Chapter 3

Environmental Disturbances Caused by Human Activities and Uses of the Land

3.1 Reader's Guide to this Chapter

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

3.1.1 Chapter Contents

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

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

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

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

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

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

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

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

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

3.1.2 Where to Find Summary Information and Conclusions

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

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

- Section 3.2.6
- Section 3.3.11
- Section 3.4.9

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

3.1.3 Sources and Gaps in Information

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

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

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

3.2 Introduction to Human-Caused Disturbances

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

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

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

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

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

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

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

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

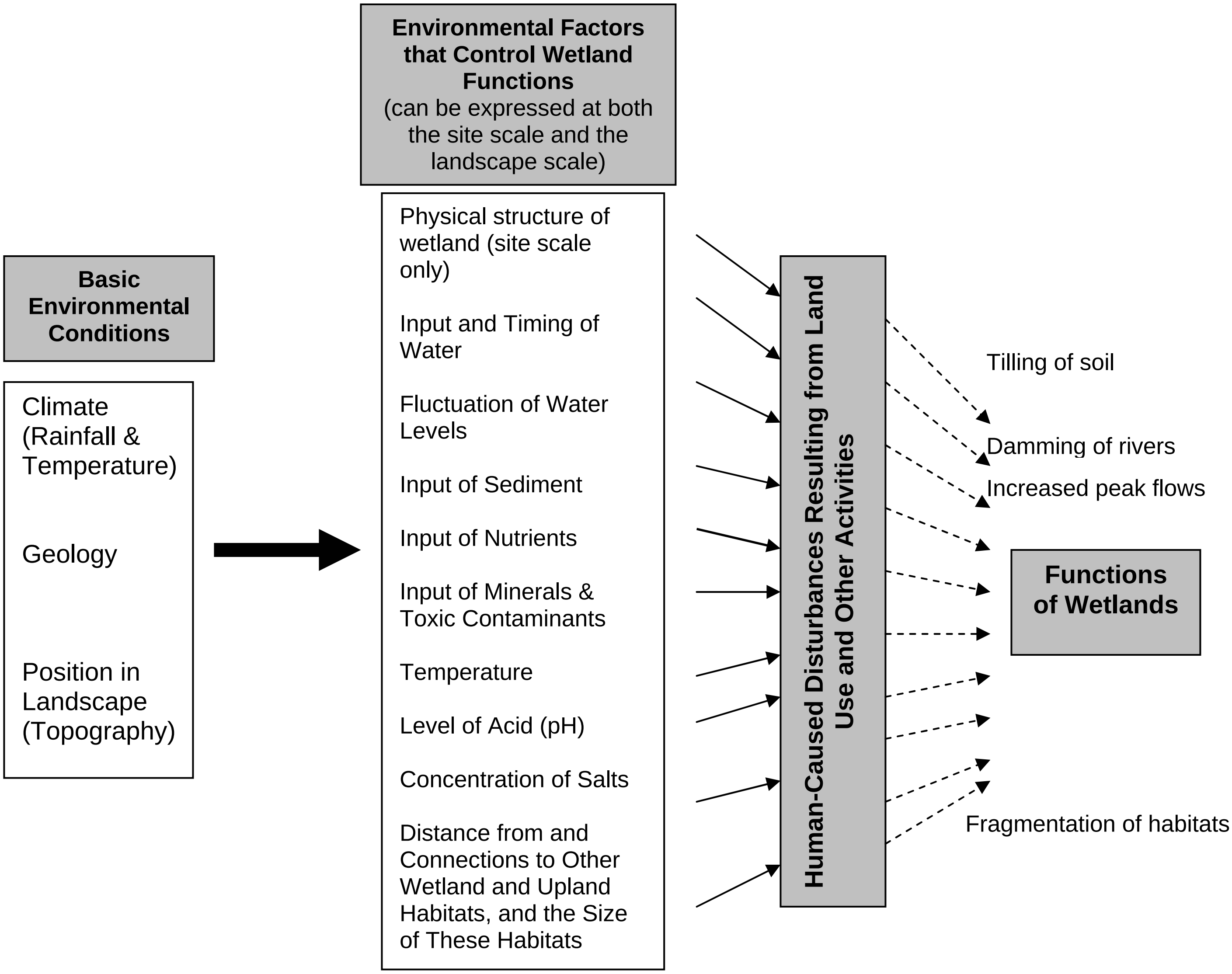

Figure 3-1. Diagram summarizing some major environmental factors that control functions of wetlands and how they interact with human-caused disturbances.

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

3.2.2 Types of Disturbances Resulting from Human Land Uses

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

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

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

3.2.3 Disturbances to the Movement of Water at the Landscape Scale

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

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

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

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

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

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

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

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

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

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

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

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

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

3.2.3.1 Movement of Water in Undisturbed Landscapes

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

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

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

3.2.3.2 Movement of Water in Disturbed Landscapes

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

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

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

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

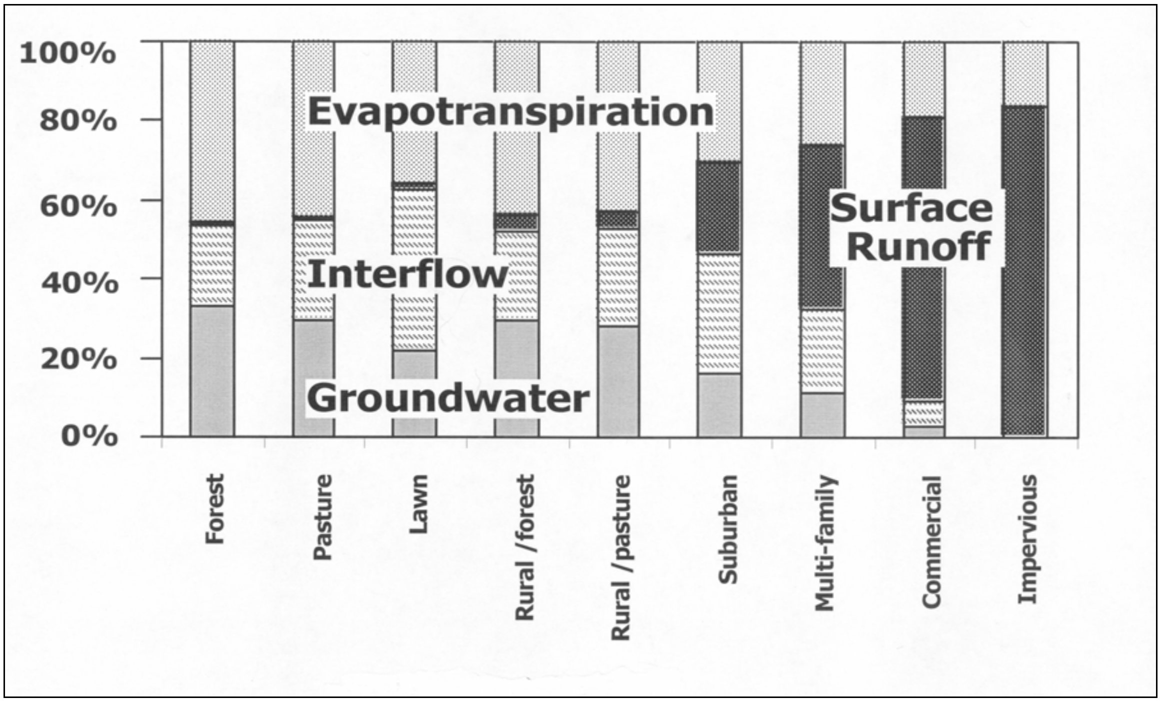

Figure 3-2. Changes in the proportion of groundwater, interflow, evapotranspiration, and surface runoff with different types of land cover in western Washington (Beyerlein 1999; reprinted with permission).

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

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

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

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

3.2.3.3 The Role Of Impervious Surface In Changing Water Regimes

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

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

Defining and assessing impervious surface

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

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

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

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

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

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

3.2.3.4 The Role Of Dams In Changing Water Regimes

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

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

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

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

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

3.2.4 Disturbances to the Quality of Water at the Landscape Scale

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

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

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

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

3.2.5 Disturbances to Habitats at the Landscape Scale (Fragmentation)

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

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

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

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

3.2.6 Summary of Key Points

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

3.3 Disturbances Caused by Agriculture

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

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

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

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

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

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

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

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

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

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

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

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

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

3.3.2 Increased Amounts of Water in Wetlands Resulting from Agricultural Practices

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

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

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

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

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

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

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

Adamus (1993) also noted:

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

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

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

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

3.3.3 Decreased Amounts of Water in Wetlands Resulting from Agricultural Practices

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

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

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

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

3.3.4 Increased Fluctuations of Water Levels in Wetlands Resulting from Agriculture

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

3.3.5 Increased Input of Sediment Resulting from Agriculture

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

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

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

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

3.3.6 Increased Input of Nutrients Resulting from Agriculture

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

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

3.3.7 Increased Input of Toxic Contaminants Resulting from Agriculture

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

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

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

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

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

3.3.8 Increased Levels of Salt Resulting from Agriculture

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

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

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

3.3.9 Fragmentation of Habitat Resulting from Agriculture

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

3.3.10 Other Disturbances Resulting from Agriculture

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

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

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

3.3.11 Summary of Key Points

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

3.4 Disturbances Caused by Urbanization

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

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

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

3.4.1 Loss of Wetlands Resulting from Urbanization

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

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

3.4.2 Increased Amount of Water in Wetlands Resulting from Urbanization

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

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

3.4.2.1 Increased Frequency of Erosive Flows

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

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

3.4.2.2 Increased Volume of Runoff and Longer Duration of Flows

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

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

3.4.2.3 Consequences of Changes in Water Regime

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

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

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

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

3.4.3 Increased Fluctuations of Water Levels Resulting from Urbanization

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

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

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

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

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

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

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

3.4.4 Increased Input of Sediment Resulting from Urbanization

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

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

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

3.4.5 Increased Input of Nutrients Resulting from Urbanization

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

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

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

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

3.4.6 Increased Input of Toxic Contaminants Resulting from Urbanization

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

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

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

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

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

3.4.6.1 Heavy Metals and Hydrocarbons

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

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

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

3.4.6.2 Organic Matter

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

Contaminants in urban runoff that cause increases in BOD include:

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

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

3.4.6.3 Pesticides

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

3.4.7 Fragmentation of Habitat Resulting from Urbanization

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

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

3.4.8 Other Disturbances Resulting from Urbanization

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

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

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

3.4.9 Summary of Key Points

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

3.5 Disturbances Caused by Forest Practices

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

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

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

3.6 Disturbances Caused by Mining

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

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

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

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

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

3.7 Chapter Summary and Conclusions

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

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

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

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

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

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

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

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

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

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

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