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).

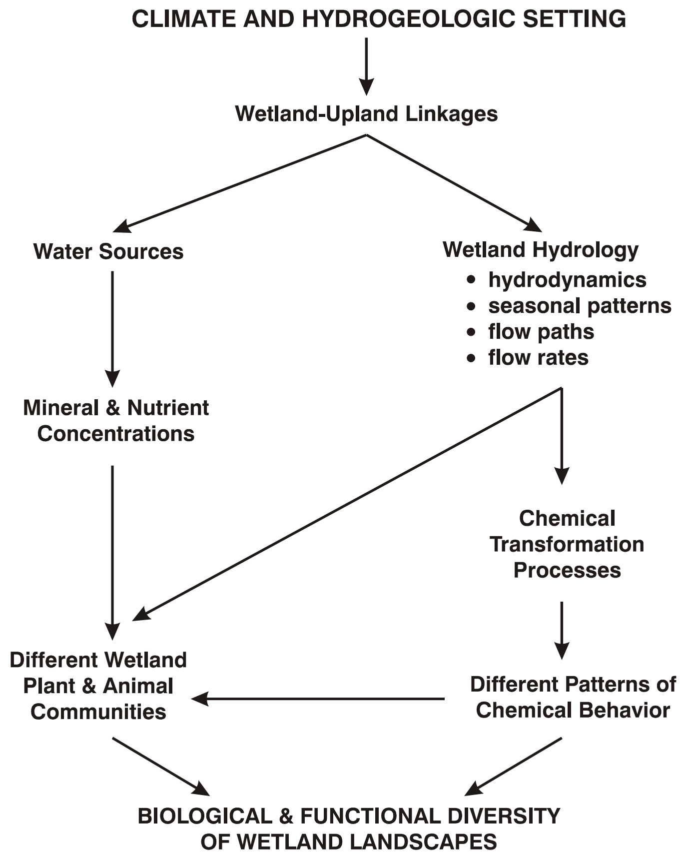

Figure 2-1. A model of the environmental factors that control wetland functions. (Bedford 1999; reprinted with permission)

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.

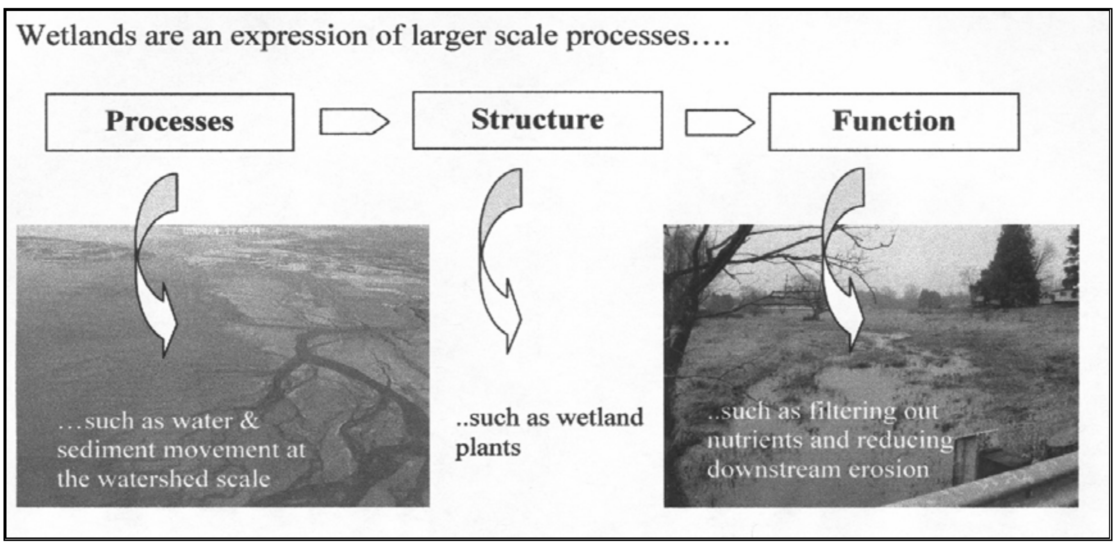

Figure 2-2. "Process-structure-function" model.

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).	

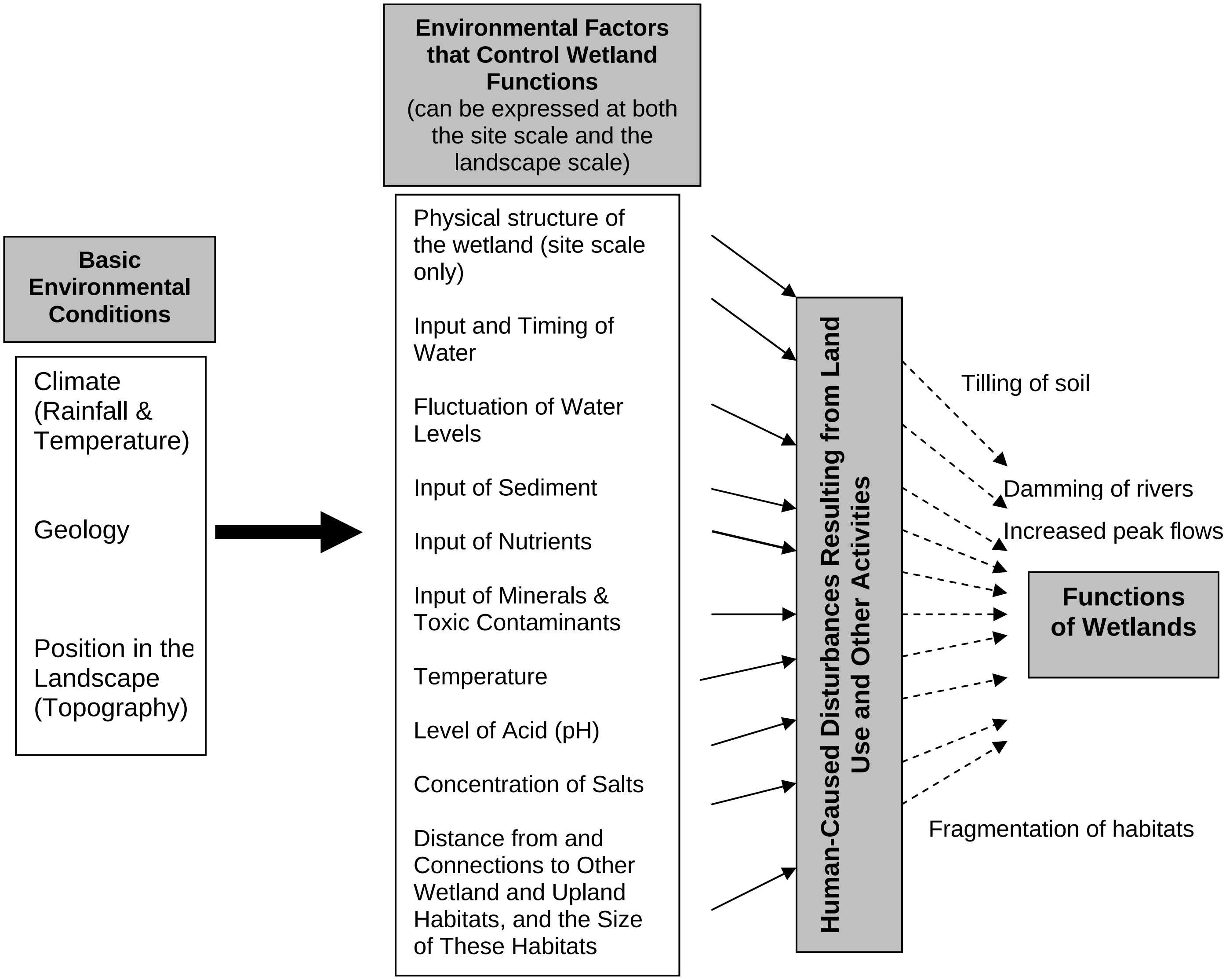

Figure 2-3. Diagram summarizing some major environmental factors that control functions of wetlands and how they interact with human-caused disturbances.

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

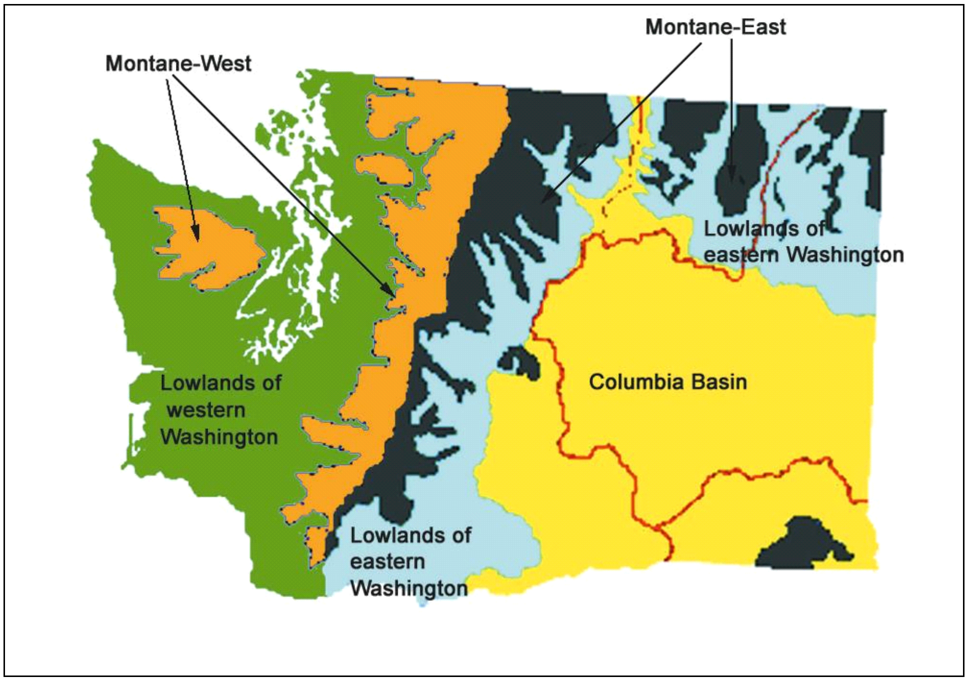

Figure 2-4. Regions in Washington used for classifying wetlands.

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.

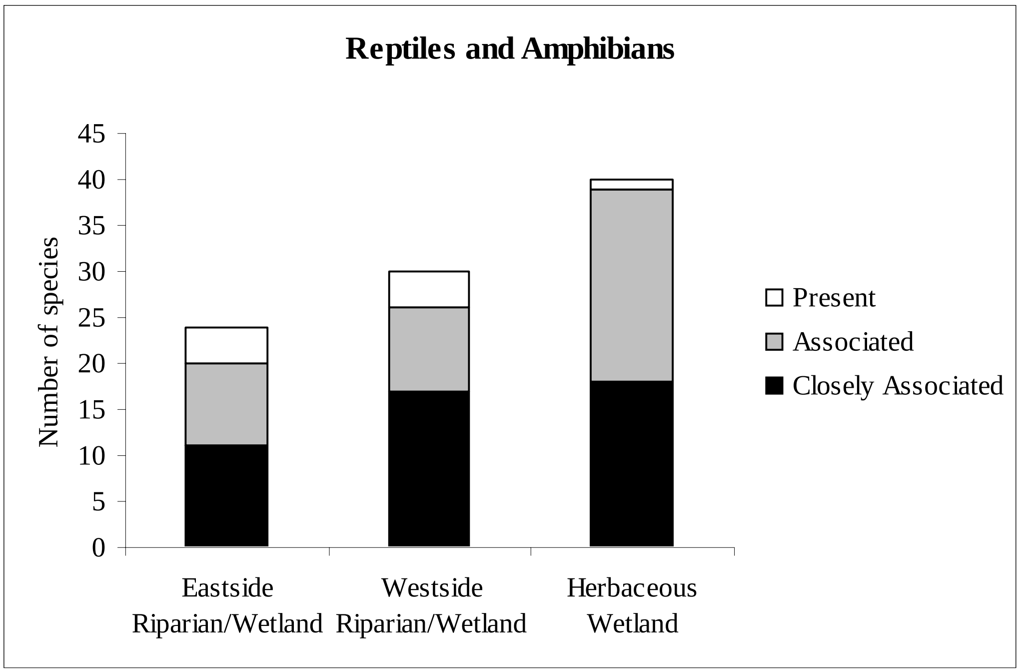

Figure 2-12. The number of reptile and amphibian species found in wetlands in Washington and Oregon. (from Kauffman et al. 2001)

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.

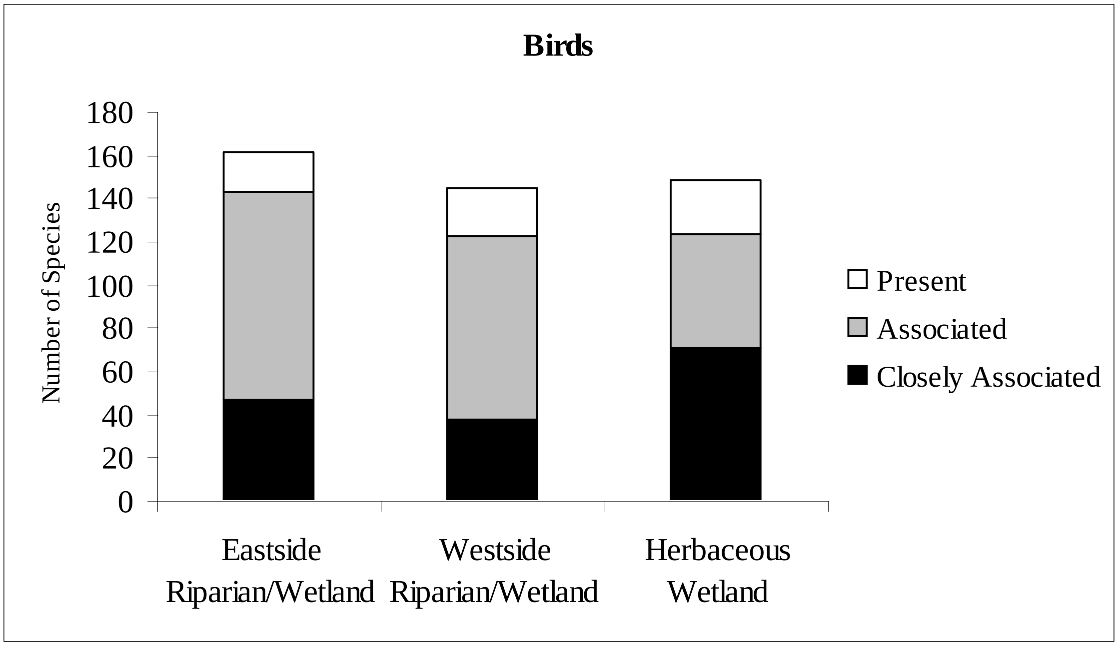

Figure 2-13. The number of bird species found in wetlands in Washington and Oregon (from Kauffman et al. 2001).

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).

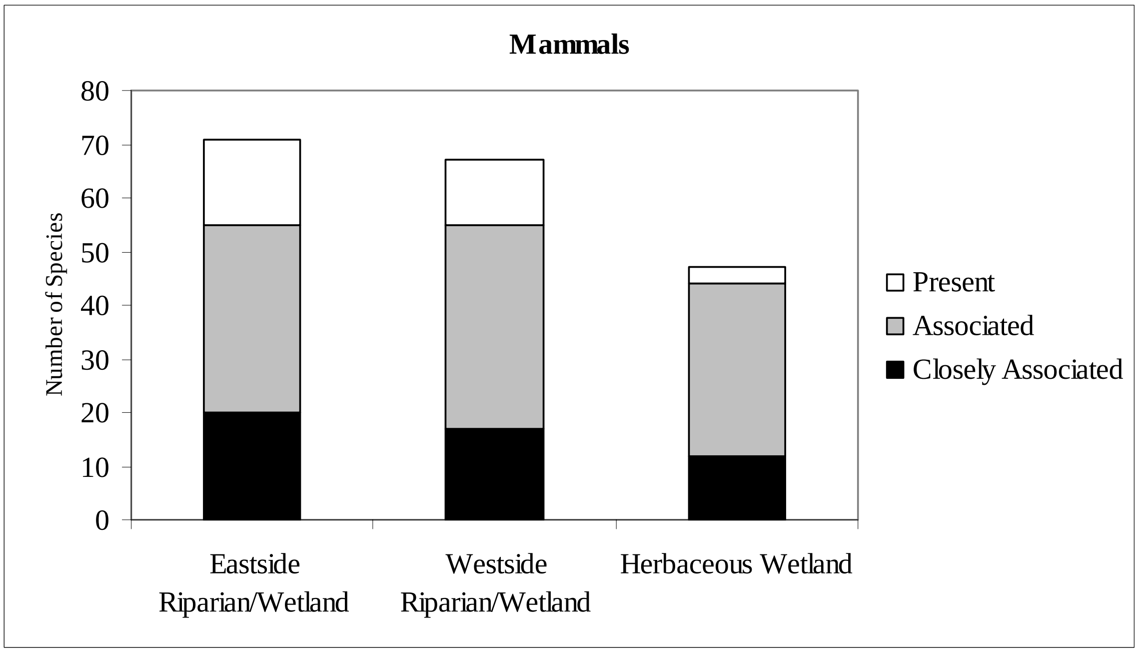

Figure 2-14. The number of mammal species found in wetlands in Washington and Oregon (from Kauffman et al. 2001).

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.