*.

Connectivity. The structures on the landscape that facilitate movement of living organisms between patches or their habitat that are found across the landscape. The movement can occur either within the lifetime of an organism or over a period of generations. The purpose of facilitating movement is to maintain viable populations that allow species and communities of species to persist in time. Connectivity can be achieved via a continuous and linear habitat feature (as in a corridor) or discrete habitat patches comprised of but not limited to individual forests, wetlands, shrub lands, and shorelines.

Conservation easement. A restriction placed on a piece of property to protect the resources (natural or man-made) associated with the parcel. It restricts the type and amount of development that can take place on a parcel of land. For example, the landowner may sell or donate the development rights while retaining the ownership of the property. Easements are recorded on the property deed and are held in trust by a conservation easement "holder" such as a land trust or government agency. The holder polices the terms of the easement for the duration of its existence, which is usually into perpetuity.

Contingency plan. A plan outlining actions that would be triggered if monitoring of a project revealed a problem that would prevent the site from attaining its stated goals, objectives, and performance standards. Contingency plans should identify anticipated problems and the specific maintenance activity that would be implemented to rectify each problem.

Contributing basin. The geographic area from which surface water drains to a particular wetland.

Corixids. A group of aquatic insects commonly called "water boatmen."

Corridor: Corridors are areas that contain relatively undisturbed habitat and/or vegetation that maintain connections for wildlife throughout the landscape. Corridors usually represent linear habitats with the range of environmental functions necessary to permit the movement of animals between larger and more fully functioning habitats. Corridors can include but are not limited to, annual or seasonal migration corridors that connect wintering and breeding habitat, or intra-seasonal corridors that connect foraging and nesting habitat or breeding and dispersal habitat.

Cowardin classification. The first commonly used classification system for wetlands developed in 1979 by the U.S. Fish and Wildlife Service. The Cowardin system classifies wetlands based on water flow, substrate types, vegetation types, and dominant plant species.

Cumulative impacts. The incremental effect of an impact added to other past, present, and reasonably foreseeable future impacts.

Deed restriction (definition from legal dictionary). Clauses in a deed limiting the future uses of the property. Deed restrictions may impose a vast variety of limitations and conditions, for example, they may limit the density of buildings, dictate the types of structures that can be erected or prevent buildings from being used for specific purposes or even from being used at all.

Depressional wetland. A *class* of wetlands in the *hydrogeomorphic classification*. These are wetlands that occur in topographic depressions that exhibit closed contour interval(s) on three sides and elevations that are lower than the surrounding landscape.

Dioxin. A group of several hundred chemical compounds that share certain chemical structures and biological characteristics. They include the chlorinated dibenzo-*p*-dioxins (CDDs), chlorinated dibenzofurans (CDFs), and some polychlorinated biphenyls (PCBs). The term dioxin is also used to refer to a well-studied and toxic dioxin, 2, 3, 7, 8-tetrachlorodibenzo-*p*-dioxin (TCDD).

Disturbance. An event that disrupts the processes or structure of ecological systems. Disturbances may occur naturally (e.g., wildfires, storms, floods) or be caused by human actions (e.g., clearing land, building roads, altering stream channels). The effects of disturbances on ecological systems are controlled in large part by their intensity, duration, frequency, timing, and size and shape of area affected.

Ditch. Any channel that has been specifically dug to facilitate drainage.

Drainage systems. Often called basins, sub-basins, watersheds, or river basins depending on the size of the area. In this document, drainage systems are generally referred to using one of two terms: 1. *Watershed.* A geographic area of land bounded by topographic high points in which water drains to a common destination; and 2. *Contributing basin.* A geographic area from which surface water drains to a particular wetland.

Drawdown. A lowering of the ground-water surface caused by pumping.

Dytiscids. Predaceous diving beetles.

Ecoregion. Geographic regions where climatic conditions are similar and the ecosystems (including wetlands) are relatively homogeneous. Omernik and Gallant (1986) mapped the following ecoregions in Washington: Coast Range, Puget Lowland, Cascades, Eastern Cascades Slopes and Foothills, North Cascades, Columbia Plateau, Blue Mountains, and Northern Rockies.

Ecosystem. A loosely defined assemblage of co-occurring organisms and the geographic location which they inhabit. The term is an operational convenience defined by the user of the term for the convenience of description (Levin 2001). There is no basic geographic scale associated with the term ecosystem, and that also has to be defined by a user. For example, the term can be used to describe the micro-organisms co-occurring in a spoonful of soil (soil ecosystem) at one end of the scale to the ecosystem of the world that encompasses all organisms on the planet.

Ecotone. An area that is transitional between two different types of ecosystems and has some of the features of both. Wetlands are often characterized as being ecotones between aquatic and terrestrial ecosystems.

Edge. The boundary where habitats meet or where successional stages of plant communities come together.

Emergence trap. A device placed over the water or sediment in a wetland to capture flying aquatic insects as they emerge from their non-flying larval state into their winged adult form.

Environmental processes. The same as *landscape processes*.

Eutrophication. The undesirable overgrowth of vegetation caused by high concentrations of plant nutrients in bodies of water, especially nitrogen and phosphorous, often as a result of human activities.

Evapotranspiration. The combination of water that is evaporated from the surface and that is transpired from the leaves of plants as part of their metabolic process.

Fen. A type of wetland that is similar to a bog, containing accumulated peat. Fens support marsh-like vegetation including sedges and wildflowers. Fens differ from bogs in their plant communities, hydrology, and water chemistry. They are fed by groundwater and are not as acidic as bogs.

Flats. A class of wetlands in the *hydrogeomorphic classification*. These are wetlands that occur in topographically flat areas that are hydrologically isolated from surrounding ground or surface water. They are primarily maintained by precipitation.

Forb. Any herbaceous plant that is not a grass or sedge.

Forested wetland. A wetland *class* in the Cowardin classification where woody plants taller than 20 feet form the dominant cover. Shrubs often form a second layer beneath the forest canopy, with a layer of herbaceous plants growing beneath the shrubs.

Fragmentation. The breaking up of ecosystems into patches of habitat that are separated by areas altered by human land uses. Fragmentation always consists of both the reduction in the area of the original habitat and a change in spatial configuration of what remains.

Functions. The physical, biological, chemical, and geologic interactions among different components of the environment. See *wetland functions*.

Functional feeding group. A group of animals (aquatic insects, birds, etc) that feed in a similar way. For example, insects that scrape algae from rocks in a stream are called scrapers; those that shred leaf material are caked shredders; and those that filter small particles from the water column are filter feeders.

Furans. A chemical substance resulting from the manufacture of organic compounds, such as nylon.

Geomorphic setting. The topographic location of a site within the surrounding landscape and the geology that underlies it.

Geomorphology. The geologic composition and structure of a landscape—its topography, landforms, soils, and geology.

Hemipterans. A group of insects with straw-like, sucking mouth parts.

Herbaceous (stratum). A layer of non-woody vegetation, usually less than 6 feet (2 m) tall.

Hertz (Hz). A unit of frequency equal to one cycle per second.

Humic. Of or pertaining to humus, which consists of partially or wholly decayed plant matter.

Hydrodynamics. Refers to the movement of water and its capacity to do work. There are three qualitative categories of hydrodynamics: (1) vertical fluctuations of the water levels or water table, (2) unidirectional surface or near-surface flows that range from strong currents contained in channels to slow sheet flow down a slope, and (3) bidirectional flows resulting from tides or wind-driven currents in lakes.

Hydrogeomorphic (HGM) classification. A system used to classify wetlands based on the position of the wetland in the landscape (geomorphic setting), the water source for the wetland, and the flow and fluctuation of the water once in the wetland.

Hydroperiod. The pattern of water level fluctuations in a wetland. Includes the depth, frequency, duration, and timing of inundation or flooding. Patterns can be daily, monthly, seasonal, annual, or longer term.

Impact. Changes to the environment that are caused by human disturbances. Impacts can be either beneficial or detrimental to the ecosystem, environmental process, or species.

Interior (species). Animal species that require the conditions found on the interior of a habitat type and which are subject to disturbance in areas toward the edges of that habitat. For example, forest interior birds find optimum conditions within the center of a forested area where they are not subject to domestic pets, noise, severe weather, or other disturbances that penetrate the outer forest edge.

Jurisdictional wetland. A wetland that is regulated by the provisions of the law under the jurisdiction of one or more federal, state, or local agencies. Not all areas of the landscape that have the biological characteristics of wetlands are regulated or jurisdictional wetlands.

Lacustrine. Pertaining to lakes or lake shores.

Lacustrine (lake) fringe wetlands. A wetland *class* under the *hydrogeomorphic classification*. These are wetlands that occur at the margins of topographic depressions in which surface water is greater than 8 hectares (20 acres) and greater than 2 meters deep in western Washington and 3 meters in eastern Washington.

Landscape processes. Environmental factors that occur at larger geographic scales such as basins, sub-basins, and watersheds. Processes are dynamic and usually represent the movement of a basic environmental characteristic such as water, sediment, nutrients and chemicals, energy, or animals and plants. The interaction of landscape processes with the physical environment creates specific geographic locations where groundwater is recharged, flood waters are stored, stream water is oxygenated, pollutants are removed, and wetlands are created.

Landscape scale. The geographic scale that encompasses the broader landscape (i.e., large areas such as basins, sub-basins, watersheds, and habitat corridors). Also see *site scale* and *large scale*.

Large scale. Large in scope. This term is used specifically to indicate geographic areas that extend beyond the boundaries of an individual site, wetland, or resource. Please note that this term has the opposite meaning when it is used in cartography. Large scale maps are ones that cover a smaller geographic area than a small scale map.

Large woody debris (LWD). Large pieces of downed wood, such as logs, rootwads, and limbs, that are in or near a body of water. LWD provides habitat structure for fish and other aquatic organisms.

Lentic. Having slow moving or still water, such as a pond or lake (as compared to lotic – having running water, such as a river or stream).

Metapopulation. A group of local populations between which individuals can migrate.

Microbe. A microscopic organism, such as a bacterium.

Microhm. A unit of measure describing the resistance of a substance to electrical current.

MilliSiemens. A unit of measure for conductivity. See *specific conductance*.

Mitigation (or mitigation sequencing). Mitigation is a series of actions that requires addressing each action, or step, in a particular order. This sequence of steps is used to reduce the severity of negative impacts from activities that potentially affect wetlands. Mitigation involves the following: 1. Avoiding the impact altogether by not taking a certain action or parts of an action; 2. Minimizing impacts by limiting the degree or magnitude of the action and its implementation, by using appropriate technology, or by taking affirmative steps, such as project redesign, relocation, or timing, to avoid or reduce impacts; 3. Rectifying the impact by repairing, rehabilitating, or restoring the affected environment; 4. Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; 5. Compensating for the impact by replacing, enhancing, or providing substitute resources or environments; and 6. Monitoring the required compensation and taking remedial action when necessary (WAC 197.11.768). See *compensatory mitigation*.

Natural Heritage (Wetlands) (as defined by the Natural Heritage Program of the Washington State Department of Natural Resources). Wetlands that are either high quality undisturbed wetlands or wetlands that support threatened, endangered, or sensitive plant species.

Niche. The area within a habitat occupied by an organism; the set of functional relationships of an organism or population to the environment it occupies.

PCBs. Polychlorinated biphenyls, a type of toxic chemical compound once widely used in electrical equipment. See *dioxin*.

Phreatic zone. The area above the groundwater table.

Redox (potential). Reduction-oxidation potential, or a measure of the potential movement of electrons in a system. Reduction refers to the chemical process whereby molecules of a substance gain an electron. Oxidation refers to loss of electrons. Measuring the redox potential of a wetland soil provides information about the types of chemical reactions that are occurring in the soil, and thus whether the soil is more aerobic (contains oxygen) or anaerobic (lacks oxygen).

Richness. The number of different species of organisms present in a community.

Riparian. The strip of land adjacent to a body of water that is transitional between the aquatic system and the upland. Some riparian areas contain wetlands.

Riverine wetlands. A *class* of wetlands in the *hydrogeomorphic classification*. Wetlands that occur in floodplains and riparian corridors in association with stream or river channels where there is frequent overbank flooding.

Rotifers. Minute organisms that live in fresh and salt water. A crown of hair-like structures (cilia) propels them through the water.

Roughness. The amount of friction or resistance a surface provides against water flow. For example, an area containing shrubs and downed branches has greater roughness than a mowed lawn.

Site processes. Environmental factors that occur within the wetland itself or within its buffer. The interactions of site processes with landscape processes define how a wetland functions.

Site scale. The geographic scale that encompasses the area within the boundary of a single wetland and its immediate surroundings. Also see *landscape scale*.

Slope wetlands. A *class* of wetlands in the *hydrogeomorphic classification***.** These are wetlands that occur on the slopes of hills or valleys. The principal water source is usually seepage from groundwater.

Specific conductance. A measure of electrical conductivity standardized to 25^{o}C. Use of specific conductance accounts for the fact that the conductivity of water changes as its temperature changes. It is measured in units of milliSiemens per centimeter.

Sub-basin. A smaller drainage basin that is part of a larger drainage basin or watershed. For example, the watershed of a large river may be composed of several sub-basins, one for each of the river's tributaries.

Temporal loss (of functions). The concept that there is a time lag between the loss of existing wetland functions through human or natural disturbance and the reestablishment of functions over time.

Tidal Fringe wetlands. A *class* of wetlands in the *hydrogeomorphic classification*. Wetlands that occur on continental margins where marine waters are greater than 2 meters deep and more than 8 hectares (20 acres) in size.

Trophic level. A concept used to describe feeding levels in a foodweb. Plants fill the first trophic level by utilizing sunlight to create carbohydrates and other compounds. Plants are consumed by plant-eating animals (herbivores) in the second trophic level, which in turn become food for predators in the next trophic level, and so on.

Values. See *wetland values***.**

Watershed. A geographic area of land bounded by topographic high points in which water drains to a common destination.

Wetland functions. The physical, biological, chemical, and geologic interactions among different components of the environment that occur within a wetland. Wetlands perform many valuable functions and these can be grouped into three categories: functions that improve water quality, functions that change the water regime in a watershed such as flood storage, and functions that provide habitat for plants and animals.

Wetland rating. Also called a wetland rating system. is a tool for dividing or grouping wetlands into groups that have similar needs for protection. One method used in Washington is the Washington State wetland rating systems (Hruby 2004a,b), which places wetlands in categories based on their rarity, sensitivity, our inability to replace them, and their functions.

Wetland Values. Wetland processes, characteristics, or attributes that are considered to benefit society.

Appendix 1-A
Team Guiding Production of Volume 1

An interagency team (the Core Team) guided all aspects of and participated in the search and reading of the scientific literature, wrote the synthesis, and produced Volume 1. Additional members were added during the production of Volume 2 (see Volume 2).

For Volume 1, the team consisted of staff from the Washington State Department of Ecology, the Washington State Department of Fish and Wildlife, the U.S. Environmental Protection Agency, and Sheldon and Associates, the consulting firm hired to assist with production. Additional Ecology staff served as authors (see the list of authors on the title page of this document). The editor was included on the Core Team in the later stages of production of draft of Volume 1 and was involved through the development of the review draft of Volume 2.

The Core Team included the following individuals (alphabetical by last name):

Teri Granger	Washington State Department of Ecology (coordinator)
Kim Harper	Sheldon and Associates[1]
Tom Hruby	Washington State Department of Ecology
Katherine March	Washington State Department of Fish and Wildlife
Andy McMillan	Washington State Department of Ecology
Sara Noland	2N Publications (editor of the draft)
Ralph Rogers	U.S. Environmental Protection Agency
Dyanne Sheldon	Sheldon and Associates
Erik Stockdale	Washington State Department of Ecology

[1] Currently with the Washington State Department of Ecology.

Appendix 1-B
Characteristics of a Valid Scientific Process

The characteristics of a valid scientific process in the context of “best available science” are defined below, as quoted directly from WAC 365-195-905:

1. ***Peer review.*** *The information has been critically reviewed by other persons who are qualified scientific experts in that scientific discipline. The criticism of the peer reviewers has been addressed by the proponents of the information. Publication in a refereed scientific journal usually indicates that the information has been appropriately peer-reviewed.*

2. ***Methods.*** *The methods that were used to obtain the information are clearly stated and able to be replicated. The methods are standardized in the pertinent scientific discipline or, if not, the methods have been appropriately peer-reviewed to assure their reliability and validity.*

3. ***Logical conclusions and reasonable inferences.*** *The conclusions presented are based on reasonable assumptions supported by other studies and consistent with the general theory underlying the assumptions. The conclusions are logically and reasonably derived from the assumptions and supported by the data presented. Any gaps in information and inconsistencies with other pertinent scientific information are adequately explained.*

4. ***Quantitative analysis.*** *The data have been analyzed using appropriate statistical or quantitative methods.*

5. ***Context.*** *The information is placed in proper context. The assumptions, analytical techniques, data, and conclusions are appropriately framed with respect to the prevailing body of pertinent scientific knowledge.*

6. ***References.*** *The assumptions, analytical techniques, and conclusions are well referenced with citations to relevant, credible literature and other pertinent existing information.*

Information derived from one of these sources can be considered scientific information if it possesses the required characteristics shown in Table 1B-1.

Table 1B-1. Source and characteristics of scientific information.

Sources of Scientific Information	Characteristics: Peer Review	Methods	Logical Conclusions & Reasonable Inferences	Quantitative Analysis	Context	References
A. **Research**. Research data collected and analyzed as part of a controlled experiment (or other appropriate method) to test a specific hypothesis.	X	X	X	X	X	X
B. **Monitoring**. Monitoring data collected periodically over time to determine a resource trend or evaluate a management program.	NA	X	X	Y	X	X
C. **Inventory**. Inventory data collected from an entire population or population segment (e.g., individuals in a plant or animal species) or an entire ecosystem or ecosystem segment (e.g., the species in a particular wetland).	NA	X	X	Y	X	X
D. **Survey**. Survey data collected from a statistical sample from a population or ecosystem.	NA	X	X	Y	X	X
E. **Modeling**. Mathematical or symbolic simulation or representation of a natural system. Models generally are used to understand and explain occurrences that cannot be directly observed.	X	X	X	X	X	X
F. **Assessment**. Inspection and evaluation of site-specific information by a qualified scientific expert. An assessment may or may not involve collection of new data.	NA	X	X	NA	X	X
G. **Synthesis**. A comprehensive review and explanation of pertinent literature and other relevant existing knowledge by a qualified scientific expert.	X	X	X	NA	X	X
H. **Expert Opinion**. Statement of a qualified scientific expert based on his or her best professional judgment and experience in the pertinent scientific discipline. The opinion may or may not be based on site-specific information.	NA	NA	X	NA	X	X

X = Characteristic must be present for information derived to be considered scientifically valid and reliable.
Y = Presence of characteristic strengthens scientific validity and reliability of information derived, but is not essential to ensure scientific validity and reliability.
NA = The characteristic does not apply to the source type. For example, monitoring data are not typically peer reviewed.

Appendix 1-C

Methods Used for Searching and Reviewing the Literature

Searching the Literature

To begin the literature review for Volume 1, personal bibliographies were solicited from a small number of professionals known to have extensive libraries on wetlands in the Pacific Northwest. Other published reference lists were reviewed for relevant documents. In addition to the specified reference lists, computer searches were conducted of databases that are publicly available using a variety of keywords. Table 1C-1 lists the sources of reference lists and the names of the databases searched, as well as the approximate number of documents contained in each source.

Table 1C-2 lists the keywords that were used in the searches of computer databases. This list was developed by the Core Team and expanded based on comments from focus groups (see Chapter 1 for information on focus groups). The searches were done combining the word “wetland” plus one of the keywords. The words in the last column were used to exclude wetland types not covered by this report. Specific wetland types not found in Washington and known to be very dissimilar from Washington wetlands were also excluded, as were estuarine and marine wetlands. Lists resulting from the searches of the computer databases were compiled into a ProCite® database for the project.

Table 1C-1. Summary of reference lists and databases searched for Volume 1.

List Source	Approx. No. of Documents	Notes
Personal Bibliographies		
Dr. Paul Adamus, EPA	1,600	Broad range of documents
Dr. Tom Hruby, WA Ecology	600	Broad range of documents, many focus on wetland functions
Mary Kentula, EPA	170	Focus on wetland mitigation, management, policy effectiveness
Dr. Klaus Richter, King County	3,500	Focus on amphibians w/Pacific NW emphasis
Published Reference Lists		
Management recommendations for WA priority habitats: freshwater wetlands and fresh deepwater (Morgan 1998)	640	Focus on wildlife and aquatic habitats
Management recommendations for WA priority habitats: riparian (Knutson and Naef 1997)	550	Focus on riparian habitats, not necessarily wetlands
Managing for enhancement of riparian and wetland areas of the Western U.S.: an annotated bibliography (Koehler and Thomas 2000)	1,900	Broad application to western U.S.; many documents not relevant to Pac. NW
Classification and management of aquatic, riparian and wetland sites on the national forests of Eastern Washington (Kovalchik 2004)	400	Focus on eastside and forested areas
Effects of urbanization on pond-breeding amphibians: an annotated literature review (Ostergaard 2000)	100	Focus on amphibians and urban effects
Database Searches		
Keyword searches of various databases	9,800	Databases searched included Ovid, ProQuest, Biosis, Dissertation Abstracts, Agricola, Current Contents, Biological Abstracts
Total	**~17,860**	**Total includes an unknown number of duplicates among the various sources**

Table 1C-2. Keywords used in searching computer databases of literature.

Base Word	Keywords		Exclusions
Wetland	Aesthetics	Land Use	Bottomland Hardwood
	Agriculture	Landscape	California Vernal Pools
	Alkali	Maintenance	Estuarine
	Alluvial	Mammals	Intertidal
	Amphibians	Mapping	Lacustrine
	Aquifer Recharge	Mining	Marine
	Arid Land	Mitigation	Mississippi Floodplain
	Artesian	Mollusks	Mudflats
	Birds	Monitoring	Salt Marsh
	Bog	Nutrients	Saltwater
	Buffers	Perched	
	Compensation	Policy	
	Conservation	Public Access	
	Cumulative Impacts	Recreation	
	Development	Regulation	
	Disturbed	Reptiles	
	Dynamic	Residential	
	Economics	Restoration	
	Enhancement	River	
	Erosion	Rural	
	Farmed	Seasonal	
	Fen	Septic	
	Fish	Slope	
	Floodplain	Soils	
	Fluvial	Spatial	
	Functions	Stewardship	
	Geology	Stormwater	
	Geomorphology	Transportation	
	Grazing	Corridors	
	Groundwater	Urban	
	Habitat	Utility Corridors	
	Hydraulic	Values	
	Hydric	Variation	
	Hydrology	Vegetation Types	
	Hyporheic	Vernal Pools (not	
	Industrial	Calif.)	
	Inventory	Water Quality	
	Invertebrates	Water Regime	
	Irrigation	Wells	
	Isolated	Wildlife	

Reviewing, Sorting, and Prioritizing the Reference Lists

All reference lists were reviewed by one or more of the Core Team members. From these lists, the Core Team selected those documents that were determined to be relevant to the project, based solely on the title of the article and its date. Those marked documents were then prioritized using a two-tiered system in which those considered most critical to the project were designated as those to be obtained first. Eventually, attempts were made to obtain all the documents on the lists that were believed to be relevant based on their titles. In addition, references were found while individual authors searched for subjects for which information was lacking. These references are provided in the list of references cited in the report.

Criteria Used to Identify Articles Relevant to the Project

When screening lists of articles, the Core Team used the following criteria to determine, through reading the title and looking at the date, which were relevant to the project and should be obtained. Those that were deemed a "definite yes" were those that were:

- Related to wetland protection and management
- Applied to Washington or the Pacific Northwest
- Were out of region but dealt with land uses
- The only paper on a subject

Those that were rejected out-right were those that were:

- Very old and superceded by newer information
- Related to estuarine and marine systems, which were not going to be covered in the document
- Primarily scientific minutia that weren't useful to managing and protecting wetlands
- Not related because of region
- Related to wetlands and waste-water treatment, which was not going to be covered in the document

Obtaining & Reading Documents & Writing the Report

Of the more than 17,000 documents on all lists used, copies of over 1,400 documents were obtained after review of the titles and dates, as prioritized using the screening process described above. References were skimmed and those dealing with Washington or the Pacific Northwest and with practical application to the protection and management of wetlands were prioritized for reading.

Each reader summarized the article in the ProCite® database. Searches of the database or the original articles were used by each author to write their portions of the draft document. Additional articles were discovered during the course of writing the draft document. These references were not included in the ProCite® database.

The documents used to write the synthesis included scientific journal articles, government publications, technical books, and other sources, all of which meet the definition and characteristics of BAS in WAC 365-195-905 (see Appendix 1-B and Chapter 1). Conference proceedings and personal communications were occasionally used when no other information was available. In most cases, we were unable to ascertain to what level these additional sources were peer reviewed.

For the most part, available documents from the past ten years were used as the primary sources for this report. It was assumed that this more recent literature would incorporate relevant science from the preceding years. Older documents were used in instances where they had not been superseded by more recent studies.

In a few instances, we used unpublished data collected during the calibration of the Washington State wetland function assessment methods and the Washington State wetland rating systems. These data have not been published in scientific journals. However, these observations reported as "unpublished data" in Volume 1, were collected in the field by interdisciplinary teams of wetland experts and used to support and calibrate the assessment methods and the wetland rating system. The methods and rating system have been extensively reviewed and field tested by peer experts, as well as the public. The data were offered for review upon request during public review and continue to be available on request. See Chapter 1 for discussion of the occasional use of hypotheses and assumptions made by the authors based on the literature or their professional experience.

Obtaining References Suggested by Reviewers

A questionnaire was circulated with the review draft of the document. The draft of Volume 1 was reviewed by peer experts. In addition, we invited anyone who so desired to review it. Reviewers were asked to provide additional references that we may have missed, for topics for which we lacked information, or to support suggested changes to the document. Many references were provided and a screening process was used to prioritize and obtain references. See the document containing our responses to comments for a table listing the references that were suggested, the references which were obtained, and notes of explanation for each reference suggested. (The Comments and Responses for Volume 1 can be found at http://www.ecy.wa.gov/biblio/0506007.html.)

Establishing a Repository

The ProCite® database is not available for general use because of technical reasons and the time and money required in making it accessible to a wide variety of users and their varied software programs. However, paper copies of many of the articles reviewed for the synthesis of the science are being held in an archive at the Washington State Department of Ecology. The archive is accessible to the public by appointment.

A number of theses, dissertations, and books are not included in the archive, as well as some articles in private libraries, due to copyright laws and the limited options for purchasing some documents. In these cases, borrowed copies were used and returned, with only the title pages and tables of contents copied for the archive.

Appendix 1-D
Reviewers of Volume 1

Name of Individual or Organization	Affiliation at the Time of Review (if individual)
Paul Adamus, PhD	Private Consultant
Jeff Azerrad, Wildlife Biologist	WA State Department of Fish and Wildlife
Joann Bartlett, PWS	Wiltermood Associates
Doug Beyerlein, PE	Aqua Terra Consultants
Elizabeth Binney, PhD, PWS	ATSI
Catherine Conolly, PWS and Teresa H. Vanderburg, PWS (submitted comments jointly)	Adolfson Associates
Brent Davis, Wetland Biologist	Clark County Community Development Department
Tim Determan, Puget Sound Ambient Monitoring Program Coordinator	WA State Department of Health
Donald F. Flora	Private citizen
Richard R. Horner, PhD	University of Washington
Richard Jack	WA State Department of Ecology
Jim Kelley, PhD	Parametrix, Inc.
Bernard L (Bud) Kovalchik, retired U.S. Forest Service -- Eastern Washington Area Ecologist	Kovalchik Riparian Wetland Consulting
Ivan Lines, Regional Biologist	Ducks Unlimited, Inc.
Scott Luchessa, Certified Ecologist, MS.	Ecological Solutions, Inc.
Chris L. McAuliffe, Ecologist	Private citizen, retired from the Seattle District of the Army Corps of Engineers
Elliot Menashe, Environmental Consultant	Greenbelt Consulting
Jeff Meyer, PWS	Parametrix, Inc.
Jim Mitchell, PE, PWS	Mitchell Consultants L.L.C.
Lyn Morgan-Hill, Natural Resources Specialist	Whatcom County Planning and Development
Francis Naglich	Ecological Land Services, Inc.
Scott Williams, Land Planner	Puget Sound Energy
Klaus Richter, PhD, PWS	King County Department of Natural Resources
Scott J. Rozenbaum, PWS, Certified Professional Soil Scientist	Rozewood Environmental Services, Inc.
Todd Thompson, Fish & Wildlife Program Lead	Spokane District Bureau of Land Mngmt
WETNET (Audubon) Science Committee	
Megan White	WA State Department of Transportation
Bob Zeigler	WA State Department of Fish and Wildlife
Unidentified Individual	

Appendix 2-A

Methods for Organizing and Grouping Information about Wetlands

The following information is adapted from Hruby (1999).

Many groups including federal and state agencies have been developing techniques for analyzing wetland functions ever since wetlands were first subject to regulation in the 1970s. The motivation for developing such methods has primarily been the need to predict the effects of alterations to wetlands and set appropriate requirements for compensatory mitigation.

Methods for organizing knowledge about wetlands have been called classifications, categorizations, characterizations, ratings, assessments, and evaluations. These groupings are meant to indicate the type of information a method provides. Unfortunately, the scientific community has been sloppy in the use of these terms to the extent of misnaming many of the analytical tools developed. Users of methods developed for analyzing wetlands should be aware of some of these problems with definitions. Standard definitions for analytical methods based on Webster's Seventh New Collegiate Dictionary (1963) are described below.

Classification/categorization—a systematic grouping into categories according to established criteria or shared characteristics. The two most common wetland classifications are those of Cowardin et al. (1979), which is based on shared characteristics of vegetation and water regime, and the hydrogeomorphic classification (Brinson 1993b), which is based on shared characteristics of geomorphic setting and water regime. The criteria used for grouping are generally not linked to specific functions, and thus classifications are not true methods for assessing functions. They can, however, provide a basis on which to develop assessment methods (Brinson 1995).

Characterization—a grouping by a distinguishing trait, quality, or property. For example, the Oregon method (Roth et al. 1993) characterizes wetlands by the properties: "provides" a specific function; "has the potential to provide" a function; or "does not provide" a function. These are three distinct attributes that give some information about whether a wetland performs a function, but no information is generated about levels of performance. The Washington State wetland rating systems are characterizations based on five properties (sensitivity to disturbance, rarity, importance, ability to replicate, and relative level of functioning) (Hruby 2004a, b).

Rating—classification based on a grade. Ratings usually group wetlands using the qualitative grades of high, medium, or low on a variety of scales such as the performance of a function or its value. The wetland evaluation technique or WET (Adamus et al. 1987) is probably the most widely used rating method.

Assessment—an estimate or determination of importance or value. This is the first level at which numbers are generated to represent an estimate of performance or value of a function. All commonly used "rapid" numeric methods fall into this category. These methods only provide an assessment that is relative to some predetermined standard. They do not provide an assessment of actual levels of performance or value. The term *assessment* is one of the most commonly misused words in the lexicon of wetland scientists. Almost any method developed is now called an assessment, regardless of whether it might actually be a categorization, a rating, or a true assessment.

Evaluation—a determination or fixing of value. The fixing of value for any item is based on having a generally acceptable currency. Up to now the only currency used has been monetary, and evaluations of wetland functions have most often tried to generate dollar values based on different types of economic models such as the travel cost method, random utility model, hedonic techniques, contingent valuation method (Titre and Henderson 1989, Lipton et al. 1995), or willingness-to-pay method (Farber and Costanza 1987).

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Appendix 2-B
Associations between Species of Wildlife and Wetlands in Washington and Oregon

This appendix shows the level of association between species of wildlife and wetlands in Washington and Oregon in a table. The data are copied directly from the tabulated data on a computer disk provided with Johnson and O'Neil (2001).

Four types of wetland habitat were identified in the document by Johnson and O'Neil. The definitions for these types are summarized below and are from Chappell et al. (2001) and O'Neil and Johnson (2001). Detailed descriptions of the geographic distribution, physical setting, landscape setting, structure, and composition are given in Chappell et al. (2001).

Herbaceous Wetlands (list of species starts on page 4)

Wetlands with the following vegetation types:

- Graminoid Wet Meadow
- Freshwater Aquatic Bed
- Herbaceous and Sedge Wetlands

This habitat is called palustrine emergent wetlands in Cowardin et al. (1979).

Westside Riparian – Wetlands (list of species starts on page 15)

Wetlands with the following vegetation types:

- *Alnus viridis* ssp. *sinuata – Acer circinatum* Shrublands
- Westside Riparian and Wetland Deciduous Forests
- *Picea sitchensis* Wetland Forests and Woodlands
- *Tsuga heterphylla-Thuja plicata* Coniferous Wetlands
- Westside Riparian/Wetland Shrublands
- Shrub/herbaceous Sphagnum Bogs
- Wooded Bogs

This habitat includes all palustrine forested wetlands and scrub-shrub wetlands at lower elevations west of the Cascades as well as a small subset of persistent emergent wetlands, those with sphagnum bogs. However, drier portions of this habitat in riparian flood plains may not qualify as wetlands according to the Cowardin definition.

Montane Coniferous Wetlands (list of species starts on page 29)

Wetlands with the following vegetation types:

- Westside Montane Coniferous Wetlands
- *Picea engelmannii* Forested Wetlands

This habitat includes nearly all the wettest forests within the *Abies amabilis* and *Tsuga mertensiana* zones of western Washington and most of the wet forests in the *Tsuga heterophylla* and *Abies lasiocarpa* zones of eastern Oregon and Washington.

Eastside (Interior) Riparian – Wetlands (list of species starts on page 38)

Wetlands with the following vegetation types:

- Eastside Midmontane *Alnus incana-Salix* spp. Riparian Shrublands
- Eastside Lowland Riparian Shrublands
- Eastside *Populus balsamifera* spp. *trichocarpa*
- *Alnus rhombifolia* Riparian
- *Pinus ponderosa* Riparian Woodlands
- *Populus tremuloides* Riparian/Wetland Forests and Woodlands

This habitat is called palustrine scrub-shrub and palustrine forest in Cowardin and includes some palustrine emergent in the National Wetland Inventory.

Definitions for the Types of Association

(copied from O'Neil and Johnson 2001)

Closely Associated. A species is widely known to depend on a habitat for part or all of its life history requirements. Identifying this association implies that the species has an essential need for this habitat for its maintenance and viability. Some species may be closely associated with more than one habitat; others may be closely associated with only one habitat.

Generally Associated. A species exhibits a high degree of adaptability and may be supported by a number of habitats. In other words, the habitats play a supportive role for its maintenance and viability.

Present. A species demonstrates occasional use of a habitat. The habitat provides marginal support to the species for its maintenance and viability.

The expert panelists developing this list also assigned an overall "confidence rating" to the categorization for each species within each habitat type. The confidence ratings were high (e.g., many peer or published accounts), moderate, and low (e.g., few or no published accounts).

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PLEASE NOTE: The following tables of data do not contain the Latin name of the species. The original tables on Johnson and O'Neil (2001, data on CD) did not have the Latin names although they do have information on each individual species and its Latin name in other databases on the computer disk.

Wildlife Species Found in Herbaceous Wetlands

Amphibians Associated with Herbaceous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Bullfrog	Closely Associated	Feeds and Breeds	High	Requires warm-water ponds, marshes, or river/stream backwaters for breeding.
Columbia Spotted Frog	Closely Associated	Feeds and Breeds	High	Rare or absent where predatory fish or bullfrogs occur. Requires shallow water in wet meadows or stream/pond edges with abundant aquatic vegetation for breeding.
Great Basin Spadefoot	Closely Associated	Feeds and Breeds	High	Requires ponds or temporary rain-filled depressions for breeding.
Long-toed Salamander	Closely Associated	Feeds and Breeds	High	Rare or absent where predatory fish are occur. Requires ponds, shallow lake edges, seasonal pools (like elk wallows) or slow streams for breeding.
Northern Leopard Frog	Closely Associated	Feeds and Breeds	High	Requires ponds or lake edges with dense aquatic and emergent vegetation for breeding.
Northwestern Salamander	Closely Associated	Feeds and Breeds	High	Requires ponds or stream backwaters for breeding.
Oregon Spotted Frog	Closely Associated	Feeds and Breeds	High	Rare or absent where predatory fish or bullfrogs occur. Requires shallow water in wet meadows or stream/pond edges with abundant aquatic vegetation for breeding.
Pacific Chorus (Tree) Frog	Closely Associated	Feeds and Breeds	High	Requires ponds, seasonal pools, temporary rain-filled depressions or slow streams for breeding.
Red-legged Frog	Closely Associated	Feeds and Breeds	High	Requires cool-water ponds, lake edges or slow streams for breeding.
Rough-skinned Newt	Closely Associated	Feeds and Breeds	High	Requires ponds or stream backwaters with abundant aquatic vegetation for breeding.
Tiger Salamander	Closely Associated	Feeds and Breeds	High	Rare or absent where predatory fish occur. Requires warm ponds or shallow lake edges for breeding.
Western Toad	Closely Associated	Feeds and Breeds	High	Requires ponds or shallow lake edges for breeding.
Woodhouse's Toad	Closely Associated	Feeds and Breeds	High	Requires warm, shallow water in ponds, lakes, or slow streams for breeding.
Cascades Frog	Generally Associated	Feeds and Breeds	Moderate	Range limited to Cascade axis fringe. Requires bogs or ponds with cold springs for breeding.

Birds Associated with Herbaceous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
American Avocet	Closely Associated	Feeds and Breeds	High	None noted.
American Bittern	Closely Associated	Feeds and Breeds	High	None noted.
American Black Duck	Closely Associated	Feeds and Breeds	Low	None noted.
American Coot	Closely Associated	Feeds and Breeds	High	None noted.
American Wigeon	Closely Associated	Feeds and Breeds	High	None noted.
Baird's Sandpiper	Closely Associated	Feeds	Moderate	None noted.
Barn Swallow	Closely Associated	Feeds	High	Can nest anywhere buildings, bridges, or overhanging cliffs occur in close proximity to water.
Black Tern	Closely Associated	Feeds and Breeds	High	None noted.
Black-crowned Night-heron	Closely Associated	Feeds	High	Requires shrubs or trees for nesting.
Black-necked Stilt	Closely Associated	Feeds and Breeds	High	None noted.
Blue-winged Teal	Closely Associated	Feeds and Breeds	High	None noted.
Bufflehead	Closely Associated	Feeds	High	Nests in tree cavities near ponds or lakes.
Canada Goose	Closely Associated	Feeds and Breeds	High	None noted.
Canvasback	Closely Associated	Feeds and Breeds	High	None noted.
Caspian Tern	Closely Associated	Feeds	High	None noted.
Cattle Egret	Closely Associated	Feeds	High	Requires shrubs or trees for nesting.
Cinnamon Teal	Closely Associated	Feeds and Breeds	High	None noted.
Clark's Grebe	Closely Associated	Feeds and Breeds	High	Nests placed on a floating platform of fresh and decaying vegetation in shallow water.
Common Loon	Closely Associated	Feeds and Breeds	Moderate	Nests in emergent vegetation at lake edges. No nesting confirmed in Oregon.
Common Snipe	Closely Associated	Feeds and Breeds	High	None noted.
Common Yellowthroat	Closely Associated	Feeds and Breeds	High	None noted.

Birds Associated with Herbaceous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Dunlin	Closely Associated	Feeds	Moderate	None noted.
Eared Grebe	Closely Associated	Feeds and Breeds	Moderate	Nests placed on a floating platform of fresh and decaying vegetation in shallow water.
Forster's Tern	Closely Associated	Feeds and Breeds	High	None noted.
Franklin's Gull	Closely Associated	Feeds and Breeds	High	Breeds at Mahleur Lake, Oregon.
Gadwall	Closely Associated	Feeds and Breeds	High	None noted.
Great Blue Heron	Closely Associated	Feeds	High	Requires trees for nesting.
Great Egret	Closely Associated	Feeds	High	Requires tall shrubs or trees for nesting.
Greater White-fronted Goose	Closely Associated	Feeds	High	None noted
Greater Yellowlegs	Closely Associated	Feeds	High	Has bred at least four times at Downy Lake, Wallowa County, Oregon.
Green Heron	Closely Associated	Feeds	High	Requires shrubs or trees for nesting.
Green-winged Teal	Closely Associated	Feeds and Breeds	High	None noted.
Horned Grebe	Closely Associated	Feeds and Breeds	Moderate	Nests placed on a floating platform of fresh and decaying vegetation in shallow water.
Least Bittern	Closely Associated	Feeds and Breeds	High	Rare breeder in Oregon; does not occur in Washington.
Least Sandpiper	Closely Associated	Feeds	Moderate	None noted.
Lesser Scaup	Closely Associated	Feeds and Breeds	High	None noted.
Lesser Yellowlegs	Closely Associated	Feeds	High	None noted.
Lincoln's Sparrow	Closely Associated	Feeds and Breeds	Moderate	None noted.
Long-billed Dowitcher	Closely Associated	Feeds	High	None noted.
Mallard	Closely Associated	Feeds and Breeds	High	None noted.
Marsh Wren	Closely Associated	Feeds and Breeds	Moderate	None noted.
Mute Swan	Closely Associated	Feeds and Breeds	Moderate	This is an introduced species which breeds only in urban wetlands.
Northern Pintail	Closely Associated	Feeds and Breeds	High	None noted.

Birds Associated with Herbaceous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Northern Rough-winged Swallow	Closely Associated	Feeds	High	Requires burrows in dirt banks, usually next to water, for nesting.
Northern Shoveler	Closely Associated	Feeds and Breeds	High	None noted.
Pectoral Sandpiper	Closely Associated	Feeds	Moderate	None noted.
Pied-billed Grebe	Closely Associated	Feeds and Breeds	High	Nests placed on a floating platform of fresh and decaying vegetation in shallow water.
Redhead	Closely Associated	Feeds and Breeds	High	None noted.
Red-necked Grebe	Closely Associated	Feeds and Breeds	High	Nests placed on a floating platform of fresh and decaying vegetation in shallow water.
Red-winged Blackbird	Closely Associated	Feeds and Breeds	High	None noted.
Ross's Goose	Closely Associated	Feeds	High	None noted.
Ruddy Duck	Closely Associated	Feeds and Breeds	High	None noted.
Sandhill Crane	Closely Associated	Feeds and Breeds	High	None noted.
Short-eared Owl	Closely Associated	Feeds and Breeds	Moderate	None noted.
Snow Goose	Closely Associated	Feeds	High	None noted.
Snowy Egret	Closely Associated	Feeds	High	Requires tall shrubs or trees for nesting.
Solitary Sandpiper	Closely Associated	Feeds	Moderate	None noted.
Sora	Closely Associated	Feeds and Breeds	High	None noted.
Swamp Sparrow	Closely Associated	Feeds	High	None noted.
Tree Swallow	Closely Associated	Feeds	Moderate	Requires snags not far from open water for nesting.
Tricolored Blackbird	Closely Associated	Feeds and Breeds	High	None noted.
Trumpeter Swan	Closely Associated	Feeds and Breeds	High	None noted.
Tundra Swan	Closely Associated	Feeds	High	None noted.
Virginia Rail	Closely Associated	Feeds and Breeds	High	None noted.

Birds Associated with Herbaceous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Western Grebe	Closely Associated	Feeds and Breeds	High	Nests placed on a floating platform of fresh and decaying vegetation in shallow water.
Western Sandpiper	Closely Associated	Feeds	Moderate	None noted.
White-faced Ibis	Closely Associated	Feeds and Breeds	High	None noted.
Willet	Closely Associated	Feeds and Breeds	High	None noted.
Wilson's Phalarope	Closely Associated	Feeds and Breeds	High	None noted.
Yellow Rail	Closely Associated	Feeds and Breeds	High	None noted.
Yellow-headed Blackbird	Closely Associated	Feeds and Breeds	High	None noted.
American Goldfinch	Generally Associated	Feeds	High	None noted.
American Kestrel	Generally Associated	Feeds	High	None noted.
American Robin	Generally Associated	Feeds	High	None noted.
American White Pelican	Generally Associated	Feeds	High	Feeds in open water areas of wetlands.
Bald Eagle	Generally Associated	Feeds	High	None noted.
Bank Swallow	Generally Associated	Feeds	High	Requires burrows in dirt banks, usually next to water, for nesting.
Barn Owl	Generally Associated	Feeds	High	None noted.
Barrow's Goldeneye	Generally Associated	Feeds	Moderate	Nests in tree cavities near ponds or lakes.
Black-chinned Hummingbird	Generally Associated	Feeds	Low	None noted.
Bobolink	Generally Associated	Feeds and Breeds	Moderate	None noted.
Brewer's Blackbird	Generally Associated	Feeds and Breeds	Moderate	None noted.
Brown-headed Cowbird	Generally Associated	Feeds and Breeds	High	None noted.
Burrowing Owl	Generally Associated	Feeds	High	None noted.
California Gull	Generally Associated	Feeds and Breeds	Moderate	None noted.
Cliff Swallow	Generally Associated	Feeds	High	Can nest anywhere rimrock, over-hanging cliffs, buildings or bridges occur in close proximity to water.

Birds Associated with Herbaceous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Common Nighthawk	Generally Associated	Feeds	Moderate	None noted.
Common Raven	Generally Associated	Feeds	High	None noted.
Cooper's Hawk	Generally Associated	Feeds	High	None noted.
Double-crested Cormorant	Generally Associated	Reproduces	High	None noted.
Eastern Kingbird	Generally Associated	Feeds	Moderate	None noted.
Eurasian Wigeon	Generally Associated	Feeds	High	None noted.
European Starling	Generally Associated	Feeds	Moderate	Requires snags or trees with cavities or buildings with crevices for nesting. Most likely to use this habitat where adjacent to agriculture or urban habitats.
Glaucous Gull	Generally Associated	Feeds	Low	None noted.
Golden-crowned Sparrow	Generally Associated	Feeds	Moderate	None noted.
Great Gray Owl	Generally Associated	Feeds	High	None noted.
Great Horned Owl	Generally Associated	Feeds	High	None noted.
Gyrfalcon	Generally Associated	Feeds	Moderate	None noted.
Herring Gull	Generally Associated	Feeds	High	None noted.
Hooded Merganser	Generally Associated	Feeds	High	Nests in tree cavities near ponds or lakes.
Killdeer	Generally Associated	Feeds and Breeds	Moderate	None noted.
Long-billed Curlew	Generally Associated	Feeds	Moderate	None noted.
Long-eared Owl	Generally Associated	Feeds	Moderate	None noted.
Northern Goshawk	Generally Associated	Feeds	Moderate	None noted.
Northern Harrier	Generally Associated	Feeds and Breeds	High	None noted.
Palm Warbler	Generally Associated	Feeds	Low	Only along the coast.
Peregrine Falcon	Generally Associated	Feeds	High	None noted.

Birds Associated with Herbaceous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Purple Martin	Generally Associated	Feeds	Low	None noted.
Red-tailed Hawk	Generally Associated	Feeds	High	None noted.
Ring-billed Gull	Generally Associated	Feeds and Breeds	Moderate	None noted.
Ring-necked Duck	Generally Associated	Feeds and Breeds	High	None noted.
Ring-necked Pheasant	Generally Associated	Feeds	High	None noted.
Rough-legged Hawk	Generally Associated	Feeds	Moderate	None noted.
Savannah Sparrow	Generally Associated	Feeds and Breeds	High	None noted.
Sharp-shinned Hawk	Generally Associated	Feeds	High	None noted.
Song Sparrow	Generally Associated	Feeds and Breeds	High	None noted.
Spotted Sandpiper	Generally Associated	Feeds and Breeds	Moderate	None noted.
Swainson's Hawk	Generally Associated	Feeds	Moderate	None noted.
Thayer's Gull	Generally Associated	Feeds	Moderate	None noted.
Turkey Vulture	Generally Associated	Feeds	High	None noted.
Upland Sandpiper	Generally Associated	Feeds and Breeds	High	Has been found at Sycan Marsh, Lake County, Oregon.
Vaux's Swift	Generally Associated	Feeds	Low	None noted.
Violet-green Swallow	Generally Associated	Feeds	Moderate	None noted.
White-crowned Sparrow	Generally Associated	Feeds	Moderate	None noted.
White-throated Swift	Generally Associated	Feeds	Low	Could forage over herbaceous wetlands incidently, such as those found in desert playas.
American Crow	Present	Feeds	High	None noted.
American Dipper	Present	Feeds	Moderate	None noted.
American Pipit	Present	Feeds	Moderate	Winter only.
Bewick's Wren	Present	Feeds	Low	None noted.
Black Swift	Present	Feeds	Low	Black swifts are long-distance foragers that may travel many miles from breeding sites and take advantage of flying insects caught in updrafts over just about any habitat.

Birds Associated with Herbaceous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Black-billed Magpie	Present	Feeds	High	None noted.
Black-capped Chickadee	Present	Feeds	Moderate	None noted.
Calliope Hummingbird	Present	Feeds	Low	None noted.
Cedar Waxwing	Present	Feeds	Moderate	None noted.
Common Goldeneye	Present	Feeds	Moderate	Nests in tree cavities near ponds or lakes.
Golden Eagle	Present	Feeds	High	None noted.
House Finch	Present	Feeds	Moderate	Uses this habitat where it is not too far from urban or agricultural areas.
Lapland Longspur	Present	Feeds	Low	None noted.
Loggerhead Shrike	Present	Feeds	Moderate	None noted.
Merlin	Present	Feeds	Low	None noted.
Northern Pygmy-owl	Present	Feeds	High	None noted.
Northern Shrike	Present	Feeds	High	None noted.
Pine Siskin	Present	Feeds	Low	None noted.
Ruby-crowned Kinglet	Present	Feeds	High	Winter only.
Rufous Hummingbird	Present	Feeds	Moderate	None noted.
Snowy Owl	Present	Feeds	Moderate	None noted.
Western Meadowlark	Present	Feeds	Low	None noted.
Western Screech-owl	Present	Feeds	Moderate	None noted.
Wood Duck	Present	Feeds	Moderate	Nests in tree cavities near ponds or lakes.
Yellow-rumped Warbler	Present	Feeds	Low	None noted.

Mammals Associated with Herbaceous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
American Beaver	Closely Associated	Feeds and Breeds	High	None noted.
Deer Mouse	Closely Associated	Feeds and Breeds	High	None noted.
Long-tailed Vole	Closely Associated	Feeds and Breeds	High	None noted.
Meadow Vole	Closely Associated	Feeds and Breeds	Low	None noted.
Mink	Closely Associated	Feeds	Moderate	None noted.
Montane Vole	Closely Associated	Feeds and Breeds	High	None noted.
Moose	Closely Associated	Feeds	High	None noted.
Muskrat	Closely Associated	Feeds and Breeds	Moderate	None noted.
Northern Bog Lemming	Closely Associated	Feeds and Breeds	Moderate	Cold, wet bogs above 5000 feet.

Mammals Associated with Herbaceous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Northern River Otter	Closely Associated	Feeds and Breeds	High	None noted.
Nutria	Closely Associated	Feeds and Breeds	Moderate	None noted.
Pallid Bat	Closely Associated	Feeds	High	None noted.
Raccoon	Closely Associated	Feeds	Moderate	None noted.
Townsend's Vole	Closely Associated	Feeds and Breeds	High	None noted.
Western Harvest Mouse	Closely Associated	Feeds and Breeds	High	None noted.
Yuma Myotis	Closely Associated	Feeds	High	None noted.
Big Brown Bat	Generally Associated	Feeds	Moderate	None noted.
Black Bear	Generally Associated	Feeds	High	None noted.
Black-tailed Deer	Generally Associated	Feeds	High	None noted.
Bobcat	Generally Associated	Feeds	Moderate	None noted.
Brazilian Free-tailed Bat	Generally Associated	Feeds	High	None noted.
California Myotis	Generally Associated	Feeds	High	None noted.
Columbian White-tailed Deer	Generally Associated	Feeds	High	None noted.
Coyote	Generally Associated	Feeds	High	None noted.
Feral Pig	Generally Associated	Feeds and Breeds	Moderate	Eastern Oregon wet meadows.
Fringed Myotis	Generally Associated	Feeds	Low	None noted.
Hoary Bat	Generally Associated	Feeds	Low	None noted.
Keen's Myotis	Generally Associated	Feeds	Low	None noted.
Little Brown Myotis	Generally Associated	Feeds	High	None noted.
Long-eared Myotis	Generally Associated	Feeds	Moderate	None noted.
Long-legged Myotis	Generally Associated	Feeds	Moderate	None noted.
Long-tailed Weasel	Generally Associated	Feeds	Moderate	None noted.
Mountain Caribou	Generally Associated	Feeds	Moderate	None noted.

Mammals Associated with Herbaceous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Mountain Lion	Generally Associated	Feeds	High	None noted.
Mule Deer	Generally Associated	Feeds	High	None noted.
Pacific Jumping Mouse	Generally Associated	Feeds and Breeds	Moderate	None noted.
Pacific Water Shrew	Generally Associated	Feeds and Breeds	Moderate	Closely tied to water.
Rocky Mountain Elk	Generally Associated	Feeds	High	None noted.
Roosevelt Elk	Generally Associated	Feeds	High	None noted.
Shrew-mole	Generally Associated	Feeds and Breeds	High	None noted.
Silver-haired Bat	Generally Associated	Feeds	Low	None noted.
Spotted Bat	Generally Associated	Feeds	Moderate	None noted.
Striped Skunk	Generally Associated	Feeds	Moderate	None noted.
Townsend's Big-eared Bat	Generally Associated	Feeds	Low	None noted.
Townsend's Mole	Generally Associated	Feeds and Breeds	High	None noted.
Vagrant Shrew	Generally Associated	Feeds and Breeds	Moderate	None noted.
Western Jumping Mouse	Generally Associated	Feeds and Breeds	Low	None noted.
Western Small-footed Myotis	Generally Associated	Feeds	Low	None noted.
White-tailed Deer (Eastside)	Generally Associated	Feeds	High	None noted.
Yellow-bellied Marmot	Generally Associated	Feeds	Low	Requires talus slopes, lava fields, rimrock, or boulder fields in close proximity to grassy openings or meadows.
Common Porcupine	Present	Feeds	Moderate	Needs large shrubs for food.
Feral Horse	Present	Feeds	Low	None noted.
Grizzly Bear	Present	Feeds	Low	None noted.
Preble's Shrew	Present	Feeds and Breeds	Low	None noted.
Wild Burro	Present	Feeds	Low	In southeastern Oregon, this habitat is mostly unavailable due to the fact that they are situated primarily on private lands and are fenced.

Reptiles Associated with Herbaceous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Common Garter Snake	Closely Associated	Feeds and Breeds	High	None noted.
Pacific Coast Aquatic Garter Snake	Present	Feeds and Breeds	Moderate	Uses this habitat where near marshes, streams, rivers, ponds or lakes.
Painted Turtle	Closely Associated	Feeds	Moderate	None noted.
Red-eared Slider Turtle	Closely Associated	Feeds	High	None noted.
Snapping Turtle	Closely Associated	Feeds	Moderate	None noted.
Western Pond Turtle	Closely Associated	Feeds	High	None noted.
Western Terrestrial Garter Snake	Generally Associated	Feeds	High	None noted.

Wildlife Species Found in Westside Riparian - Wetlands

Amphibians Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Bullfrog	Closely Associated	Feeds and Breeds	High	Requires warm-water ponds, marshes, or river/stream backwaters for breeding.
Cascade Torrent Salamander	Closely Associated	Feeds and Breeds	High	Requires very cold, clear seeps, springs, and small streams for breeding.
Columbia Torrent Salamander	Closely Associated	Feeds and Breeds	High	Requires very cold, clear seeps, springs, and small streams for breeding.
Cope's Giant Salamander	Closely Associated	Feeds and Breeds	Moderate	Requires clear, cold steep-gradient streams with a streambed of gravel, boulders and large logs for breeding.
Long-toed Salamander	Closely Associated	Feeds and Breeds	High	Rare or absent where predatory fish are occur. Requires ponds, shallow lake edges, seasonal pools (like elk wallows) or slow streams for breeding.
Northwestern Salamander	Closely Associated	Feeds and Breeds	High	Requires ponds or stream backwaters for breeding.
Olympic Torrent Salamander	Closely Associated	Feeds and Breeds	High	Requires very cold, clear seeps, springs, and small streams for breeding.
Oregon Spotted Frog	Closely Associated	Feeds and Breeds	High	Rare or absent where predatory fish or bullfrogs occur. Requires shallow water in wet meadows or stream/pond edges with abundant aquatic vegetation for breeding.
Pacific Chorus (Tree) Frog	Closely Associated	Feeds and Breeds	High	Requires ponds, seasonal pools, temporary rain-filled depressions or slow streams for breeding.
Pacific Giant Salamander	Closely Associated	Feeds and Breeds	Moderate	Requires small to mid-sized streams with a streambed of gravel, boulders and large logs for breeding.
Red-legged Frog	Closely Associated	Feeds and Breeds	High	Requires cool-water ponds, lake edges or slow streams for breeding.
Rough-skinned Newt	Closely Associated	Feeds and Breeds	High	Requires ponds or stream backwaters with abundant aquatic vegetation for breeding.
Southern Torrent Salamander	Closely Associated	Feeds and Breeds	High	Requires very cold, clear seeps, springs, and small streams for breeding.
Tailed Frog	Closely Associated	Feeds and Breeds	Moderate	Requires clear, cold steep-gradient streams for breeding.

Amphibians Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Western Toad	Closely Associated	Feeds and Breeds	High	None noted.
Black Salamander	Generally Associated	Feeds and Breeds	Low	Requires logs, woody debris, or moist talus with woody debris.
California Slender Salamander	Generally Associated	Feeds and Breeds	Moderate	Requires logs.
Cascades Frog	Generally Associated	Feeds and Breeds	Moderate	Requires bogs or ponds with cold springs for breeding.
Dunn's Salamander	Generally Associated	Feeds and Breeds	Moderate	Requires moist or wet rock outcrops, talus, gravel, boulders, or rock crevices
Ensatina	Generally Associated	Feeds and Breeds	High	Requires logs, woody debris, or moist talus with woody debris.
Foothill Yellow-legged Frog	Generally Associated	Feeds and Breeds	High	Requires still-water or gentle gradient portions of streams for breeding.
Oregon Slender Salamander	Generally Associated	Feeds and Breeds	Moderate	Requires large logs, woody debris, or moist talus with woody debris.
Van Dyke's Salamander	Generally Associated	Feeds and Breeds	Moderate	Requires moist talus, rock outcrops, logs, seeps, or woody debris and rocks along streams.
Western Red-backed Salamander	Generally Associated	Feeds and Breeds	High	Requires moist or shaded talus, rocks, or large logs. Occasionally uses springs or stream edges.

Birds Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
American Black Duck	Closely Associated	Feeds and Breeds	Low	None noted.
American Dipper	Closely Associated	Feeds and Breeds	High	None noted.
Band-tailed Pigeon	Closely Associated	Feeds and Breeds	Moderate	None noted.
Barn Swallow	Closely Associated	Feeds and Breeds	High	Can nest anywhere buildings, bridges, or overhanging cliffs occur in close proximity to water.
Belted Kingfisher	Closely Associated	Feeds and Breeds	High	None noted.
Black Phoebe	Closely Associated	Feeds and Breeds	Moderate	None noted.
Black-throated Gray Warbler	Closely Associated	Feeds and Breeds	High	None noted.

Birds Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Bullock's Oriole	Closely Associated	Feeds and Breeds	Moderate	None noted.
Cliff Swallow	Closely Associated	Feeds and Breeds	High	Can nest anywhere rimrock, overhanging cliffs, buildings or bridges occur in close proximity to water.
Common Merganser	Closely Associated	Feeds and Breeds	High	Nests in tree cavities near large lakes or rivers.
Common Yellowthroat	Closely Associated	Feeds and Breeds	High	None noted.
Downy Woodpecker	Closely Associated	Feeds and Breeds	Moderate	None noted.
European Starling	Closely Associated	Feeds and Breeds	High	Requires snags or trees with cavities or buildings with crevices for nesting. Most likely to use this habitat where adjacent to agriculture or urban habitats.
Great Blue Heron	Closely Associated	Feeds and Breeds	High	None noted.
Green Heron	Closely Associated	Feeds and Breeds	High	None noted.
Harlequin Duck	Closely Associated	Feeds and Breeds	High	None noted.
Hooded Merganser	Closely Associated	Feeds and Breeds	High	Nests in tree cavities.
Lesser Goldfinch	Closely Associated	Feeds and Breeds	Moderate	None noted.
Lincoln's Sparrow	Closely Associated	Feeds and Breeds	High	None noted.
Mallard	Closely Associated	Feeds and Breeds	High	None noted.
Mourning Dove	Closely Associated	Feeds and Breeds	High	None noted.
Northern Rough-winged Swallow	Closely Associated	Feeds and Breeds	High	Requires burrows in dirt banks, usually next to water, for nesting.
Northern Waterthrush	Closely Associated	Feeds and Breeds	High	None noted.
Purple Finch	Closely Associated	Feeds and Breeds	Moderate	None noted.
Red-eyed Vireo	Closely Associated	Feeds and Breeds	Moderate	Range of red-eyed vireo overlaps that of large black cottonwood groves.

Birds Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Ring-necked Duck	Closely Associated	Feeds and Breeds	Moderate	None noted.
Ruffed Grouse	Closely Associated	Feeds and Breeds	High	None noted.
Solitary Sandpiper	Closely Associated	Feeds	High	None noted.
Spotted Sandpiper	Closely Associated	Feeds and Breeds	Moderate	None noted.
Swamp Sparrow	Closely Associated	Feeds	High	None noted.
Tree Swallow	Closely Associated	Feeds and Breeds	Moderate	Requires snags not far from open water for nesting.
Warbling Vireo	Closely Associated	Feeds and Breeds	High	None noted.
Western Screech-owl	Closely Associated	Feeds and Breeds	High	None noted.
Willow Flycatcher	Closely Associated	Feeds and Breeds	Moderate	None noted.
Wilson's Warbler	Closely Associated	Feeds and Breeds	High	None noted.
Wood Duck	Closely Associated	Feeds and Breeds	High	Nests in tree cavities.
Yellow Warbler	Closely Associated	Feeds and Breeds	High	None noted.
Yellow-breasted Chat	Closely Associated	Feeds and Breeds	Moderate	None noted.
Allen's Hummingbird	Generally Associated	Feeds and Breeds	Low	None noted.
American Crow	Generally Associated	Feeds and Breeds	High	None noted.
American Goldfinch	Generally Associated	Feeds and Breeds	High	None noted.
American Kestrel	Generally Associated	Feeds and Breeds	High	None noted.
American Robin	Generally Associated	Feeds and Breeds	High	None noted.
American Wigeon	Generally Associated	Feeds	High	None noted.
Bald Eagle	Generally Associated	Feeds and Breeds	High	None noted.
Barn Owl	Generally Associated	Feeds and Breeds	High	Requires cliffs, caves, rimrock, or tree cavities for nesting.

Birds Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Barred Owl	Generally Associated	Feeds and Breeds	Moderate	None noted.
Bewick's Wren	Generally Associated	Feeds and Breeds	Moderate	None noted.
Black Swift	Generally Associated	Feeds and Breeds	Low	Requires suitable cliffs behind waterfalls for breeding.
Black-capped Chickadee	Generally Associated	Feeds and Breeds	Moderate	None noted.
Black-crowned Night-heron	Generally Associated	Feeds	High	Only one and maybe two known breeding sites exist west of the Cascades, though historically a large breeding colony occurred near Portland.
Black-headed Grosbeak	Generally Associated	Feeds and Breeds	High	None noted.
Brewer's Blackbird	Generally Associated	Feeds and Breeds	Moderate	None noted.
Brown Creeper	Generally Associated	Feeds and Breeds	Moderate	None noted.
Brown-headed Cowbird	Generally Associated	Feeds and Breeds	High	None noted.
Bufflehead	Generally Associated	Feeds and Breeds	High	Nests in tree cavities.
Bushtit	Generally Associated	Feeds and Breeds	Moderate	None noted.
California Quail	Generally Associated	Feeds and Breeds	High	Uses this habitat where adjacent to more open habitats.
Cedar Waxwing	Generally Associated	Feeds and Breeds	High	None noted.
Chestnut-backed Chickadee	Generally Associated	Feeds and Breeds	Moderate	None noted.
Common Nighthawk	Generally Associated	Feeds	Moderate	None noted.
Common Raven	Generally Associated	Feeds and Breeds	High	None noted.
Cooper's Hawk	Generally Associated	Feeds and Breeds	High	None noted.
Dark-eyed Junco	Generally Associated	Feeds and Breeds	High	None noted.
Evening Grosbeak	Generally Associated	Feeds and Breeds	Moderate	None noted.

Birds Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Fox Sparrow	Generally Associated	Feeds	High	Winter only.
Golden-crowned Kinglet	Generally Associated	Feeds and Breeds	High	None noted.
Golden-crowned Sparrow	Generally Associated	Feeds	Moderate	None noted.
Gray Jay	Generally Associated	Feeds and Breeds	Moderate	None noted.
Great Egret	Generally Associated	Feeds and Breeds	Moderate	None noted.
Great Horned Owl	Generally Associated	Feeds and Breeds	High	None noted.
Greater Yellowlegs	Generally Associated	Feeds	Low	None noted.
Green-winged Teal	Generally Associated	Feeds	High	None noted.
Hairy Woodpecker	Generally Associated	Feeds and Breeds	Moderate	None noted.
Hermit Thrush	Generally Associated	Feeds	High	None noted.
Hermit Warbler	Generally Associated	Feeds and Breeds	Moderate	None noted.
House Wren	Generally Associated	Feeds and Breeds	Moderate	None noted.
Hutton's Vireo	Generally Associated	Feeds and Breeds	High	None noted.
Killdeer	Generally Associated	Feeds and Breeds	Moderate	None noted.
Lazuli Bunting	Generally Associated	Feeds and Breeds	Moderate	None noted.
Least Flycatcher	Generally Associated	Feeds and Breeds	Low	Found nesting near Monroe, Snohomish County, Washington.
Lesser Yellowlegs	Generally Associated	Feeds	Low	None noted.
Macgillivray's Warbler	Generally Associated	Feeds and Breeds	High	None noted.
Merlin	Generally Associated	Feeds and Breeds	Moderate	None noted.
Mountain Quail	Generally Associated	Feeds and Breeds	Moderate	None noted.

Birds Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Nashville Warbler	Generally Associated	Feeds and Breeds	Moderate	None noted.
Northern Flicker	Generally Associated	Feeds and Breeds	Moderate	None noted.
Northern Goshawk	Generally Associated	Feeds	Moderate	None noted.
Northern Pygmy-owl	Generally Associated	Feeds and Breeds	High	None noted.
Olive-sided Flycatcher	Generally Associated	Feeds and Breeds	Moderate	None noted.
Orange-crowned Warbler	Generally Associated	Feeds and Breeds	High	None noted.
Osprey	Generally Associated	Feeds and Breeds	High	None noted.
Pacific-slope Flycatcher	Generally Associated	Feeds and Breeds	Moderate	None noted.
Palm Warbler	Generally Associated	Feeds	Moderate	Only along the coast.
Peregrine Falcon	Generally Associated	Feeds	High	None noted.
Pied-billed Grebe	Generally Associated	Feeds and Breeds	High	Uncertain about the frequency of breeding in this type of habitat.
Pileated Woodpecker	Generally Associated	Feeds and Breeds	Moderate	None noted.
Pine Siskin	Generally Associated	Feeds and Breeds	Moderate	None noted.
Purple Martin	Generally Associated	Feeds and Breeds	Low	None noted.
Red-breasted Nuthatch	Generally Associated	Feeds and Breeds	Moderate	None noted.
Red-breasted Sapsucker	Generally Associated	Feeds and Breeds	Moderate	None noted.
Red-shouldered Hawk	Generally Associated	Feeds and Breeds	Low	None noted.
Red-tailed Hawk	Generally Associated	Feeds and Breeds	High	None noted.
Red-winged Blackbird	Generally Associated	Feeds and Breeds	Low	None noted.
Ring-necked Pheasant	Generally Associated	Feeds and Breeds	High	None noted.
Ruby-crowned Kinglet	Generally Associated	Feeds	High	Winter only.

Birds Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Rufous Hummingbird	Generally Associated	Feeds and Breeds	Moderate	None noted.
Savannah Sparrow	Generally Associated	Feeds and Breeds	Moderate	None noted.
Song Sparrow	Generally Associated	Feeds and Breeds	High	None noted.
Spotted Towhee	Generally Associated	Feeds and Breeds	Moderate	None noted.
Steller's Jay	Generally Associated	Feeds and Breeds	Moderate	None noted.
Swainson's Thrush	Generally Associated	Feeds and Breeds	High	None noted.
Townsend's Warbler	Generally Associated	Feeds and Breeds	High	None noted.
Turkey Vulture	Generally Associated	Feeds and Breeds	High	Requires rocky outcrops, small caves, boulder piles, ledges on high cliffs or large hollow logs for nesting.
Vaux's Swift	Generally Associated	Feeds and Breeds	Moderate	None noted.
Violet-green Swallow	Generally Associated	Feeds and Breeds	Moderate	None noted.
Western Tanager	Generally Associated	Feeds and Breeds	Moderate	None noted.
Western Wood-pewee	Generally Associated	Feeds and Breeds	Moderate	None noted.
White-breasted Nuthatch	Generally Associated	Feeds and Breeds	Moderate	None noted.
White-crowned Sparrow	Generally Associated	Feeds and Breeds	Moderate	None noted.
Wild Turkey	Generally Associated	Feeds	Moderate	Low elevation sites only; likely uses this habitat more for cover than feeding.
Winter Wren	Generally Associated	Feeds and Breeds	Moderate	None noted.
Yellow-rumped Warbler	Generally Associated	Feeds	Moderate	None noted.
American Redstart	Present	Feeds and Breeds	Low	None noted.
American Tree Sparrow	Present	Feeds	Moderate	None noted.
Anna's Hummingbird	Present	Feeds and Breeds	Low	None noted.

Birds Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Ash-throated Flycatcher	Present	Feeds and Breeds	Low	Requires an oak component.
Blue Grouse	Present	Feeds and Breeds	Moderate	None noted.
Bohemian Waxwing	Present	Feeds	Moderate	Occurs in Westside habitats only during irruption years.
Canada Goose	Present	Feeds and Breeds	Moderate	None noted.
Chipping Sparrow	Present	Feeds	Low	None noted.
Common Redpoll	Present	Feeds	Moderate	Only in Skagit and Whatcom counties, Washington.
Double-crested Cormorant	Present	Feeds and Breeds	High	None noted.
House Finch	Present	Feeds and Breeds	Moderate	Uses this habitat where it is not too far from urban or agricultural areas.
Lewis's Woodpecker	Present	Feeds	Moderate	May use as wintering habitat in Oregon; historically occurred in this habitat in western Washington.
Northern Harrier	Present	Feeds and Breeds	High	None noted.
Northern Saw-whet Owl	Present	Feeds and Breeds	Moderate	None noted.
Red Crossbill	Present	Feeds and Breeds	Moderate	None noted.
Rough-legged Hawk	Present	Feeds	High	None noted.
Snowy Egret	Present	Feeds	Moderate	None noted.
Townsend's Solitaire	Present	Feeds	Moderate	None noted.
Veery	Present	Feeds and Breeds	High	None noted.
Western Scrub-Jay	Present	Feeds and Breeds	Moderate	None noted.
White-tailed Kite	Present	Feeds and Breeds	Moderate	None noted.
White-winged Crossbill	Present	Feeds	Low	None noted.

Mammals Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
American Beaver	Closely Associated	Feeds and Breeds	High	None noted.
Deer Mouse	Closely Associated	Feeds and Breeds	High	None noted.
Dusky-footed Woodrat	Closely Associated	Feeds and Breeds	Moderate	None noted.
Fisher	Closely Associated	Feeds and Breeds	Moderate	None noted.
Fog Shrew	Closely Associated	Feeds and Breeds	High	None noted.
Long-tailed Vole	Closely Associated	Feeds and Breeds	High	None noted.
Mink	Closely Associated	Feeds and Breeds	Moderate	None noted.
Mountain Beaver	Closely Associated	Feeds and Breeds	High	None noted.
Muskrat	Closely Associated	Feeds and Breeds	Moderate	None noted.
Northern River Otter	Closely Associated	Feeds and Breeds	High	None noted.
Nutria	Closely Associated	Feeds and Breeds	Moderate	None noted.
Pacific Jumping Mouse	Closely Associated	Feeds and Breeds	High	None noted.
Pacific Shrew	Closely Associated	Feeds and Breeds	High	None noted.
Pacific Water Shrew	Closely Associated	Feeds and Breeds	High	Closely tied to water.
Raccoon	Closely Associated	Feeds and Breeds	Moderate	None noted.
Southern Red-backed Vole	Closely Associated	Feeds and Breeds	High	None noted.
Water Shrew	Closely Associated	Feeds and Breeds	High	Lead a semi-aquatic life and require cold, clear water in small streams or ponds with abundant cover in the form of rocks, overhanging banks, etc.
Water Vole	Closely Associated	Feeds and Breeds	Low	None noted.
White-footed Vole	Closely Associated	Feeds and Breeds	Moderate	None noted.

Mammals Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Yuma Myotis	Closely Associated	Feeds and Breeds	High	More closely associated with water than other bat species. Uses caves, mines, loose bark and bark crevices typically close to water.
Big Brown Bat	Generally Associated	Feeds and Breeds	Moderate	Requires snags, caves, mines, rock crevices, or bridges for breeding and roosting.
Black Bear	Generally Associated	Feeds and Breeds	High	None noted.
Black-tailed Deer	Generally Associated	Feeds and Breeds	High	None noted.
Bobcat	Generally Associated	Feeds and Breeds	Moderate	None noted.
Broad-footed Mole	Generally Associated	Feeds and Breeds	Moderate	None noted.
Brush Rabbit	Generally Associated	Feeds and Breeds	Moderate	None noted.
California Myotis	Generally Associated	Feeds and Breeds	High	Uses rock crevices, hollow trees, mines or caves for breeding.
Coast Mole	Generally Associated	Feeds and Breeds	Moderate	None noted.
Columbian Mouse	Generally Associated	Feeds and Breeds	High	None noted.
Columbian White-tailed Deer	Generally Associated	Feeds and Breeds	High	None noted.
Common Porcupine	Generally Associated	Feeds and Breeds	Moderate	None noted.
Coyote	Generally Associated	Feeds and Breeds	High	None noted.
Creeping Vole	Generally Associated	Feeds and Breeds	High	None noted.
Eastern Cottontail	Generally Associated	Feeds and Breeds	Low	Likely uses this habitat where adjacent to urban or agricultural habitats.
Ermine	Generally Associated	Feeds and Breeds	Low	None noted.
Fringed Myotis	Generally Associated	Feeds and Breeds	Low	Requires caves, mines or rock crevices.
Gray Fox	Generally Associated	Feeds and Breeds	Low	None noted.
Hoary Bat	Generally Associated	Feeds	Low	Requires trees for roosting, but forages in openings and at edges of forests.

Mammals Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Keen's Myotis	Generally Associated	Feeds and Breeds	Low	Little studied; hard to distinguish from long-eared myotis. Likely requires tree cavites for breeding, caves for hibernacula.
Little Brown Myotis	Generally Associated	Feeds and Breeds	High	Uses caves, mines, or hollow trees, often near water.
Long-eared Myotis	Generally Associated	Feeds and Breeds	Moderate	Uses caves, mines, hollow trees, loose bark or rock crevices.
Long-legged Myotis	Generally Associated	Feeds and Breeds	Moderate	Uses caves or mines as hibernacula. Uses hollow trees, loose bark or rock crevices for maternity colonies.
Long-tailed Weasel	Generally Associated	Feeds and Breeds	Moderate	None noted.
Mountain Lion	Generally Associated	Feeds and Breeds	High	None noted.
Northern Flying Squirrel	Generally Associated	Feeds and Breeds	High	None noted.
Pallid Bat	Generally Associated	Feeds	Low	None noted.
Red Fox	Generally Associated	Feeds and Breeds	Low	Non-native Red fox.
Rocky Mountain Elk	Generally Associated	Feeds and Breeds	High	None noted.
Roosevelt Elk	Generally Associated	Feeds and Breeds	High	None noted.
Shrew-mole	Generally Associated	Feeds and Breeds	High	None noted.
Silver-haired Bat	Generally Associated	Feeds	Low	None noted.
Snowshoe Hare	Generally Associated	Feeds and Breeds	High	None noted.
Striped Skunk	Generally Associated	Feeds and Breeds	Moderate	None noted.
Townsend's Big-eared Bat	Generally Associated	Feeds	Moderate	None noted.
Townsend's Chipmunk	Generally Associated	Feeds and Breeds	High	None noted.
Townsend's Mole	Generally Associated	Feeds and Breeds	High	None noted.
Townsend's Vole	Generally Associated	Feeds and Breeds	High	None noted.

Mammals Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Trowbridge's Shrew	Generally Associated	Feeds and Breeds	High	None noted.
Virginia Opossum	Generally Associated	Feeds and Breeds	Low	None noted.
Western Red-backed Vole	Generally Associated	Feeds and Breeds	High	None noted.
Western Spotted Skunk	Generally Associated	Feeds and Breeds	Low	None noted.
American Marten	Present	Feeds and Breeds	Moderate	None noted.
Brazilian Free-tailed Bat	Present	Feeds	Moderate	None noted.
Bushy-tailed Woodrat	Present	Feeds and Breeds	Moderate	None noted.
Heather Vole	Present	Feeds and Breeds	Moderate	None noted.
Masked Shrew	Present	Feeds and Breeds	Moderate	None noted.
Montane Shrew	Present	Feeds and Breeds	Moderate	None noted.
Red Tree Vole	Present	Feeds and Breeds	Moderate	None noted.
Vagrant Shrew	Present	Feeds and Breeds	Moderate	None noted.

Reptiles Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Common Garter Snake	Closely Associated	Feeds and Breeds	High	None noted.
Western Pond Turtle	Closely Associated	Feeds and Breeds	High	None noted.
Northern Alligator Lizard	Generally Associated	Feeds and Breeds	High	None noted.
Northwestern Garter Snake	Generally Associated	Feeds and Breeds	High	None noted.
Pacific Coast Aquatic Garter Snake	Generally Associated	Feeds and Breeds	High	None noted.
Painted Turtle	Generally Associated	Feeds and Breeds	Moderate	None noted.
Red-eared Slider Turtle	Generally Associated	Feeds and Breeds	Moderate	None noted.

Reptiles Associated with Westside Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Rubber Boa	Generally Associated	Feeds and Breeds	High	Usually does not occur far from water.
Sharptail Snake	Generally Associated	Feeds and Breeds	Moderate	None noted.
Snapping Turtle	Generally Associated	Feeds and Breeds	Moderate	Avoids flowing water that lacks vegetation.
Western Rattlesnake	Generally Associated	Feeds and Breeds	High	None noted.
Western Terrestrial Garter Snake	Generally Associated	Feeds and Breeds	High	None noted.
California Mountain Kingsnake	Present	Feeds and Breeds	Moderate	None noted.
Common Kingsnake	Present	Feeds and Breeds	Low	None noted.
Ringneck Snake	Present	Feeds and Breeds	Moderate	None noted.
Southern Alligator Lizard	Present	Feeds and Breeds	Moderate	None noted.

Wildlife Species Found in Montane Coniferous Wetlands

Amphibians Associated with Montane Coniferous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Long-toed Salamander	Closely Associated	Feeds and Breeds	High	Rare or absent where predatory fish are occur. Requires ponds, shallow lake edges, seasonal pools (like elk wallows) or slow streams for breeding.
Northwestern Salamander	Closely Associated	Feeds and Breeds	High	Requires ponds or stream backwaters for breeding.
Pacific Chorus (Tree) Frog	Closely Associated	Feeds and Breeds	High	Requires ponds, seasonal pools, temporary rain-filled depressions or slow streams for breeding.
Rough-skinned Newt	Closely Associated	Feeds and Breeds	High	Requires ponds or stream backwaters with abundant aquatic vegetation for breeding.
Western Toad	Closely Associated	Feeds and Breeds	High	None noted.
Cascades Frog	Generally Associated	Feeds and Breeds	High	Requires bogs or ponds with cold springs for breeding.
Columbia Spotted Frog	Generally Associated	Feeds and Breeds	Moderate	Rare or absent where predatory fish or bullfrogs occur. Requires shallow water in wet meadows or stream/pond edges with abundant aquatic vegetation for breeding.
Oregon Spotted Frog	Present	Feeds and Breeds	High	Rare or absent where predatory fish or bullfrogs occur. Requires shallow water in wet meadows or stream/pond edges with abundant aquatic vegetation for breeding.
Pacific Giant Salamander	Present	Feeds and Breeds	High	Requires small to mid-sized streams with a streambed of gravel, boulders and large logs for breeding.
Red-legged Frog	Present	Feeds and Breeds	High	Requires cool-water ponds, lake edges or slow streams for breeding.

Birds Associated with Montane Coniferous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Bufflehead	Closely Associated	Feeds and Breeds	Moderate	Nests in tree cavities.
Evening Grosbeak	Closely Associated	Feeds and Breeds	Moderate	None noted.
American Robin	Generally Associated	Feeds and Breeds	High	None noted.
Barrow's Goldeneye	Generally Associated	Feeds and Breeds	Moderate	Nests in tree cavities.
Black Swift	Generally Associated	Feeds	Low	Black swifts are long-distance foragers that may travel many miles from breeding sites and take advantage of flying insects caught in updrafts over just about any habitat.
Black-backed Woodpecker	Generally Associated	Feeds and Breeds	Moderate	Reach highest densities in recently burned forests or areas of bark beetle infestations.
Blue Grouse	Generally Associated	Feeds and Breeds	Moderate	None noted.
Bohemian Waxwing	Generally Associated	Feeds	Moderate	There are a few confirmed records of breeding. Nesting habitat usually is beaver ponds and bog areas.
Boreal Chickadee	Generally Associated	Feeds and Breeds	Low	None noted.
Brown Creeper	Generally Associated	Feeds and Breeds	Moderate	None noted.
Calliope Hummingbird	Generally Associated	Feeds and Breeds	Moderate	None noted.
Cassin's Finch	Generally Associated	Feeds and Breeds	High	None noted.
Cedar Waxwing	Generally Associated	Feeds and Breeds	Moderate	None noted.
Chestnut-backed Chickadee	Generally Associated	Feeds and Breeds	Moderate	None noted.
Common Nighthawk	Generally Associated	Feeds	Moderate	None noted.
Common Raven	Generally Associated	Feeds and Breeds	High	None noted.
Common Redpoll	Generally Associated	Feeds	Moderate	None noted.
Cooper's Hawk	Generally Associated	Feeds and Breeds	High	None noted.
Dark-eyed Junco	Generally Associated	Feeds and Breeds	High	None noted.

Birds Associated with Montane Coniferous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Dusky Flycatcher	Generally Associated	Feeds and Breeds	Moderate	None noted.
Golden-crowned Kinglet	Generally Associated	Feeds and Breeds	High	None noted.
Gray Jay	Generally Associated	Feeds and Breeds	High	None noted.
Great Gray Owl	Generally Associated	Feeds and Breeds	High	None noted.
Hairy Woodpecker	Generally Associated	Feeds and Breeds	Moderate	None noted.
Hermit Thrush	Generally Associated	Feeds and Breeds	High	None noted.
Hermit Warbler	Generally Associated	Feeds and Breeds	Moderate	None noted.
Macgillivray's Warbler	Generally Associated	Feeds and Breeds	High	None noted.
Mountain Chickadee	Generally Associated	Feeds and Breeds	Moderate	None noted.
Nashville Warbler	Generally Associated	Feeds and Breeds	Moderate	None noted.
Northern Flicker	Generally Associated	Feeds and Breeds	Moderate	None noted.
Northern Goshawk	Generally Associated	Feeds and Breeds	High	None noted.
Northern Pygmy-owl	Generally Associated	Feeds and Breeds	Low	None noted.
Northern Saw-whet Owl	Generally Associated	Feeds and Breeds	Moderate	None noted.
Olive-sided Flycatcher	Generally Associated	Feeds and Breeds	Moderate	None noted.
Pacific-slope Flycatcher	Generally Associated	Feeds and Breeds	Moderate	None noted.
Peregrine Falcon	Generally Associated	Feeds	High	None noted.
Pileated Woodpecker	Generally Associated	Feeds and Breeds	Moderate	None noted.
Pine Grosbeak	Generally Associated	Feeds and Breeds	Moderate	None noted.
Pine Siskin	Generally Associated	Feeds and Breeds	High	None noted.
Red Crossbill	Generally Associated	Feeds and Breeds	Moderate	None noted.

Birds Associated with Montane Coniferous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Red-breasted Nuthatch	Generally Associated	Feeds and Breeds	Moderate	None noted.
Red-breasted Sapsucker	Generally Associated	Feeds and Breeds	Moderate	None noted.
Ruby-crowned Kinglet	Generally Associated	Feeds and Breeds	High	None noted.
Ruffed Grouse	Generally Associated	Feeds and Breeds	Moderate	None noted.
Rufous Hummingbird	Generally Associated	Feeds and Breeds	Moderate	None noted.
Song Sparrow	Generally Associated	Feeds and Breeds	Moderate	None noted.
Spruce Grouse	Generally Associated	Feeds and Breeds	High	Uses this habitat where adjacent to lodgepole alpine forest.
Steller's Jay	Generally Associated	Feeds and Breeds	Moderate	None noted.
Swainson's Thrush	Generally Associated	Feeds and Breeds	High	None noted.
Three-toed Woodpecker	Generally Associated	Feeds and Breeds	Moderate	Reach highest densities in recently burned forests or areas of bark beetle infestations.
Townsend's Warbler	Generally Associated	Feeds and Breeds	Moderate	None noted.
Tree Swallow	Generally Associated	Feeds and Breeds	Moderate	Requires snags not far from open water for nesting.
Varied Thrush	Generally Associated	Feeds and Breeds	Moderate	None noted.
Vaux's Swift	Generally Associated	Feeds and Breeds	Moderate	None noted.
Violet-green Swallow	Generally Associated	Feeds and Breeds	Moderate	None noted.
Warbling Vireo	Generally Associated	Feeds and Breeds	Low	None noted.
Western Tanager	Generally Associated	Feeds and Breeds	Moderate	None noted.
Williamson's Sapsucker	Generally Associated	Feeds and Breeds	Low	None noted.
Willow Flycatcher	Generally Associated	Feeds and Breeds	Moderate	None noted.
Wilson's Warbler	Generally Associated	Feeds and Breeds	High	None noted.

Birds Associated with Montane Coniferous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Winter Wren	Generally Associated	Feeds and Breeds	Moderate	None noted.
Yellow-rumped Warbler	Generally Associated	Feeds and Breeds	Moderate	None noted.
American Crow	Present	Feeds and Breeds	High	None noted.
American Kestrel	Present	Feeds and Breeds	Moderate	None noted.
Barn Swallow	Present	Feeds and Breeds	Moderate	Can nest anywhere buildings, bridges, or overhanging cliffs occur in close proximity to water.
Brown-headed Cowbird	Present	Feeds and Breeds	Moderate	None noted.
Chipping Sparrow	Present	Feeds and Breeds	Low	None noted.
Clark's Nutcracker	Present	Feeds	Low	None noted.
European Starling	Present	Feeds and Breeds	Low	Requires snags or trees with cavities or buildings with crevices for nesting. Most likely to use this habitat where adjacent to agriculture or urban habitats.
Great Horned Owl	Present	Feeds and Breeds	High	None noted.
Merlin	Present	Feeds	Low	None noted.
Mountain Bluebird	Present	Feeds and Breeds	Moderate	None noted.
Northern Rough-winged Swallow	Present	Feeds	Moderate	Requires burrows in dirt banks, usually next to water, for nesting.
Turkey Vulture	Present	Feeds and Breeds	Low	Requires rocky outcrops, small caves, boulder piles, ledges on high cliffs or large hollow logs for nesting.
Western Screech-owl	Present	Feeds and Breeds	Moderate	None noted.
White-winged Crossbill	Present	Feeds and Breeds	Moderate	None noted.
Wood Duck	Present	Feeds and Breeds	Moderate	Nests in tree cavities.

Mammals Associated with Montane Coniferous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Big Brown Bat	Closely Associated	Feeds and Breeds	High	Requires snags, caves, mines, rock crevices, or bridges for breeding and roosting.
Deer Mouse	Closely Associated	Feeds and Breeds	High	None noted.
Long-tailed Vole	Closely Associated	Feeds and Breeds	High	None noted.
Pacific Jumping Mouse	Closely Associated	Feeds and Breeds	High	None noted.
Snowshoe Hare	Closely Associated	Feeds and Breeds	High	None noted.
Southern Red-backed Vole	Closely Associated	Feeds and Breeds	High	None noted.
Water Shrew	Closely Associated	Feeds and Breeds	High	Lead a semi-aquatic life and require cold, clear water in small streams or ponds with abundant cover in the form of rocks, overhanging banks, etc.
Water Vole	Closely Associated	Feeds and Breeds	Low	None noted.
Yuma Myotis	Closely Associated	Feeds and Breeds	High	More closely associated with water than other bat species. Uses caves, mines, loose bark and bark crevices typically close to water.
American Beaver	Generally Associated	Feeds and Breeds	High	None noted.
American Marten	Generally Associated	Feeds and Breeds	Moderate	None noted.
Black Bear	Generally Associated	Feeds and Breeds	High	None noted.
Black-tailed Deer	Generally Associated	Feeds and Breeds	High	None noted.
Bobcat	Generally Associated	Feeds	Moderate	None noted.
Bushy-tailed Woodrat	Generally Associated	Feeds and Breeds	Moderate	None noted.
California Myotis	Generally Associated	Feeds and Breeds	High	Uses rock crevices, hollow trees, mines or caves for breeding.
Columbian Ground Squirrel	Generally Associated	Feeds and Breeds	Moderate	None noted.
Columbian Mouse	Generally Associated	Feeds and Breeds	High	None noted.

Mammals Associated with Montane Coniferous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Common Porcupine	Generally Associated	Feeds and Breeds	Moderate	None noted.
Coyote	Generally Associated	Feeds and Breeds	High	None noted.
Creeping Vole	Generally Associated	Feeds and Breeds	High	None noted.
Fisher	Generally Associated	Feeds and Breeds	Low	None noted.
Golden-mantled Ground Squirrel	Generally Associated	Feeds and Breeds	Moderate	None noted.
Hoary Bat	Generally Associated	Feeds	Low	Requires trees for roosting, but forages in openings and at edges of forests.
Little Brown Myotis	Generally Associated	Feeds	High	Uses caves, mines, or hollow trees, often near water.
Long-eared Myotis	Generally Associated	Feeds and Breeds	Moderate	Uses caves, mines, hollow trees, loose bark or rock crevices.
Long-tailed Weasel	Generally Associated	Feeds and Breeds	Moderate	None noted.
Mink	Generally Associated	Feeds and Breeds	Moderate	None noted.
Montane Vole	Generally Associated	Feeds and Breeds	High	None noted.
Moose	Generally Associated	Feeds and Breeds	Moderate	None noted.
Mountain Caribou	Generally Associated	Feeds and Breeds	High	None noted.
Mountain Lion	Generally Associated	Feeds	High	None noted.
Mule Deer	Generally Associated	Feeds and Breeds	High	None noted.
Northern Bog Lemming	Generally Associated	Feeds and Breeds	Moderate	None noted.
Northern Flying Squirrel	Generally Associated	Feeds and Breeds	High	None noted.
Northern Pocket Gopher	Generally Associated	Feeds and Breeds	Moderate	None noted.
Pacific Water Shrew	Generally Associated	Feeds and Breeds	High	Closely tied to water.
Rocky Mountain Elk	Generally Associated	Feeds and Breeds	High	None noted.

Mammals Associated with Montane Coniferous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Roosevelt Elk	Generally Associated	Feeds and Breeds	High	None noted.
Shrew-mole	Generally Associated	Feeds and Breeds	High	None noted.
Silver-haired Bat	Generally Associated	Feeds and Breeds	Moderate	Uses trees, bark crevices, and snags for summer roosts; if present in winter, may use caves, mines, or rock crevices for hibernacula.
Townsend's Big-eared Bat	Generally Associated	Feeds	Moderate	None noted.
Townsend's Chipmunk	Generally Associated	Feeds and Breeds	High	None noted.
Trowbridge's Shrew	Generally Associated	Feeds and Breeds	High	None noted.
Western Jumping Mouse	Generally Associated	Feeds and Breeds	Moderate	None noted.
Western Spotted Skunk	Generally Associated	Feeds and Breeds	Low	None noted.
Wolverine	Generally Associated	Feeds and Breeds	Low	None noted.
Coast Mole	Present	Feeds and Breeds	Moderate	None noted.
Ermine	Present	Feeds and Breeds	Low	None noted.
Fringed Myotis	Present	Feeds	Low	Requires caves, mines or rock crevices.
Grizzly Bear	Present	Feeds	Moderate	None noted.
Heather Vole	Present	Feeds and Breeds	Moderate	None noted.
Long-legged Myotis	Present	Feeds and Breeds	Moderate	Uses caves or mines as hibernacula. Uses hollow trees, loose bark or rock crevices for maternity colonies.
Lynx	Present	Feeds	Low	None noted.
Masked Shrew	Present	Feeds and Breeds	Moderate	None noted.
Montane Shrew	Present	Feeds and Breeds	Low	None noted.
Vagrant Shrew	Present	Feeds and Breeds	Moderate	None noted.

Reptiles Associated with Montane Coniferous Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Common Garter Snake	Closely Associated	Feeds and Breeds	Moderate	None noted.
Rubber Boa	Generally Associated	Feeds and Breeds	High	Usually does not occur far from water.

Wildlife Species Found in Eastside (Interior) Riparian -Wetlands

Amphibians Associated with Eastside (Interior) Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Bullfrog	Closely Associated	Feeds and Breeds	High	Requires warm-water ponds, marshes, or river/stream backwaters for breeding.
Columbia Spotted Frog	Closely Associated	Feeds and Breeds	High	Rare or absent where predatory fish or bullfrogs occur. Requires shallow water in wet meadows or stream/pond edges with abundant aquatic vegetation for breeding.
Great Basin Spadefoot	Closely Associated	Feeds and Breeds	High	Requires ponds or temporary rain-filled depressions for breeding.
Long-toed Salamander	Closely Associated	Feeds and Breeds	High	Rare or absent where predatory fish are occur. Requires ponds, shallow lake edges, seasonal pools (like elk wallows) or slow streams for breeding.
Northern Leopard Frog	Closely Associated	Feeds and Breeds	High	Requires ponds or lake edges with dense aquatic and emergent vegetation for breeding.
Pacific Chorus (Tree) Frog	Closely Associated	Feeds and Breeds	High	Requires ponds, seasonal pools, temporary rain-filled depressions or slow streams for breeding.
Tailed Frog	Closely Associated	Feeds and Breeds	Moderate	Requires clear, cold steep-gradient streams for breeding.
Tiger Salamander	Closely Associated	Feeds and Breeds	High	Rare or absent where predatory fish occur. Requires warm ponds or shallow lake edges for breeding.
Western Toad	Closely Associated	Feeds and Breeds	High	None noted.
Woodhouse's Toad	Closely Associated	Feeds and Breeds	High	Requires warm, shallow water in ponds, lakes, or slow streams for breeding.
Cascades Frog	Generally Associated	Feeds and Breeds	Moderate	Requires bogs or ponds with cold springs for breeding.
Northwestern Salamander	Present	Feeds and Breeds	High	Range extends only peripherally into the eastside Cascades in Washington only. Requires ponds or stream backwaters for breeding.
Red-legged Frog	Present	Feeds and Breeds	High	Range extends only peripherally into the eastside Cascades.

Amphibians Associated with Eastside (Interior) Riparian - Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Rough-skinned Newt	Present	Feeds and Breeds	High	Range doesn't extend very far east of Cascades. Needs ponds/backwaters & profuse aquatic vegetation breed.

Birds Associated with Eastside (Interior) Riparian -Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
American Black Duck	Closely Associated	Feeds and Breeds	Low	None noted.
American Dipper	Closely Associated	Feeds and Breeds	High	None noted.
American Redstart	Closely Associated	Feeds and Breeds	High	None noted.
Bank Swallow	Closely Associated	Feeds and Breeds	High	Requires burrows in dirt banks, usually next to water, for nesting.
Barn Swallow	Closely Associated	Feeds and Breeds	High	Can nest anywhere buildings, bridges, or overhanging cliffs occur in close proximity to water.
Belted Kingfisher	Closely Associated	Feeds and Breeds	High	None noted.
Black-billed Magpie	Closely Associated	Feeds and Breeds	High	None noted.
Black-crowned Night-heron	Closely Associated	Feeds and Breeds	High	Occur in wide bottomlands, not narrow canyons.
Blue Grouse	Closely Associated	Feeds and Breeds	High	None noted.
Bullock's Oriole	Closely Associated	Feeds and Breeds	Moderate	None noted.
Cedar Waxwing	Closely Associated	Feeds and Breeds	High	None noted.
Cliff Swallow	Closely Associated	Feeds and Breeds	Moderate	Can nest anywhere rimrock, overhanging cliffs, buildings or bridges occur in close proximity to water.
Common Merganser	Closely Associated	Feeds and Breeds	High	Nests in tree cavities near large lakes or rivers.
Common Yellowthroat	Closely Associated	Feeds and Breeds	High	None noted.
Cordilleran Flycatcher	Closely Associated	Feeds and Breeds	Moderate	None noted.
Double-crested Cormorant	Closely Associated	Feeds and Breeds	High	None noted.

Birds Associated with Eastside (Interior) Riparian -Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
European Starling	Closely Associated	Feeds and Breeds	High	Requires snags or trees with cavities or buildings with crevices for nesting. Most likely to use this habitat where adjacent to agriculture or urban habitats.
Fox Sparrow	Closely Associated	Feeds and Breeds	High	None noted.
Gray Catbird	Closely Associated	Feeds and Breeds	High	None noted.
Great Blue Heron	Closely Associated	Feeds and Breeds	High	None noted.
Great Egret	Closely Associated	Feeds and Breeds	High	More common in broad flood plains; does not occur in narrow riparian corridors as a breeder.
Harlequin Duck	Closely Associated	Feeds and Breeds	High	None noted.
Hooded Merganser	Closely Associated	Feeds and Breeds	Moderate	Nests in tree cavities.
Lazuli Bunting	Closely Associated	Feeds and Breeds	High	None noted.
Lincoln's Sparrow	Closely Associated	Feeds and Breeds	Moderate	None noted.
Long-eared Owl	Closely Associated	Feeds and Breeds	High	Typically nests in the abandoned nests of other corvids, raptors or squirrels.
Mallard	Closely Associated	Feeds and Breeds	High	None noted.
Mourning Dove	Closely Associated	Feeds and Breeds	High	None noted.
Northern Rough-winged Swallow	Closely Associated	Feeds and Breeds	High	Requires burrows in dirt banks, usually next to water, for nesting.
Northern Waterthrush	Closely Associated	Feeds and Breeds	High	None noted.
Pygmy Nuthatch	Closely Associated	Feeds and Breeds	Moderate	Uses this habitat where ponderosa pine occurs.
Red-eyed Vireo	Closely Associated	Feeds and Breeds	Moderate	Range of red-eyed vireo overlaps that of large black cottonwood groves.
Red-naped Sapsucker	Closely Associated	Feeds and Breeds	High	None noted.
Ring-necked Pheasant	Closely Associated	Feeds and Breeds	High	None noted.

Birds Associated with Eastside (Interior) Riparian -Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Ruffed Grouse	Closely Associated	Feeds and Breeds	High	None noted.
Sharp-tailed Grouse	Closely Associated	Feeds	High	In Oregon this was historically very important overwintering habitat.
Snowy Egret	Closely Associated	Feeds and Breeds	High	Requires tall shrubs or trees for nesting.
Solitary Sandpiper	Closely Associated	Feeds	Moderate	None noted.
Spotted Sandpiper	Closely Associated	Feeds and Breeds	Moderate	None noted.
Tree Swallow	Closely Associated	Feeds and Breeds	Moderate	Requires snags not far from open water for nesting.
Veery	Closely Associated	Feeds and Breeds	High	None noted.
Warbling Vireo	Closely Associated	Feeds and Breeds	High	None noted.
Western Screech-owl	Closely Associated	Feeds and Breeds	High	None noted.
Willow Flycatcher	Closely Associated	Feeds and Breeds	Moderate	None noted.
Wood Duck	Closely Associated	Feeds and Breeds	High	Nests in tree cavities.
Yellow Warbler	Closely Associated	Feeds and Breeds	High	None noted.
Yellow-billed Cuckoo	Closely Associated	Feeds and Breeds	Moderate	Not known from eastside Washington (even historically); in Oregon species may still occur in a few scattered locations.
Yellow-breasted Chat	Closely Associated	Feeds and Breeds	Moderate	None noted.
American Crow	Generally Associated	Feeds and Breeds	High	None noted.
American Goldfinch	Generally Associated	Feeds and Breeds	High	None noted.
American Kestrel	Generally Associated	Feeds and Breeds	High	None noted.
American Robin	Generally Associated	Feeds and Breeds	High	None noted.
American Tree Sparrow	Generally Associated	Feeds	Moderate	None noted.
Bald Eagle	Generally Associated	Feeds and Breeds	High	None noted.

Birds Associated with Eastside (Interior) Riparian -Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Barn Owl	Generally Associated	Feeds and Breeds	High	Requires cliffs, caves, rimrock, or tree cavities for nesting.
Black Swift	Generally Associated	Feeds and Breeds	Low	Requires suitable cliffs behind waterfalls for breeding.
Black-capped Chickadee	Generally Associated	Feeds and Breeds	Moderate	None noted.
Black-chinned Hummingbird	Generally Associated	Feeds and Breeds	Low	None noted.
Black-headed Grosbeak	Generally Associated	Feeds and Breeds	High	None noted.
Black-throated Gray Warbler	Generally Associated	Feeds and Breeds	Low	None noted.
Bobolink	Generally Associated	Feeds and Breeds	Moderate	None noted.
Bohemian Waxwing	Generally Associated	Feeds	Moderate	None noted.
Brewer's Blackbird	Generally Associated	Feeds and Breeds	Moderate	None noted.
Broad-tailed Hummingbird	Generally Associated	Feeds and Breeds	Low	High elevation, montane riparian. Breeding suspected but not confirmed. Birds have been found in eastside riparian aspen and willow habitats.
Brown Creeper	Generally Associated	Feeds and Breeds	Moderate	None noted.
Brown-headed Cowbird	Generally Associated	Feeds and Breeds	High	None noted.
Bufflehead	Generally Associated	Feeds and Breeds	Moderate	Nests in tree cavities.
Bushtit	Generally Associated	Feeds and Breeds	Moderate	None noted.
California Quail	Generally Associated	Feeds and Breeds	High	Uses this habitat where adjacent to more open habitats.
Calliope Hummingbird	Generally Associated	Feeds and Breeds	Moderate	None noted.
Canyon Wren	Generally Associated	Feeds and Breeds	Moderate	Requires rocky outcrops, cliffs for nesting.
Cassin's Finch	Generally Associated	Feeds and Breeds	High	None noted.
Cassin's Vireo	Generally Associated	Feeds and Breeds	Moderate	None noted.

Birds Associated with Eastside (Interior) Riparian -Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Cattle Egret	Generally Associated	Feeds and Breeds	High	Requires shrubs or trees for nesting.
Chipping Sparrow	Generally Associated	Feeds and Breeds	Moderate	None noted.
Common Nighthawk	Generally Associated	Feeds	Moderate	None noted.
Common Raven	Generally Associated	Feeds and Breeds	High	None noted.
Common Redpoll	Generally Associated	Feeds	Moderate	None noted.
Cooper's Hawk	Generally Associated	Feeds and Breeds	High	None noted.
Dark-eyed Junco	Generally Associated	Feeds and Breeds	High	None noted.
Downy Woodpecker	Generally Associated	Feeds and Breeds	Moderate	None noted.
Dusky Flycatcher	Generally Associated	Feeds and Breeds	Moderate	None noted.
Eastern Kingbird	Generally Associated	Feeds and Breeds	Moderate	Requires groves of hardwoods for breeding.
Evening Grosbeak	Generally Associated	Feeds and Breeds	Moderate	None noted.
Flammulated Owl	Generally Associated	Feeds and Breeds	Moderate	Must have ponderosa pine/aspen.
Golden Eagle	Generally Associated	Feeds and Breeds	High	Needs cliffs for nesting.
Golden-crowned Kinglet	Generally Associated	Feeds and Breeds	Moderate	None noted.
Golden-crowned Sparrow	Generally Associated	Feeds	Moderate	None noted.
Gray Jay	Generally Associated	Feeds and Breeds	Moderate	None noted.
Great Horned Owl	Generally Associated	Feeds and Breeds	High	None noted.
Greater Yellowlegs	Generally Associated	Feeds	Low	None noted.
Green-winged Teal	Generally Associated	Feeds	High	None noted.
Hairy Woodpecker	Generally Associated	Feeds and Breeds	Moderate	None noted.

Birds Associated with Eastside (Interior) Riparian -Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Hermit Thrush	Generally Associated	Feeds and Breeds	High	None noted.
House Wren	Generally Associated	Feeds and Breeds	Moderate	None noted.
Killdeer	Generally Associated	Feeds and Breeds	Moderate	None noted.
Least Flycatcher	Generally Associated	Feeds and Breeds	Low	Has bred regularly at Clyde Holiday State Wayside, Grant County, Oregon, and numerous singing males have been found in eastside hardwood riparian habitats in Washington.
Lesser Yellowlegs	Generally Associated	Feeds	Low	None noted.
Lewis's Woodpecker	Generally Associated	Feeds and Breeds	Moderate	None noted.
Macgillivray's Warbler	Generally Associated	Feeds and Breeds	High	None noted.
Mountain Bluebird	Generally Associated	Feeds and Breeds	Moderate	None noted.
Mountain Chickadee	Generally Associated	Feeds and Breeds	Moderate	None noted.
Mountain Quail	Generally Associated	Feeds and Breeds	High	None noted.
Nashville Warbler	Generally Associated	Feeds and Breeds	High	None noted.
Northern Flicker	Generally Associated	Feeds and Breeds	Moderate	None noted.
Northern Goshawk	Generally Associated	Feeds and Breeds	High	None noted.
Northern Pygmy-owl	Generally Associated	Feeds and Breeds	High	None noted.
Olive-sided Flycatcher	Generally Associated	Feeds and Breeds	Moderate	None noted.
Orange-crowned Warbler	Generally Associated	Feeds and Breeds	High	None noted.
Osprey	Generally Associated	Feeds and Breeds	High	None noted.
Peregrine Falcon	Generally Associated	Feeds and Breeds	High	Needs cliffs for nesting.
Pied-billed Grebe	Generally Associated	Feeds and Breeds	High	None noted.

Birds Associated with Eastside (Interior) Riparian -Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Pileated Woodpecker	Generally Associated	Feeds and Breeds	Moderate	None noted.
Pine Siskin	Generally Associated	Feeds and Breeds	High	None noted.
Red-breasted Nuthatch	Generally Associated	Feeds and Breeds	Moderate	None noted.
Red-breasted Sapsucker	Generally Associated	Feeds and Breeds	Moderate	Only in south-central Oregon: may hybridize with Red-naped sapsucker in Eastside riparian.
Red-tailed Hawk	Generally Associated	Feeds and Breeds	High	None noted.
Red-winged Blackbird	Generally Associated	Feeds and Breeds	High	None noted.
Ring-necked Duck	Generally Associated	Feeds and Breeds	High	None noted.
Rufous Hummingbird	Generally Associated	Feeds and Breeds	Moderate	None noted.
Sandhill Crane	Generally Associated	Feeds and Breeds	High	Uses open riparian areas with only scattered willows or willow clumps.
Savannah Sparrow	Generally Associated	Feeds and Breeds	Moderate	None noted.
Say's Phoebe	Generally Associated	Feeds and Breeds	Moderate	Needs cliffs or rimrock for nesting.
Song Sparrow	Generally Associated	Feeds and Breeds	High	None noted.
Spotted Towhee	Generally Associated	Feeds and Breeds	Moderate	None noted.
Steller's Jay	Generally Associated	Feeds and Breeds	Moderate	None noted.
Swainson's Hawk	Generally Associated	Feeds and Breeds	High	None noted.
Swainson's Thrush	Generally Associated	Feeds and Breeds	High	None noted.
Townsend's Solitaire	Generally Associated	Feeds	Moderate	None noted.
Turkey Vulture	Generally Associated	Feeds and Breeds	High	Requires rocky outcrops, small caves, boulder piles, ledges on high cliffs or large hollow logs for nesting.
Violet-green Swallow	Generally Associated	Feeds and Breeds	Moderate	None noted.

Birds Associated with Eastside (Interior) Riparian -Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Western Bluebird	Generally Associated	Feeds and Breeds	High	None noted.
Western Tanager	Generally Associated	Feeds and Breeds	Moderate	None noted.
Western Wood-pewee	Generally Associated	Feeds and Breeds	Moderate	None noted.
White-breasted Nuthatch	Generally Associated	Feeds and Breeds	Moderate	Uses this habitat where ponderosa pine and hardwoods occur in the riparian zone.
White-crowned Sparrow	Generally Associated	Feeds and Breeds	High	None noted.
White-headed Woodpecker	Generally Associated	Feeds and Breeds	Low	Requires a ponderosa pine component.
White-throated Swift	Generally Associated	Feeds	Low	May use riparian areas as travel corridors.
Wild Turkey	Generally Associated	Feeds and Breeds	High	None noted.
Williamson's Sapsucker	Generally Associated	Feeds and Breeds	Low	None noted.
Wilson's Warbler	Generally Associated	Feeds and Breeds	High	None noted.
Winter Wren	Generally Associated	Feeds and Breeds	Moderate	None noted.
Yellow-rumped Warbler	Generally Associated	Feeds and Breeds	Moderate	None noted.
American Wigeon	Present	Feeds	Moderate	None noted.
Ash-throated Flycatcher	Present	Feeds and Breeds	Low	None noted.
Band-tailed Pigeon	Present	Feeds	Moderate	None noted.
Barred Owl	Present	Feeds and Breeds	Moderate	None noted.
Black-backed Woodpecker	Present	Feeds and Breeds	Moderate	None noted.
Canada Goose	Present	Feeds and Breeds	Moderate	None noted.
Chukar	Present	Feeds	Moderate	None noted.
Green-tailed Towhee	Present	Feeds and Breeds	Moderate	None noted.
House Finch	Present	Feeds and Breeds	Moderate	Uses this habitat where it is not too far from urban or agricultural areas.

Birds Associated with Eastside (Interior) Riparian -Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Lesser Goldfinch	Present	Feeds and Breeds	Moderate	None noted.
Merlin	Present	Feeds	Low	None noted.
Northern Harrier	Present	Feeds and Breeds	High	None noted.
Northern Saw-whet Owl	Present	Feeds and Breeds	Low	None noted.
Prairie Falcon	Present	Feeds and Breeds	High	Needs cliffs for nesting.
Red Crossbill	Present	Feeds	Low	None noted.
Rough-legged Hawk	Present	Feeds	High	None noted.
Ruby-crowned Kinglet	Present	Feeds and Breeds	Moderate	None noted.
Three-toed Woodpecker	Present	Feeds and Breeds	Moderate	None noted.
Townsend's Warbler	Present	Feeds and Breeds	Low	Heavy use during migration, and occasional breeding where conifers are present.
Vaux's Swift	Present	Feeds and Breeds	Low	None noted.

Mammals Associated with Eastside (Interior) Riparian -Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
American Beaver	Closely Associated	Feeds and Breeds	High	None noted.
Big Brown Bat	Closely Associated	Feeds and Breeds	High	Requires snags, caves, mines, rock crevices, or bridges for breeding and roosting.
Bushy-tailed Woodrat	Closely Associated	Feeds and Breeds	High	None noted.
Deer Mouse	Closely Associated	Feeds and Breeds	High	None noted.
Long-legged Myotis	Closely Associated	Feeds and Breeds	Moderate	Uses caves or mines as hibernacula. Uses hollow trees, loose bark or rock crevices for maternity colonies.
Long-tailed Vole	Closely Associated	Feeds and Breeds	High	None noted.
Meadow Vole	Closely Associated	Feeds and Breeds	Low	None noted.
Mink	Closely Associated	Feeds and Breeds	Moderate	None noted.

Mammals Associated with Eastside (Interior) Riparian -Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Muskrat	Closely Associated	Feeds and Breeds	Moderate	None noted.
Northern River Otter	Closely Associated	Feeds and Breeds	High	None noted.
Pacific Jumping Mouse	Closely Associated	Feeds and Breeds	High	None noted.
Pallid Bat	Closely Associated	Feeds and Breeds	Moderate	Requires rock cliffs, caves or mines for breeding.
Raccoon	Closely Associated	Feeds and Breeds	Moderate	None noted.
Snowshoe Hare	Closely Associated	Feeds and Breeds	High	None noted.
Southern Red-backed Vole	Closely Associated	Feeds and Breeds	High	None noted.
Water Shrew	Closely Associated	Feeds and Breeds	High	Lead a semi-aquatic life and require cold, clear water in small streams or ponds with abundant cover in the form of rocks, overhanging banks, etc.
Water Vole	Closely Associated	Feeds and Breeds	Low	None noted.
Western Harvest Mouse	Closely Associated	Feeds and Breeds	High	None noted.
Western Jumping Mouse	Closely Associated	Feeds and Breeds	High	None noted.
Western Pipistrelle	Closely Associated	Feeds and Breeds	High	Requires cliffs, rimrock, caves or mines for breeding and roosting.
Western Small-footed Myotis	Closely Associated	Feeds and Breeds	Moderate	Requires cliffs, rimrock, boulders, or talus for breeding.
White-tailed Deer (Eastside)	Closely Associated	Feeds and Breeds	High	None noted.
Yuma Myotis	Closely Associated	Feeds and Breeds	High	More closely associated with water than other bat species. Uses caves, mines, loose bark and bark crevices typically close to water.
Black Bear	Generally Associated	Feeds and Breeds	High	None noted.
Black-tailed Deer	Generally Associated	Feeds and Breeds	High	None noted.
Bobcat	Generally Associated	Feeds and Breeds	Moderate	None noted.
Broad-footed Mole	Generally Associated	Feeds and Breeds	Moderate	None noted.

Mammals Associated with Eastside (Interior) Riparian -Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Brush Rabbit	Generally Associated	Feeds and Breeds	Moderate	None noted.
California Myotis	Generally Associated	Feeds and Breeds	High	Uses rock crevices, hollow trees, mines or caves for breeding.
Columbian Ground Squirrel	Generally Associated	Feeds and Breeds	Moderate	None noted.
Columbian Mouse	Generally Associated	Feeds and Breeds	Moderate	None noted.
Common Porcupine	Generally Associated	Feeds and Breeds	Moderate	None noted.
Coyote	Generally Associated	Feeds and Breeds	High	None noted.
Creeping Vole	Generally Associated	Feeds and Breeds	High	None noted.
Eastern Cottontail	Generally Associated	Feeds and Breeds	Low	Likely uses this habitat where adjacent to urban or agricultural habitats.
Eastern Fox Squirrel	Generally Associated	Feeds and Breeds	Moderate	None noted.
Ermine	Generally Associated	Feeds and Breeds	Low	None noted.
Feral Horse	Generally Associated	Feeds	Low	None noted.
Feral Pig	Generally Associated	Feeds and Breeds	Moderate	None noted.
Fisher	Generally Associated	Feeds and Breeds	Low	None noted.
Fringed Myotis	Generally Associated	Feeds and Breeds	Low	Requires caves, mines or rock crevices.
Hoary Bat	Generally Associated	Feeds	Moderate	Requires trees for roosting, but forages in openings and at edges of forests.
Little Brown Myotis	Generally Associated	Feeds and Breeds	High	Uses caves, mines, or hollow trees, often near water.
Long-eared Myotis	Generally Associated	Feeds and Breeds	Moderate	Uses caves, mines, hollow trees, loose bark or rock crevices.
Long-tailed Weasel	Generally Associated	Feeds and Breeds	Moderate	None noted.
Masked Shrew	Generally Associated	Feeds and Breeds	High	None noted.
Montane Vole	Generally Associated	Feeds and Breeds	High	None noted.

Mammals Associated with Eastside (Interior) Riparian -Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Moose	Generally Associated	Feeds and Breeds	High	None noted.
Mountain Caribou	Generally Associated	Feeds and Breeds	High	None noted.
Mountain Lion	Generally Associated	Feeds and Breeds	High	None noted.
Mule Deer	Generally Associated	Feeds and Breeds	High	None noted.
Northern Flying Squirrel	Generally Associated	Feeds and Breeds	High	None noted.
Northern Pocket Gopher	Generally Associated	Feeds and Breeds	Moderate	None noted.
Pacific Water Shrew	Generally Associated	Feeds and Breeds	Moderate	Closely tied to water.
Red Fox	Generally Associated	Feeds and Breeds	Low	Non-native Red fox.
Rocky Mountain Elk	Generally Associated	Feeds and Breeds	High	None noted.
Shrew-mole	Generally Associated	Feeds and Breeds	High	None noted.
Silver-haired Bat	Generally Associated	Feeds and Breeds	Moderate	Uses trees, bark crevices, and snags for summer roosts; if present in winter, may use caves, mines, or rock crevices for hibernacula.
Spotted Bat	Generally Associated	Feeds and Breeds	Moderate	Requires clliffs for breeding.
Striped Skunk	Generally Associated	Feeds and Breeds	Moderate	None noted.
Townsend's Big-eared Bat	Generally Associated	Feeds	Moderate	None noted.
Trowbridge's Shrew	Generally Associated	Feeds and Breeds	High	None noted.
Virginia Opossum	Generally Associated	Feeds and Breeds	Low	None noted.
Western Spotted Skunk	Generally Associated	Feeds and Breeds	Low	None noted.
Wild Burro	Generally Associated	Feeds	Low	None noted.
Yellow-bellied Marmot	Generally Associated	Feeds and Breeds	Moderate	Requires talus slopes, lava fields, rimrock, or boulder fields in close proximity to grassy openings or meadows.

Mammals Associated with Eastside (Interior) Riparian -Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Yellow-pine Chipmunk	Generally Associated	Feeds and Breeds	Moderate	None noted.
American Badger	Present	Feeds	Moderate	None noted.
American Marten	Present	Feeds and Breeds	Moderate	None noted.
Coast Mole	Present	Feeds and Breeds	Moderate	None noted.
Golden-mantled Ground Squirrel	Present	Feeds and Breeds	Moderate	None noted.
Grizzly Bear	Present	Feeds	Moderate	None noted.
Heather Vole	Present	Feeds and Breeds	Moderate	None noted.
Least Chipmunk	Present	Feeds and Breeds	Low	None noted.
Montane Shrew	Present	Feeds and Breeds	Moderate	None noted.
Preble's Shrew	Present	Feeds and Breeds	Low	None noted.
Pronghorn Antelope	Present	Feeds	Moderate	None noted.
Vagrant Shrew	Present	Feeds and Breeds	Moderate	None noted.
White-tailed Jackrabbit	Present	Feeds and Breeds	Moderate	None noted.

Reptiles Associated with Eastside (Interior) Riparian-Wetlands				
Species (alphabetically by common name within each association)	**Association**	**Activity**	**Confidence**	**Comments**
Common Garter Snake	Closely Associated	Feeds and Breeds	High	None noted.
Gopher Snake	Generally Associated	Feeds and Breeds	High	None noted.
Northern Alligator Lizard	Generally Associated	Feeds and Breeds	High	None noted.
Painted Turtle	Generally Associated	Feeds and Breeds	Moderate	None noted.
Racer	Generally Associated	Feeds and Breeds	High	None noted.
Rubber Boa	Generally Associated	Feeds and Breeds	High	Usually does not occur far from water.
Sharptail Snake	Generally Associated	Feeds and Breeds	Moderate	None noted.
Western Rattlesnake	Generally Associated	Feeds and Breeds	High	None noted.
Western Terrestrial Garter Snake	Generally Associated	Feeds and Breeds	High	None noted.
Southern Alligator Lizard	Present	Feeds and Breeds	Low	None noted.