Yakima County's Review of Best Available Science For Inclusion in Critical Areas Ordinance Update

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The use of BAS is required in updating comprehensive plan policies and critical areas ordinances by RCW 36.70A.172(1), and the guidelines for this requirement are found in the Washington Administrative Code (WAC) 365-195-900 through -925. The guidelines are intended to assist local jurisdictions in establishing or reviewing critical areas ordinances and planning policies to include the use of best available science to designate and protect critical areas.

The BAS review focused on an examination of the range of science in order to assess how the existing CAO fits within that range. An emphasis on one piece of science, or "cherry picking" specific science documents to support a position does not meet the intent of the Act. The Washington State Supreme Court, in its decision on Ferry County v. Concerened Citizens of Ferry County quoted:

> "*a ' {c} ounty cannot choose its own science over all other science and cannot use outdated science to support its choice*." (Western Washington Growth Management Hearings Board, March 6, 2000, Island County Citizens Growth Management Coalition v. Island County).

While Best Available Science is intended to be clearly documented as local jurisdictions designate and protect critical areas through plan policies and ordinance review and development, BAS is not intended to be used to regulate specific land use projects. Projects applying for permits must meet the ordiance requirements, but do not have to submit BAS with an application. However, future science is encouraged to be submitted with future applications and will be considered under the same criteria as any other science which meets the WAC requirements. Future science submitalls may be useful in justifying a project request to vary or adjust certain development standards on particular technical issues, though it would not typically negate the BAS reviewed in this document and the standards supported by this document.

Science will continue to improve and as it does, Yakima County anticipates that today's BAS will evolve and change in the future. For this reason, Yakima County wants to clearly state that BAS is currently being used in reviewing and updating Yakima County's comprehensive plan policies and critical areas ordinance, and that future science is encouraged to be submitted and will be considered in the review of development applications.

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GLOSSARY

Advection—the horizontal movement of a mass of fluid.

Alluvial channels—beds and banks made of material that is transported by the stream.

Anadromous—refers to fish that reproduce in freshwater streams or lakes, migrate to salt water for some portion of their lives, and then return to freshwater.

Andesite—a volcanic rock (or lava) characteristically medium dark in color and containing 54 to 62 percent silica and moderate amounts of iron and magnesium.

Anticlinal—a fold, generally convex.

Aquifer—a soil formation capable of transmitting large, measurable quantities of water.

Basaltic—a volcanic rock (or lava) that characteristically is dark in color, contains 45% to 54% silica, and generally is rich in iron and magnesium.

Colluvial—loose, incoherent deposits, usually at the foot of a slope or a cliff and brought there chiefly by gravity.

Cornice—an overhanging mass of snow, ice, or rock usually on a ridge

Debris flow—a moving mass of rock, soil, and mud.

Denitrification—the loss or removal of nitrogen or nitrogen compounds; specifically: the reduction of nitrates or nitrites, commonly by bacteria (as in soil), which usually results in the escape of nitrogen into the air.

Equilibrium—a state of balance between opposing forces or actions that is either static or dynamic.

Evapotranspiration—that portion of precipitation returned to the air through evaporation or transpiration.

Extirpate—to destroy completely.

Faults—a fracture or fracture zone in the Earth's crust across which there has been relative displacement.

Fluvial—produced by the action of a stream or river.

Food web—the complex system of energy transfer among living things; in other words, what eats what.

Fumaroles—a small vent in the ground from which volcanic gases and heated groundwater emerge, but not lava.

Glaciation—the formation, movement, and recession of glaciers or ice sheets.

Graben—depressed segment of the crust of the earth bounded on at least two sides by faults.

Hydrophytic—a plant growing in water or in soil too waterlogged for most plants to survive.

Impervious—not allowing entrance or passage.

Joining—the GIS procedure that connects the attributes of one database with that of another based on a common field.

Loess—a sediment of silt deposited by the wind.

Macroinvertebrates—animals without backbones and big enough to see with the naked eye, which includes most aquatic insects, snails, and crayfish.

Neotropical—of, relating to, or constituting the biogeographic region that extends south, east, and west from the central plateau of Mexico.

Niche—the role of a particular species; what it does within its habitat.

Nitrogenous—of or pertaining to nitrogen.

Photosynthesis—synthesis of chemical compounds with the aid of radiant energy and light; formation of carbohydrates from carbon dioxide and a source of hydrogen (water) in the chlorophyll-containing tissues of plants exposed to light

Planar—of, relating to, or lying in a plane.

Potability—Safe to drink and palatable for human use.

Quartzite—a very hard, clean, white metamorphic rock formed from quartz sandstone.

Rain-on-snow-event—the rapid melting of snow as a result of rainfall. The combined effect of rainfall and snow melt can cause high overland and stream flows resulting in severe hillslope and channel erosion

Reach—the length of a stream channel that is uniform with respect to discharge, depth, area, and slope.

Redox—of or relating to oxidation-reduction, a chemical reaction in which one or more electrons are transferred from one atom or molecule to another.

Rill—a tiny drainage channel cut in a slope by the flow of water.

Salmonids—any of a family (Salmonidae) of elongate bony fishes (as a salmon or trout) that have the last three vertebrae upturned.

Smoltification—refers to the physiological changes anadromous salmonids and trout undergo in freshwater while migrating toward saltwater that allow them to live in the ocean.

Sublimation—the transition of a substance directly from the solid state to the vapor state or vice versa without passing through the intermediate liquid stage.

Substrate—the gravel bed of a stream.

Susceptibility—the ease with which contaminants can move from the land surface to the aquifer based on the types of surface and sub-surface materials in the area.

Synclinal—a fold, generally concave upward.

Tectonics—a branch of geology concerned with the structure of the crust of a planet (as earth) especially with the formation of folds and faults.

Tectonic—the movement and deformation of the earths crust.

Transpiration—the passage of watery vapor from a living body through a membrane or pores.

Tributary—a stream feeding a larger stream or a lake.

Vadose zone—the area between the surface and groundwater, including soil and the underlying geologic material.

Vulnerability—the combined effect of susceptibility to contamination and the presence of potential contaminants.

DRAFT

CHAPTER 1: INTRODUCTION AND OVERVIEW OF GROWTH MANAGEMENT ACT REQUIREMENTS CONCERNING CRITICAL AREAS, ANADROMOUS FISH, AND BEST AVAILABLE SCIENCE

1.0 OVERVIEW

The purpose of this report is to meet state requirements to include best available science (BAS) in development of policies and regulations to protect critical areas. The requirement to include BAS in critical area policies and regulations has significant implications both for Yakima County and for its citizens. In the past, there was little state guidance for designating and protecting critical areas. The recent changes in state law direct the County to document the best available science it considered, to explain its rationale for departing from science-based recommendations, and to identify potential risks to the functions and values of the critical areas if the County does depart from science-based recommendations.

In order to assist the County with the review of scientific literature, a science advisory group (SAG) was formed. The SAG consists of state, federal, tribal, and private scientific professionals. The role of the SAG has been to:

- assess the County's collected bibliography of scientific citations for applicability to the relevant critical areas;
- recommend additional or alternative science citations, including the most recent scientific work in the various critical area disciplines;
- recommend data sets that might be relevant to the various critical areas, or to recommend methods of acquiring the needed data;
- review drafts of the BAS reports, to ensure the County is interpreting the science correctly.

A list of SAG members is found in Appendix B.

2.0 GROWTH MANAGEMENT ACT REQUIREMENTS

The 1990 Washington State Growth Management Act (GMA) requires cities and counties planning under the Act to designate Critical Areas and to adopt developmental regulations for the protection of these areas. The GMA lists the following environmentally sensitive areas as Critical Areas (RCW 36.70A.030):

- frequently flooded areas;
- wetlands;
- geologically hazardous areas;
- fish and wildlife habitat conservation areas;
- critical aquifer recharge areas.

In 1995, the legislature added a new section to the GMA—RCW 36.70A.172—to ensure that counties and cities consider reliable scientific information when adopting policies and development regulations that designate and protect Critical Areas. In 2000, the Washington State Office of Community Development (OCD) adopted guidelines to implement these changes and provided guidance for identifying the BAS. Washington Administrative Code (WAC) 365-195-905 clarifies common sources of BAS, and the characteristics those sources must possess. Common sources of BAS are:

- **Research**—data collected and analyzed as part of a controlled experiment to test a specific hypothesis.
- **Monitoring**—data collected periodically to determine a resource trend or to evaluate a management program.
- **Inventory**—data collected from an entire population or population segment or from an entire ecosystem.
- **Survey**—data collected from a statistical sample.
- **Modeling**—mathematical or symbolic simulation or representation.
- **Assessment**—inspection and evaluation of site-specific information that may or may not involve collection of new data.
- **Synthesis**—a comprehensive review and explanation of pertinent literature and other relevant existing knowledge.
- **Expert opinion**—statement of a qualified scientific expert based on the best professional judgment and experience in the pertinent scientific discipline.

Characteristics of a valid scientific process are:

- **Peer review**—The information has been critically reviewed by other qualified scientific experts in that scientific discipline.
- **Methods**—The methods used to obtain the information are clearly stated and can be replicated.
- **Logical conclusions and reasonable inferences**—The conclusions presented are based on reasonable assumptions supported by other studies and are consistent with the general theory underlying the assumptions.
- **Quantitative analysis**—The data have been analyzed using appropriate statistical or quantitative methods.
- **Context**—The information is placed in proper context.
- **References**—The assumptions, analytical techniques, and conclusions are well referenced with citations to relevant, credible literature and other pertinent existing information.

The GMA (RCW 36.70A.172) also requires that special consideration be given to the conservation or protection measures necessary to preserve or enhance anadromous fisheries. The Yakima Basin currently supports spring chinook, fall chinook, coho, summer steelhead, and bull trout in addition to other resident salmonid and non-salmonid fish species. Summer chinook and sockeye were once numerous in the basin but have been extirpated from the watershed. Summer chinooks were last observed in the early 1970s, and sockeye were extirpated following the construction of the five storage reservoirs in their natural rearing lakes in the late

teens and early 1920s. Wild Coho were last seen in the basin in the 1980s and are assumed to be extinct. Coho have now been reintroduced through artificial production. Pacific lamprey also have become very rare in the Yakima Basin and are a U.S. Fish and Wildlife Service Category 2 candidate species (Fast et al. 2001).

In March 1995 (64 FR 14517) the U.S. National Marine Fisheries Service listed summer steelhead in the mid-Columbia Evolutionary Significant Unit (ESU), which includes the Yakima Subbasin, as *threatened* under the Endangered Species Act. In June 1998, the U.S. Fish and Wildlife Service listed bull trout as *threatened* under the Endangered Species Act.

State guidelines (WAC 365-195-925) suggest that measures necessary to preserve or enhance anadromous fisheries include protecting habitat important for all life stages, including but not limited to:

- spawning and incubation;
- juvenile rearing and adult residence;
- juvenile migration downstream to the sea; and
- adult migration upstream to spawning areas.

The guidelines also recommend that special consideration be given to habitat protection measures based on the BAS relevant to:

- stream flows;
- water quality and temperature;
- spawning substrates;
- instream structural diversity;
- migratory access; and
- the maintenance of salmon prey species.

3.0 SUMMARY

The state guidelines are intended to protect critical areas by accurately describing the functions and values documented in the science, understanding the likely adverse impacts associated with proposed land use planning alternatives, and making land use decisions that minimize or eliminate those adverse impacts to the extent possible. Identifying and describing the functions and values, and estimating the types and likely magnitudes of adverse impacts, are scientific activities. In updating critical areas policies and regulations, documentation must show that special consideration has been given to anadromous fisheries and that such policies and regulations are based on the BAS. The guidelines go to great lengths to describe what science is, but the determination of what constitutes the best science is left to local governments.

4.0 WORKS CITED IN CHAPTER 1

Fast, D., Berg, L., et al. 2001. *2001 Yakima Subbasin summary.* Prepared for the Northwest Power Planning Council and Columbia Fish and Wildlife Authority. [Online] pp.http://www.cbfwa.org/files/province/plateau/subsum.htm.

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CHAPTER 2: A REVIEW OF THE BEST AVAILABLE SCIENCE REGARDING THE STREAM CORRIDOR: STREAMS, RIPARIAN AREAS, FLOODPLAINS, AND ASSOCIATED AQUATIC HABITAT

1.0 OVERVIEW

The GMA guidelines (WAC 365-190-030) define the minimum jurisdiction of frequently flooded areas as "lands in the floodplain subject to a one percent or greater chance of flooding in any given year. These areas include, but are not limited to, streams, rivers, lakes, coastal areas, wetlands, and the like." In Yakima County these areas, except for coastal, are almost exclusively located in the stream corridor. The stream corridors are dramatically different than the arid and forested landscapes they flow through, and they consist of multiple, extremely dynamic components. Consequently, the diverse components of the stream corridor have been grouped together and reviewed as a functioning system. (While frequently flooded areas include wetlands, wetlands will be reviewed separately due to their complexity and legal mandates.) This report also reviews flood hazards, aquatic habitat, the effects of channelization, general management strategies, and stream corridor inventory methodology.

2.0 PHYSICAL FEATURES OF THE STREAM CORRIDOR

2.1 Introduction

The "one percent or greater chance of flooding" correlates to the Federal Emergency Management Agency's (FEMA) delineation of the 100-year floodplain depicted on the flood insurance rate maps (FIRM). The 100-year floodplain is an engineering calculation of a 1 percent chance that a flood will inundate an area within a given year, and it is intended for the determination of flood insurance rates.

The delineation of any floodplain, whether it is a 10-year or a 500-year floodplain, is only one component of the stream corridor. Stream corridors generally consist of four major conceptual elements:

- stream channel;
- riparian area;
- "zone of influence"; and
- floodplain.

Washington State Hydraulic Code guidelines (WAC 220-110-020) define a watercourse as

> any portion of a channel, bed, bank, or bottom, waterward of the ordinary high water line of waters of the state, including areas in which fish may spawn, reside, or through which they may pass, and tributary waters with defined bed or banks, which influence the quality of fish habitat downstream. This includes watercourses which flow on an intermittent basis or which fluctuate in level during the year and applies to the entire bed of such watercourse whether or not the water is at peak level. This definition does not include irrigation ditches, canals, stormwater runoff devices, or other entirely artificial watercourses, except where they exist in a natural watercourse which has been altered by humans.

In addition, the ordinary high water line is defined as

> the mark on the shores of all waters that will be found by examining the bed and banks and ascertaining where the presence and action of waters are so common and usual, and so long continued in ordinary years, as to mark upon the soil or vegetation a character distinct from that of the abutting upland. Provided, that in any area where the ordinary high water line cannot be found, the ordinary high water line adjoining freshwater shall be the elevation of the mean annual flood.

A riparian area lies adjacent to flowing water (e.g., rivers, perennial or intermittent streams, seeps or springs) and contains elements of both aquatic (water) and terrestrial (land) ecosystems (Cramer et al. 2002).

The zone of influence is the transitional area between the riparian area and the uplands, where vegetation is not directly influenced by hydrologic conditions, but where vegetation still influences the stream (Kovalchik 2001; Portland Metro 2002).

A floodplain is generally defined as the flat area adjacent to a stream, formed by the stream in the current climate and regularly inundated by floods (Leopold 1997). Rapp and Abbe (2003) define a floodplain as "alluvial depositional features formed by a combination of in-channel and overbank deposits that have been constructed under current climatic conditions" (p. 4). Floodplain evolution is controlled by the rate of sediment supply (volume and size distribution), the availability of sites suitable for accumulation of sediments (valley gradient and confinement), and the stream power of the channel (which determines the volume and size of material that can be transported). Floodplain vegetation and the presence of beavers also create opportunity for the deposition of sediment in the floodplain. The interaction of these four elements forms a dynamic system essential for maintaining life, performing functions such as filtering contaminants, cycling nutrients, absorbing and slowly discharging floodwaters, providing and maintaining fish and wildlife habitat, recharging groundwater, and maintaining stream flow (FISRWB 1998).

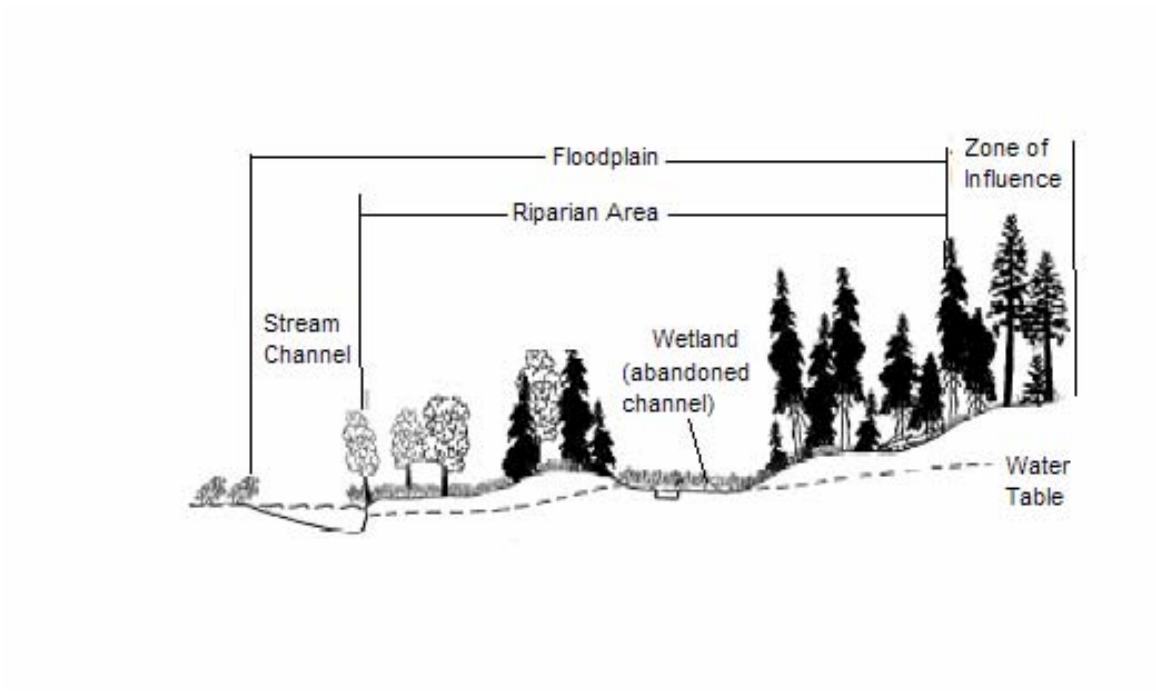


Figure 1. Stream corridor features (adapted from Kovalchik 2001).

Stream corridors form a complex arrangement of physical, chemical, and biological systems in three dimensions:

- the longitudinal dimension (from headwaters to mouth);
- the vertical dimension (the circulation of water into the bed sediments); and
- the horizontal dimension (the circulation of river water onto floodplains).

The physical component is made up of water, sediment, and other matter. The chemical component includes the dissolved nutrients in the air, water, and soil. The biological component includes all of the plants and animals. The interaction of the physical, chemical, and biological through space exhibits constant change through time (Snyder and Stanford 2001).

Stream corridors are one component of a watershed. A watershed (or drainage system) is that portion of the landscape where water, sediment, and other materials drain to a common point (Portland Metro 2002). A watershed consists of all elements of the landscape that water flows over or through, including underlying geology, soil, vegetation, stream channels (for surface water), and groundwater.

Watersheds can be broken down into progressively smaller subbasins, each of which contains all the elements of the drainage system that contribute water to the stream channel. Each stream channel collects a portion of the precipitation from within its drainage basin. The form of the stream channel is a consequence of the

runoff processes that occur in the watershed. Processes that take place on the uplands within a watershed have effects on the stream corridor. For example, adding an impervious surface like a parking lot affects stormwater runoff to the stream channel, which affects the form of the stream (Booth 1991).

2.2 Stream Channel

Stream channels exhibit many shapes and forms depending upon their location in the landscape, the underlying geology, and the climate. Cuffney et al. (1997, quoted in Snyder and Stanford 2001) found that there are basically three stream types in Yakima County:

- small streams of the Cascades and eastern Cascades,
- small streams of the Columbia Basin, and
- large rivers.

Another way to characterize the difference among stream channels is to categorize by water flow:

- perennial;
- intermittent, or
- ephemeral.

Perennial streams generally flow year-round, even during periods of no rainfall. Groundwater is a source of much of the water in the channel. Intermittent streams flow only during certain times of the year, usually more than 30 days per year, with inputs from precipitation and groundwater. Ephemeral streams flow only in response to precipitation, with no groundwater interaction, and usually flow less than 30 days per year (FISRWB 1998).

All three of these flow characteristics can be found in Yakima County, and in some circumstances varied combinations can be found within a single stream corridor. Ephemeral streams typically are found on steep ridges and hillslopes, apart from groundwater interaction. As the slope decreases, the streambed becomes more associated with groundwater and may flow on a more intermittent basis. As the slope continues to decrease, the streambed may have a more direct association with groundwater, which typically provides the stream with sufficient perennial flow. Low-gradient, perennial streams in the Columbia Basin may have intermittent portions, where flow alternates between the surface and subsurface. In the more arid parts of the County, even low-gradient streams may naturally flow on an ephemeral basis. In some areas of the County, application of irrigation water has complicated stream flow regimes, altering ephemeral streams into intermittent and perennial, and draining perennial streams into intermittent.

An analysis of StreamNet Geographic Information System (GIS) data reveals that the majority of streams in the Cascade crest and foothills flow perennially, with a minority flowing intermittently. The majority of streams in the Columbia Basin are

intermittent and ephemeral. Overall, more than half of the stream corridors within Yakima County flow on an intermittent or ephemeral basis.

A basic function of the stream corridor is to move water and sediment through the system, from the mountains and hillslopes to the ocean. In general, sediment movement through the stream corridor is accomplished through a "dynamic equilibrium", where the water and sediment transported into a stream reach is approximately equal to the sediment transported out of a reach (Cramer et al. 2002).

Montgomery and Buffington (1993) organized stream reaches into three categories according to the reaches' ability to move sediment:

- source reaches,
- transport reaches, or
- response reaches.

Source reaches are steep headwater and hillslope corridors that are sediment sources. Headwaters and hillslopes typically lack sufficient flow to effectively move sediment; therefore, they act as sediment storage sites until sporadic debris flows are triggered by intense thunderstorms or rain-on-snow events. Transport reaches are medium-gradient zones connecting upslope source reaches to downslope response zones. Transport reaches typically are resilient, due to a balance of sediment input and sufficient water flow.

Response reaches have a gentle slope, where sediment storage and residence times can be high. Response reaches react to variable sediment inputs in a variety of ways. A reach may:

- widen;
- deepen;
- change its slope through deposition, erosion, or a change of channel form;
- change streambed structure or particle size; or
- change the depth of bed scour.

These possible channel responses describe the relationship among "sediment supply, transport capacity, and sediment storage" through the stream corridor (Montgomery and Buffington 1993). The low-gradient response reaches correlate to the alluvial river floodplains of the Yakima River Basin.

2.3 Riparian Areas

Streams and lakes naturally have riparian vegetation along their margins. Riparian areas are dynamic biological and physical systems that represent the interface between terrestrial and aquatic ecosystems. The riparian area encompasses an aquatic area between the low and high water marks and that portion of the terrestrial landscape, from the high water mark toward the upland, where elevated water tables or flooding may influence vegetation and the ability of the soils to hold

water (Naiman and D'ecamps 1997). Standing surface water and/or high groundwater levels produce unique soil conditions that generate plant communities distinct from those found in terrestrial habitats (Mikkelsen and Vesho 2000). Allen et al. (1992, quoted in Knutson and Naef 1997) estimate that each acre of functional riparian habitat provides an annual $18,000 in services toward flood protection, groundwater recharge, and water purification.

The size of the riparian area can vary with stream flow. Intermittent streams typically have a limited interaction with the landscape and contain narrow riparian corridors, while large perennial rivers may have expansive riparian areas with multiple vegetation layers (Bilby 1988, quoted in Portland Metro 2002). Generally, as the size of the stream increases, the influence of the stream on the riparian area increases because of the larger volume of water. Conversely, the influence of riparian area on the stream decreases as stream size increases (Bilby 1988, quoted in Knutson and Naef 1997). Intermittent and perennial streams located in the arid portions of Yakima County may have little or no riparian vegetation. Such streams exhibit irregular vegetation patterns, with patches of shrubs interspersed with stretches of grass and forbs (Knutson and Naef 1997). Land use practices may exacerbate a lack of mature, healthy riparian stands.

The dynamic variability of the stream corridor is essential for the recruitment and maintenance of riparian vegetation. For example, cottonwood, a dominant riparian tree in Yakima County, relies on the annual flood to recharge groundwater and to rearrange sediment to create moist, barren seedbeds. Cottonwoods have evolved to synchronize their seed production with the spring flood, to promote successful reproduction (Jamieson and Braatne 2001). Channel migration creates a diverse collection of vegetation types and ages, which promotes a healthy aquatic, riparian, and terrestrial system (Naiman and D'ecamps 1997).

Riparian areas provide a diverse array of habitats for aquatic, semiaquatic, and terrestrial wildlife. Approximately 80 percent of all wildlife in Washington State uses riparian areas at some life stage. Riparian corridors are important for wildlife as migration and dispersion corridors; this is especially true in urban and developing landscapes (Knutson and Naef 1997). Beavers exert a significant impact on the structure and function of riparian areas by enhancing complexity and increasing vegetative succession (Naiman and D'ecamps 1997).

There are two basic types of riparian areas in Yakima County: those in the forested or previously forested areas of the Cascade foothills and crest, and those in the arid Columbia Basin. In the Cascade foothills and crest, the vegetation of riparian areas is often younger and lower in profile than the surrounding upland forest. In the arid Columbia Basin, the riparian vegetation is usually prominent, being taller and/or greener than the surrounding landscape (Hirsch and Segelquist 1979, Kauffman 1988, quoted in Knutson and Naef 1997).

Riparian areas in the Cascade foothills and crest of Yakima County typically are found in incised ravines in mountainous terrain (Carlson et al. 1990, quoted in Knutson and Naef 1997). At lower elevations, the moist soils and temperate

microclimate characteristic of riparian areas support communities of cedar, western hemlock, bigleaf maple, quaking aspen, water birch, and other deciduous trees. A variety of shrubs and herbs occur in the understory, including willow, Oregon boxwood, red-osier dogwood, mountain alder, ninebark, ocean spray, tall Oregon grape, serviceberry, devil's club, thimbleberry, trillium, queencup beadlily, and ladyfern (Franklin and Dyrness 1988, and Tabor 1976, quoted in Knutson and Naef 1997). At drier sites, characterized by ponderosa pine in the uplands, trees of the riparian zone include Douglas fir, paper birch, black cottonwood, Oregon white oak, and quaking aspen (Taber 1976, quoted in Knutson and Naef 1997). Shrubs include common snowberry, spirea, bearberry, and Oregon boxwood.

Alpine riparian sites are identifiable more by their understory species and saturated soils than by their tree species. Where trees exist, sites are dominated by subalpine fir or Engelmann spruce (Kauffman 1988 and Williams and Lillybridge 1983, quoted in Knutson and Naef 1997). Woody debris is abundant on the forest floor due to slow decomposition in the cold environment. The shrub and herb layer is stunted but rich and includes giant horsetail, bunchberry dogwood, Sitka alder, prickly currant, and twinflower.

Native riparian areas in the shrub-steppe region of Yakima County are characterized by a mosaic of shrubs, with patches of deciduous trees and an understory of grass/forb plant communities. Ponderosa pine and Douglas fir are widely scattered in eastern Washington riparian areas and were likely more abundant historically. A diversity of shrub and deciduous tree species occurred historically and still occurs in some places. Varieties include snowberry, wild rose, black hawthorn, hackberry, parsnip, common chokecherry, bitter cherry, mock orange, red osier dogwood, water birch, willow, black cottonwood, and quaking aspen. Herbaceous ground cover includes sticky geranium, northern bedstraw, fescue, waterleaf, and bracken fern. Riparian vegetation in the semi-arid portion of the Columbia Basin tends to a have a naturally irregular distribution, occurring in patches of various sizes at variable intervals along streams, interspersed with grass and forb riparian communities. Small, intermittent streams and draws may naturally have little or no characteristic riparian vegetation. Instead, they may consist of largely upland plant species, including big sagebrush, bitterbrush, rabbitbrush, and spiny hopsage (Knutson and Naef 1997).

A dynamic interaction exists between water and plants in the riparian zone, such that the availability of water supports plants that could not otherwise survive in semi-arid regions of Yakima County, and the type of vegetation that survives reflects the water regime that supports it (USDIBOR 2002).

Undisturbed riparian communities provide abundant food, cover, and water for wildlife. Riparian vegetation supplies food and cover for insects emerging from the river as well as for its own resident invertebrate populations. These invertebrates, in turn, support numerous mammals, birds, reptiles and amphibians, and assorted invertebrates. For these reasons, riparian areas generally provide high-value wildlife habitat.

Existing riparian conditions in the Yakima River basin vary, ranging from severely degraded to nearly pristine. Good riparian habitat generally is found along some forested headwater reaches, whereas degraded riparian habitat is concentrated in the valleys and is frequently associated with agriculture, grazing, and fluctuating regulated stream flow. The Yakima River basin still contains remnants of contiguous aquatic and riparian vegetative cover types suitable for wildlife habitat. Riparian habitats are associated with backwaters, sloughs, and oxbows, as well as with the main river channel. Higher elevation riparian forests are used by elk, deer, furbearers, raptors, grouse, Pacific tree frogs, many neotropical birds, and other species. At lower elevations, the riparian forests are used by mule deer, furbearers, rodents, bats, raptors, owls, herons, waterfowl, pheasant, quail, neotropical bird species, and many other species (USDIBOR 2002).

Riparian herbaceous habitat is common along many irrigation canals and drains, mainly because of regular disturbance (mowing, burning, and pesticides) to destroy weeds. Oakerman (1979, quoted in USDIBOR 2002) found that unlined canal/drain systems provide habitat (nesting, brood rearing, feeding, and thermal and escape cover) for upland game, waterfowl, furbearers, and many non-game birds. Woody vegetation makes up a very small percentage of the total plant cover along canals, and very little riparian vegetation exists along canals and ditches. However, because canals and delivery ditches are human-made, they originally had no native riparian vegetation.

Irrigation districts have noxious weed control programs on ditch banks and rights-of-way. Generally, vegetation along these conveyances is removed by irrigation district personnel or by irrigators, to simplify maintenance. Delivery canals must be kept free of large plant growth for proper operation. Both mechanical and chemical measures are used to remove vegetation.

Irrigation drains in the Yakima basin generally have little, if any, riparian vegetation. Some of the drains were developed in natural watercourses; their function has been to remove irrigation tailwater from cultivated areas and to lower the water table in areas of shallow groundwater. Because drains often rapidly fill with sediment carried by agricultural return water, they must be frequently cleaned with heavy equipment. Riparian vegetation is destroyed during such maintenance activities. Additionally, the numerous pesticides and the high nutrient levels carried by agricultural return water can be harmful to native riparian plants. It should be noted that some water will reach riparian areas through and because of irrigation return flows. Some of these return flows can create wetlands in areas where none existed before (USDIBOR 2002).

Since no historical reference has been done on the past versus the current status of riparian areas in the Yakima River basin, the following discussion is based on national and state trends. Riparian areas currently are estimated to encompass less than 1 percent of the land area in the Pacific Northwest, yet they support the greatest diversity and abundance of wildlife in the arid portions of the region (FWS, 1990, quoted in USDIBOR 2002). In the United States as a whole, about 70 to 90 percent of the natural riparian areas have been lost because of human activities

(Ohmart and Anderson 1986, quoted in USDIBOR 2002). The importance of riparian areas, combined with the large losses that have already occurred, make it vital that remaining riparian areas be protected (USDIBOR 2002).

The valley portion of the Yakima River's subbasin still contains remnants of contiguous aquatic and riparian vegetative cover types suitable for wildlife habitat. These riparian habitats are associated with existing backwaters, sloughs, and oxbows, as well as with the sinuous wandering of the main river channel. Riparian and wetland conditions in the Yakima Subbasin range from severely degraded to high quality, depending on the level of impact by activities such as development, agriculture, and grazing. Diking and urban development have constricted floodplains throughout the subbasin and have reduced wetland and riparian habitats. Natural stream side-channels and distributaries have been converted to canals and drains. The flow timing in these channels has been highly altered, causing loss of natural function. Hydrologic alteration has caused loss of native vegetation and replacement by nonnative species. The long history of intensive, year-round livestock grazing has resulted in extensive damage to many riparian plant communities throughout the shrub-steppe and valley portions of the subbasin. Riparian habitats are degraded along both Toppenish Creek and Satus Creek because of draining and excessive livestock grazing. These areas are lacking the vegetation to slow water runoff and reduce stream velocity (Fast et al. 2001).

2.4 Zone of Influence

The zone of influence, or transition zone, generally provides functions similar to the riparian area and the floodplain. This is a subirrigated transition from the riparian area to the uplands, where vegetation is not truly hydrophytic but is nonetheless unique from that of the uplands (Kovalchik 2001). Vegetation in this zone influences the stream channel and the riparian area by providing shade, microclimate, fine or large woody materials, nutrients, organic and inorganic debris, terrestrial insects, and habitat for wildlife. The zone of influence is spatially limited by stream flow, underlying geology, and topography. For example, large, flat floodplains are more influenced by adjacent riparian areas, but smaller canyon reaches, with a limited riparian zone, are influenced by upland vegetation (Naiman et al. 1992, quoted in Portland Metro 2002).

2.5 Floodplain

The basic function of a floodplain is to store water and sediment. As a flood exits a transport or canyon reach, the waters overtop the bank and spread over the floodplain, losing velocity and depositing sediment. The floodwater then either returns to the channel or percolates into the floodplain and later returns to the channel through cool groundwater discharge (Eitemiller, Arango, Clark, and Uebelacker 2002; Ring and Watson 1999). Flooding is a fundamental element of stream corridor productivity. Floodwaters transfer organic and inorganic material to and from the floodplain and the stream channel, enriching both stream and floodplain productivity (Bayley 1991 and Power et al. 1995, quoted in Snyder and Stanford 2001).

Floodplains contain many surface and subsurface features. Common surface features include:

- side channels with varying degrees of connectivity to the main channel;
- abandoned channels in varying degrees of succession from lakes to wetlands;
- natural levees of fine material deposited during floods;
- a ridge-and-swale texture of abandoned channels and natural levees;
- inundation of the active floodplain, annually to biannually; and
- one or more levels of terraces or abandoned floodplains (Ward and Stanford 1995).

There can be multiple levels of terraces within and outside the active stream corridor. Terraces can be formed by the lowering of the streambed, by a change in water quantity, or by a rise in the surrounding geology. Climate change can bring about a change in stream flow and sediment supply. Altering either of these variables can cause a stream to downcut and create a new floodplain. Terraces are also created as the stream channel migrates across the floodplain. Stream migration can erode the existing floodplain and terraces. Alluvial floodplains may contain paleochannels—abandoned channels filled with sediment. Paleochannels function as connective pathways for hyporheic and groundwater (Snyder and Stanford 2001).

An alluvial terrace is an abandoned floodplain constructed by past vertical instability in the stream corridor. Alluvial terraces are generally inactive depositional features formed in a previous hydrologic, climatic, or tectonic setting. They typically result from a lowering of the river's base level, from channel incision, or from a modification in hydrology. Alluvial terraces give the stream corridor cross-section a stepped appearance. Active floodplain surfaces are sometimes incorrectly identified as alluvial terraces because they may appear to exceed the elevation of flood inundation. If a stream channel adjoins the bank of an alluvial terrace, the terrace is at risk of channel erosion even if it is not subject to flood inundation. Conversely, strath terraces are nonalluvial features composed of bedrock and formed by geologic uplift. Strath terraces are resistant to erosion, and unlike alluvial terraces, their underlying geology poses a barrier to channel migration (Rapp and Abbe 2003).

Alluvial channels may naturally move around, or migrate, within their floodplain. Channel migration includes channel meandering or cut-and-fill alluviation, and avulsion. Channel meander or cut-and-fill alluviation is the erosion of outside and the deposition of inside channel bends. Channel avulsion is the abrupt switch of the stream channel location during a flood event. As a channel migrates or avulses across the floodplain it creates a diverse collection of channel features both above— and belowground. This shifting mosaic creates an assortment of different habitats that are used by a variety of organisms at different life stages. These habitats include side channels, with varying degrees of connection to the main channel, which create slack water refuge. Spring-fed side channels (spring brooks or wall-based channels) are vital to aquatic systems, serving as food sources and as

thermal refuge when temperatures become too high or too low in the main channel (Snyder and Stanford 2001; Stanford et al. 2002; Ward and Stanford 1995).

Maintenance of this "shifting habitat mosaic" depends on the capability of the stream channel to move freely about the floodplain, and on the presence of necessary stream power to complete the geomorphic work of channel migration or avulsion. Mosaic maintenance also depends on an adequate supply of sediment to construct in-channel features such as new bars and islands, and to prevent channel incision that would disconnect important groundwater-surface water interactions (Stanford et al. 2002).

Floodplains may also have a varied and productive subsurface hyporheic zone. The hyporheic zone can be defined as the saturated area beneath the streambed and banks that contains some channel water, or as an area that has been altered by channel water (White 1993, quoted in Bolton and Shellberg 2001) (Figure 2). The hyporheic zone is an area of dynamic water exchange between surface and groundwater. The water in this zone is a mixture of surface and groundwater, but is uniquely different from both.

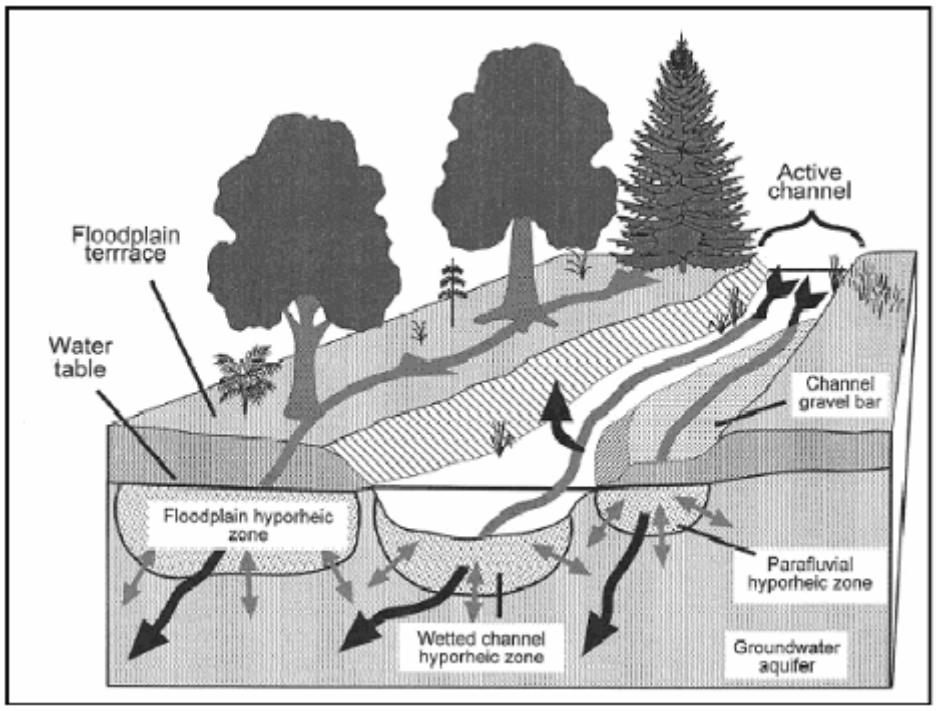


Figure 2. The hyporheic zone (Edwards 1998, quoted in Bolton and Shellberg 2001).

At the reach scale, the alluvial channels of the Yakima Basin generally downwell, or "lose" surface water to the hyporheic zone and to the groundwater aquifer, as the channel leaves a canyon or gap reach and enters the floodplain. Canyon and gap

reaches are situated on bedrock and have a limited water holding capacity. The alluvium, made up of deep deposits of sand, gravel, and cobbles, serves as a reservoir for water storage and movement. As the stream begins to enter a canyon or gap reach, ground and hyporheic water is forced to the surface by the underlying geology. The underlying geology of the layered basalts and the folded ridges acts as a barrier to groundwater movement (Ring and Watson 1999). The upwelling ends of the gaps have a wide array of habitat types, due to abundant surface water features and inputs from tributaries. Upwelling ground—and hyporheic water moderates surface water temperatures and is an important source of nutrients for aquatic organisms. The alternating structure of "losing" and "gaining" reaches forms beads of alluvial floodplains on strings of canyons and gaps. It is these beads that form the areas of high bioproductivity and structural diversity that support a wide range of organism (Eitemiller et al. 2002; Ring and Watson 1999; Snyder and Stanford 2001; Stanford et al. 2002).

At the channel unit scale there is constant water exchange both up and down the stream corridor, which is dependent upon water table elevation, bed and bank material, and woody debris placement (Snyder and Stanford 2001). The visible stream channel and water level is only a surface expression of a much larger underground system (Ubelacker, pers. comm. 2003). Many organisms spend a portion of their life cycle in the hyporheic zone and then migrate to surface water features for other life cycles. Some of these organisms are at the base of the food web and are crucial for the overall productivity of the system (Snyder and Stanford 2001).

Pre-irrigation maps show that the Yakima River system was historically much more complex, with multiple side channels and dense riparian vegetation. In the absence of the current reservoirs, which capture and regulate most of the winter and spring runoff, overbank flooding was much more frequent. Floodwaters infiltrated the floodplain alluvium and were naturally released later, sustaining summer flows and moderating water temperatures (Kinnison and Sceva 1963; Parker and Storey 1916). Published information on the natural hydrography of the Yakima River is found in Parker and Storey and in historical streamflow records of the U.S. Geological Survey (USGS).

Parker and Storey (1916) estimated that natural flow at Union Gap followed a basic pattern of peak runoff from April through June (Figure 3). Flows receded throughout the summer, with annual lows occurring in September and October. Major floods historically (and presently) occurred during the winter (mid November through February), usually resulting from a rain-on-snow precipitation event coupled with a rapid thaw. Reservoir storage has reduced the frequency and limited the distribution of significant channel-forming flood events, though major floods still provide sufficient hydraulic energy to periodically reshape the river channel and its associated riparian vegetation (USDIBOR 2002).

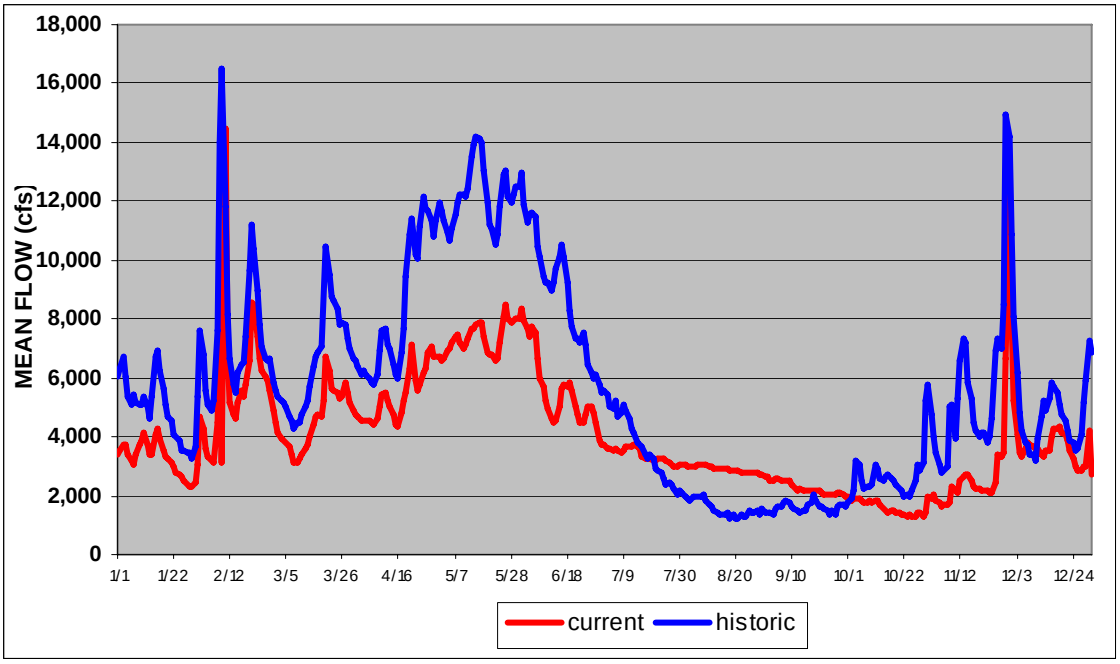


Figure 3. Regulated ("current") and estimated unregulated ("historic") mean daily flows, Yakima River at Terrace Heights, 1994-1999 (Fast et al. 2001).

2.6 Summary

The stream corridor contains many interrelated features that perform a multitude of functions in the aquatic and terrestrial environment. The natural disturbance regimes of channel migration, avulsion, flooding, and fire maintain the stream corridors' varied and diverse structure. Maintaining this shifting habitat mosaic depends on the ability of the stream to maintain its natural disturbance regimes. Instability of the physical system creates overall stability for the biological system (Snyder and Stanford 2001). The alternating structure of gaining and losing reaches creates "beads on a string," in which diverse habitats promote and produce a unique habitat structure for all organisms (Eitemiller et al.; 2002; Watson and Ring 1999; Snyder and Stanford 2001; Stanford et al. 2002).

3.0 STREAM CORRIDOR FUNCTIONS

3.1 Introduction

While the stream corridor can be divided into four components—stream channel, riparian area, zone of influence, and floodplain—the functions provided throughout the entire system cannot be so easily assigned. Variability in landscape position, climate, and geology distributes functions across the range of stream corridor surfaces. Below is a general review of functions found throughout the system.

Application of this review to any specific reach within the Yakima Basin would require site-specific analysis.

3.2 Woody Debris

Woody debris consists of root wads, trees, and limbs that fall into the stream as a result of bank undercutting, mass slope movement, normal tree mortality, windthrow, or debris flow. The majority of woody debris is supplied by the riparian area, and to a lesser extent, by the zone of influence. Woody debris is often transferred from tributaries during debris flows. Woody debris affects channel shape by forming obstructions (in single pieces or in large jams) that alter stream flow and velocity, which in turn promotes erosion and deposition in the channel bed and creates a variety of habitat niches.

Woody debris traps organic and inorganic matter. Trapped organic matter such as leaves, insects, or fish carcasses, provides the basic food supply within the environment. Trapped salmon carcasses, for instance, import nutrients from the ocean and function as fertilizer for downstream habitats. Trapped inorganic matter such as sand and gravel creates habitat and provides spawning grounds for fish. Woody debris in and around the stream channel creates upland habitat for a variety of organisms. Decaying woody debris functions as habitat for riparian seedlings, influencing plant succession. Woody debris amends the physical and chemical properties of the underlying soil. By trapping water, woody debris increases the amount of biologically and chemically active surface area, activating consumption of organic matter by invertebrates (Bolton and Monohan 2001; Chesney 2000; Knutson and Naef 1997; Montgomery and Buffington 1993, Mikkelsen and Vesho 2000; Naiman and D'ecamps 1997).

3.3 Organic Matter

Organic matter comprises dissolved compounds and other matter, such as leaves, branches, fruit, cones, and insects. Organic matter from the stream corridor is a significant source of food for aquatic systems. "Forest ecosystems adjacent to stream corridors provide over 99 percent of the energy and carbon sources in aquatic food webs" (Budd et al. 1987, quoted in Portland Metro 2002, p. 24). Organic matter can fall directly into the stream channel, or it may move by wind, by erosion, or as dissolved materials in subsurface water flowing from the hyporheic zone. Organic inputs vary by stream size; smaller streams receive almost all inputs from surrounding vegetation and subsurface flow. In larger rivers, the main inputs are from sunlight, which allows for the internal production of organic material via photosynthesis (Bolton and Monohan 2001; Knutson and Naef 1997; Naiman and D'ecamps 1997; Ward and Stanford 1995).

Large runs of anadromous fish historically were the underpinnings of the food chain/energy flow in the Yakima Basin. The loss of this annual source of nutrients contributed to the decline of top-level carnivores (e.g., bald eagle and grizzly bear) and lowered the productivity of the basin for all wildlife. The native wildlife populations in the Yakima Basin were extremely dependent on the constant energy

sources brought up from the oceans by the fish runs. The loss of these runs caused a large loss in energy to the system, altering wildlife population dynamics by causing less vegetation, fewer invertebrates, and less wildlife dependent on eating salmon (USDIBOR 2002).

3.4 Streambank Stabilization

Riparian vegetation greatly increases streambank resistance to erosion by increasing streambank and floodplain roughness. This roughness reduces water velocity, decreases erosional power, holds materials in place, and traps waterborne sediment and debris. Plant species arrangement (grasses, trees, or shrubs) affects the cohesive properties of floodplain surfaces and bank stability. "Major bank erosion is 30 times more prevalent on non-vegetated banks exposed to currents as on vegetated banks" (Naiman and D'ecamps 1997, p. 10). Vegetative roughness also prevents stormwater sheet flow from becoming channelized flows, which can initiate erosion and undermine bank stability (Bolton and Monohan 2001; Knutson and Naef 1997; Montgomery and Buffington 1993; Naiman and D'ecamps 1997).

3.5 Sediment, Nutrient, and Pollutant Control

The surface roughness of living and decomposing vegetation traps waterborne sediments from sheet flow runoff and low velocity floodwaters. Finer sediments carry both nutrients and pollutants; for that reason their removal is important in maintaining water quality. Vegetative roughness also prevents stormwater sheet flow from becoming erosive channelized flows. Once stormwater becomes channelized it bypasses the riparian area and is deposited directly to surface waters. Stream corridor vegetation absorbs some nutrients from overland flow, from groundwater input, and through hyporheic water exchange, and stores these nutrients in short-term leafy and long-term woody material. The pathway by which most nitrogenous wastes are degraded prior to entering streams is through denitrification by soil bacteria. The concentration of some nutrients in streams exhibits seasonal fluctuation, and plant absorption may be limited to the growing season. Nutrient processing in the stream corridor can exhibit spatial variability across the landscape (Knutson and Naef 1997; Mikkelsen and Vesho 2000; Naiman and D'ecamps 1997).

3.6 Microclimate

The microclimates of stream corridors are distinctive from those of upland areas due to their proximity to water, which influences soil moisture, air temperature, and relative humidity. Stream corridor vegetation influences humidity and stream flow through transpiration during photosynthesis. Stream corridors are generally more moist and mild (cooler in summer and warmer in winter) than the uplands (Knutson and Naef 1997; Naiman and D'ecamps 1997; Portland Metro 2002).

3.7 Water Temperature Moderation

Stream corridor vegetation influences humidity and stream flow through transpiration during photosynthesis. Vegetation and soils moderate the climate of the stream corridor through increased humidity, greater air movement, and shading. Stream corridor vegetation and soils influence the climatic drivers, stream morphology, groundwater influences, and riparian canopy conditions that affect stream temperature. The climatic drivers consist of

- air temperature,
- solar radiation, and
- wind speed (Adam and Sullivan 1989).

According to Adam and Sullivan (1989), the ability of stream corridor vegetation to provide these functions is dependent upon the vegetation's

- composition,
- stand height,
- stand density,
- latitude (which determines solar angle),
- topography, and
- stream orientation.

There are at least six main modes of energy transfer important in stream temperature:

- shortwave solar radiation;
- longwave radiation exchange between the stream and both the adjacent vegetation and the sky;
- evaporative exchange between the stream and the air;
- convective exchange between the stream and the air;
- conduction transfer between the stream and the streambed; and
- groundwater exchange with the stream, which moderates overall stream temperatures (Adam and Sullivan 1989).

3.8 Terrestrial Habitat

Stream corridors provide a structurally complex habitat range that fulfills most life stage requirements for a multitude of aquatic, semiaquatic, and terrestrial organisms. The structural complexity of the stream corridor is expressed in four general ways:

- the plant species are diverse;
- multiple canopy layers, especially a well-developed shrub layer, are present;
- snags and downed woody debris are available; and
- there is a high percentage of edge habitat.

Stream corridors provide connectivity to adjacent habitat types and function as migration and dispersal corridors. Stream corridors provide abundant sources of food, water, and shelter, and a moderated climate from surrounding habitat types (Bolton and Shellberg 2001; Knutson and Naef 1997; Naiman and D'ecamps 1997).

3.9 Aquatic Habitat

A connective and diverse aquatic ecosystem provides

- suitable substrate;
- adequate food and shelter;
- adequate water quality, quantity, and temperature; and
- adequate levels of dissolved oxygen for aquatic organisms.

The natural disturbance regime commonly found in alluvial floodplains forms a shifting habitat mosaic in which many organisms have evolved and to which they have adapted (Bolton and Monohan 2001; Knutson and Naef 1997; Snyder and Stanford 2001).

3.10 Hyporheic Zone

The hyporheic zone is the saturated area beneath the streambed and banks that contains some channel water, or an area that has been altered by channel water (White 1993, quoted in Bolton and Shellberg 2001). Hyporheic zones are part of a continuum of stream-catchment connections between stream, soil, root-zone, and riparian water. Hyporheic zones influence the biogeochemistry of the stream corridor by increasing solute residence times, and more specifically, solute contact with substrates, in environments with spatial gradients in dissolved oxygen and pH (Bencala 2000).

Hyporheic flow influences spawning locations for bull trout, chinook, sockeye, and other salmonids (Baxter and Hauer 2000; Geist and Dauble 1998). Instream structure regulates hyporheic flow (Kasahara and Wondzell 2003), and management changes or alterations to instream structure can alter hyporheic flow. Kasahara and Wondzell found that at base flow a second-order stream may "turn over" (i.e., 100 percent of discharge enters the hyporheic zone) every 100 meters; a structurally complex fifth-order stream may turn over every mile. Hyporheic flow can regulate stream temperatures, providing both winter and summer temperature refuge. Hyporheic flow can reduce ice cover and anchor ice, which is important for maintaining fish habitat during cold periods (Baxter and Hauer 2000). Hyporheic flow is also an important regulator of dissolved oxygen and of nutrients, especially nitrogen. The hyporheic zone is part of the stream food web. It also serves as a refuge for invertebrate eggs and pupae, acting as a recolonization source after disturbance, and serves as a refuge for salmonid eggs (Boulton, Findlay, Marmonier, Stanley, and Valett 1998).

Bolton and Shellberg (2001) outline the major functional attributes of the hyporheic zone:

- Retention and storage of floodwater.
- Longer runoff flow paths, due to influent (losing stream) conditions during flood events.
- Reduction in magnitude of peak flows and sustained base flows.
- Promotion of habitat complexity through lateral and vertical advection.
- Regulation of stream temperature. Hyporheic upwelling zones (spring brooks) are influent areas that are cooler than surface water in summer and warmer than surface water in winter.
- Providing interstitial volume as habitat for hyporheic organisms, or hyporheos. Hyporheos help maintain their hyporheic habitat by modifying the porosity of the subsurface sediments through feeding and burrowing.
- Providing channel invertebrates, fish eggs, and pupae with refugia from floods, droughts, and water quality disturbances (whether natural or human-induced).
- Buffering and filtering the ecotone between the terrestrial and aquatic.
- Release of retained organic material from the hyporheic zone during disturbances (e.g., bed load movement).
- Control of biodiversity and ecosystem metabolism through hyporheic residence time.
- Retaining and transforming nutrients (nitrogen, phosphorus, Fe, Ca, and Mg).
- Enriching habitats. Hyporheic zones are generally enriched with solutes, compared to surface waters. Hyporheic zones retain and transform solutes for biotic production and future release.
- Downwelling stream water provides dissolved oxygen (DO) and organic matter for hyporheos and salmonid embryos.
- Substrate at a downwelling area, which promotes the trapping and retention of organic matter in the hyporheic zone, which in turn:
  - stimulates boil growth in downwelling areas,
  - stimulates organic decomposition and transformation by bacteria,
  - provides food resources for primary consumers, and
  - promotes watershed nutrient retention.
- Upwelling hyporheic/subsurface water, which provides:
  - nutrient-enriched water for stream organisms;
  - a source of inorganic nutrients after mineralization in the hyporheic zone;
  - input of phosphorus due to loss of DO, change in redox, and release of phosphorus;
  - hyporheic nitrification;
  - accumulation of nitrogen along flow paths;
  - mineralization of organic matter;
  - regeneration of inorganic nitrogen;
  - source or sink for dissolved organic carbon (DOC);
  - spawning sites for certain salmonids; and
  - increased ecological diversity and biological production in otherwise nutrient-poor river systems.

3.11 Aquifer Recharge / Discharge

At the reach scale the alluvial channels of the Yakima Basin generally downwell, or lose surface water to the hyporheic zone and to groundwater, as the channel leaves a canyon or gap reach and enters the floodplain. Canyon and gap reaches are situated on bedrock and have a limited water holding capacity. The alluvium, comprising deep deposits of sand, gravel, and cobbles, are reservoirs for water storage and movement. As the stream begins to enter a canyon or gap reach, the underlying geology of layered bedrock and folded ridges acts as a barrier to groundwater movement, forcing ground and hyporheic water to the surface. Upwelling groundwater moderates surface water temperatures and is a source of nutrients from the hyporheic zone.

At the channel unit scale, there is dynamic exchange between surface water and groundwater up and down the stream corridor, contingent upon water table elevation, bed and bank material, and woody debris placement. Overbank flooding within the stream corridor moderates peak flows, promotes the retention and storage of water in the soil, and allows the slow release of hyporheic water over longer periods of time. Vegetation in the stream corridor interacts with stream flow by increasing roughness, which reduces water velocity, which enhances infiltration and storage (Leavitt 1998; Ring and Watson 1999; Stanford et al. 2002).

4.0 RIPARIAN AND AQUATIC HABITAT WITHIN THE STREAM CORRIDOR

4.1 Habitat Formation in the Yakima Basin

The distinctive assemblage of aquatic, semiaquatic, and upland habitats in the Yakima River Basin are the result of the interrelation of stream corridor features formed by the distribution of precipitation and the unique local geology. Precipitation in the Cascades, caused by uplift and cooling of moist air from the Pacific Ocean, contrasts with the semi-arid rain shadow of the Columbia Basin (120 inches per year precipitation on the crest; less than 10 inches per year in most of the lower basin). Snow accumulations in the Cascades build from October through April, with a dry season lasting from late spring through summer. Cascade snowpack endures well into the summer, causing stream flows to persist through the summer. Estimates of unregulated stream flow in the lower Yakima River show annual peaks from April through June, with annual lows in September or October. Rain-on-snow events and Chinook winds occurring between November and February generally initiate late fall and early winter flooding. The folding and faulting of the Columbia Basalts and the uplift of the Cascades, in concert with glacial erosion and deposition, built the large alluvial floodplain reaches of the Selah, Union Gap, Wapato, Lower Naches, Nile, Ahtanum, Wenas, Toppenish, and American (Ring and Watson 1999). These large alluvial reaches of the Yakima Basin are known to be historical centers of biological productivity and ecological diversity (Snyder and Stanford 2001; Stanford et al. 2002).

The flow pattern of surface and groundwater through the alluvial basins is important to overall system function. The basalt ridges form constrictions between the alluvial floodplains and control the exchange of groundwater, hyporheic water, and surface water. As spring runoff recedes through the summer, cool groundwater discharge maintains base flow, with major upwelling zones located upstream of the bedrock constrictions, or gaps. Prior to European settlement, the alluvial floodplains were large and diverse, connected to a complex of braided and distributary channels that spread over a large portion of the valley floor (Figure 4). This system promoted the distribution of floodwaters over a large area that absorbed flood flows, and it promoted infiltration of cold water into the alluvial sediments. Side channels, sloughs, and wetlands provided a variety of habitat types for numerous aquatic, semiaquatic, and upland species. These off-channel systems increase productivity, carrying capacity, and life history diversity by providing a variety of habitat niches for different species life stages (Ring and Watson 1999).

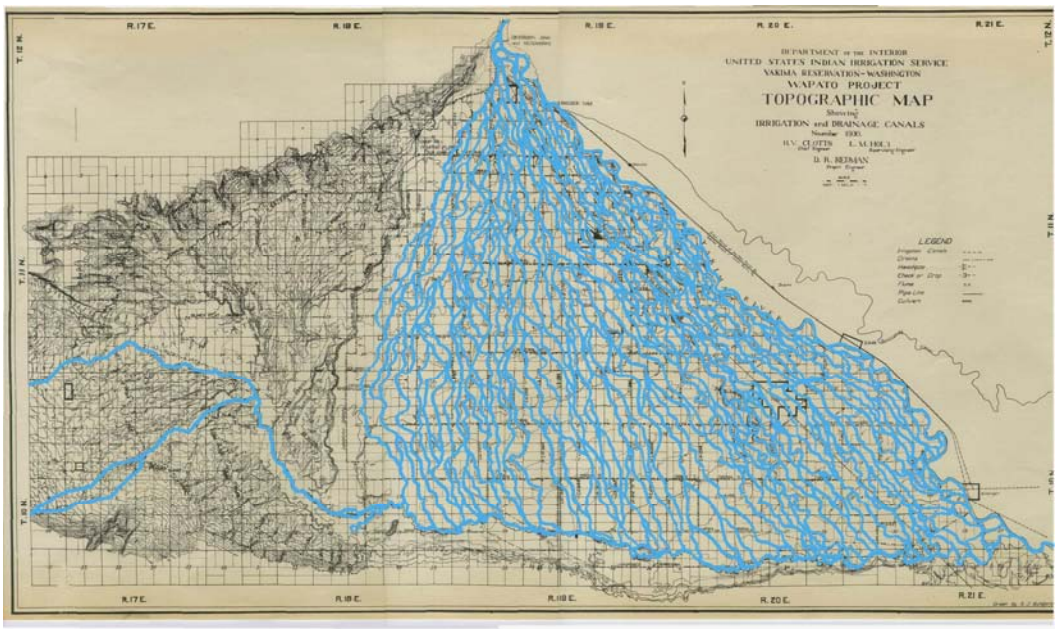


Figure 4. Indian Irrigation Service map of the Wapato alluvial reach in 1909 (map courtesy USBR Yakima Project). The tributary entering from the left is Toppenish Creek (Fast et al. 2001).

Natural stream corridor disturbance regimes contribute to both diversity and productivity as they create and maintain a shifting habitat mosaic. The mosaic is the basis for organization of aquatic organisms both above—and belowground (Snyder and Stanford 2001). Disturbances range from minor events, such as seasonal changes in flow and progressive bank erosion, to high intensity events such as wildfire, debris flows, and channel avulsion. Aquatic, semiaquatic, and upland habitats evolve as impacted areas recover from disturbance, resulting in a diverse set of habitats that varies over both time and space. The most complex assemblage of habitats is associated with alluvial floodplain reaches, where much of

the river's energy is dissipated and sediment deposition is greatest (Cederholm et al. 2000).

Beyond structural changes in the stream channel, there are observable changes in stream ecosystems, from the headwaters to the mouth. The characteristics of biological communities vary in different reaches of a river system. Observation of abrupt changes in species distribution—associated with changes in stream size, channel width, gradient, stream flow, and temperature—supports the concept of *stream zones*.

The River Continuum Concept (RCC) (Vanote et al. 1980, quoted in FISRWB 1998) organizes observed longitudinal changes in stream ecosystems (Figure 5). It suggests that rivers change continuously, on a longitudinal gradient. The RCC identifies relationships between progressive changes in stream structure, such as channel size and stream flow, and species distribution. According to the RCC, characteristics of particular reaches are associated not only with discrete factors such as water temperature, but also with their position along the length of the river. Freshwater ecosystems are inhabited by a large variety of macroinvertebrates, which play an integral part in the ecosystem food web and thus play a key role in energy distribution within aquatic ecosystems. The consumption of algae, organic matter, and bacteria is the basis for transfer of this energy. The type and location of food consumed by invertebrates within the aquatic environment determines their functional designation (Cederholm et al. 2000, FISRWB 1998).

Beavers are an important component of the stream corridor. Beavers create and maintain beneficial aquatic conditions in many stream reaches, wetlands, and riparian systems. Beavers have multiple effects on stream corridor, including altering hydrology, channel morphology, biochemical pathways, and stream productivity. Beaver ponds provide a sink for nutrients and promote anaerobic decomposition and denitrification. These processes increase primary and secondary production downstream from the pond, and increase nutrient retention time and enhanced invertebrate production in the pond. Beaver ponds also increase water storage, which enhances cool summer base flows, reduces downstream flooding, and enhances riparian habitat development. Beaver ponds provide thermal refuge to aquatic organisms during the winter (Cederholm et al. 2000).

Historically, beavers inhabited most stream corridors in the Yakima Basin; these included both dam-building beaver in side channels, spring-brooks, and tributaries, and bank-building beavers in the main river stems. By 1855, the beaver population had been dramatically reduced by trapping. At the present time, beaver distribution and density is still greatly reduced, although where adequate riparian vegetation exists—mostly native cottonwood and willow—beavers usually will be found. Because historic beaver populations were much greater, the effect of their loss on numerous ecosystemwide processes—hydrology, channel geomorphology, rates of nutrient transformation, and secondary community productivity—has been quite dramatic (Snyder and Stanford 2001).

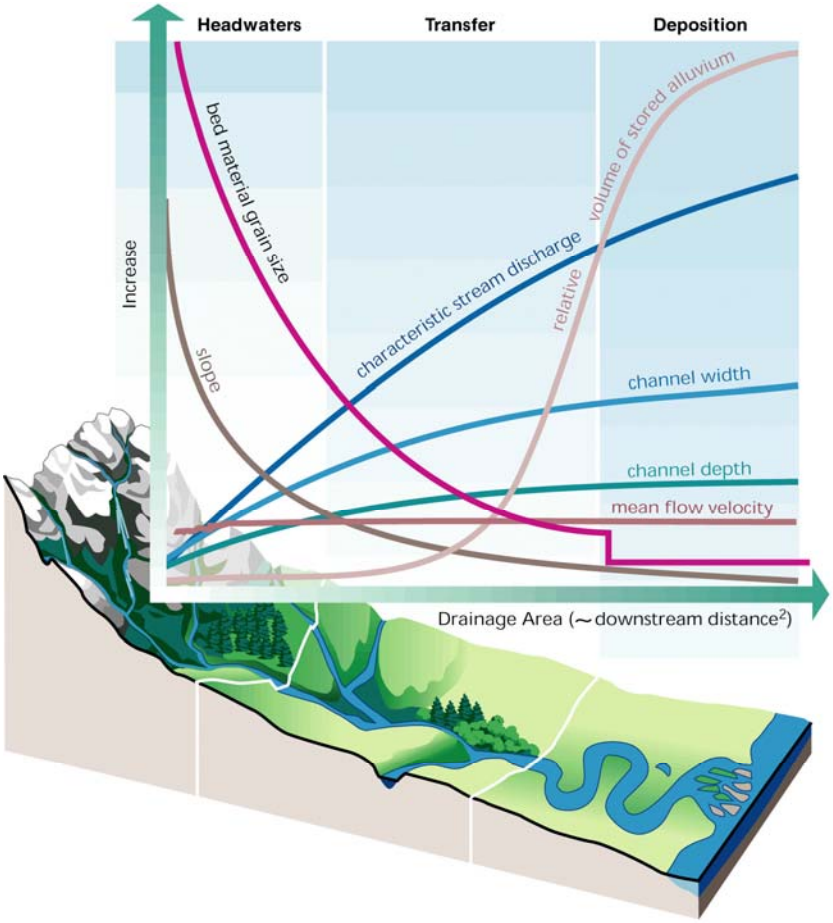


Figure 5. Image Courtesy of Stream Corridor Restoration: Principles, Processes, and Practices, by the Federal Interagency Stream Restoration Working Group (FISRWG 1998).

4.2 Yakima Basin Fisheries

Diverse arrays of fish species inhabit the Yakima River basin, including a number of exotic species. Fish that exhibit similar life history and habitat characteristics are grouped into one of five groups:

- resident migratory,
- resident local,
- lentic,
- exotic, or
- anadromous (UDIBOR 2002)

4.2.1 Resident migratory

Resident migratory fish are native species that reside in the Yakima Basin nearly year-round. These fish exhibit migration at certain times of the year, primarily as adults moving to spawning grounds. Species included in this group are:

- mountain whitefish,
- northern pike minnow,
- largescale/mountain/bridgelip sucker, and
- rainbow and bull trout (USDIBOR 2002).

Although the notion is undocumented, distribution of resident migratory species in the main stem of the Yakima River today is believed to be unchanged, except in the case of bull trout. This belief is based on the fact that resident migratory fish currently occur throughout the basin, and that there is reason to believe they were there previously. However, the abundance has been reduced, particularly in the lower basin (Patten 1970, quoted in USDIBOR 2002).

4.2.2 Resident local

Resident local fish are native species that generally do not exhibit large-scale annual migration. These fish include:

- western brook lamprey,
- rainbow trout,
- westslope cutthroat trout,
- bull trout,
- chiselmouth,
- peamouth,
- redside shiner,
- longnose dace,
- leopard dace,
- speckled dace (umatilla dace),
- three-spine stickleback,
- piute sculpin,
- torrent sculpin, and
- mottled sculpin (USDIBOR 2002).

All native species are present today. Bull trout are listed as threatened under the Engangered Species Act (ESA). Little is known about the population of western brook lamprey, thus warranting concern. Little historic documentation is available on the abundance and distribution of resident local fish. In the mid 1950s, Patten et al. (1970, quoted in USDIBOR 2002) suggested that native fish populations in the lower Yakima River have experienced declines; information available today generally supports that work. Rainbow trout and westslope cutthroat trout are major game fish and are considered priority species in Washington State (WDFW 1991, quoted in USDIBOR 2002). Special regulations are in effect to preserve the quality of trophy rainbow trout angling in the main stem of the Yakima River.

4.2.3 Lentic (lake)

The unifying characteristic of these fish is that they reside primarily in reservoirs. All reservoirs except Rimrock were natural lakes that have since been impounded. Primary lentic species include:

- pygmy whitefish,
- kokanee,
- burbot,
- bull trout,
- rainbow trout,
- westslope cutthroat trout,
- redside shiner,
- largescale/mountain/longnose sucker,
- pike minnow,
- sculpin, and
- dace (USDIBOR 2002).

Kokanee, a resident sockeye that resides solely in fresh water, were introduced as sport fish in the mid 1900s. Most of these species utilize reservoir tributaries for spawning, incubation, and early rearing. Historic and current abundance estimates of reservoir fish are unavailable, with the exception of bull trout. Within the last ten years, redd counts for bull trout have been conducted by the Washington Department of Fish and Wildlife on index reaches to reservoir tributaries. Data suggests that bull trout stocks within Yakima County reservoirs are healthy in Rimrock and depressed in Bumping (WDFW 1997). Concern for the pygmy whitefish and the burbot stems from the lack of information on life history and population status, as well as their limited range (Bonar et al. 1997 and Hallock and Mongillo 1998, quoted in USDIBOR 2002).

4.2.4 Exotic

Humans introduced exotic fish species from another area. Exotic species are a concern because of their negative interaction with native species. Introduction of exotics began in the late 1800s, with the completion of the railways. By the 1920s, the exotic species present today were fairly established, and state agencies became involved with transplants of established stocks into suitable habitats. Intense management of warm-water species began with the coming of tournament bass fishing in the 1970s. Today the management objective for introduced game fish species is to maximize long-term recreational benefits while minimizing adverse impacts to native fish and wildlife and their habitats. Exotic species present today include:

- brook trout,
- lake trout,
- brown trout,
- largemouth/smallmouth bass,

- black/white crappie,
- bluegill,
- pumpkinseed,
- green sunfish,
- walleye,
- yellow perch,
- channel catfish,
- brown/black bullhead,
- mosquitofish,
- goldfish, and
- carp (USBOR 2002).

Several hatchery strains of two native fish (rainbow and cutthroat trout) have been introduced to the basin from other states. Most warm-water exotic species are located in the lower river, downstream from the city of Yakima, and provide for viable recreation opportunities, including bass tournaments. Introduced salmonids are generally found in the cooler parts of the upper watershed, including reservoirs, and also provide for recreational fishing opportunities (USDIBOR 2002).

4.3 Salmonid Fisheries Overview

Historic runs of anadromous salmonids in the Yakima Basin have been estimated at approximately 200,000 to 800,000 returning adults (Fast et al. 2001). Historically, the Yakima River Basin was one of the primary anadromous salmonid production areas within the Columbia River Basin (Tuck 1993, quoted in Haring 2001). By 1900, it is estimated that the number of returning adults had been reduced by 90 percent (Davidson 1965, quoted in Haring 2001). Salmon and steelhead runs continued to decline, and by 1920 only 11,000 adults are estimated to have returned to the Yakima River Basin (BOR 1979, quoted in Haring 2001)—a reduction of over 98 percent from the historic run.

The first hydropower dam on the Columbia River that could have affected Yakima River salmon and steelhead was Bonneville Dam, constructed in 1938 (Tuck 1993, quoted in Haring 2001). Thus, the dramatic decline of salmon populations occurred prior to hydropower development. Other than screening one small irrigation diversion on the Naches River, in 1928, none of the hundreds of diversions in the Yakima watershed were screened, until the advent of the Works Progress Administration program of 1934–1940, under President Franklin Roosevelt's New Deal (Tuck 1995, quoted in Haring 2001). The probability that a smolt could survive emigration from the Yakima River or its tributaries was extremely small, and the bulk of the initial decline can be attributed primarily to smolt entrainment in irrigation diversions (Brannon 1929 and Tuck 1993, quoted in Haring 2001).

Although the Columbia River commercial fisheries in the late 1800s and early 1900s likely contributed in part to the decline of Yakima River salmon and steelhead, the peak harvest in the Columbia River occurred in 1911, and large harvests continued until 1920 (Craig and Hacker 1940, quoted in Haring 2001), all well after the observed collapse of adult returns to the Yakima River. The high harvests of the

early 1900s appear to have been supported by Columbia River tributary watersheds other than the Yakima. For instance, the peak harvest of coho in the lower Columbia River occurred in 1925, by which time only a remnant coho run existed in the Yakima River Basin (Tuck 1993, quoted in Haring 2001). It is possible that the collapse of anadromous salmonid production in the Yakima Basin preceded the construction of hydropower dams and was associated with factors other than harvest, although harvest likely also contributed to some extent.

The Yakima Basin currently supports spring chinook, fall chinook, coho, summer steelhead, and bull trout, in addition to other resident salmonid and non-salmonid fish species. Summer chinook and sockeye were once numerous in the basin, but have been extirpated from the watershed. Summer chinooks were last observed in the early 1970s, and sockeye were extirpated following the construction of the five storage reservoirs in their natural rearing lakes, in the late teens and early 1920s. Coho were last seen in the basin in 1980 and are assumed to be extinct, though they have now been reintroduced through artificial production. Pacific lamprey have also become very rare in the Yakima Basin, and are a U.S. Fish and Wildlife Service Category 2 candidate species (Fast et al. 2001).

In March 1995, the National Marine Fisheries Service listed summer steelhead in the mid-Columbia Evolutionary Significan Unit (ESU), which includes the Yakima Subbasin, as threatened under the Endangered Species Act (64 FR 14517). In June 1998, the U.S. Fish and Wildlife Service listed bull trout as threatened under the Endangered Species Act.

4.3.1 Salmonid life history

Over the past 10,000 years since the last ice age, salmonids in the Yakima Basin have evolved into their unique habitats. Water chemistry, flow, and the physical stream components unique to each stream have shaped the character of every population. This unique character has resulted in a wide variety of distinct salmon stocks throughout the basin. Individual populations do not extensively interbreed, because returning adults rely on a stream's unique chemical and physical characteristics to guide them to their original spawning grounds. This maintains the separation of stocks during reproduction, and preserves the individuality of each stock (Smith 1993, quoted in Haring 2001).

General requirements for juvenile salmonid overwintering habitat include slack water and cover, which are generally found in off-channel areas such as spring brooks and sloughs. Food resources are more abundant in these backwater habitats due to hyporheic inputs of organics, nutrients, microbes, and macroinvertebrates. Spawning habitat requirements include substrate availability, substrate size and permeability, patterns of upwelling and downwelling, water velocity and depth, temperature and dissolved oxygen concentration, and cover (Snyder and Stanford 2001).

A typical anadromous salmon life history has five main stages:

- spawning and egg incubation,
- freshwater rearing,
- seaward migration,
- ocean rearing, and
- return migration to freshwater to spawn, and the deposition of marine-derived nutrients into the freshwater ecosystem (Cederholm et al. 2000).

A host of additional life stages are necessarily identified when making management decisions, and these are closely linked to specific species' aquatic requirements (Lichatowich and Mobrand 1995). These are:

In the case of spring and summer/fall chinook, these stages include:

- Spawning
- Egg incubation
- Fry colonization
- 0-age active rearing
- 0-age migrant
- 0-age inactive
- 1-age active rearing
- 1-age migrant
- 1-age transient rearing
- 2+-age transient rearing

In the case of steelhead, these stages include:

- Spawning
- Egg incubation
- Fry colonization
- 0-age active rearing
- 0,1 age inactive
- 1-age migrant
- 1-age active rearing
- 2+-age active rearing
- 2+-age migrant
- 2+-age transient rearing
- Prespawning migrant
- Prespawning holding

Sockeye also have a 0,1-age lake rearing life history requirement.

Chinook, coho, and sockeye salmon die after spawning just once. This life strategy may have evolved in order to transport inland the energy obtained from the ocean, and to dedicate it to the production and survival of future generations. Survival after spawning was no longer an advantage, and the death of the spawning run offered a substantial advantage to the overall population. By fertilizing the

environment, the growth and survival rates of juveniles could be increased. The repeat spawning strategy of resident trout and steelhead most often occurs in the headwater reaches of larger rivers, where non-anadromous populations can be maintained year round. These species are generally smaller in size and less fertile, with a more sparse distribution and lower abundance than the anadromous forms (Cederholm et al. 2000).

4.3.2 Salmonid habitat requirements

Salmon habitat includes the physical, chemical, and biological components of the environment that supports salmon. These components include water quality, water quantity, physical stream features, adjacent riparian zones, upland terrestrial conditions, and ecosystem interactions as they pertain to habitat (Smith 1993, quoted in Haring 2001).

Spence et al. (1996) outline five general classes of features or characteristics that determine the suitability of aquatic habitats for salmonids:

- **Flow regime**— Flow regimes have a direct influence on the depth and velocity of water and represent the total accessible habitat area for the fish and their food.
- **Water quality**—Water quality requirements for fish include cool temperatures, high dissolved oxygen content, natural nutrient levels, and low levels of pollutants. Salmon prefer cold water, and excessive temperatures can be lethal to most species. Deviation in temperature triggers spawning, supports growth, and initiates smoltification. Salmon require well-oxygenated water throughout their life cycles. Nutrient levels vary among streams and must be sufficient to support natural plant and animal populations.
- **Habitat structure**—Important structural features of streams include pools, riffles, substrate, cover (e.g., undercut banks or overhanging vegetation), depth, and habitat complexity. Large woody debris promotes channel complexity, creating hydraulic diversity, pools, side channels, back eddies, and other features that are used by salmon and other aquatic organisms.
- **Food (energy) source**—Sustaining adequate food sources depends upon natural inputs of material (type, amount, and timing) as well as stream corridor structures to retain these materials.
- **Biotic interactions**—Normal biotic interactions, including competitive, predator-prey, and disease-parasite relations, must be preserved to ensure the health of aquatic ecosystems.

Spence et al. (1996) also indicate that four general principles should be considered when determining habitat requirements of salmonids.

- Watersheds and streams differ in their flow, temperature, sedimentation, nutrients, physical structure, and biological components.
- Fish populations adapt and have adapted—biochemically, physiologically, morphologically, and behaviorally—to natural environmental fluctuations.

- Specific habitat requirements of salmonids differ among species and life-history types, and these requirements change with season, life stage, and the presence of other biota.
- Aquatic ecosystems change over evolutionary time.

Accordingly, there are no simple definitions for salmonid habitat requirements, and the goal of salmonid conservation should be to maintain habitat elements within the natural range for the particular system.

4.3.3 Species-specific information

The following species-specific information is summarized from Fast et al. (2001).

4.3.3.1 Spring chinook

The abundance and productivity of Yakima Basin spring chinook is a fraction of historical values. Estimates of the size of historical Yakima spring chinook returns ranged from approximately 50,000 to 200,000. Current spring chinook production ranges from 1.5 percent to 8.5 percent of historical values, with the average contribution, by stock, from 1982 to 2000 being approximately 13 percent American River fish, 26 percent Naches stock, and 60 percent upper Yakima stock.

Historically, spring chinook spawned in the upper reaches of the mainstem Yakima and Naches Rivers, in most of their larger tributaries, and in the three largest lower river tributaries—Satus, Toppenish, and Ahtanum Creeks—and in a substantial portion of Wenas Creek below its forks, in addition to Logy Creek. In the Naches drainage, spawning occurred in all of the mainstem Naches above the Tieton River confluence, in portions of the lower Tieton River (especially the North Fork), in all of the Bumping River below Bumping Lake, in the American River, and in the lower portions of such smaller tributaries as Cowiche and Rattlesnake Creeks.

Except for streams rendered inaccessible or unusable by unladdered dams (e.g., North and South Fork Tieton River) or by excessive irrigation diversions or releases (e.g., Wenas Creek and the lower Tieton River), the current distribution of spring chinook spawning areas is basically the same as it was historically. The major difference is simply that many fewer fish utilize the remaining areas. The situation is rather different for the three lower tributaries, Ahtanum Creek, Toppenish Creek, and Satus Creek, which no longer support spring chinook runs.

The onset of spawning activity is earliest for the American River stock, intermediate for the Naches stock, and latest for the upper Yakima stock. Although elevated water temperatures can delay the onset of spawning, American River fish usually begin spawning in late July, Naches fish in late August, and upper Yakima fish in early September. Depending on water temperature, peak spawning activity for American River fish ranges from August 8 to August 15, while spawning peaks for Naches and upper Yakima fish range from September 8 to September 18, and from September 15 to October 1, respectively.

Emergence of chinook fry is generally synchronized across stocks, despite five—to seven-week differences in spawning timing. Emergence timing generally ranges from early March through mid June, with a peak in mid April.

Juvenile spring chinook redistribute themselves downstream in the spring and summer after emergence, with highest summer densities found well below the major spawning areas, but above Sunnyside Dam. The lack of fish in the lower Yakima mainstem (the mainstem below Sunnyside Dam) is attributed to excessive summertime water temperatures.

The dominant life history for all wild Yakima spring chinook follows a winter-migrant pattern. The gross timing of the outmigration is a function of the dramatic water temperature decrease in late fall and early winter. Subyearling chinook begin appearing in the lower Naches and the mid Yakima in October and November, and migrate to the lower Yakima in December. Approximately 10 to 35 percent of juvenile chinook migrate below Prosser Dam during the winter, with the majority overwintering in the deep, slackwater portion of the mainstem Yakima between Marion Drain and Prosser Dam. They begin their outmigration from the lower river the following spring as yearling smolts.

The 2000 spring chinook return was the largest in recent history. Over 90 percent of the returning adults were four-year-olds, which represented the 1996 brood year. The 1996 brood spawned after the February 1996 flood, an event that scoured and cleaned streambeds. Fry then emerged into a renovated environment that had become considerably more complex as a result of the river carving new side channels and acquiring substantial amounts of large woody debris. Instream flows throughout the Yakima Basin were unusually high, and water temperatures unusually cool as young spring chinook reared in the summer of 1997. Instream flows were also good in both the Yakima and the Columbia during the outmigration of 1998. In addition, there is both direct and indirect evidence that ocean conditions improved substantially in 1998.

4.3.3.2 Fall chinook

Fisheries managers and scientists understand little about the historical distribution of fall chinook, although data suggests that the primary production area was the same as it is today: the lower one hundred miles of the Yakima mainstem, from Sunnyside Dam to the Columbia confluence. The historical distribution of fall chinook was probably somewhat broader, given that current temperatures in the lower portion of the drainage are much higher. The limited literature on fall chinook distribution suggests that historical abundance probably ranged from about 38,000 to 100,000.

One anomaly is a genetically distinct population of fall chinook that now occurs in Marion Drain. Marion Drain is a 19-mile-long drainage ditch for the Wapato Irrigation Project (WIP), which was dug early in the twentieth century to drain wetlands and was enlarged over the years to serve as a major delivery canal for

the WIP. It discharges into the Yakima River, 2.2 miles upstream from the mouth of Toppenish Creek.

The mainstem stock of fall chinook spawns in the lower Yakima River, primarily below Wapato Dam, and most intensively between the Benton City bridge and Horn Rapids Dam. The Marion Drain stock spawns primarily in Marion Drain, although some fish probably spawn in the mainstem near the mouth of the drain.

Fisheries managers and scientists know little about the life history strategies of historical fall chinook populations in the Yakima Basin. Due to the loss of habitat diversity in the lower basin, it is realistic to assume that historical life history diversity was greater than it is today. Fall chinook spawning begins in late September, peaks in mid October, and is almost always totally finished by the second week of November. The variability in run timing is related to flow, but not to water temperature, and the flow-passage relationship is the opposite of that seen for spring chinook: higher flows accelerate passage.

Spawning is relatively concentrated above Prosser Dam, and appears to be synchronous in Marion Drain and the mainstem. It begins about the middle of October, peaks the first week of November, and is complete by the third week of November. Spawning in the lower mainstem, however, apparently includes some fish that spawn much later than the norm. Typical fry emergence occurs from mid February to late April. Marion Drain is fed by groundwater through the winter, and is often 10^0F warmer than the mainstem. Accordingly, emergence occurs earliest for Marion Drain fish, ranging from mid February to late March. In the mainstem, emergence does not occur before late March and extends into the third week of April.

Wild fall chinook in the Yakima Basin typically outmigrate during their first year of life, as subyearlings. Historic populations of Yakima Basin chinook probably began their outmigration in May, with a peak in June or July and continued migration through September, but current outmigration typically ends in early July. This is most likely due to temperature increases in the lower Yakima River.

4.3.3.3 Summer chinook

Historic estimates of Yakima Basin summer chinook range from approximately 86,000 to 100,000. The Yakima River supported native summer chinook until the early 1970s. The Yakama Nation counted a total of three summer chinook redds in the Yakima River, between the confluence of the Naches River and Ahtanum Creek, in 1970. This was the last year summer chinook redd surveys were conducted. Historic summer chinook spawned in the Yakima mainstem from approximately Marion Drain to Roza Dam, and in the lower Naches from its mouth to the Tieton confluence.

4.3.3.4 Summer steelhead

Historically, steelhead were probably found wherever spring chinook were found, in addition to a variety of other stream habitat types. Yakima Basin steelhead generally spawn in intermittent streams, in side channels of larger rivers, and in smaller streams and streams with steeper gradients, which are typically unsuitable for spring chinook or coho. Summer steelhead are capable of spawning in practically any stream reach that contains at least a pocket of gravel and suitable water depths and velocities. It is probable that the historical spawning distribution of summer steelhead included virtually all accessible portions of the Yakima Basin, with the highest spawning densities occurring in complex, multichannel reaches of the mainstem Yakima and Naches Rivers, and in third—and fourth-order tributaries with moderate (1 to 4 percent) gradients. Estimates of the size of the historical steelhead run range from 20,000 to 100,000.

Current steelhead distribution in the Yakima Basin is much more restricted and more spatially variable than it was historically. Satus and Toppenish Creeks represent over half of the spawning, with a smaller proportion in the Naches and a much smaller proportion in the upper Yakima (the Yakima mainstem and tributaries upstream of the Naches confluence). The average number of spawning adults between 1985 and 2000 was approximately 1,256 fish (the range being between 505 in 1996 and 2,840 in 1988), which is only about 1.3 to 6 percent of historical estimates.

Historically, the Upper Yakima basin supported the largest numbers of steelhead, but it now supports the fewest. The upper basin was able to support such a large proportion due to its overall size and its abundance of habitats, including mainstem and tributary reaches. The steelhead decline of the upper basin can be attributed to habitat simplification, habitat blockage, log splash damming, unscreened diversions, and unnatural releases from the reservoirs during the summer, when fry are just emerging from their redds.

There are four genetically distinct populations of wild steelhead in the Yakima basin: upper Yakima stock, Naches stock, Satus Creek stock, and Toppenish Creek stock. Scientific analyses indicate that wild and hatchery-raised rainbow trout and steelhead in the upper Yakima and Naches interbreed. Wild Satus and Toppenish Creek steelhead, on the other hand, show no evidence of interbreeding with hatchery trout or steelhead. Over 3 million hatchery trout (primarily South Tacoma and Goldendale stock) have been planted in the upper Yakima and Naches since 1950, and 1.6 million hatchery steelhead (primarily Skamania stock) have been planted since 1961. Hatchery rainbow trout have never been released in either Satus or Toppenish Creeks, and except for one release of 25,000 hatchery-reared Yakima-stock smolts into Toppenish Creek in 1989, the same is true for hatchery steelhead.

Spawning steelhead begin passing Prosser Dam in September, and tend to reside there during the colder parts of December and January, before resuming migration from February through June. The steelhead migration has two peaks, one in late

October, and one in late February or early March. The relative numbers of wild fish returning during the fall and winter-spring migration periods varies from year to year, depending on the duration of the thermal window in the fall.

Scientific studies of steelhead migration patterns between 1990 and 1993 indicate that most fall run steelhead spawners actually overwinter in the mainstem Yakima, in reaches with deep holes and low velocity. About 25 percent hold below Prosser Dam, 60 percent between Prosser Dam and Sunnyside Dam (many in the vicinity of the Satus Creek confluence), and 6 percent between Sunnyside Dam and Roza Dam. The final migration to the spawning grounds begins between January and May, with fish that will eventually spawn in lower elevation tributaries generally beginning to move earlier. There is some evidence that the cue triggering this final run is thermal, as very few fish ascended Satus Creek during midwinter floods, and virtually none of the eventual Naches spawners began moving until water temperatures reached 30°C. Most Yakima steelhead are tributary spawners; over 90 percent of the tagged steelhead spawned in the Naches River and its tributaries, in Satus Creek, or in Toppenish Creek.

In Satus Creek, 70 percent of the spawning occurs in three areas: in Satus Creek between Logy and Bull Creek, in Dry Creek, and in Logy Creek. The remainder occurs in smaller tributaries and various Satus Creek reaches above Dry Creek, including 15 percent in tributaries that regularly go dry by mid- to late May.

In the Naches, 69 percent of spawning occurs in only two reaches: in the Naches between Cowiche Creek and the Tieton River, and in the Naches between Rattlesnake Creek and the Little Naches River. The Bumping River, and the Naches between the Tieton River and Rattlesnake Creek, each support 11.5 percent. Rattlesnake Creek, and the Naches from the mouth to Cowiche Creek, each support 3.8 percent. Importantly, about 43 percent of all spawning occurs below the Tieton River confluence, and progeny are therefore subject to the most severe impacts of "flip-flop," when water flow from the upper Yakima ceases and water begins flowing from the Naches. No spawning has been observed in either the Tieton or the American River. The lack of spawning in the Tieton is to be expected, in light of the fact it has been swept virtually clean of spawning gravel, but the absence of steelhead in the American River, one of the most pristine streams in the basin, is puzzling.

In the Naches as elsewhere in the basin, spawning begins earliest at the lowest elevations. Steelhead spawn in the lower Naches (below Tieton) and its tributaries from early March through mid May. In the upper Naches, the spawning period is from late March through late May. In the higher-elevation tributaries of the upper Naches (the Little Naches River, Bumping River, and Rattlesnake Creek), spawning occurs from late April through late May, with a peak in early May.

Toppenish Creek drains a large watershed (approximately 650 square miles), but only the upper half of the drainage is used for spawning. Over 57 percent of the steelhead spawning in Toppenish Creek occurs between Willy Dick Creek and Panther Creek; the remainder occurs in the major tributary to Toppenish Creek,

Simcoe Creek, which is also located relatively high in the drainage. In upper Toppenish Creek, about 60 percent of the spawning occurs in Toppenish Creek itself, with the remainder occurring in two small tributaries. All but 9.7 percent of the spawning in the Simcoe drainage occurs in a number of small tributaries. Several of the upper Toppenish and Simcoe Creek tributaries are intermittent. Marion Drain is an irrigation return which parallels Toppenish Creek and into which Toppenish Creek water is diverted. It is probable that all of the steelhead that spawn in Marion Drain are or were ancestrally Toppenish Creek fish, lured into a cul-de-sac by Toppenish Creek water. The Toppenish Creek stock would be about 15 percent larger if the Marion Drain fish were included. Steelhead spawn in Toppenish Creek from early March to early May, with a peak in early April.

Over 70 percent of the fish referred to as upper Yakima spawners actually spawn in the Yakima mainstem between Roza Dam and Ahtanum Creek. Of the remaining 30 percent, 14 percent spawn in the Teanaway River and its forks, and the rest spawn in various upper Yakima tributaries and mainstem reaches. As nearly as can be determined, spawning occurs in the middle Yakima between Roza Dam and Sunnyside Dam, the upper Yakima mainstem, and the higher-elevation upper Yakima tributaries according to the following approximate schedule:

- **Middle Yakima**—late February through early April; peak in late March.

- **Upper Yakima mainstem**—in Yakima Canyon (including Umtanum and Wilson/Naneum Creeks) late March to mid May, with a peak in late April; and above Yakima Canyon from mid April to late May, with a peak in early May.

Steelhead fry emergence probably occurs at the following times in the following places:

- **Satus Creek**—early May to early June.
- **Toppenish Creek**—late May through early July.
- **Lower Naches and Cowiche**—early June through mid July.
- **Upper Naches**—mid June through mid July.
- **Upper Naches tributaries**—late June through late July.
- **Middle Yakima and tributaries**—early June through early July.
- **Upper Yakima mainstem in Yakima Canyon** (including Umtanum and Wilson/Naneum Creeks)—early June through early July.
- **Upper Yakima mainstem above the Yakima Canyon**—mid June through late July.
- **Upper Yakima tributaries**—late June through early August.

Steelhead rearing migrations are not well understood compared to spring chinook. The presence of steelhead juveniles in small tributaries throughout the summer, sometimes in high densities, indicates that the fish are less inclined to migrate downstream for early rearing than are spring chinook. However, steelhead juveniles are found in substantial numbers in the Yakima Canyon, far from spawning areas, so a gradual downstream dispersal obviously occurs.

Juvenile wild steelhead typically rear in freshwater for one or more years before outmigrating to sea. The midpoint of steelhead outmigration at Wapatox is also generally around the first week in May. Given the distances involved and the smolt migration rates observed, the midpoint of the outmigration of Naches steelhead would not occur at Prosser for at least another week. Thus, as many as half of the smolts leaving the Naches must negotiate the perilous lower river in late May and early June.

4.3.3.5 Coho

Although native coho were extirpated in the early 1980s, natural reproduction of hatchery-reared coho is now occurring in both the Yakima and Naches Rivers. Adult passage data at Roza Dam from 1941 to 1968 indicates that the native stock was early-run. The vast majority of the hatchery coho smolts planted since 1985 have also been early-run.

Based on limited WDFW survey data, native coho spawned in the Naches, primarily in the lower alluvial reaches below the Tieton confluence. Affidavits from early settlers of the Wenatchee basin state that "silvers" were found in virtually every perennial creek and river in the basin, before extensive development. It is now assumed that coho utilized virtually every low-gradient perennial stream in the basin, prior to extensive habitat alteration in the late nineteenth century.

Efforts to restore coho within the Yakima basin largely rely upon releases of hatchery coho. The Yakama Nation has released between 85,000 and 1.4 million coho smolts in the Yakima Basin annually since 1985. However, before 1995 the primary purpose of these releases was harvest augmentation; after 1995 the primary purpose became a test of the feasibility of reestablishing natural production.

The current hatchery-raised coho run spawns in reaches downstream of the historical areas because until 1999 the vast majority of hatchery smolts were acclimated and/or released well downstream of historical spawning areas. Most coho now spawn in proximity to their acclimation and release points, primarily in the middle Yakima below Sunnyside Dam. In recent years, coho spawning has been documented in side channels of the mainstem Yakima between Roza Dam and the town of Wapato and in the Yakima Canyon; in the Naches River below the Tieton confluence; and in numerous smaller tributaries, including Corral Creek, Spring/Snipes Creek, Toppenish Creek, Marion Drain, Wanity Slough, Ahtanum Creek, Wide Hollow Creek, Cowiche Creek, and Buckskin Slough.

Historical coho runs have been estimated from 44,000 to 150,000. Coho returns since hatchery-raised planting began in 1985 have increased steadily, climbing from 0 in 1984 to a peak of 5,700 in 2000.

The spawning distribution and spawning success of coho returning to the Yakima is just beginning to be determined. Earlier attempts to determine the spatial distribution of spawning coho in the Yakima were compromised by difficulty in

finding redds. A measure of the problem is the fact that during the period between 1989 and 1996 the ratio of adults passing Prosser Dam to redds counted later in the season was approximately 25:1. Thus, assuming a 50 percent sex ratio, only about 8 percent of the potential redds were discovered.

A three-year study was initiated in 1999 to determine the spawning distribution of coho in the Yakima basin. The first year of this study found that most coho returned to the general vicinity of the three lowest acclimation sites, from which coho smolts were released in the spring of 1998.

4.3.3.6 Sockeye

Before unladdered irrigation dams were built at the outlets of all four natural sockeye rearing lakes, during the period from 1904 to 1910, the sockeye run was probably larger than any other in the Yakima Basin in terms of numerical abundance. Historically, juvenile sockeye reared in all of the headwaters lakes—Keechelus, Kachess, Cle Elum, and Bumping; adults probably spawned both in the lakes and in feeder tributaries. Historic sockeye run size prior to the construction of seven mainstem Yakima dams has been estimated at 211,104 fish. Except for a handful of fish returning from experimental releases of hatchery-reared Wenatchee-stock sockeye smolts in the years 1992 to 1995, and a number of experimental releases of sockeye smolts in the 1940s, sockeye have not returned to the Yakima basin since the 1920s.

4.3.3.7 Pacific lamprey

While the Pacific lamprey is not a salmonid, it is an anadromous species. The U.S. Fish and Wildlife Service currently recognizes them as a Category 2 candidate species for listing under the Endangered Species Act. Pacific lamprey are declining in most if not all areas of the Columbia Basin. Historically, Native Americans fished for lamprey in the Yakima basin, which suggests that the species was quite abundant. Lamprey are not currently harvested in the Yakima River because of their scarcity. Although fish-counting facilities at Prosser and Roza dams are not equipped properly for counting adult lamprey, some have nonetheless been observed during the past few years. Five adult Pacific lamprey were observed on videotapes between 1992 and 1996 at Prosser Dam, and one was observed at Roza Dam. In 1995, five adults were collected, and in 1996 one adult was collected, at the Chandler Juvenile Fish Facility.

4.3.3.8 Bull trout

Historically, wild bull trout occurred throughout the Yakima River Subbasin. Today they are fractured into isolated stocks. Although bull trout were likely never as abundant as other salmonids in the Yakima basin, they were certainly more abundant and more widely distributed than they are today. In June 1998, the U.S. Fish and Wildlife Service listed bull trout in the Columbia River basin as *threatened* under the Endangered Species Act. Currently, nine bull trout stocks have been identified in the Yakima Basin. Five stocks are present in Yakima County: in

Ahtanum Creek, the Naches River, Rimrock Lake, and in Bumping Lake. All bull trout stocks are native fish sustained by wild production; there are no hatchery bull trout stocks in Washington State. According to WDFW, there is no information to indicate that these are genetically distinct stocks; they are treated separately because of the geographical, physical, and thermal isolation of the spawning populations (USDIBOR 2002).

Three bull trout life-history forms are present in the Yakima basin: adfluvial, fluvial, and resident. Adfluvial stocks occur in Rimrock and Bumping. Adfluvial stocks spawn and, in the early stage, rear in streams, with most growth and maturation occurring in lakes or reservoirs. Adults enter mainstem rivers early in summer, often holding near their natal tributaries for months before migrating upstream. Most mature adults range in size from 20 to 32 inches.

A fluvial stock is present in the mainstem Yakima River; a resident stock occurs in Ahtanum Creek; and fluvial/resident forms are present in the Naches River drainage. Fluvial bull trout spawn and, in the early stage, rear in smaller tributaries, with major growth and maturation occurring in mainstem rivers. They may move randomly throughout river systems, generally congregating near spawning tributaries in the summer. Mature adults are usually smaller than anadromous or adfluvial char, ranging from 16 to 26 inches long.

Resident bull trout spend all life stages (spawning, rearing, growth, and maturation) in small headwater streams, often upstream from impassable barriers. Mature adults can vary in size from 8 to 15 inches, but they are seldom larger than 12 inches in total length. Resident native char have been observed to mix and interbreed with migratory forms unless physically separated by barriers. It is possible that anadromous forms occurred in the Yakima basin in the past. The run timing of the Keechelus Lake stock and the spawning population in the South Fork Tieton River (part of the Rimrock Lake stock) are distinct. Run timing for other Yakima stocks either is not distinct from other Washington State bull trout or is unknown. According to WDFW, of the nine stocks identified in the basin, only the Rimrock Lake stock is healthy; the Bumping Lake stock is depressed; the condition of the Yakima River, Ahtanum Creek, and Naches stocks are unknown. Additional data are needed to determine the status of these unknown stocks (USDIBOR 2002).

There are only a few historical references (mostly old catch records) that indicate the presence of bull trout in Yakima River tributaries. In all streams where bull trout are noted in the historical catch records, relatively few fish were recorded compared to other game fish. Whether this is a reflection of historically low population is difficult to tell. Until information is collected to determine otherwise, all bull trout in the upper Yakima River mainstem will be considered as one stock with a fluvial life history pattern. For now, the Yakima fluvial stock is assumed to be composed of fish that inhabit the mainstem between Roza Dam and the upper reservoir dams (i.e., Cle Elum, Kachess, and Keechelus Dams). Although the genetic characteristics of the stock have not been determined, bull trout in the mainstem of the Yakima River are considered distinct from other Yakima subbasin

stocks, based on physical, geographical, and thermal isolating factors (e.g., dams, warm water temperatures, or irrigation diversions) (USDIBOR 2002).

Bull trout are strongly influenced by temperature and are seldom found in streams exceeding summer temperatures of 18ºC. Cool water temperatures during early life history results in higher egg survival rates, and faster growth rates in fry and possibly juveniles as well. All life history stages of native char are associated with complex forms of cover, including large woody debris, undercut banks, boulders, and pools. Preferred spawning habitat consists of low gradient streams with loose, clean gravel, and water temperatures of 5 to 9º C in late summer and early fall. Depending on the life-history form, rearing and overwintering habitats vary, but all require cool, clean water, with insects, macro-zooplankton, and small fish for larger adults. Slow juvenile growth delays maturation until about age five, and reproduction may only occur on alternate years. Native char may live for 12 or more years, and can reach over 20 pounds when adequate forage is available. Stock densities of native char are generally much lower than that of other native game fish such as cutthroat trout, rainbow trout, or mountain whitefish. The migratory forms of native char may travel long distances to reach spawning tributaries. Mature native char normally penetrate farther upstream than any other salmonids present in the watershed (USDIBOR 2002).

James (2002) conducted research on bull trout over a six-year period, in Rimrock and Bumping Lakes within Yakima County. Nearly 1,384 adult bull trout were tagged and released in Indian Creek and the South Fork Tieton River, combined. Of the 1,384 fish tagged, 494 were recaptured sometime during the study, and only one of the 494 was tagged in one stream and then recaptured in another. Based on the number of same-stream recaptures, James (2002) concluded that each of the spawning streams available to bull trout in Rimrock Lake constitutes a separate subpopulation. The one fish that switched streams resulted in a 0.2 percent estimated crossing rate between different streams, indicating a low rate of gene flow between the two subpopulations. Based on recaptures of tagged fish, James also was able to estimate population sizes. Population estimates ranged from 706 to 1,364 adults, resulting in an average estimate of 994 adults in South Fork Tieton River. Population estimates ranged from 447 to 486 adults, resulting in an average estimate of 466 adults in Deep Creek.

Based on all of the data analyses and observations made during the study, James (2002) found that bull trout populations in Rimrock Lake and Bumping Lake are generally healthy and relatively stable. However, it should be noted that the study was of a relatively short duration (less than one bull trout life cycle) and was directed only at the adult population. With respect to the dynamics of the bull trout populations studied, it was difficult to determine if the bull trout populations in Rimrock Lake or Bumping Lake are increasing, are decreasing, or are stable because each population is composed of a multiple-age and occasionally alternate-year spawning population.

4.4 Limiting Factors

Salmonid habitat conditions and productivity have been impacted by a variety of land—and water use actions in the watershed. These uses contributed to the development of the important agricultural, forestry, and mining industries in the Yakima Basin, but historical watershed modifications were often implemented with little or limited consideration of effects on salmonid resources. According to Haring (2001), the dramatic decline in salmon and steelhead production in the Yakima Basin is most likely associated with the combination of habitat-related impacts in the late 1800s and early 1900s:

- **Irrigation development**—Irrigation diversions were constructed on the mainstem Yakima and many of its tributaries. Most were constructed without upstream fish passage facilities or downstream juvenile fish screening, and many dewatered reaches downstream from the diversion.
- **Construction of irrigation storage reservoirs**—Dams at the outlets of Keechelus Lake, Kachess Lake, Cle Elum Lake, and Bumping Lake were built without upstream fish passage, precluding access and anadromous salmonid production from approximately 70 miles of highly productive fish habitat upstream of the dams. Tieton dam at the outlet of the Rimrock reservoir blocked access to approximately 43 miles of upstream habitat, including inundation of the highly productive historic floodplain complex at McCallister Meadows, on the Tieton River.
- **Splash damming (log drives)**—From 1879 through approximately 1915, splash dams were constructed on tributaries in the upper Yakima, and the channels were cleared in order to drive large log rafts downriver to lumber mills, resulting in a significant decline in suitable salmonid habitat in those basins.
- **Mining**—Discovery of gold in Swauk Creek in the 1870s led to extensive placer mining, which created extensive alteration of the channel, substrate, and banks, and caused extensive turbidity. This affected salmonid production in Swauk Creek and likely downstream in the Yakima River.
- **Removal of beaver**—Beaver dams were historically common throughout the watershed. Beaver trapping in the mid 1800s resulted in a loss of beaver dams that helped maintain hydrology during dry periods, resulting in an associated loss of valuable juvenile salmonid rearing habitat and possibly creating additional impairments to upstream fish passage.
- **Grazing**—Extensive grazing occurred in the late 1800s, particularly in higher-elevation subwatersheds.

Snyder and Stanford (2001) acknowledge five factors limiting salmonid production in the Yakima Basin:

- negative interactions between fish species—wild versus exotic and wild versus hatchery,
- alteration of the flow regime,
- impairment of water quality,
- alteration of the natural temperature regime, and
- reduction in habitat heterogeneity and floodplain connectivity.

In functional terms, the factors that limit the current productivity and carrying capacity of the component reaches of the subbasin may be divided into 10 classes. Factors affecting current natural production have been classified in terms of the specific element of the aquatic ecosystem they most directly impact. Aquatic ecosystems can be disaggregated into abiotic and biotic components. Six distinct parameters fully describe the abiotic components, and four describe the biotic components.

Abiotic elements include the following (Fast et al. 2001):

- **Water quality**—temperature, suspended sediment, turbidity, chemical pollution/pesticides, nutrient concentration, dissolved oxygen, biological oxygen demand.
- **Habitat accessibility**—the presence or absence of physical barriers to anadromous salmonids.
- **Habitat structure**—pool frequency and quality; fine sediment delivery and deposition; size distribution of substrate; and the quantity and distribution of large woody debris, off-channel habitat (e.g., side channels and sloughs), and refugia (near-pristine habitat patches sheltering core populations).
- **Channel condition and dynamics**—width-to-depth ratio, streambank stability, channel stability, channel confinement and simplification, floodplain connectivity.
- **Instream flow/hydrology**—similarity of peak and base flows to normative values, similarity of drainage network to the historical drainage network, and mortalities (e.g., entrainment, predation, or stranding) caused by irrigation or hydropower diversions.
- **Watershed condition**—road density, condition, and location; disturbance history; and the quantity and distribution of riparian reserves (i.e., habitat patches of natural, late-succession riparian vegetation providing normative rates of large woody debris recruitment, shading, etc.).

The four major biotic elements are (Fast et al. 2001):

- **Predation**—both inter- and intraspecific.
- **Competition**—both inter- and intraspecific (e.g., between hatchery and wild fish, and between resident and anadromous morphs of the same species, especially in the case of steelhead).
- **Pathogens/parasites.**
- **Mutualism**—species that benefit each other, such as the fertilization by salmon carcasses of infertile streams, to the benefit of the entire aquatic community, or such as water retention and the beneficial habitat structure provided by beaver dams. (For the sake of organization, a major mutualistic element, riparian vegetation, has been grouped with habitat structure, an abiotic parameter.)

4.4.1 Altered flow regime

Dam construction and operation within the Yakima basin drastically altered the natural flow regime of the Yakima River. The current flow regime:

- produces flows that are unnaturally low during fall and winter;
- reduces available fall and winter salmonid rearing habitat;
- fails to produce spring flood flows, which formerly helped flush smolts through the system;
- creates unnatural fluctuations that strand and kill fish or displaces them to suboptimal habitat;
- has unnaturally high flows all summer, which results in channel erosion and loss of habitat structure such as large woody debris. (USDIBOR 2002)

Flow fluctuations within the Yakima River that occur as part of Yakima Project operations may exacerbate erosion of riverbanks, harming native riparian vegetation. Pollution from agricultural return waters may impair the riparian vegetation along the river. Impaired riparian vegetation is especially evident in the lower Yakima Basin. Pesticides, sediment, and unnatural nutrient balances may deter native plant growth, possibly promoting the growth of nonnative species. In the late summer in the lower basin, very low water levels in the Yakima River may cause the water table to drop below the potential root zones of native riparian vegetation, preventing the growth of these plants (USDIBOR 2002).

One byproduct of the Yakima Project that has become a key element in Yakima Basin water management is flood control. Flood control reduces both flood frequency and the extent of flooding, allowing counties to permit the development of the floodplain for other uses (e.g., agriculture or home building), which often results in diminishing riparian vegetation. Grazing livestock can damage riparian vegetation, as can the development of home sites along the river or tributaries, when new residents clear areas adjacent to the waterbody. However, not all development is necessarily detrimental to local riparian vegetation. For instance, upslope irrigation may actually raise a surface water table and increase the water available to some natural riparian areas, thereby increasing the growth of riparian vegetation (USDIBOR 2002).

Development of irrigated agricultural areas, made possible by U.S. Bureau of Reclamation projects such as the Yakima Project, has reduced riparian areas by encouraging development of farmland in riparian and adjacent arid zones. Additionally, some natural stream channels are used to deliver irrigation water. Many of the natural streambeds in the upper Yakima Basin are used as delivery canals. Water is put into these waterbodies upstream, to provide water to downstream irrigators. The flow fluctuations that occur as a result of these practices may erode streambanks and destroy natural riparian vegetation (USDIBOR 2002).

4.4.2 Habitat concerns

The following are the most critical habitat concerns, unranked but grouped by subbasin (Haring 2001).

Lower Yakima

- Altered hydrography, resulting in lower flows than normal through the irrigation period; lack of instream flow downstream of Prosser.
- High water temperatures and lower spring flows associated with high predation rates on juvenile salmonids.
- High delivery of fine sediments and associated toxics, primarily from irrigation return flows (though significant reductions in fine sediment delivery have been achieved in recent years).
- Fish passage barriers associated with irrigation diversions (particularly in Toppenish and Ahtanum creeks), and lack of screening.
- Lack of habitat complexity (e.g., little large woody debris, channel simplification, lack of pools).
- Loss of floodplain function.
- Impaired riparian functions due to land use impacts, and altered hydrology that impairs riparian regeneration.
- False attraction due to irrigation operational spills and return flows.

Naches

- Impaired habitat quality and rearing potential resulting from altered hydrology effects (flip-flop) on the Tieton River and the lower Naches River.
- Lack of anadromous fish passage at Tieton and Bumping Dams.
- Impaired floodplain and riparian function on the Naches River and several tributaries.
- Lack of habitat complexity (e.g., little large woody debris, channel simplification, lack of pools).

Upper Yakima

- Fish passage barriers (lack of instream flow, lack of fish passage), and lack of screening associated with irrigation diversions, which impairs fish passage into suitable habitat in the upper portions of tributaries.
- Impaired floodplain function on the Yakima River and many tributaries.
- Altered hydrology, resulting in unnaturally high flows through the irrigation season, and substantially reduced spring runoff in most years.
- Impaired riparian function on many tributaries.
- Lack of habitat complexity (e.g., little large woody debris, channel simplification, lack of pools).
- High delivery of fine sediment and associated toxics, primarily from irrigation return flows.
- Lack of anadromous fish passage at Cle Elum, Keechelus, and Kachess Dams.

The salmonid production potential in the Yakima Basin is not nearly as bleak as the information above might indicate. The watershed has both existing production potential and significant habitat restoration potential. There are still areas with

highly productive habitat conditions (e.g., American River), and other areas where high quality habitat exists upstream of existing fish passage barriers (e.g., Ahtanum Creek). There is general support for the tenets of 1) protecting the best remaining habitat, 2) restoring those habitat areas that are still functioning, and 3) restoring severely impaired, nonfunctioning habitat where feasible.

Salmonid recovery will require a combination of efforts (Haring 2001):

- Habitat restoration and resource protection will require landowner commitment, participation, and stewardship. Land use regulations alone will not be effective.
- Revision, implementation, and enforcement of land use ordinances that provide protection for natural ecological processes within the instream and riparian corridors.
- Protection of currently functioning instream and riparian habitat, particularly in key habitat areas.
- Restoration of natural instream and riparian ecological processes, where they have been impaired.

4.4.3 Climate and ocean conditions

There is mounting evidence that Pacific salmon, both of hatchery and natural origins, experience large year-to-year and decade-to-decade changes in productivity as a result of ocean conditions (Mantau and Francis 2003). In the Pacific Northwest, temperature and precipitation data go back about 100 years. During that time there have been four relatively distinct climatic periods:

- **1896-1914**—Generally wet and cool.
- **1915-1946**—Generally dry and warm.
- **1947-1975**—Generally wet and cool.
- **1976-1994**—Generally dry and warm.

Scientists have found that salmon returns in the Northwest show long-term behavior that closely follows climatic cycles (ISG 1999; NRC 1996). Anderson (1995, quoted in Taylor and Southards 1997) analyzed climatic data and determined patterns of cool, wet periods and warm, dry ones. Anderson then compared these findings with Columbia River spring chinook salmon returns going back to 1940. The correlation between spring chinook and climatic patterns are very strong, and indicate that salmon returns increase during cool, wet periods and decline during warm, dry periods. While there are undoubtedly human-induced effects on the fish, the natural variability may be a very significant influence as well (Taylor and Southards 1997).

While salmon stocks in the Northwest have showed low numbers in recent decades, Alaska salmon have had a tremendous boom period. Climatologists have found that weather patterns in Alaska and the Northwest are out of phase: wet periods in the Northwest tend to be dry in Alaska and vice versa. The El Niño-Southern Oscillation and the Pacific Decadal Oscillation appear to be major drivers for this phenomenon. Salmon returns in the Northwest and Alaska are similarly out of phase. Anderson

(1997) found that chinook returns in the Rogue and Columbia/Snake Rivers behave similarly over time; however, Columbia and Alaska salmon are out of phase, with the abundant 1950-1975 period in the Northwest corresponding with a very poor salmon period in Alaska (Taylor and Southards 1997).

There are indications that global ocean and atmosphere conditions are the cause of the long-term climate variations. There also is data that indicates a switch in climate regimes occurred in 1994, and that the Pacific Northwest has returned to a wet, cool winter cycle. Some returning salmon numbers have increased dramatically over the last several years, following the 1997-1998 El Niño event (Taylor and Southards 1997).

While it might be tempting to attribute all changes in salmon abundance to ocean conditions and to conclude therefore that stream corridor management is unnecessary, all human effects on the stream corridor reduce the capacity of the environment to produce and sustain salmon populations, which makes stream corridor management even more important when ocean conditions reduce natural production (NRC 1996).

4.4.4 Harvest

Salmon are harvested by multiple activities in the Columbia River Basin; these include intentional harvest for commercial, subsistence, ceremonial, and recreational purposes. Unintentional harvest of salmon occurs as a result of activities that are not intended to capture the salmon species or life history stage. For instance, incidental harvest of Columbia River salmon occurs in the course of marine and freshwater fisheries for other species of fish, during salmon fisheries targeted at older life-history stages of salmon, at hydroelectric dams, during and after logging operations, during and after irrigation withdrawals, during land development operations such as road and real estate building, and during and after some types of mining operations (ISG 1999).

In the Columbia River Basin, directed harvest is only one of many sources of salmonid mortality, and all sources of mortality should be accounted for when considering salmon declines. Both unlimited fishing and habitat loss and degradation are parallel contributors to the decline of salmon species in the basin. Harvests impact salmon productivities directly—by reducing the numbers in the spawning populations—and indirectly—by reducing the diversity in the population, which impacts factors important to basic productivity. Overfishing occurs when fishing removes enough spawners from a population to cause it to decline. Overfishing reduces the production of salmon by reducing or eliminating the populations that have adapted to the habitat types and environmental conditions of the basin (ISG 1999).

Prior to 1941, excessive harvest exploitation and widespread habitat degradation acted together to reduce the abundance of Columbia River Basin salmon stocks. Overfishing of the salmon runs by the commercial fishery in the lower Columbia River was documented as early as the 1870s. Seventeen years later, biologists

were looking to the lower river fisheries to explain sharp declines in salmon returns to the Yakima River (particularly spring chinook and sockeye) (McDonald 1894, quoted in ISG 1999). As late as 1936, salmon fisheries were an important part of the economy of the region, employing 3,820 harvesters and generating $10 million annually for the regional economy (Craig 1899, quoted in ISG 1999).

Craig and Hacker (1940, quoted in ISG 1999) recognized that preventing overfishing was important, and they emphasized that maintaining suitable spawning and nursery grounds was paramount to the success of salmon conservation. Craig and Hacker discuss in detail human population growth, logging, mining, hydroelectric power, and flood control and navigation as causes for the decline in salmon resources during the nineteenth and early twentieth centuries. Regarding factors contributing to the first major Columbia River chinook salmon harvest declines, from 1884 to 1889, Craig and Hacker cite the reduction of late spring and early summer chinook by fishing, and reductions in fishing effort as a result of falling demand for the relatively high-priced Columbia River salmon.

Since the time of Craig and Hacker, a number of authorities have concluded that overfishing was a factor in the decline of Columbia River chinook. Thompson (1951, quoted in ISG 1999) documented declines in catch numbers of spring and summer chinook between 1876 and 1919 that were clearly associated with declines in actual chinook population size. In a comprehensive review of the historical evidence for overfishing of Columbia River salmon, Chapman (1986, quoted in ISG 1999) concluded that overfishing was a factor in the decline of chinook. Netboy (1974, quoted in ISG 1999) reported that the chinook salmon runs of the Columbia River were overfished and in radical decline after 1885.

After 1941, the negative impact of fishing on Columbia River chinook salmon was well grounded in observation. Van Hyning (1973, quoted in ISG 1999) documented the increase of ocean fishing as the main contributor to the decline of Columbia River fall chinook between 1938 and 1959. By this time, fall chinook were the dominant species of chinook in the Columbia River drainages, since runs of spring and summer chinook had been reduced in abundance over the preceding 70+ years. Craig and Hacker (1940, quoted in ISG 1999) estimated historical Columbia Basin annual aboriginal harvest at 18.2 million pounds of chinook (about 900,000 individuals); other sources have estimated higher levels of aboriginal salmon harvests (Schalk 1986, quoted in ISG 1999).

5.0 EFFECTS OF CHANNELIZATION

5.1 Overview

Stream channelization is the intentional or unintentional modification of one or more of the interdependent hydraulic variables of a stream channel, including slope, width, depth, sediment roughness or size, or sediment load. Stream channelization can be caused either by human-made structures or by natural channel processes. Human-made structures that can cause channelization include

levees, embankments, berms, dikes, revetments, bridges, floodplain fill, roads (road prisms), railroads, training structures (e.g., groins or spurs), bioengineering structures (e.g., cribwalls or rootwad/rock mixtures), and concrete walls. While these structures vary in their physical dimensions and longevity, all are similar in that they typically produce an alteration of one or more of the hydraulic variables.

The physical and biological changes that result from channelization lead to numerous alterations of biological systems. These changes affect macroinvertebrates, fish, and aquatic/riparian vegetation, as well as terrestrial animals. The biological effects of channelization occur in response to physical changes in depth, shade, sediment, temperature, and hydrology; to isolation of floodplain habitats; and to changes in nutrient cycling and biologic populations (Bolton and Shellberg 2001).

Floodplain isolation and channelization, combined with alteration of the natural flow regime, has dramatically reduced river-floodplain interactions and has degraded the aquatic environment in the Yakima River basin. Stream management for irrigation and flood control alters the natural flow regime by controlling and storing the spring flood, by significantly increasing summer stream flow, and by decreasing winter flow. Channelization limits the frequency and extent of overbank flooding and alluvial aquifer recharge. Limiting aquifer recharge reduces cool summer base flow, which is necessary to maintain optimal water temperatures for aquatic organisms. Channel simplification eliminates side channel habitat and dramatically reduces habitat diversity (Ring and Watson 1999).

Eitemiller et al. (2001) found that stream corridors in the Yakima River Basin were basically unaffected at the time of the 1855 Treaty between the United States and the Yakama Nation, though it is noted that thousands of horses were present within the basin (Ross 1855, quoted in Eitemiller et al. 2002) and that beaver populations already had been reduced by trapping (Glauert and Kunz 1972, quoted in Eitemiller et al. 2002). Shortly after 1855, cattle (1860) and then sheep (1880) were introduced to the Yakima Basin (Sullivan 2000, quoted in Eitemiller et al. 2002). Horses, cattle, and sheep significantly altered the native shrub-steppe, forest, meadow, and riparian communities from the mouth of the Yakima River to the crests of the Cascade Range. These alterations caused increased soil erosion and compaction, and stream siltation, which caused multiple stream corridor impacts. Timber harvests during this time was focused on the forest edge and in mainstem valleys. Splash damming was utilized to flood timber downstream, a practice that channelized the stream to create a single-thread river across the floodplains of the mainstem Yakima.

By the mid 1880s, the Northern Pacific Railroad had rail lines and had built bridges up the mainstem valleys of the Yakima River Basin (Campbell et al. 1916, quoted in Eitemiller et al. 2002). The establishment of rail lines was the first step to cut off and redirect stream corridor processes on most major floodplains of the mainstem river and to institute confined points of entry at many of the tributary-mainstem confluences. The rail lines detached critical links between stream corridor processes that created and maintained biotic diversity.

During the early 1900s, the federal government joined in the industrial development of the Yakima River Basin (Anderson 1996, Buckley 1936, and Tuck 1995, quoted in Eitemiller et al. 2002). Settlement by European Americans, starting around 1880, focused on floodplain farming and canal building. Individual farms and private irrigation companies constructed the first sizeable diversions off the larger tributaries, from the 1870s through the 1890s. By 1900, water rights claims exceeded the total available water within the entire basin—55,442 hectares were under irrigation during the summer of 1905, and "the entire flow of the Yakima River had been diverted" (Tuck 1995, quoted in Eitemiller et al. 2002). The 1902 Reclamation Act provided public funds for the first large-scale irrigation projects, and in 1906 Congress authorized the building of the Yakima Project (Anderson 1996, quoted in Eitemiller et al. 2002). The U.S. Bureau of Reclamation started construction of the first storage reservoir at Bumping Lake in 1908.

Flow regulation affects at least three fundamental ecological principles essential to the proper functioning of riverine systems (Stanford et al. 1996, quoted in Eitemiller et al. 2002).

- Habitat diversity is reduced.
- Native biodiversity decreases and nonnative species multiply.
- Biophysical conditions reset in relation to influences of tributaries, and as downstream distance from the dam increases.

In addition, some effects of flow regulation may include (Eitemiller et al. 2002):

- Increased vegetation recruitment due to less frequent scouring flows, leading to locally increased channel stability and decreased channel capacity;
- stranding of aquatic insects after flip-flop;
- reduced nutrient exchange between the floodplain and the river channel, due to less frequent overbank flows;
- reduced occurrence of the frequent small-discharge flood events that are central components to maintaining habitat connectivity, resulting in altered habitat formation processes;
- altered thermal dynamics due to the large proportion of flow from reservoirs, which leads to fewer degree days available, decreased insect fertility, less secondary production, and decreased productivity.

Snyder and Stanford (2001) found that that the floodplains of the Yakima Basin are considerably altered by human structures and activities, which has significantly degraded aquatic habitat. There is a pattern of decreasing water quality from upstream to downstream. Water quality impairment has been attributed to various factors, but all are related to increasing human interaction with the river via urbanization and irrigation activities.

Restoration of aquatic systems relies on the protection of existing high-quality habitat and the restoration of degraded habitats, as well as on watershed conservation. This includes off-channel habitats associated with the large alluvial

floodplains. Human activity that disrupts the shifting habitat mosaic reduces biodiversity and bioproduction of the ecosystem that includes the aquatic and riparian areas. The successful restoration of salmonids is dependent both on habitat protection and restoration and on implementing normative flows that will serve to sustain and rejuvenate habitat (Snyder and Stanford 2001).

Floodplain isolation and channel simplification, combined with inversion and truncation of the natural hydrography, have dramatically reduced river-floodplain interactions and have degraded the aquatic environment. The floodplain is isolated from the river by diking, channelization, wetland draining, gravel mining, and highway and railroad building. Many of these same activities have eliminated or isolated vast areas of side channels and sloughs. River operations for irrigation and flood control alter natural hydrography by impounding spring freshets, substantially increasing summer flow and decreasing winter flow. A common effect of these developments is a sharp reduction in the frequency with which spring floods recharge the alluvial floodplain aquifer system. Water temperatures in the lower river are therefore higher in the summer, and the number and extent of thermal refugia are reduced (Snyder and Stanford 2001).

Truncation of flood peaks by capture in reservoirs reduces the frequency, duration, magnitude, and spatial extent of floodplain inundation. This in turn decreases the size of the regulatory floodplain. Thus, project operations have indirectly allowed commercial and residential development of floodplains. By reducing recharge from overbank flow, and by increasing irrigation-induced recharge that has different timing and location, project operations have altered the quantity, quality, and timing of groundwater discharge to the river and floodplain spring brook habitats (USDIBOR 2002).

5.2 Floodplain Mining

In Yakima County many floodplain gravel pits have been excavated, a process that further complicates floodplain functions. These pits have the potential to significantly change the physical and ecological function of floodplains (Collins, 1996, 1997, quoted in Norman, Cederholm, and Lingley 1998). Floodplain mining has both cumulative and site-specific impacts that can influence the functional values of the stream corridor. A critical impact is pit capture and the temporal reduction in channel complexity. Pit captures cause disruption of sediment transport, lowering of the river bed upstream and downstream of the captured pit, lateral bank erosion below the pit site, and simplification of channel morphology, including the abandonment of spawning and rearing channels and the loss of spawning gravels (Clark 2003). The time required for recovery from pit capture is highly dependent on the availability of sediment, particle size, gradient, and the size of the pits. Over the long term, stream capture by gravel pits is a near certainty because the gravel pits have a lower base elevation, and there is a risk of rapid channel change into the pits during high flows (Norman et al. 1998).

Pit capture occurs because the pit surface is lower than the river, and pit captures typically occur during floods. Pit capture is characterized by a sudden change in the

course of a river that causes it to break through a low point. The old river channel can be partially or completely abandoned in the capture process. After capture, the temporary fluvial base level is the pit bottom. Therefore, for a considerable distance upstream, the river channel tends to incise and straighten as it works to establish a new equilibrium and grade. While the breached pit is gradually filling with gravel from upstream sources, little gravel will be transported past the pit to downstream areas. The downstream channel and bars consequently will erode if they are not replenished with coarse bed material (Norman et al. 1998).

When a river breaches a pit, river biota can be catastrophically changed. Pits that are warmer than the adjacent river may be ideal habitat for warm-water fish such as large mouth bass or yellow perch, which are predators of juvenile salmon (Kondolf et al. 1996, quoted in Norman et al. 1998). This may be particularly applicable in the lower reaches of the Yakima River, where low flows and warming river water during summers is already a chronic problem.

The classic method of attempting to prevent a river from flooding a pit is by armoring the bank to minimize lateral erosion, which may reduce the supply of sand and gravel to the active channel and thus prevent maintenance or creation of habitat diversity in both the main stem river and side channels. Dikes and levees are only short-term solutions to long-term natural processes such as channel migration and flooding (Norman et al. 1998).

The Yakima River has received widespread acknowledgement as being one of the rivers in Washington State most impacted by gravel mining (Norman et al. 1998). Currently within Yakima County (excluding the Yakama Indian Reservation), there are 110 mines within the geomorphic floodplain. Along the Yakima River and tributary streams, floodplain mining has altered large areas of floodplain into open water ponds. These ponds are commonly separated from the active channel by dikes or levees. Gravel pits adjacent to the active channel often are the paths of least resistance during high flow (Kondolf 1994, quoted in Clark 2003). Therefore, gravel pits are especially vulnerable to capture during major flood events. Floods that overtop dikes can allow a river to rapidly headcut through these structures as the flow drops from the river surface into the pit (Norman et al. 1998).

Pit capture throughout the Yakima Basin occurred frequently in the past and continues to occur. Pit capture of the lower Edler Pond near Union Gap, in April of 2002, is a prime example. One of the most detrimental avulsion events on record occurred during the 1971 flood, when the Yakima River breached a dike between the channel and an abandoned gravel pit below the State Route 24 bridge, north of Union Gap. According to Dunne et al. (1976, quoted in Clark 2003), the Yakima River left its former channel and flowed out of the downstream end of the gravel pit, across the floodplain, and into a second pit 4,000 feet downstream. Then it breached a second dike and flowed back into the main channel. During this single event, the channel was moved 100 to 1,000 feet away from its former course.

During the February 1996 flood, part of the Yakima River avulsed through the gravel pits near Parker, on the south side of Union Gap. The river entered several

gravel pit ponds totaling 35 acres and averaging 10 feet deep. The river currently has a braided, meandering course through the ponds. In this instance, the channel has become more complicated, and because the ponds were shallow, no negative effects have yet been recorded. However, there is no monitoring of the site (Norman et al. 1998).

Also during the flood of February 1996, at Selah Gap, ice jams, high water flow, and gravel mining combined to cause avulsion into Washington's (areally) largest floodplain mining area. The mined area covered approximately 250 acres, and the maximum depth of excavation was about 25 feet. When the dike upstream from the pit was breached, the entire Yakima River flow entered the gravel pits, exiting at the downstream end of the site. Results of the avulsion are difficult to quantify. About 6 to 8 feet of incision occurred immediately upstream. There was local knickpoint migration, as evidenced by a migrating standing wave and increased bank erosion, as the river began to reestablish its grade (Lorraine Powell, WADNR, pers.comm. 1996, quoted in Norman et al. 1998). The Washington Department of Natural Resources estimated that at least 300,000 cubic yards of gravel was scoured from the riverbed and deposited as a layer a minimum of 6 feet thick in the excavated pits, over a 33-acre area. (Norman et al. 1998).

Clark (2003) found that during the most intense gravel-mining phase in the Union Gap reach of the Yakima River (from about 1945 to 1973), channel complexity decreased, especially during the peak of the mining activity, which occurred from the early 1960s through the early 1970s in conjunction with the construction of Interstate 82. The drop in channel complexity was attributed primarily to channel simplification associated with mining, and with subsequent pit capture during high flow events. In addition, the presence and configuration of the channelization features themselves probably exaggerated the flow processes, which influenced the pit captures during the active gravel mining phase, but this was not the primary factor in the decline of channel complexity.

The Union Gap reach is a highly dynamic floodplain, due to frequent and favorable flow and sediment influxes, largely from the Naches River. These flood pulses have resulted in multiple gravel pit captures throughout the reach. However, these same processes have resulted in the self-reclamation of the Union Gap reach. Though the Union Gap reach has reclaimed itself from pit capture by filling the former pit areas with sediment, the presence and configuration of the channelization features has generated severe aggradation and erosion problems.

6.0 FLOOD HAZARD AREAS

6.1 Introduction

Stream corridors are areas of natural disturbance that can be hazardous to life and property. Flood hazards within Yakima County include:

- flooding,

- channel migration,
- *channel avulsion*,
- debris flows, and
- alluvial fans.

While it is important to protect the functions and values of stream corridors for water quality, quantity, and wildlife habitat, it is also important to protect life and property from the natural hazards found within the stream corridor.

6.2 Flooding

Flooding of the stream corridor generally occurs in three different ways:

- severe but less frequent winter floods resulting from warm Chinook winds or rain-on-snow;
- spring floods resulting from rapid snow melt; and
- short, intense thunderstorms that cause localized flooding and debris flows (Kinnison and Sceva 1963; USACOE 1972).

Flooding typically occurs when stormwater runoff reaches the stream channel quickly, usually within a day or so of falling on the ground. Stormwater occurs when the amount of precipitation exceeds the soil's ability to absorb it, causing the excess to run into the stream corridor as sheet or channelized flow. Severe stormwater events in eastern Washington are caused by intense precipitation over a short time period. The shallow soils and sparse vegetation of the Columbia Basin also play a vital role in stormwater management. Vegetation serves to intercept precipitation before it reaches the soil. Vegetation also uses groundwater during photosynthesis; this allows for more water capacity in the soil. Winter flooding events can occur when the soil is frozen and cannot absorb any rainfall. Another flooding process occurs when stormwater percolates into the soil, charging the shallow groundwater. As the water table rises and saturates the soil, new stormwater cannot infiltrate and therefore ponding occurs (Booth 1991).

Winter floods, expected from October to March, are historically more destructive than spring floods, but they tend to have a lower total volume due to their shorter duration. Spring floods, expected in April through June, typically have a larger total volume but are less destructive and last for a longer time period (Tetra Tech/KCM 2003; USACOE 1975).

The Yakima River has exceeded flood stage 45 times since 1894. Yakima County has been declared a federal disaster area nine times since 1970, which includes the most recent flooding in 1995 and 1996. The largest flood on record occurred in December 1933, with flows estimated at 67,000 cubic feet per second (cfs) at the Kiona gauging station; the average annual discharge at Kiona is 3,700 cfs. The February 1996 flood is the second largest flood on record, with flows recorded at 57,500 cfs at the Parker Dam and an estimated total damage cost exceeding $17 million (KCM 1998). For more information on flood history in Yakima County, see the *Upper Yakima River Comprehensive Flood Hazard Management Plan* (KCM

1998), which was written to identify flooding issues and to gain an understanding of flood hazard management options.

6.3 Channel Migration and Avulsion

Channel migration can be either a slow, predictable pattern or a quick, catastrophic event. Channel avulsions usually are unpredictable, erosive events that occur during high flood flows. Channel avulsions generally occur when the existing channel cannot transport all of the water and sediment supplied to it (O'Connor and Watson 1998). Sediment transport and deposition during a flood is dependent upon water velocity, depth of flow, and the size of the sediment in the channel and the floodplain. Deep, high-velocity floodwaters can move large quantities of sediment, causing severe erosion of the bed and banks (Tetra Tech/KCM 2003).

In natural stream systems, the ability of the stream to erode, mobilize, transport, and deposit sediment are the main functions that influence channel migration and avulsion (Tetra Tech/KCM 2003). The natural meander patterns of stream channels are the result of the dissipation of energy of flowing water and the transportation of sediment (Rosgen 1994). The bed of a stream channel may rise (aggrade) and fall (incise) as it reacts to changes in woody debris, sediment, and flooding activity. Activities that initiate aggradation and increase the hazard of avulsion include log/ice jams, landslides, human-made constrictions such as dams and bridges, and reduction in the erosion resistance of the floodplain (e.g., removal of riparian vegetation).

As a channel aggrades, flooding patterns and depths change, reactivating inactive stream corridor features. Stream channel incision causes a channel to abandon portions of its floodplain, which diminishes avulsion hazards. If the incised segment is below an aggraded one, it may increase avulsion risk. This occurs when flood flows return to the channel in the incised segment, causing headcutting across the floodplain and, potentially, avulsion. Incised channels may still be unstable, given that incision often initiates a period of channel widening as unstable banks collapse. Constrictions in the stream channel, whether natural or artificial, reduce the stream's capacity to transport water and sediment upstream of the constriction, which promotes channel instability. Alternately, incision caused by channelization reduces channel migration potential.

Natural, unregulated systems can encounter fluctuations between incision and aggradation in response to naturally occurring changes in sediment supply and amounts of woody debris. Alternatively, regulated and channelized streams are susceptible to increased sediment inputs (aggradation) due to high levels of erosion and mass wasting, and are susceptible to irreversible long-term incision due to corresponding increases in discharge and decreases in channel roughness and sediment inputs (Rapp and Abbe 2003).

Rosgen (1994) developed a stream classification system that utilizes an entrenchment ratio (ER). The ER is the ratio of the width of the flood-prone area to

the width of the stream channel, and is used to illustrate the relationship between the stream channel and the valley in which it is positioned.

- Streams with a ratio of 1.0 to 1.4 are entrenched, with no floodplain.
- Streams with a ratio of 1.41 to 2.2 are moderately entrenched, with little or no floodplain.
- Streams with a ratio of 2.2 or greater are slightly entrenched, with a well-developed floodplain.

O'Connor and Watson (1998) developed a system to predict the potential of channel migration and avulsion using ER and slope (Table 1). Slightly entrenched channels (ER > 2.2) with a low gradient (< 1.5 percent) have the greatest potential for channel migration, while entrenched channels (ER < 1.41) with a high gradient (4 to 8 percent) have the least potential. It is important to recognize that forced morphologies can occur anywhere within the stream corridor. Forced morphologies are caused by flow obstruction, like a logjam, that enhances sediment storage in an otherwise sediment-limited reach (Rapp and Abbe 2003).

Channel migration zone (CMZ) potential generally hinges on whether the amount of sediment is in balance with or greater than the stream's ability to transport sediment. When the amount of sediment exceeds the stream's ability to transport it, the stream channel will aggrade and raise its bed elevation. Aggraded channels tend to form multiple or braided channels in order to deposit sediment. If the amount of sediment is reduced or cut off, or if stream flow increases, channels will incise and become entrenched. Increased entrenchment can cause the channel to abandon former floodplains, which become terraces that are seldom flooded or entirely isolated from the stream, although abandoned floodplains are still at risk from channel migration.

6.4 Debris Flows

Debris flows, often referred to as mudslides, mudflows, lahars, or debris avalanches, are common types of fast-moving landslides. Debris flow volume depends on the amount of water supplied by a cloudburst, by a rain-on-snow

event, by a lake outburst, or by a volcanic eruption. The consistency of the debris flow must have a high sediment-to-water ratio so that the mixture has a low permeability—the water cannot separate and the sediment cannot drop out. Debris flows can be composed of a variety of sediment sizes. Flows with a high proportion of fine material have a high internal strength. Flows with a high internal strength are capable of transporting large objects such as boulders, trees, or cars (Highland, Stephenson, Christian, and Brown 1997; Schumm et al. 1996).

Table 1
CMZ potential (O'Connor and Watson 1998)

Level of confinement or entrenchment	**Low gradient < 1.5% channel slope**	**Moderate gradient 1-6% channel slope**	**High gradient 4-8% channel slope**
Confined/ entrenched (ER ≤ 1.4)	Uncommon channel type; no hypotheses regarding channel migration processes	Channel migration unlikely	Channel migration unlikely
Moderately confined/ moderately entrenched (1.4 < ER ≤ 2.2)	Uncommon channel type; no hypotheses regarding channel migration processes	**CMZ (3-6%)** Channel migration by avulsion is not uncommon, but is likely to be spatially-discontinuous, depending on local variation in valley slope and width and disturbance regime	**CMZ** Channel migration by avulsion is uncommon, and is likely related to debris flows and torrents; may be locally significant depending on local variation in valley slope and width and disturbance regime
Unconfined or slightly entrenched (ER > 2.2)	**CMZ (<1.5%)** Channel migration by gradual erosion of meander bends is common; avulsions may also occur. Areas of potential migration are spatially continuous and include much or all of the floodplain.	**CMZ (1-3.5%)** Channel migration by avulsion may be common. Areas of potential migration are spatially discontinuous and include much or all of the floodplain.	**CMZ** Channel migration by avulsion may be common, and is likely to be related to alluvial fan and debris flow fan processes. Process may be spatially discontinuous continuous, or localized, depending on fan-building processes.

Steep (greater than 30 percent) source reaches are sediment storage sites subject to debris flows. Montgomery and Buffington (1993) describe source reaches as one of two valley types:

- unchanneled colluvial, or
- channeled colluvial.

Unchanneled colluvial valleys, also known as hollows or swales, lack sufficient stream flow to maintain a consistent, defined channel. Hollows function as sediment storage sites that collect sediment from the surrounding landscape. The depth of colluvial sediment is dependent upon the rate at which material is delivered, and on the time elapsed since deposits began accumulating. Intense precipitation events initiate debris flows that flush the collected colluvia downslope. After a debris flow, the valley may become channeled or eroded to bedrock, and may refill with sediment over time. Debris flows tend to occur in concave depressions on a slope, but can also form on the convex face of a slope (Montgomery and Buffington 1993).

Channeled colluvial valleys are located downslope from unchanneled valleys, at the upper ends of the stream system in low-gradient systems, or where there is an abrupt change in transport capacity. Channeled valleys are basically similar to unchanneled valleys, except that there is sufficient stream flow to maintain a constant channel (Montgomery and Buffington 1993).

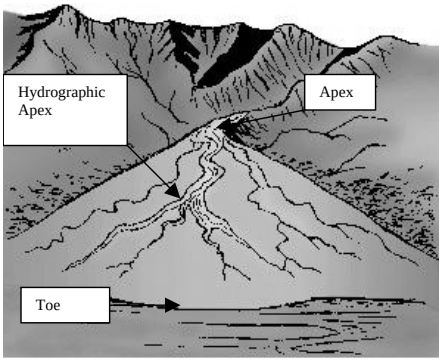
The arid and semi-arid areas of eastern Washington are especially susceptible to debris flow events. The Yakima River Canyon was subject to such an event on July 3, 1998. Precipitation data from a weather recorder on Manastash Ridge indicated that 3 inches of rain fell within less than one hour (Kaatz 2001). Kaatz found that flow depths exceeded 6 feet, mobilizing basalt boulders of 1 foot or more in diameter. Eight sections of State Route 821 were covered in debris fans exceeding 15 feet. Six debris fans extended well into the river, filling approximately 60 percent of the stream channel.

6.5 Alluvial Fans

Schumm et al. (1996) define an alluvial fan as "a sedimentary deposit located at a topographic break, such as the base of a mountain front, escarpment, or valley side, that is composed of fluvial and/or debris flow sediments and which has the shape of a fan either fully or partially extended" (p. 6). Alluvial fans are constructed by:

- stream flow,
- debris flow, or
- a composite of the two.

Alluvial fans typically form where a stream exits a steep canyon; the point where the fan begins is called the apex (Figure 6). The apex forms a major break in gradient that drastically affects the stream's ability to transport sediment. Lateral channel movement at the mouth of the canyon progressively deposits sediment, building the fan into a cone-shaped feature. Two or more fans that coalesce together are known as a bajada. Arid and semi-arid areas are particularly prone to alluvial fan formation, due to high sediment loading and debris flow potential (Schumm et al. 1996).



An Alluvial Fan from Merriam-Websters online Collegiate Dictionary.

Figure 6. Alluvial fan. (Source: Merriam-Webster's dictionary, online)

Stream flow depositional fans usually consist of braided or multiple distributary channels radiating from the apex. Deposition typically occurs as bars within the channel. Bar formation within the channel promotes lateral migration as the bank opposite bar formation is eroded, similar to cut-and-fill alluviation in floodplains. Large amounts of sediment within the channel can reduce transport capacity and force overbank flooding. High-velocity overbank flows can avulse or erode a new channel, or may occupy an older channel. Channels generally diverge and become smaller as they flow downfan. Due to the convex cone shape of the fan, distributary channels diverge and usually do not reconnect.

Stream flow–dominated fans that were constructed during different climates, or those in which tectonics has caused uplift, can become entrenched and relatively stable. Entrenched channels may be incised deeply below the fan surface, where flooding and avulsion are rare or nonexistent in the current climate. Separation of flow into multiple channels is reversed and channel complexity is diminished. Channel banks can be colonized by vegetation, which adds additional strength. Fans that are no longer accumulating sediment can be considered stable in whole or in parts. Entrenched channels can emerge downfan, at a point called the hydrographic apex, and again take on a stream-flow characteristic (Schumm et al. 1996).

Debris flow–dominated fans occur on very steep reaches where there is a high and constant accumulation of colluvium, or where there is a high concentration of flow. Debris flows with a high internal strength are capable of coming to rest at steep gradients near the apex. Such deposits can block fluvial channels formed between debris flow events. Blocked channels cause overbank flooding with a high potential for avulsion. Debris flow–dominated fans typically have coarser sediment near the apex, with a progressively finer sediment size downfan. Some fans are blocked with boulders near the apex and do not exhibit stream or debris flow, but instead are dominated by sheet flow (Schumm et al. 1996).

Composite fans are formed by both stream and debris flow. Some fans may be divided, with debris flow domination near the apex, and stream flow from the hydrographic apex to the toe.

The Federal Emergency Management Agency (FEMA) (2000) has outlined the most common flooding processes found on alluvial fans. The prediction of flooding on alluvial fans is extremely difficult if not impossible, due to channel migration and avulsion. Flooding processes are not strictly limited in the case of a particular fan; one fan may pose all four processes along its profile. FEMA has defined alluvial fan flooding processes as:

- stable channel flow,
- unstable channel flow,
- sheet flow, and
- debris flow.

Stable channel flow occurs in entrenched channels or in channel networks formed in different climatic or tectonic conditions. Channels consisting of large sediment are typically more stable than fans with fine or gravelly sediment. Channels are established and are not prone to the severe erosion or deposition that would decrease channel transport capacity. Stable channels tend to have established vegetation, which increases stability.

Unstable channel flow occurs on fans with multiple or braided channels with a high likelihood of avulsion. Fans with fine to gravelly sediment are more prone to erosion and deposition that promotes lateral channel movement. Recently formed or actively eroded channels lack stabilizing vegetation.

Sheet flow occurs in broad sheets unconfined by channel banks. Sheet flow can develop from stormwater or from overbank flooding on a stable fan surface that does not erode to form a new channel. Sheet flow may occur where multiple channels come together near the toe, where the gradient is low and the flows merge.

Debris flow–dominated fans are discussed above.

6.6 Summary

Yakima County contains a number of significant flood hazards. These natural disturbance regimes, while destructive in the short term, are usually beneficial to the overall function of the stream corridor. Streams function to move water and sediment. Alluvial fans provide sediment storage, and debris flows provide sediment to downstream reaches. Channel migration and avulsion are natural mechanisms for sediment transport and storage. Overbank flooding deposits beneficial sediments and exchanges nutrients on the floodplain, in addition to recharging the groundwater. While it is important to protect the functions and values of stream corridors for water quality, quantity, and wildlife habitat, it also is

important to protect life and property from the natural hazards found within the stream corridor.

7.0 GENERAL MANAGEMENT STRATEGIES

7.1 Introduction

Management strategies that promote and allow natural stream corridor processes to evolve over time tend to succeed because they work with the natural tendencies of a stream corridor, rather than working against them (Ebersole et al. 1997, quoted in Bolton and Shellberg 2001).

7.2 Water Quality in the Yakima Basin

Typically, water quality in the upper portions of the Yakima River Basin is high, and degrades downstream. In several reaches of the mainstem Yakima River and its tributaries, water quality does not comply with one or more state water quality criteria, either seasonally or on a year-round basis. When a waterbody fails to meet State water standards it is placed on the state's 303(d) list and is targeted for a total maximum daily load (TMDL). The 303(d) list is prepared every four years by the State of Washington and is submitted to the U.S. Environmental Protection Agency (EPA) in compliance with the Federal Clean Water Act. The list identifies waterbodies that are known to exceed state water quality standards.

A TMDL for the Lower Yakima River was completed in 1997. Many reaches within the Yakima basin were included on the 303(d) list. Pollutants include (Joy and Patterson 1997):

- turbidity,
- pesticides,
- low dissolved oxygen,
- elevated temperatures,
- metals,
- fecal coliform bacteria (FC), and
- pH.

7.2.1 Sediment

Significant suspended sediment loads have been associated with the discharge of agricultural return flows to the river during the irrigation season. The prevalence of suspended sediment from eroded farm soils has long been recognized as a problem in the tributaries and mainstem of the Yakima River, where furrow and flood irrigation are employed. In the lower basin, high sediment levels have been correlated with high levels of turbidity and high levels of FC, which exceed water quality standards during the irrigation season (WDOE 1997, quoted in Joy 2002). This is particularly apparent in the reaches below the City of Yakima. Suspended sediment has been directly correlated with the presence of the banned pesticide

DDT in some of the drains and in the mainstem Yakima. DDT and its breakdown products have been found in fish tissue well in excess of levels recommended in human health criteria. It is suspected that agricultural drain systems also may be associated with the transport of other pesticides, of FC, and of nutrients such as phosphorus and nitrites to the Yakima River.

The ongoing lower Yakima River suspended sediment and DDT TMDL is designed to reduce suspended sediments, improve water clarity, and reduce pesticides (most notably DDT) in the river. Turbidity standards, which are being used as a surrogate for sediment loads, have been set for the irrigation returns and tributaries discharging into the lower Yakima River. These enforceable limits, set in 5-year increments over the next 15 years, will improve water clarity and reduce the amount of sediment and pesticides entering the river. The primary implementation activities of this TMDL will be to improve irrigation water management practices and to reduce tailwater runoff. To accomplish these goals, growers are being encouraged to convert furrow- and flood-irrigated fields to sprinkler and drip irrigation, or to install facilities that remove sediment from return water. The Roza-Sunnyside Board of Joint Control developed and is implementing policy that will require grower observance of the TMDL targets.

7.2.2 Temperature

Exceeding temperature criteria is the most prevalent pollutant parameter on the 1998 state 303(d) list for the Yakima Basin. Of the 180 Yakima Basin listings on the 1998 list, 73 are for failure to meet temperature criteria. The highest temperatures have occurred in the lower portion of the basin, although there are numerous 303(d) listings in the upper basin tributaries. Water is usually cooler in the upper basin, but warms as it flows to the lower basin. Human activities have dramatically altered the Yakima River system in ways that may influence water temperature, including changes to channel morphology, removal of riparian cover, and disruption of floodplain function, hyporheic flow, and flow regimes.

7.2.3 Fecal coliform bacteria

There are eighteen 303(d) listings for FC in the Yakima Basin. FC contamination is found periodically in several reaches of the Yakima River, and regularly in several tributaries. These pollution problems are often noted downstream from areas where livestock operations are prevalent or failing septic systems are suspected. Activities that will reduce FC include a sediment TMDL that targets the reduction of surface water runoff from agricultural lands; recent dairy legislation, including periodic compliance inspections; local irrigation district policies requiring the exclusion of livestock from drains and watercourses; and increased monitoring to identify failing septic systems. A Granger Drain FC TMDL was developed and is being implemented to specifically reduce bacterial loadings to the Granger Drain, a tributary of the lower Yakima River, through best management practices directed at reducing the runoff of suspended sediment from irrigated agricultural lands.

7.2.4 Pesticides and other organic compounds

There are 46 Yakima Basin listings for pesticides and organic compounds on the 1998 state 303(d) list. Pesticides and other organic compounds continue to have a significant presence in the Yakima River system. During a 1987–1991 study, USGS scientists detected more than 110 different organic compounds in Yakima River Basin streams. These findings included pesticides applied to agricultural fields during that period, persistent pesticides used historically (such as DDT), and organic compounds associated with industrial and urban activities (Morace et al. 1999, quoted in Joy 2002).

7.2.5 Metals

There are 16 Yakima Basin listings for metals on the 1998 state 303(d) list, including arsenic, silver, mercury, cadmium, and copper.

7.2.6 Nutrients

Nutrients include nitrate/nitrite nitrogen, ammonia nitrogen, and phosphorus. Giffin Lake, which receives agricultural return flows, is 303(d) listed for phosphorus. Two waterbody segments, Selah Ditch and Granger Drain, are listed for ammonia nitrogen (WDOE 1998, quoted in Joy 2002).

7.2.7 Dissolved oxygen and pH

There are nine dissolved oxygen listings in the Yakima Basin; all occur in areas heavily influenced by agricultural return flows. There are also four listings for pH. Both DO and pH have a tendency to react to other changes in water quality. DO may fall out of compliance with standards as water temperature increases, and as decomposing compounds that require oxygen (biological oxygen demand) are added to the waterbody. A waterbody's pH may rise above criteria levels as water levels drop and aquatic plants thrive, changing the chemistry of the waterbody.

7.2.8 Instream flow

Eight stream segments are listed for insufficient instream flow within the Yakima Basin. Of these, two are in the mainstem Yakima River itself. While there are no state water quality standards for low instream flows at this time, insufficient flow can interfere with many of a waterbody's characteristic uses and can influence other pollutant criteria. The EPA and the U.S. Supreme Court have indicated that low instream flow can be considered pollution and will be addressed by increasing instream flows, using such methods as buying water rights and implementing water conservation measures on agricultural lands (Joy 2002).

An upper Yakima River Basin suspended sediment and pesticide TMDL evaluation was conducted by the Washington State Department of Ecology in 2002. This evaluation was an extension of the 1997 lower Yakima Basin TMDL and addressed several pesticide 303(d) listings of water column and fish tissue in the upper basin.

Turbidity and suspended sediment were included, both as transport mechanisms for the pesticides and as pollutants themselves. The data evaluation for the upper Yakima River Basin indicated that (Joy 2002):

- In many tributaries and in the mainstem, turbidity and suspended sediment (total suspended solids) were too high for too long and could be harmful to salmon.
- DDT had decreased in mainstem fish, but some fish samples still exceeded total DDT criteria for human health.
- Water-column DDT levels exceeded chronic aquatic toxicity and human health criteria at two sites in the Cherry Creek subbasin (Kittitas County).
- Upper basin water quality is improving (and is less severe than was reported for the lower basin in 1997), but nonpoint sources will require TMDL targets, to protect aquatic communities and human health.

7.3 Alluvial River Characteristics and Their Relation to Stream Corridor Management

Historically, natural resource management has been behind on current science and theory concerning the stream corridor processes that form and maintain alluvial river ecosystems. Trusch, McBain, and Leopold (2000) outline a number of characteristics that control how healthy alluvial channels work. These characteristics provide a minimum checklist of critical processes, to track and assess policies for restoring and conserving alluvial river systems.

The laws of physics hold that for every action there is a reaction; this theory applies to alluvial river systems, where an action might be a management decision (flip-flop or a new bridge) and the reaction might be bed scour or altered channel migration that affects aquatic species. The repercussions of any action depend on a threshold beyond which a specific reaction is expected, where the process comprises both an action and an expected reaction. In order to use alluvial river system characteristics as guidelines for restoring and conserving essential stream processes, thought should be given to how the "magnitude, duration, frequency, and timing" of an action will exceed a threshold to produce a desired response. However, a single action taken in a river system rarely is linked to only a single reaction.

The alluvial river system characteristics can assist natural resource managers in identifying the desired system processes, and can then assist in applying the appropriate actions, based on river system relationships and thresholds developed through the best available science. It should be acknowledged that this system might not apply to all alluvial river ecosystems. Some rivers may not be capable of achieving certain characteristics because of prevailing limitations.

- **Characteristic 1**—"The primary geomorphic and ecological unit of an alluvial river is the alternate bar sequence" (Trusch et al. 2000, p. 1).

The process of cut-and-fill alluviation and maintenance of the shifting habitat mosaic through channel migration and avulsion are the basic structure for aquatic and riparian communities in healthy alluvial river ecosystems. The essential element of an alluvial river is the alternate bar unit, comprising a point bar and a pool connected by a riffle (Figure 7). A connection of two alternate bar units is a meander wavelength. The perfect alternate bar sequence is rarely found in nature, due to natural inconsistency (e.g., valley width contractions or bedrock exposures). Floods flowing through alternating bar sequences rearrange the bar topography, producing diverse, high-quality aquatic and terrestrial habitat.

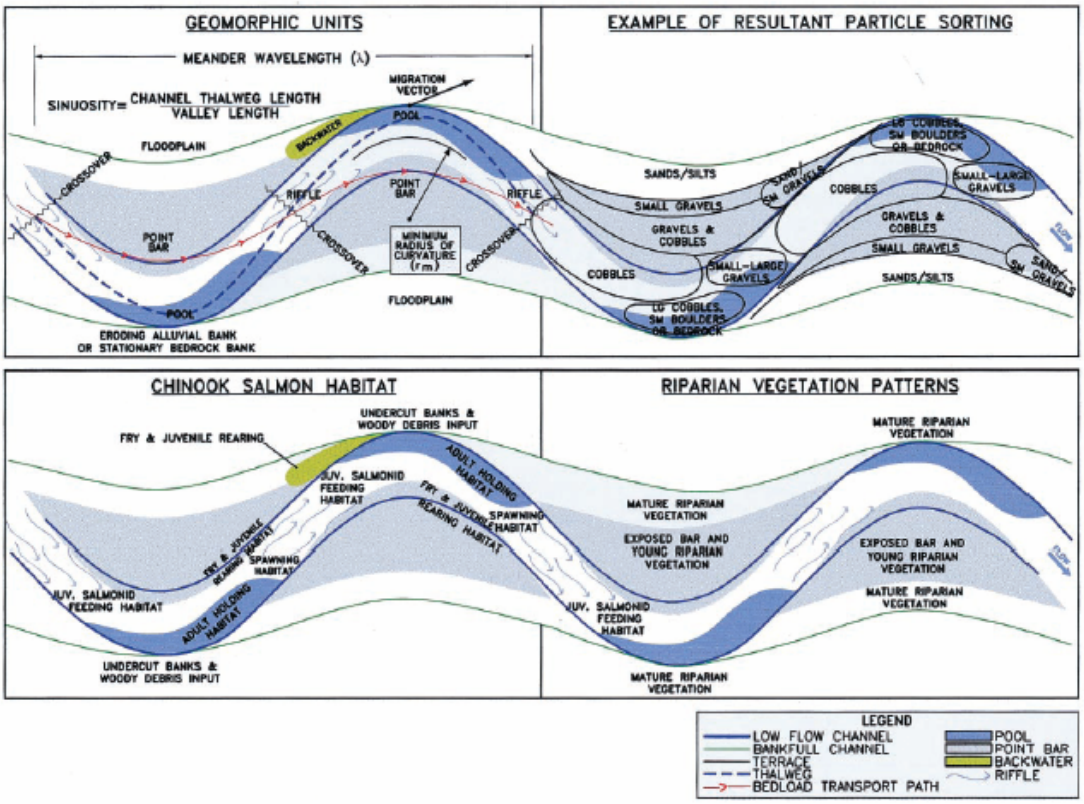


Figure 7. Alternate Bar Sequence.

- **Characteristic 2**—"Each annual hydrograph component accomplishes specific geomorphic and ecological functions" (Trusch et al., 2000 p. 2).

  Floods, base flow, snowmelt peaks, and snowmelt recession limbs cooperatively stimulate the processes that shape and maintain alluvial river ecosystems. Each annual component can be characterized by its interannual variability in flow magnitude, duration, frequency, and timing. Each component is necessary to create and sustain alluvial river ecosystems, and eliminating or altering the

interannual variability of the hydrograph components invariably alters the ecosystem.

- **Characteristic 3**—"The channel bed surface is frequently mobilized" (Trusch et al. 2000, p. 2).

  Streambed surfaces require mobilization by bankfull or greater floods. As stream flow rises in response to a storm event, or during the spring snowmelt, a geomorphic threshold for mobilizing alluvial sediments is eventually exceeded. This threshold generally occurs over a narrow range of flow and is typically spatially discontinuous, depending on channel form, sediment size, and distribution. The duration of sediment mobilization is generally on the order of days. Depending on flow characteristics for a particular watershed over time, stream channel sediments are mobilized annually, on average.

- **Characteristic 4**—"Alternate bars must be periodically scoured deeper than their coarse surface layers" (Trusch et al. 2000, p. 2).

  Floods that surpass the threshold for sediment mobilization are necessary to rejuvenate stream channel structure. Floods exceeding 5- to 10-year–event size periodically scour the stream channel structure. Scouring is generally followed by redeposition, with minimal net change in structure form and volume. Complex stream channel structure is created and maintained by the natural frequency and intensity of bed scour. During the initial phase of a flood event, after the streambed sediments begin to move, the rate of sediment transport is dramatically enhanced and the streambed sediment begins to scour. During the end of a flood event, sediments redeposit, resulting in no net change in channel structure or volume.

- **Characteristic 5**—"Fine and coarse sediment budgets are balanced" (Trusch et al. 2000, p. 3).

  The ratio between imported and exported fine and coarse sediment within a stream reach should be approximately equal. The amount and mode of transport may fluctuate annually; equilibrium of stream channel structure is maintained over multiple years. The mobilization threshold is critical for balancing the overall fine and coarse sediment budget. Chronic stream channel degradation or aggradation are indicators of sediment budget imbalances.

- **Characteristic 6**—"Alluvial channels are free to migrate" (Trusch et al. 2000, p. 3).

  Channel migration erodes older floodplain and terrace deposits on the outside of a bend, while depositing new sediments on the inside of the bend, which results in long-term maintenance of channel width. Maintaining the opportunity for channel migration is essential to diverse aquatic and upland habitats.

- **Characteristic 7**—"Flood plains are frequently inundated" (Trusch et al. 2000, p. 3).

  Floodplains require frequent inundation—generally every 1 to 2 years—which diminishes flood peaks, moderates alternate bar scour, and promotes nutrient cycling. As stream flows increase beyond channel capacity, water spreads across the floodplain. The first threshold in inundation is the bankfull discharge, which allows flows to wet the floodplain surface. The second threshold requires a slightly larger discharge, to transport and deposit fine sediments and nutrients that enrich soils and promote riparian vegetation. Floodplain inundation also moderates sediment mobilization by limiting flow depth increases within the bankfull channel during floods.

- **Characteristic 8**—"Large floods create and sustain a complex mainstem and flood plain morphology" (Trusch et al. 2000, p. 3).

  Larger-magnitude floods—those exceeding 10- to 20-year–event size—are necessary to reshape and/or redirect entire meander sequences, to avulse mainstem channels, to rejuvenate mature riparian stands into early successional stages, to form and maintain side channels, to scour floodplains, and to perpetuate off-channel wetlands. Occasional large floods are essential for sustaining channel complexity because they change river location and structure on a large scale and inhibit riparian vegetation from dominating the river corridor.

- **Characteristic 9**—"Diverse riparian plant communities are sustained by the natural occurrence of annual hydrograph components" (Trusch et al. 2000, p. 4).

  Natural, annual variability of stream flow is necessary for a variety of successional woody riparian vegetation stand structures. Native riparian plant communities such as cottonwoods are adapted to and sustained by a constantly changing environment. The magnitude and duration of annual stream flows needed for sediment mobilization, channel migration, floodplain inundation and scour, and channel avulsion also provides necessary substrate conditions for successful seedling establishment and stand development. The timing and frequency of annual flow variability must coincide with seasonally dependent life history requirements, such as the short window of time when riparian plants are dispersing seeds. A sustainable supply of large woody debris from the riparian zone ultimately depends on variable-age classes of woody riparian vegetation and on a migrating channel.

- **Characteristic 10**—"Groundwater in the valley bottomlands is hydraulically connected to the mainstem channel" (Trusch et al. 2000, p. 4).

  Stream flow is hydraulically connected to hyporheic and groundwater floodplain zones that are recharged by overbank flooding. Side channels and riverine

wetlands retain direct hydraulic connectivity to mainstem surface flows, and are a direct connection to groundwater.

7.4 Riparian Buffers

7.4.1 Introduction

An evaluation of the best available science concerning riparian zones indicates that few of the citations address the unique geography of eastern Washington, and are therefore difficult to apply locally. Riparian science specifies that the width of a riparian buffer will depend on the particular function or range of functions being protected. See Chapter 3 of this document for additional discussion and review of wetland buffers.

7.4.2 Riparian buffer functions

A riparian buffer can be defined as a strip of land established to mitigate the impacts of human activities on the stream ecosystem (Johnson and Ryba 1992). Riparian buffers serve to protect natural functions as well as to minimize the impacts of stormwater runoff and to prevent property loss due to flooding (May and Horner 2000, quoted in Portland Bureau of Planning 2001). Riparian zones serve multiple functions in the aquatic ecosystem and in terrestrial and semiaquatic wildlife habitat, and they serve as migration or dispersion corridors.

Protection of a natural riparian buffer has been shown to partially mitigate the unfavorable effects of urbanization on aquatic wildlife. In some instances where multiple Critical Areas are present, it may be necessary to protect the entire width of the floodplain because this area provides essential spawning and rearing habitat for threatened and endangered fish, and important year-round habitat for semiaquatic and terrestrial wildlife. Therefore, the area necessary to maintain the functions and values of Critical Areas may include the extent of the 100-year floodplain, and should be wide enough to permit natural channel migration (Knutson and Naef 1997; Portland Metro 2002; Snyder and Stanford 2001; Stanford et.al. 2002; Ward and Stanford 1995).

The loss of riparian vegetation due to urbanization (Klein 1979, quoted in Knutson and Naef 1997):

- degrades stream conditions through increased erosion of banks no longer armored with roots and debris from natural vegetation,
- removes a source of logs and organic debris that stabilize streams and provide food and nutrients,
- increases stream temperatures through shade removal, and
- reduces the capacity of the riparian area to filter incoming sediments and pollutants.

Slopes adjacent to a stream are a significant variable in determining the effectiveness of a buffer in trapping sediments, retaining nutrients, preventing

contaminants from reaching the stream, and reducing erosion. Steeper slopes have higher velocities of surface and subsurface water flow, resulting in less time for nutrients and other contaminants to pass through the buffer and reach the stream. May (2000, quoted in Portland Metro 2002) recommends that in the case of slopes over 25 percent the buffer should be measured from the break in slope, to reduce sediment loading from mass wasting events. Wenger (1999) suggests a base width of 100 feet, plus 2 feet per each 1 percent of slope.

Palone et al. (1997) developed curves relating the relative value of the buffer in providing a specific stream order function (Figure 8). Stream ordering is a method of assigning a numeric organization to the stream network. The scale starts with headwater streams (orders 1-4), moves to mid-order streams (3-6), and then to larger streams and rivers (order 6+). As stream order increases, the relative value of the buffer in providing shade, aquatic habitat, stream bank stabilization, and removal of nutrients decreases, while flood mitigation increases. The relative value of the buffer to provide sediment control remains fairly constant.

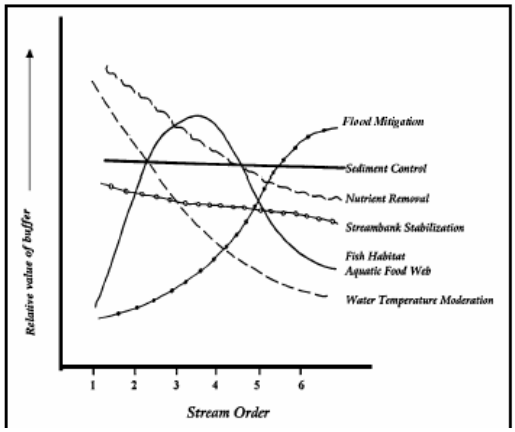


Figure 8. Curves relating the relative value of the buffer in providing a specific stream order function (Palone and Todd 1997).

When establishing scientifically based criteria for determining buffer widths, four criteria should be addressed (Wenger 1999):

- the existing or potential value of the resource to be protected;
- the site, watershed, and buffer characteristics;
- the intensity of adjacent land use; and
- the specific water-quality and/or habitat functions desired.

Generally, narrower buffers may be sufficient when the riparian area is in good condition, the resource values are low, site conditions are ideal, the adjacent land use has a low potential for impact, and/or the desired buffer functions are few. On the other hand, wider buffers are necessary when the buffer quality is poor and

high-value water resources exist adjacent to intense land uses, or where a high level of multiple buffer functions is desired (Palone and Todd 1997).

The effect of the riparian area on the stream environment is not simply proportional to the amount of the channel that is shaded. Providing for bank habitat, large woody debris, and organic matter remain important functions, regardless of stream size. Water quality (i.e., nutrients, sediment, and temperature) is affected most by the condition of headwater streams. Riparian areas may exert their greatest influence here, as the majority of water flows through the shaded riparian zone. Riparian areas may provide the greatest opportunities to enhance fish habitat on mid-order streams where there is sufficient large woody debris, stream structure, and flow to support fish and other aquatic life. Larger streams and rivers are often characterized by well-defined floodplains and adjacent wetlands. Wider buffers may be needed here, to allow meandering as well as to improve channel stability, water quality, and wildlife corridors (Palone and Todd 1997).

Generally, riparian areas associated with small streams are narrower and less distinct than those associated with large streams or rivers. The influence exerted by the riparian area on the aquatic system is greater on smaller streams than on larger ones. Conversely, the aquatic area has less influence on the riparian area in smaller streams. As stream width increases, the amount of water surface shaded by riparian vegetation decreases. Therefore, the influence of streamside vegetation on the water temperature of large streams is less than the influence on smaller streams. Stream temperature in large rivers is more dependent on water coming from upstream reaches. Small, non–fish-bearing streams significantly may still influence fish habitat because they carry water, sediment, nutrients, and woody debris downstream. Because small streams are more intimately related to their riparian area, the removal of riparian vegetation may have a relatively great effect. Conversely, due to the lesser influence of riparian habitat on large streams, the removal of riparian vegetation along large streams has less effect on stream structure and function (Knutson and Naef 1997).

7.4.3 Buffer width recommendations

Riparian areas should be sufficiently wide to achieve the full gamut of riparian and aquatic ecosystem functions, which include but are not limited to:

- protection of instream fish habitat by controlling temperature and sedimentation in streams,
- preservation of fish and wildlife habitat, and
- connection of riparian wildlife habitat to other habitats (Harris 1988, Schaefer and Brown 1992, and Steinblums et al. 1984, all quoted in Knutson and Naef 1997).

Spence et al. (1996) refer to the Forest Ecosystem Management Assessment Team's (FEMAT) (1993) site potential tree height (SPTH) standard for riparian buffers in forested environments. A SPTH can be defined as the potential height of a mature tree at a particular location. A SPTH of 110 feet for eastside forests was

established, and estimates are that a buffer width of approximately 0.75 SPTH (82.5 feet) is needed to provide minimum protection of stream shading, litter inputs, large woody debris, and nutrient regulation. FEMAT constructed curves that correlate the percent effectiveness of a function in relation to SPTH (Figure 9), and found that buffers designed to protect 100 percent of LWD recruitment will likely provide close to 100 percent of small organic litter as well.

Although data quantifying the effective zone of influence relative to root strength is scarce, FEMAT (1993) concluded that most of the stabilizing influence of riparian root structure is probably provided by trees within 0.5 SPTH of the stream channel (55 feet). As a result, buffer widths for protecting other riparian functions are likely adequate to maintain bank stability, except on steep slopes. Buffers designed to protect other riparian functions will generally control sediments to the degree that they can be controlled by riparian vegetation. Buffer widths designed to protect LWD recruitment and shading may be adequate to prevent excessive nutrient or pollution concentrations. Nevertheless, where land use activity is intense, buffers for protecting nutrient and pollutant inputs may need to be wider than those designed to protect other riparian functions, particularly when land use activities may exacerbate existing water quality problems. Little information exists and additional research is needed before buffer widths likely to protect riparian microclimate can be determined (Spence, Lomnicky, Hughes, and Novitzki 1996).

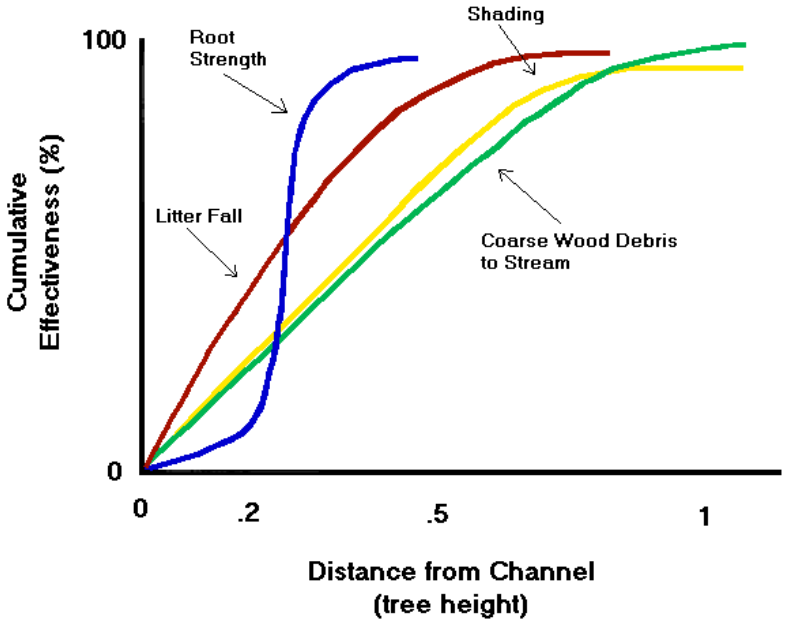


Figure 9. Curves correlating to the percent effectiveness of a function in relation to SPTH (FEMAT 1993).

Leavitt (1998) found that a buffer width of 30 meters (~98 feet) was adequate in urban environments to provide the desired functions of nutrient control, temperature moderation, and some sediment and stormwater control. However, the appropriate size of a riparian buffer is likely to vary according to the position of a stream in the landscape and the intensity of land use adjacent to the riparian area. Wider buffers may be required in urban areas with higher intensity land uses than in a forested or rural landscape (May 2000, quoted in Portland Metro 2002). Palone et al. (1997) found that in order to provide an array of riparian functions, buffers should be a minimum of 35 to 100 feet in width under most circumstances. Buffer widths toward the lower end of the range appear to provide some physical and biological components of the stream ecosystem, especially in small streams. Buffer widths at the upper end of the range are likely to provide protection for the physical, chemical, and biological characteristics of the aquatic resource.

Pizzimenti (2002) found that the appropriate role and width of riparian buffers on agricultural lands is highly variable and is both site- and function-specific, and that widths from 5 to 30 meters (16-98 feet) show improved ecological function with regards to water quality.

In experiments conducted to determine the optimum width of a grass riparian buffer adjacent to a forested riparian buffer, Parsons (1997, quoted in Osmond, Gilliam, and Evans 2002) determined sediment reduction for different grass riparian buffer widths. Analysis found that 28 feet of grass buffer retarded sediment so that there was a 86 to 90 percent reduction, whereas a narrower buffer width of 14 feet reduced sediment loss by 70 percent. Parsons found that riparian buffers in combination with forested areas appear to do the best job of reducing both sediment and phosphorus. However, dissolved phosphorus is an additional source of phosphorus, and buffers do not remove most solution phosphorus. A newly constructed buffer may adsorb entering dissolved phosphorus for a short time, but the sediments deposited in the buffer soon become a source of dissolved phosphorus, where the buffer becomes saturated, and no longer provides the filtering function. Lowrance et al. (1995, quoted in Osmond et al. 2002) found that between 2 and 12 pounds of phosphorus per acre, per year are absorbed by the aboveground woody vegetation in riparian forests.

The USDA (2000) stresses that the buffer purpose must be defined, and when applied must take into account local conditions (land use, soil composition, and climate conditions). For sedimentation problems, buffers of 20 feet are deemed adequate, while if the focus is on nitrates and pesticides, wider buffers are recommended. Buffers within the narrow range are highly dependent on the condition of the buffer, while densely vegetated buffers with the appropriate vegetative species are preferred.

The Washington Department of Fish and Wildlife's (1997) *Final Environmental Impact Statement for the Wild Salmonid Policy* developed a buffer system dependent on a stream-typing system. It requires a maximum buffer of 100 to 150 feet on each side of a stream larger than 5 feet wide, with a minimum of at least 50 feet on all other streams. The buffers may need to be expanded to accommodate

anticipated channel migration, as an additional buffer against windthrow, or to address upslope instability. Intermittent and ephemeral streams with low stream gradient and relatively flat slope may not need the full buffer width, and the buffer width may be reduced to that necessary to protect the stream from upslope sedimentation and significant changes in stream temperature.

Actual buffer width and composition should be based on site-specific conditions. For instance, the rate of upland erosion in a semi-arid climate such as Yakima County is greater than that of coastal climates, due to lesser amounts and density of vegetation. To the extent possible, buffers should be continuous along the stream channel. Plant community structural complexity (e.g., herbaceous understory and woody overstory canopy) and riparian buffer density should be similar to what would occur at the site under natural conditions. Management activities allowed within the riparian area should provide the functional characteristics of the riparian area that are necessary to protect the stream.

The Portland Bureau of Planning (2001) found that when site-specific analyses are not possible, general riparian buffer widths can be applied. The range of general riparian buffer width recommendations identified a range from 50 feet to 326 feet for the Willamette Valley. The PBP reviewed recent work by Pollock and Kennard (1998) that suggests buffers should be designed to protect all of the functional values of a stream, and should be approximately 250 feet wide, although a buffer of 100 feet is frequently noted as the minimum necessary to maintain critical fisheries-related functions. Based on the literature reviewed, the PBP concluded that a buffer of 100 to 300 feet is advisable, wherever feasible, to support fish conservation efforts along the small streams in the City of Portland. Buffers of this size also provide other benefits associated with increased aesthetics, wildlife diversity, and improved water quality.

Cederholm (1994) reviewed the scientific literature regarding recommendations of buffer widths for maintaining recruitment of LWD to streams and found most authors recommended buffers of 30 to 60 meters (98 to 197 feet) for maintaining this function.

Wenger (1999) found the buffer width required for maintenance of long-term riparian function is 30 to 100 meters (98 to 328 feet). He also found that that 30 meter (100 foot) buffers are sufficient to trap sediments under most circumstances, although buffers should be extended for steeper slopes, and that an absolute minimum width would be 9 meters (30 feet). To be most effective, buffers should extend along all streams, including intermittent and ephemeral channels. Buffer slope and the presence of wetlands are determined to be the most important and useful factors in determining buffer width.

Studies that find buffers exceeding 30 meters (98 feet) needed for stream shading have been based largely on studies in the Cascade and Coastal ranges. Unfortunately, there is little published information about the buffer widths needed to provide natural levels of shade for streams in eastside forest, rangeland, and agricultural systems. Eastside forests, particularly old-growth ponderosa pine

forests, have lower stem densities and crown closure than do westside Douglas fir systems, and they often lack the dense understory vegetation typical of many westside riparian areas. Therefore, the width of buffers needed to maintain full shading may differ. For hardwood-dominated riparian forests that once were common along streams east of the Cascades, appropriate buffer widths for shade are even less certain, in part because examples of intact riparian ecosystems are extremely rare. More research on riparian influences on shading for all ecosystems east of the Cascades is needed; however, in most instances, buffer widths designed to protect other riparian functions (e.g., LWD recruitment) are probably adequate to protect stream shading (Spence et al. 1996).

There is agreement in the scientific literature that restricted use of riparian habitat is needed to retain the functions of aquatic and riparian ecosystems. Schaefer and Brown (1992, quoted in Knutson and Naef 1997) state that width is one of the most important variables affecting riparian corridor functions. However, there is less agreement on the specific width needed to protect riparian and stream habitat (O'Connell et al. 1993, quoted in Knutson and Naef 1997). Nor is there agreement on which land use activities might be compatible with fish and wildlife in riparian habitat.

A review of the best available science regarding riparian buffer widths found a range from 10 to 984 feet. Table 2 outlines the minimum and maximum values found in the literature. See Appendix A for additional tables of buffer widths found in the literature.

Table 2
Minimum and maximum riparian buffer widths

Function	Minimum (feet)	Maximum (feet)
Large woody debris/structural complexity	90	525
Organic matter input	170	262
Stream bank stabilization	10	170
Sediment control	12	600
Nutrient and pollutant inputs control	13	860
Microclimate	141	784
Stream shading/water temp. moderation	33	525
Terrestrial wildlife habitat	25	984

7.4.4 Intensity of adjacent land use

Generally, when the density, intensity, magnitude, or potential influence of activity adjacent to aquatic areas increases, the width of the buffer required to contain the negative effects increases proportionally. The differences between developed or disturbed lands and aquatic areas are considerable; the more intensely developed or disturbed, the more significant. Similarly, the size or value of the buffer intensifies as the approaching yield of nutrients, chemicals, sediment, and runoff from adjacent land use increases. Table 3 shows how these loadings can vary by

land use. It is clearly recognized that a number of desired buffer functions, such as nutrient removal, are reduced in urban areas as impervious surface increases. Impervious surfaces increase runoff, reducing base flow to the stream and limiting the total volume of water passing through the buffer. Recommended buffer widths in urban areas are often increased to account for the threat of future encroachments and to anticipate future changes in stream morphology due to increases in stormwater runoff (Booth 2000; Horner et al. 2000; Palone and Todd 1997).

Table 3
Nutrient Loading Delivered to Edge of Stream (Palone and Todd 1997)

Land use	**Total nitrogen (lbs./acre/year)**	**Total phosphorous (lbs./acre/year)**
Forest	3.00	0.05
Pasture	9.34	0.61
Urban	11.44	0.67
Cropland	21.13	1.84

7.4.5 Fixed-width vs. variable-width buffer

Riparian buffers are applied to protect a range of functions provided by the riparian area. The size or width of the buffer depends on the function(s) to be protected and on the type of land use that occurs outside of the buffer area. There are two primary ways to define the necessary buffer width.

- The width may be set as a fixed distance, usually measured from the streambank on each side of the stream; or
- the width may be variable, depending on specific natural or human-made features adjacent to the waterway.

7.4.5.1 Fixed width

Minimum buffer widths are usually endorsed because they are simple and inexpensive to implement and administer. Because minimum buffer widths are developed by compromise or by taking into account an average of desired functions, they usually overprotect in some areas, and underprotect in others. Where compromise has resulted in very narrow buffer widths, people may have a false perception that a stream is protected when in fact serious risk may still exist.

Fixed-width buffers generally are based on a single parameter, such as a specific function, and often are developed as a compromise between protecting ecological functions and minimizing the impact on private property rights. Fixed-width buffers are reasonably easy to apply and enforce, and provide regulatory predictability. They cost less to manage because those applying the regulations do not need any specialized skills. However, the majority of documents reviewed state that a one-size-fits-all buffer is not likely to work (Portland Metro 2002; Wenger 1999).

7.4.5.2 Variable width

Variable-width approaches to buffers attempt to incorporate buffer functions with site-specific conditions. In this way, the width of the buffer depends not only on the minimum width needed for a specific function or set of functions, but also on the sensitivity and characteristics of the stream and watershed in which it is located. Variable-width buffering systems take into account site-specific conditions, and provide an increased level of protection to aquatic and riparian resources while reducing the impact on private property. Buffer expansion and contraction, as a characteristic of width design, are promoted, especially in urban settings. A range of adequate widths may also be provided.

Although variable-width approaches are likely to be more science-based, they inevitably require more extensive site investigation and evaluation and are ultimately more difficult and expensive to administer and monitor. They also offer less predictability for land use planning purposes. A hybrid of fixed- and variable-width buffers could address several of the problems of both while drawing on each method's strengths. A variable-width buffer based on existing conditions and the intensity of the adjacent land use that is generalized to the extent possible might provide the best protection for the riparian corridor while also respecting private property rights (Todd 2000, quoted in Portland Metro 2002; Wenger 1999).

7.4.6 Three-tiered riparian buffers

A number of the buffer guidance documents reviewed refer to a three-tiered riparian buffering system (Figure 10). Schueler (2000) found that according to a national survey of 36 local buffer programs, urban stream buffers range from 20 to 200 feet in width on each side of the stream, with a median of 100 feet. They found that effective stream buffers are divided into three lateral zones: streamside, middle core, and outer zone. Each zone performs a different function and has a different width, vegetative target, and management scheme, as follows:

- The streamside zone protects the physical and ecological integrity of the stream ecosystem. The vegetative target is mature riparian forest that can provide shade, leaf litter, woody debris, and erosion protection to the stream. Land use is highly restricted and is limited to stormwater channels, footpaths, and a few utility or roadway crossings.

- The middle zone extends from the outward boundary of the streamside zone, and varies in width, depending on stream order and on the extent of the 100-year floodplain, any adjacent steep slopes, and nearby protected wetland areas. Its functions are to protect key components of the stream and to provide further distance between upland development and the stream. The vegetative target for this zone is also mature forest, but some clearing may be allowed for stormwater management, access, and recreational uses. A wider range of activities and uses are allowed within this zone; for example, recreation, bike paths, and stormwater practices.

- The outer zone is the buffer's buffer, an additional 25-foot setback from the outward edge of the middle zone to the nearest permanent structure. In most instances, it is a residential backyard. The vegetative target for the outer zone is usually turf or lawn, although the property owner is encouraged to plant trees and shrubs and thus increase the total width of the buffer. Very few uses are restricted in this zone. Indeed, gardening, compost piles, yard wastes, and other common residential activities are promoted within the zone. The only major restrictions are no septic systems and no new permanent structures.

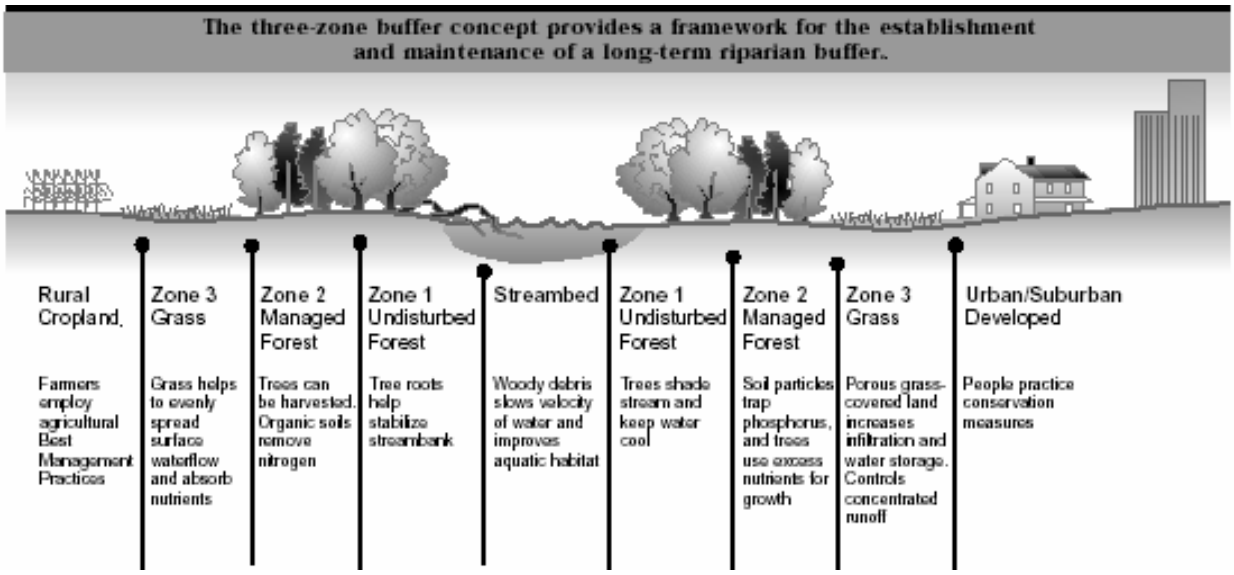


Figure 10. A three-tiered riparian buffering system (Tjaden et al. 1997).

Palone and Todd (1997) outlined the specific functions preformed by a three-tiered riparian zone (Figure 11).

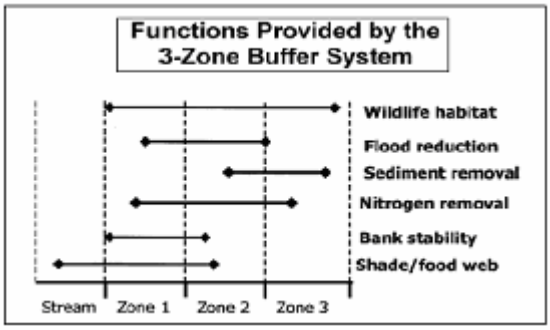


Figure 11. Specific functions preformed by a three-tiered riparian zone (Palone and Todd 1997).

7.4.7 Riparian habitat areas

Section 7.4.7 presents a summary of Knutson and Naef (1997).

Riparian habitat areas (RHA) are defined as

> the area adjacent to aquatic systems with flowing water (e.g., rivers, perennial or intermittent streams, seeps, springs) that contains elements of both aquatic and terrestrial ecosystems, which mutually influence each other, and that exhibit the full range of habitat functions necessary to support riparian-associated fish and wildlife.

Riparian habitat areas differ from riparian buffers. Riparian buffers usually are applied to protect streams from the effects of adjacent, upland activities. Riparian habitat includes the area from the ordinary high water line to that portion of the terrestrial landscape that directly influences the aquatic ecosystem, including habitat for riparian-associated wildlife. The RHA often includes the extent of the floodplain because that area appreciably influences and is influenced by the stream system during flood events. The RHA encompasses the extent of riparian vegetation in addition to the zone of influence.

Because riparian habitat area management recommendations address fish and wildlife resources statewide, they are generalized. Management recommendations are not intended as site-specific prescriptions but rather as guidelines for planning. Because natural systems are inherently complex and because human activities have added to that complexity, management recommendations may have to be modified for on-the-ground implementation.

In developed or urban landscapes, where direct connections between natural habitats are often broken, riparian areas provide invaluable habitat connectors, wildlife reserves, and temporary refuges. The significance of riparian areas as travel corridors and routes for dispersion is increased in developed or fragmented landscapes because substitute overland travel routes are often removed, irregular, or life endangering. Because riparian habitat more strongly influences the structure and function of small streams than large streams, small streams are more prone to pronounced impacts from the removal of riparian vegetation than are large streams and rivers.

According to Knutson and Naef (1997), a variety of studies demonstrate that the retention and protection of riparian habitat is successful in:

- supporting greater species diversity;
- retaining macroinvertebrate populations;
- retaining small mammal populations;
- moderating stream temperatures;
- improving infiltration and minimizing surface flows, thereby assisting in stream flow regulation;
- reducing the amount of sediments and pollutants that reach water supplies;

- recruiting large downed logs into the stream and riparian habitat;
- providing breeding, feeding, and movement habitat for fish and wildlife species;
- providing critical refuge and continuous corridors in developed landscapes,
- providing large-diameter snags for fish and wildlife use; and
- linking remaining wildlife habitat that would otherwise be fragmented.

Recommended RHA widths are derived from a review of the scientific literature, where widths generally include a zone of riparian vegetation plus a transition zone dominated by upland vegetation. Even though it may not be obvious that upland vegetation is part of riparian habitat, scientific studies clearly describe the critical function of transitional areas in maintaining riparian and aquatic systems. In addition, channel migration is a natural process in alluvial streams and rivers. For these streams and rivers, RHA width measurements should begin at the edge of the channel migration zone.

The scientific literature supports the maintenance of riparian habitat areas as restricted-use zones. Examples of activities that may affect riparian habitat features include tree cutting, road building, agriculture, grazing, clearing, earthmoving, mining, filling, burning, or construction of buildings or other facilities. Beyond the standard recommended RHAs, it must be recognized that larger areas are needed by some wildlife species, including the great blue heron, mule deer, elk, marten, osprey, and bald eagle.

Important characteristics should be retained or restored in all riparian areas in order to provide suitable habitat for fish and wildlife. Mass wasting of unstable slopes is a major factor in reducing water and instream habitat quality. An extra width of protected riparian habitat is recommended, to assist in reducing mass wasting and to provide additional area for trapping and filtering sediments produced by unstable slopes. Indications from scientific studies suggest that modification of RHAs results in negative effects on local resident fish and wildlife. These effects are (Knutson and Naef 1997):

- decreased amounts of large woody debris,
- loss of neotropical migrant songbirds,
- substantial reduction in breeding birds,
- loss of accipiter hawks,
- loss of snags and resultant reduced use by cavity-nesting birds and other snag-dependent species, and
- reduced use by elk for hiding and thermal cover.

Significant reductions to the recommended standard widths for retaining riparian habitat functions may result in short- and long-term loss of both riparian and instream habitat quality for fish and wildlife. The loss of habitat quality will depend on the degree to which recommended RHAs are compromised within a watershed and on a specific site. In a cumulative fashion, riparian habitat functions may diminish at a site and throughout the watershed as recommended standard widths are reduced. The point at which the loss of function results in significant problems is variable and unknown.

7.5 Yakima County Habitat Protection and Identification

For more information on the best available science regarding terrestrial wildlife habitat and identification see Chapter 4 of this document.

7.6 Nonregulatory Options

Yakima County has initiated a nonregulatory program to address the protection and restoration of priority natural resources and critical areas. The nonregulatory program will utilize and revise tools/procedures for fee-simple acquisition, conservation easements, property tax reduction, and donation of critical properties. In addition, the program will work to establish ownership, operations, maintenance guidelines, and receiving entities, and to secure and maintain links between projects, landowners, receiving entities, and funding sources to leverage outside dollars.

The nonregulatory program will:

- Offer property owners options and choices to complement, minimize, or reduce reliance on regulatory measures (i.e., GMA Critical Areas, SEPA, and SMA shorelines, zoning) to meet federal and state mandates.
- Utilize nonregulatory tools to protect and enhance priority Critical Areas (geologic hazards, wetlands, streams, shorelines, and flood-prone areas) and the biologic attributes (high value fish and wildlife habitats) dependent on the structure and function of those landscapes. A GIS database of physical and biological data will be used to identify and evaluate locations to pursue or implement nonregulatory protection measures.
- Collaborate with entities and agencies (e.g., BOR, the Nature Conservancy, the Yakama Nation, and any lead agency established under Salmon Recovery Act) in acquiring fee-simple and conservation easements, and assist in the integration of property monitoring and management.
- Foster private property owner stewardship by promoting environmental awareness, good land stewardship, public understanding, and the support and use of nonregulatory programs and tools.
- Partner with public/private agency teams to target funding sources to meet the goals of citizens, agencies, and County plans, policies, programs, and proprietary responsibilities.
- Develop and implement stewardship objectives, enhance forest ecosystems, restore and improve land health and water quality. Develop monitoring and benchmarks to measure success.
- Accomplish watershed maintenance and restoration, improvement of wildlife and fish habitat, and control of noxious and exotic weeds.
- Improve cooperative relationships between people and agencies that use and manage these lands.

8.0 STREAM CORRIDOR INVENTORY METHODOLOGY

8.1 Critical Areas Pilot Study

In July 2000, the Yakima County Board of Commissioners recognized the importance of Critical Areas and authorized revision of the Critical Areas Atlas to improve the quality of information presented. To initiate this effort, a pilot study was developed to test criteria consistent with best available science, to address a pattern of deficiencies present in the current atlas. Application of BAS criteria was to test those methods on a large scale and to determine their effectiveness when applied at a countywide reconnaissance level. The pilot study employed a peer review group consisting of local, state, federal, and tribal resource management personnel.

The Lower Naches Pilot Area was a major focus of the program. Initial peer discussions indicated that creating a truly accurate atlas might be impossible due to landscape complexity, natural hydrologic processes, and scale. In an attempt to capture physical features and processes in the atlas, a series of overlay zones were developed. Some of the zones have physical attributes that are identifiable in the field (e.g., a bankfull channel). Some overlays are intended as informational layers that correspond to natural hydrologic processes (e.g., hydric/aquic soils, channel migration zones, frequently flooded areas, and the holocene floodplain). The informational overlays are also intended to supplement current data gaps. The overlay zones have two functions: to act as radiating zones of environmental sensitivity, and to act as a screen to filter potential impacts that otherwise would have been missed.

For a more detailed discussion and to view draft maps, see the *Yakima County Critical Areas Atlas Pilot Study* (cit).

8.1.1 Bankfull channel

The bankfull channel is the point at which the river is at the top of its channel, where it is about to flood but has not begun to leave the channel. This occurs approximately every 1.5 years (Dunne and Leopold 1978). It was the intent of BFC delineation to depict the greatest lateral extent of the river channel, including areas of upland within the bankfull channel.

The BFC layer can be used to replace the current data for larger shoreline streams in the atlas. This will encompass all channels, allowing for more accurate estimations of setbacks, reducing confusion for development proponents, and speeding permit processing.

8.1.2 Channel migration zone (CMZ)

The CMZ delineation methodology was developed using a modified version of the Washington Department of Natural Resources Forest Practices Board (2000)

manual, *Standard Method for Measuring Physical Parameters of Streams and Channel Migration Zones.*

CMZ delineation in Yakima County can utilize 1927, 1947, 1968, 1992, 1996, and 1998 aerial photographs, 2000 color infrared, and 2002 digital aerial photography. Channel location is mapped for each data year; data from each year are measured for channel wavelength amplitude. Channel amplitudes are overlaid and analyzed in concert with topography. Most human-made revetments are consciously ignored. The WDNR (2000) criteria specifies that a CMZ can extend behind dikes or levees unless it is a continuous structure that limits lateral channel movement, would contain a 100-year flood, or supports a public right-of-way that receives regular maintenance. Dikes, levees, or roadbeds that are perforated by pipes, culverts, or other drainage structures and are below the flood-prone level are not considered permanent. Many dikes within Yakima County are discontinuous and perforated. Determining actual flood potential and heights is beyond the scope of a reconnaissance-level inventory.

The WDNR (2000) CMZ criteria suggest a data period of one hundred years. The earliest digital data layer available within Yakima County is the 1927 aerial coverage supplied by the U.S. Bureau of Reclamation. One potential problem with the mapping criteria is the level of accuracy inherent in the base data. Not all of the aerial photos are orthorectified, and they therefore place a variable amount of error in the final data. Through the peer review process, it was determined that a reconnaissance-level inventory utilizing available data was acceptable and that future refinements may be developed through other mechanisms.

The Yakima County Public Works Flood Control Zone District recently contracted for a CMZ delineation of the Lower Naches, from the Twin Bridges to the confluence with the Tieton River (Tetra Tech/KCM 2003). A draft report was submitted in October 2003, with a final report to be finalized sometime in 2004. The delineation by Tetra Tech/KCM was loosely based on the WDOE framework developed by Rapp and Abbe (2003), discussed below.

The Washington Department of Ecology has recently produced a guidance framework for mapping of a CMZ. The remainder of section 8.1.2 is summarized from Rapp and Abbe (2003).

Channel migration and avulsion are often described and mapped as a zone of potential hazard. Pollack and Kennard (1999, quoted in Bolton and Shellberg 2001) define a channel migration zone as

> the area that the stream and/or its side channels could potentially occupy under existing climatic conditions, and frequently approximates the 100-year floodplain, though it also includes lower terraces and hillslopes adjacent to the floodplain where the stream is likely to meander. (p. 5)

The Washington Department of Natural Resources (2001) forest practices rules define a CMZ as

> the area where the active channel of a stream is prone to move and this results in a potential near-term loss of riparian function and associated habitat adjacent to the stream, except as modified by a permanent levee or dike. For this purpose, near-term means the time scale required to grow a mature forest. (WAC 222-16-010)

Rapp and Abbe (2003) define a CMZ as the geographic area that a stream has occupied historically and where a stream channel is susceptible to erode and/or occupy within a given timeframe. While the timeframe used in CMZ delineation is subjective to the desired outcome, it should account for long-term modification of the environment, given that property claimed by erosion represents a permanent loss, and development within a CMZ represents a permanent loss of habitat.

Delineating a CMZ can help decrease risks to life and property by guiding development away from areas in the stream corridor that are at risk of channel erosion. Knowing where channel migration may occur provides land use information so that the stream corridor is not permanently degraded or disconnected from the river by development, in addition to reducing degradation and loss of critical aquatic and riparian habitats. Delineation of a CMZ relies on an assessment of stream corridor processes that occur within space and time. Stream channels will move horizontally (lateral migration, avulsion, channel widening, canal narrowing) and vertically (incision and aggradation) depending on site-specific circumstances and watershed conditions. Patterns and rates of channel movement can be estimated by using a combination of historical and field studies to determine future trends in channel migration (Rapp and Abbe 2003).

Rapp and Abbe (2003) developed a framework for delineating CMZ in Washington State that utilizes the sum of several different components of the stream corridor (Figure 12). Note, not all components will apply in every CMZ delineation.

$$CMZ = HMZ + AHZ + EHZ - DMA$$
$$EHA = ES + GS$$

Figure 12. Framework for delineating CMZ.
HMZ—historical migration zone
AHZ—avulsion hazard zone
DMA—disconnected migration area
EHA—erosion hazard area. The EHA has two components
ES—erosion setback
GS—geotechnical setback

The historical migration zone (HMZ) is the area the stream channel has occupied over the historical record. The amount of time that comprises the historical record depends upon the availability of data sources such as aerial photos, maps, or other historical documents. The HMZ is delineated by the outermost extent of channel

locations plotted over the historical record. There may be features in the stream corridor that appear to have been the active channel within the recent past, but for which evidence is lacking. These areas are typically excluded from the HMZ due to lack of evidence. This does not mean these features are outside of the CMZ, but only that they are not part of the HMZ. An important component of the HMZ is estimating the floodplain turnover rate, which defines the amount of time it takes for the stream channel to occupy the entire valley bottom. In some unregulated systems, the stream channel may occupy the entire valley bottom over decades, while some stream channels may take centuries.

The avulsion hazard zone (AHZ) includes areas in the stream corridor that are at risk of channel avulsion outside of the HMZ—areas such as abandoned side channels, floodplain swales, and oxbow lakes. The basis for delineating avulsion hazard zones is to predict potential changes in channel location. Delineation of the AHZ relies on three steps:

- estimating the vertical variability of the channel bed,
- gauging the general characteristics of riparian vegetation, and
- delineating stream corridor features at risk of channel avulsion.

Determining the vertical variability of the channel bed acknowledges whether the channel is aggrading or incising. Scientific research indicates that 2 meters of variation is common in stream corridors with riparian forests. Riparian area composition has a noted effect on channel form and processes, including erosion control and bank stabilization. Analysis of the current riparian condition is necessary to determine avulsion potential. Delineating stream corridor features allows analysis utilizing channel variability and vegetation composition, to determine avulsion hazard potential.

The erosion hazard area (EHA) is the area not included in the HMZ or the AHZ, which is at risk of bank erosion from stream flow or mass wasting. An eroding vertical bank of unconsolidated material is an active surface and does not mark the edge of the CMZ. If the top of the bank is low enough, erosion may be limited to that which occurs solely from stream flow. If the top of the bank exceeds the elevation of flood inundation (alluvial terraces), mass-wasting processes can accelerate bank erosion. Historical and field analyses are utilized to delineate the EHA, based on an estimated projected rate of erosion over the design life of the CMZ.

Because channels can frequently change location, the erosion setback (ES) is not determined solely by the current channel location. Areas where the river may not necessarily have migrated during the historical record still can be included in the ES because of the potential for the river to migrate there in the future. The extent of the ES is determined by using estimates of the rate of erosion that will occur over the design life of the CMZ. In the instances where bank erosion occurs as a result of mass wasting initiated by fluvial processes, the EHA includes two components: the erosion setback and the geotechnical setback (GS). The GS is the area defined by channel and terrace banks that are at risk of mass wasting due to erosion of the

toe of a slope. If the channel migrates away from the toe of an alluvial terrace bank, a flatter slope angle will develop as mass wasting establishes a more stable configuration, thereby causing even further retreat of the bank top.

The disconnected migration area (DMA) is the portion of the CMZ where human-made structures physically eliminate channel migration. It is necessary to determine which structures constitute a legitimate barrier to channel migration: structures that are semipermanent (i.e., they will endure beyond the design life of the CMZ), or structures that have public commitments to keep them intact (e.g., structures such as revetments and levees that protect populated areas). Human-made structures with no public commitment for maintenance, and structures made of erodible materials are not effective barriers to channel migration and are therefore not used to delineate a DMA.

The risk of channel migration and avulsion is not equal within the entire mapped CMZ. Depending on the needs of the CMZ study, it may be necessary to approximate the relative risk of erosion hazards. Determinations of erosion hazard can be somewhat subjective, depending on the criteria used to define *severe*, *high*, *moderate*, and *low-risk*. CMZ analysis relies on the following information for assessing relative risk:

- Rates of channel migration, trends in channel movement, and floodplain turnover rates;
- avulsion hazards;
- erosion hazards;
- locations of armored banks.

8.1.3 Frequently flooded areas

Floodplain data within Yakima County is currently limited to Federal Emergency Management Agency flood insurance rate maps, dated June 21, 1984. During the flood of 1996, the FIRMs did not accurately depict the extent of flooding and substantial channel migration has rendered most of the data obsolete. The Yakima County GIS department acquired February 1996 orthophoto coverage that clearly depicts the extent of flooding. Photo coverage extends from Selah Gap to Union Gap on the Yakima River, and from the Naches River mouth to the confluence with the Tieton River. The area within the pilot area has been delineated and is intended as an informational layer.

Analysis of soil surveys for Yakima County and the Yakama Nation has yielded maps that depict the extent of flood-prone soils, which is informational in areas outside of the FIRM.

The Yakima County Flood Control Zone District is currently in the process of developing updated digital flood insurance rate maps (DFIRM) for the Naches River and its floodplain system. The study will produce DFIRMs for the Naches River from its confluence with the Tieton River to its confluence with the Yakima River. The hydrology and hydraulics will be updated using remotely-sensed data to produce

digital elevation models (DEM)—in conjunction with GPS data, underwater surveyed cross section data, and other necessary data—to produce a detailed restudy of the Naches River and its floodplain system. The extent of the flood and floodway boundaries will be determined for 100- and 500-year events; the base map for these floods will be the 2002 orthophoto.

The Naches River mapping project also will produce data on other flood events (1-, 1.5-, 2-, 5-, 10-, 25-, and 50-year events). These flood event boundaries can be used in the design of capital improvement projects and a flood warning system.

8.1.4 Hydric/aquic soils overlay

The hydric/aquic soils overlay was developed through a local wetland inventory (LWI) process, to serve as an informational layer for the identification of potential wetlands. The layer also corresponds to the alluvial river valleys and to areas of potential groundwater/surface water interaction. Hydric soils and soils with an aquic moisture regime were extracted from the database using information obtained from the USDA Natural Resource Conservation Service (NRCS) and through peer review.

8.1.5 Holocene floodplain

The holocene floodplain, also known as the geologic floodplain, is an area the river has constructed within the last 10,000 years. The best available science indicates that this is an area in which the surficial or shallow groundwater aquifer is influenced by and influences the stream in which it was formed. The holocene floodplain overlay is intended as an informational layer and represents the outermost zone related to stream processes and environmental sensitivity.

Through use and refinement, the concept of using the BFC, CMZ, frequently flooded areas, and hydric/aquic soils overlays to portray radiating zones of environmental sensitivity has emerged as a potentially useful tool in providing better customer service and Critical Areas protection by improving the accuracy of the atlas.

8.1.6 Stream accuracy conditions

Atlas accuracy is scale-dependent. Data compiled at a small scale (1:100,000) cannot be accurately displayed at the large scale (1:1,000) necessary for planning purposes. Missing and/or misclassified data does not provide due resource protection. To properly administrate the CAO, Yakima County planning and permitting staff need an accurate representation of the physical environment. The Yakima County GIS department is currently in the process of creating updated and geographically accurate stream coverage.

8.1.7 Wetland accuracy conditions

The current Critical Areas Ordinance wetland rating system was calibrated to emphasize the nature of wetlands found in Yakima County. Wetlands in the current atlas were identified and designated based on USFWS National Wetlands Inventory

(NWI) data. NWI data is insufficient for identification of all wetlands, due to scale and date. NWI data for Yakima County is interpreted from 1981 color infrared (CIR) orthophotos with a photoscale of 1:58,000, compiled at a scale of 1:24,000, projected onto a 1958 base. NWI maps were seldom, if ever, field-checked for accuracy.

Wetlands are dynamic natural features, forming and deforming with climate and landscape processes. Three basic wetland systems existing within the county were identified for the original atlas. These are, in order of frequency, riverine, palustrine, and lacustrine.

Data development within the pilot areas compared digital NWI, aquic/hydric soil overlay, and aerial photo interpretation to identify areas of potential wetlands (PW). Potential wetlands were digitized on 1998 digital orthophotos at an approximate scale of 1:2,000. Field verification was completed utilizing GPS.

8.2 Shoreline Inventory and Characterization

The Central Washington University Department of Geography and Land Studies Geo-ecology Research Group currently is in the process of developing and completing a methodology for a shoreline inventory and characterization for Yakima County. The goal of this project is to assist Yakima County in developing a shoreline characterization and restoration plan as required for the county's Shoreline Master Program and Comprehensive Plan update.

The project will employ methods developed through integration of DOE's landscape-scale tool, which addresses water quality problems and potential sites for wetland restoration, in addition to the Sensitive Shoreline Assessment protocol developed by the Geo-ecology Research Group. The project will include fieldwork to validate data and to address data gaps.

The final deliverable will be an implementable shoreline characterization and restoration plan that integrates previous research findings, assessment maps, and fieldwork. It will include recommended environmental designations and specifically defined opportunity areas for protecting and restoring ecological function. It will reveal opportunities for coordinating with neighboring jurisdictions, and will provide a baseline for adaptive management and cumulative impact assessment.

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DRAFT
CHAPTER 3: A REVIEW OF THE BEST AVAILABLE SCIENCE REGARDING WETLANDS

1.0 OVERVIEW

Wetlands are areas "inundated or saturated by surface water or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. Wetlands do not include those artificial wetlands intentionally created from non-wetland sites, including, but not limited to, irrigation and drainage ditches, grass-lined swales, canals, detention facilities, wastewater treatment facilities, farm ponds, and landscape amenities, or those wetlands created after July 1, 1990, that were unintentionally created as a result of the construction of a road, street, or highway. Wetlands may include those artificial wetlands intentionally created from non-wetland areas created to mitigate conversion of wetlands" (RCW 36.70A.03020).

Wetlands are areas where the frequent and prolonged presence of water at or near the soil surface drives the natural system, meaning the kind of soils that form, the plants that grow, and the fish and/or wildlife communities that use the habitat. Swamps, marshes, and bogs are well-recognized types of wetlands. However, many specific wetland types have drier or more variable water systems than those familiar to the general public. Some examples of these are vernal pools (pools that form in the spring rains but are dry at other times of the year), playas (areas at the bottom of undrained desert basins that are sometimes covered with water), and prairie potholes.

When the upper part of the soil is saturated with water at growing season temperatures, soil organisms consume the oxygen in the soil and cause conditions unsuitable for most plants. Such conditions also cause the development of soil characteristics (such as color and texture) belonging to so-called hydric soils. The plants that can grow in such conditions, such as marsh grasses, are called hydrophytes. Together, hydric soils and hydrophytes give clues that a wetland area is present.

The presence of water by ponding, flooding, or soil saturation is not always a good indicator of wetlands. Except for wetlands flooded by ocean tides, and regional application of irrigation waters that augment groundwater table levels, the amount of water present in wetlands fluctuates as a result of rainfall patterns, snow melt, dry seasons, and longer droughts. Wetlands play a critical role in water resource and wildlife protection. The benefits of wetlands range from the aesthetic to functional protection of public health.

2.0 YAKIMA BASIN WETLANDS

The following section is a summary from the USDIBOR (2002) document, *Interim Comprehensive Basin Operating Plan for the Yakima Project, Washington.*

Wetlands in Yakima County typically are located along the major streams and rivers. Additional wetlands are found along smaller tributaries, at seeps and springs, in higher-elevation wet meadows, and along the shorelines of natural lakes. Many of these wetlands have been lost or degraded. As a trend, the State of Washington has seen about a 30 percent decline in wetlands (about 940,000 acres remain from an original area of about 1,350,000 acres). The loss of inland wetlands in Washington has been estimated at 25 percent (FWS 1990). Losses have been attributed to

- agriculture conversion (i.e., drainage and leveling for crop production);
- floodplain gravel mining;
- filling for solid waste disposal;
- road construction;
- commercial, residential, and urban development;
- construction of dikes, levees, and dams for flood control, water supply, and irrigation;
- discharges of materials (e.g., pesticides, herbicides, nutrient loading from domestic sewage and agricultural runoff, and sediments from agriculture and other land development);
- hydrologic alteration by canals, drains, spoil banks, roads, and other structures; and
- groundwater withdrawal.

Of the approximately 43,695 acres of wetlands in the Yakima Basin, about 19,000 are palustrine herbaceous (emergent marsh or aquatic bed), and 19,000 acres are palustrine woody (shrubs and trees). These wetlands include wet meadows, seeps, small shallow ponds and lakes, marshes, and riparian wetlands along streams. Aside from natural wetlands, many wetlands have formed and been maintained by artificial water sources such as reservoirs, sewage lagoons, stock ponds, irrigation canals, and irrigated cropland runoff. Other wetland areas include lakes and streams (about 29,000 acres) and marshy unvegetated areas (about 4,000 acres). Total wetland areas equal about 2 percent of the basin area.

In the semi-arid lowlands, wetlands are critical to many species of wildlife because they provide good vegetative growth for food and cover, allow invertebrate production, and provide water. Recognition of the value of wetlands has historically focused on waterfowl populations, and tens of thousands of waterfowl can be found in the lower Yakima River Basin in the winter and during migration. Oliver (1983) estimated that up to 300,000 ducks wintered on the Yakama Indian Reservation in the 1960s. Many wood ducks in eastern Washington are bred and raised along the Yakima and Naches Rivers. Waterfowl populations within just the Wapato Irrigation Project (WIP) account for about 20 percent of the population in eastern Washington

(pers. comm., Yakama Nation waterfowl biologist 1996). Also, as many as 40,000 Canada geese use areas flooded by Toppenish and Simcoe Creeks during the spring (BPA et al. 1994). Historically, sandhill cranes and swans nested in the basin and could conceivably return if wetland restoration and enhancement efforts were to continue (Parker 1989, quoted in FWS 1996). Many other birds, mammals, amphibians, and reptiles also depend on riparian areas.

As in other Yakima River Basin areas, most emergent wetland habitat in the Satus and Toppenish Creek areas has been removed through draining and land leveling, much the same as the wetlands in the Kittitas Valley, the Gap-to-Gap reach, and the Wenas, Ahtanum, and other once-lush riverine wetland areas. Along most of these stream reaches, remaining areas are heavily grazed during spring and summer months, further decreasing their potential as wildlife habitat. Basic protection and enhancement activities have excellent potential to increase the quality of furbearer, songbird nesting, and waterfowl brood-rearing habitats (BPA et al. 1994, quoted in USDIBOR 2002). Toppenish and Satus Creeks, with their low-gradient, braided channels, and abundant sloughs and wetlands, provide excellent wintering habitats for wildlife. Spring floods immerse large areas of pastureland next to the creeks. These flooded areas are heavily used by migratory waterfowl, annually attracting 20,000 to 40,000 Taverner's Canada geese en route to nesting grounds on the North Slope of Alaska. Streambanks and nearby wetlands provide wintering habitats for upland game bird and waterfowl use. Refuges along Toppenish Creek provide important sanctuaries, especially for migratory and wintering waterfowl.

3.0 WETLAND IMPACTS IN THE YAKIMA BASIN

The following section is a summary from Fast et al.'s (2001) Draft *Yakima Subbasin Summary.*

While some quality wetland habitats remain within the Yakima Subbasin, many have been negatively impacted by agriculture. Conversion of native habitats to irrigated agriculture has resulted in the draining of many more wetlands than it has created in the Yakima Subbasin. Irrigated agriculture and general development have altered the hydrologic cycle and the associated wetland and riparian habitat. Construction of agricultural drains has dewatered natural floodplain wetlands. Interruption of flood cycles by impoundment, along with structural exclusion of river from floodplain, has reduced riverine wetland habitats, which were the predominant predevelopment wetlands in the Yakima Valley. Loss of floodplain inundation has altered habitats by removing the ability of native vegetation (e.g., cottonwoods) to reproduce and survive, and by reducing nutrient cycling and productivity of aquatic invertebrates and other plant and animal species that form important components of the food web.

Irrigation-related changes in sediment dynamics have affected sediment delivery to wetlands, side channels, and main channels, in turn affecting the amount and type of submersed aquatic vegetation. Many wildlife species are dependent on healthy

native stands of aquatic vegetation. Delivery of irrigation water has created upland wetlands, both within the delivery systems (by water leaking through unlined earthen canals) and in tailwater wetlands. These types of wetlands, however, are disappearing as a result of implementation of irrigation water conservation practices and improvements in water delivery systems. Wetlands will be further critically reduced by these water conservation measures. In addition, the consequences of poor land use in adjacent habitats can negatively impact the quality of open water by adding numerous chemicals such as pesticides, herbicides, and fertilizers. These can impact wildlife directly through poisoning or indirectly through reduction and/or alteration of the food base.

4.0 WASHINGTON STATE WETLAND SYNTHESIS REPORT

The following sections are a summary from Sheldon, et al. (2003). *Freshwater Wetlands in Washington State Volume 1: A Synthesis of the Science.* For use in updating Yakima County's Critical Areas Ordinance and Shoreline Master program, Chapters 2 (wetland functions) and 5 (review of management tools) are more thoroughly reviewed. A more thorough review of these chapters is necessary to clarify wetland functions specific to eastern Washington and to assess current management tools for Yakima County. The summary and conclusions for chapters 3, 4, 6, and 7 are also included.

To review the original document in its entirety, or to view the complete reference list, see http://www.ecy.wa.gov/programs/sea/bas_wetlands/vol1-download.html.

The Washington State Department of Ecology, the Washington State Department of Fish and Wildlife, and Sheldon and Associates Inc. have collectively produced a draft wetland science synthesis. The U.S. Environmental Protection Agency also funded and assisted in its production. This project is scheduled to produce a two-volume document. The first volume, reviewed here, contains a summary and synthesis of the recent literature relevant to the science and management of freshwater wetlands. The second volume, not yet completed, will translate the scientific findings into options and recommendations for policies and regulations that can be used to protect and manage wetlands.

Per the Growth Management Act (RCW 36.70A), every county and city in Washington must identify and inventory and protect Critical Areas (including wetlands) within their boundaries. In 1995, an amendment to the GMA (RCW 36.70A.172[1]) required that all city and county governments rely on best available science (BAS) when developing their critical areas policies and regulations. The Volume 1 wetland synthesis meets the definition and characteristics required for a synthesis. Findings from scientific journal articles, government publications, technical books, and other sources that meet the definition and characteristics of BAS in WAC 365-195-900 were used and referenced in the synthesis. Conference proceedings, personal communications, and other "gray" literature were occasionally used, and in some cases had not been peer reviewed.

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

5.0 WETLANDS IN WASHINGTON AND HOW THEY FUNCTION (from Sheldon et al. 2003, Chapter 2)

5.1 Introduction and Background on Wetland Functions

During the 1990s Brinson (1993, quoted in Sheldon et al. 2003) and the National Academy of Sciences (National Research Council 1995, quoted in Sheldon et al. 2003) described and defined three factors that can be considered primary controls of functions within a wetland:

- the geomorphic or topographic setting of the wetland,
- the direct source of water to the wetland, and
- the hydrodynamics, or the direction of flow and strength of water movement within the wetland.

5.1.1 How wetland functions are defined

Functions are the things that wetlands "do" and they occur at many scales, from the microscopic (e.g., bacterial decomposition of organic matter) to the continental (e.g., providing refuge and feeding for migrating waterfowl along the continental flyways).

Most wetland functions are generally grouped in terms of three broad categories, summarized as follows (Adamus et al. 1991, Brinson et al. 1995, Hruby et al. 1999, USACOE 2000, all quoted in Sheldon et al. 2003):

- Biogeochemical functions, which are related to trapping and transforming chemicals, and which include functions that improve water quality in the watershed such as:
  - nutrient retention and transformation,
  - sediment retention, and
  - metals and toxics retention and transformation.

- Hydrologic functions, which are related to maintaining the water regime in a watershed, such as:
  - flood flow attenuation,
  - decreasing erosion, and
  - groundwater recharge.

- Food web and habitat functions, which includes habitat for:
  - invertebrates,
  - amphibians,
  - anadromous fish,
  - resident fish,
  - birds, and
  - mammals.

5.1.2 Controls of functions at the scale of the contributing basin to the wetland

The hydrogeologic setting of a wetland includes the climate and geology of the contributing basins, which controls how water, sediment, and nutrients move through the wetland (Bedford 1999; LaBaugh et al. 1987; Winter 1983, 1986, 1988, 1989, 1992; Winter and Woo 1990, all quoted in Sheldon et al. 2003).

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. It also determines how sediments and chemicals (e.g., salts and nutrients) are eroded from bedrock and transported throughout the system.

This process-structure-function model assumes that the biological, physical, and chemical characteristics (the structure and functions) of wetlands are determined by the interaction of many processes operating at the larger scale of the landscape. According to Beechee and Bolton (1999), Gersib (2001), and Stanley and Grigsby (2003) (all quoted in Sheldon et al. 2003), these processes include movement of:

- water (both surface and subsurface),
- sediment,
- nutrients and other chemicals (e.g., salts or toxic contaminants),
- large woody debris, and
- energy (in the form of sunlight).

The interactions of these processes with climate and geomorphology determine the structure within wetlands (e.g., substrate and plant species). The wetland structure, in turn, is one factor that influences the type and performance of wetland functions.

5.1.3 Controls of functions at the site of the wetland

The large-scale environmental factors that control functions in a wetland ultimately affect the environmental factors within the wetland itself (at the site scale) (Table 4 and Figure 13). Three factors at the site scale can be considered as primary controls of wetland functions (Bedford 1999 and Brinson 1993a, quoted in Sheldon et al. 2003).

- 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 has an effect on, for example, 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 the strength of water movement).

  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.

Table 4
Environmental factors 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 Control Occurs
Physical structure of wetlands (soils, vegetation, rocks, etc.)	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
Connectivity to other habitats or ecosystems	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 (1993), Brinson et al. (1995), Bedford (1999), Beechee and Bolton (1999), Gersib (2001), Adamus et al. (2001), Stanley and Grigsby (2003).	

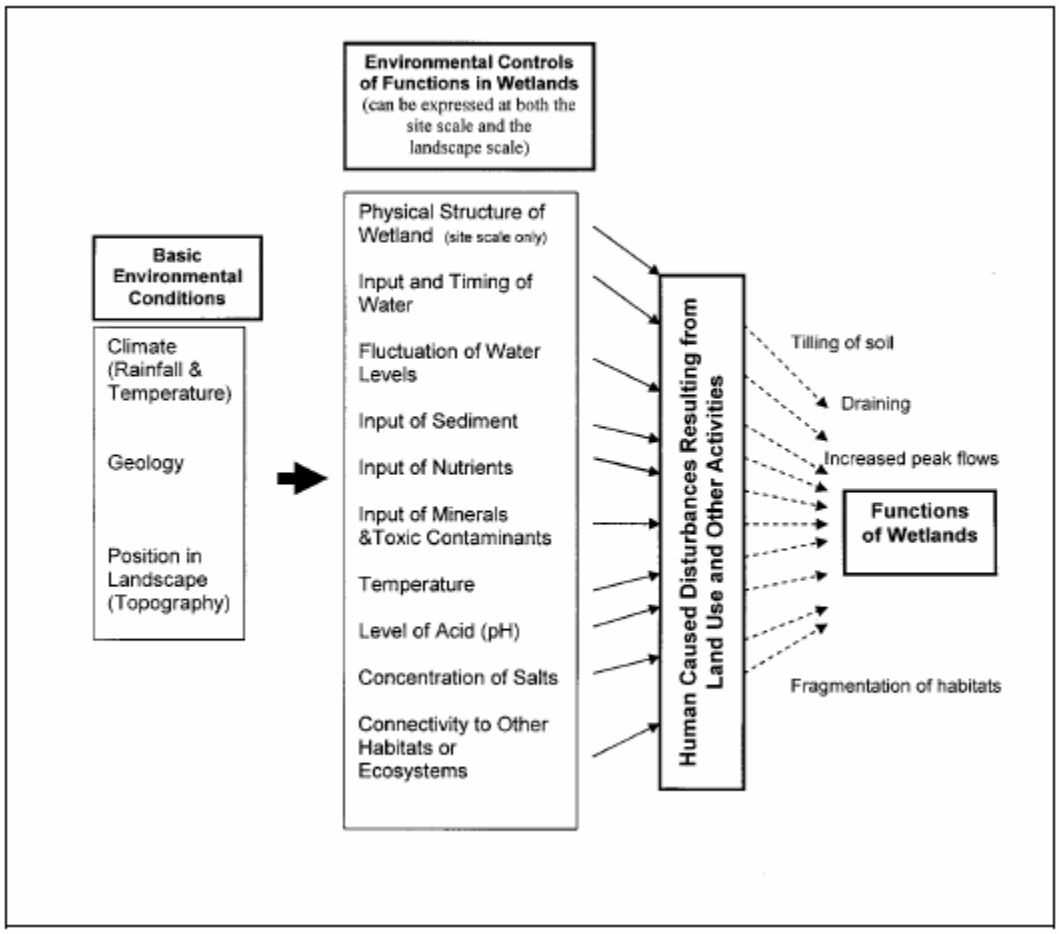

Figure 13. Diagram summarizing the environmental factors that control functions of wetlands and how they interact with human disturbances.

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.

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

5.2.1 Commonly used classification systems in Washington

The first commonly used wetland classification system was developed in 1979 by the U.S. Fish and Wildlife Service (Cowardin et al. 1979). The Cowardin system is

hierarchical and includes several layers of detail for wetland classification, 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 USFWS National Wetland Inventory (NWI). The wetlands in the state that can be identified from aerial photographs have been mapped using this classification system. 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 1993a, quoted in Sheldon et al. 2003), 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 wetland function assessment methods (Hruby et al. 1999). The HGM classification is based on:

- the position of the wetland in the landscape (the geomorphic setting),
- the water source for the wetland,
- the flow and fluctuation of the water once in the wetland.

Classifying wetlands based on how they function narrows the focus of attention to a specific type of wetland, the functions that wetlands within that type are most likely to perform, and the landscape and ecosystem factors that are most likely to control how wetlands in 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 therefore also similar.

The highest category in the HGM classification (called class) is defined nationally (Table 5) and is based on the geomorphic setting of the wetland (Brinson 1993a and Smith et al. 1995, quoted in Sheldon et al. 2003). 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, quoted in Sheldon et al. 2003).

Table 5
Characteristics of wetland classes in the hydrogeomorphic classification (from Brinson 1993)

Hydrogeomorphic Class	Dominant Source of Water	Dominant Hydrodynamics (Movement of Water)
Riverine	Overbank flow from 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

5.2.2 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. Wetlands in Washington are grouped first into *domains*, and then into *regions* based on climate and other landscape features, then into *classes* by geomorphic setting, and finally into *subclasses* and *families* according to the sources of water for the wetland and how that water moves (Hruby et al. 1999, 2000, quoted in Sheldon et al. 2003; Hruby 2003). These are some of the primary controls of wetland functions, as described earlier. This section focuses on the wetland domains and regions.

The wetlands in Washington were divided into two ecological domains, east and west, when the Washington State Wetland Rating System was first developed (DOE 1991, quoted in Sheldon et al. 2003). The teams of wetland experts who are currently revising the rating system have retained this division (Hruby 2003). At this highest level, the domains are based on the national classification of ecosystems (called ecoregions) developed by federal agencies (Bailey 1995, quoted in Sheldon et al. 2003).

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 experts developing the Washington State Wetland Function Assessment Methods further divided these domains into smaller regions because domains are too coarse a division for understanding how wetlands function in the state in a more detailed way. At present there are five regions in the state including three regions in the eastern domain. The eastern domain consists of

- montane,
- Columbia Basin, and
- lowlands of eastern Washington.

5.2.3 Description of the wetland classes in eastern Washington

5.2.3.1 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, quoted in Sheldon et al. 2003). Riverine wetlands are found in a valley or adjacent to a stream channel. 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, which structures the ecosystem in these wetlands and controls wetland functions.

5.2.3.2 Depressional wetlands

Depressional wetlands occur in topographic depressions that have closed contours on three sides. 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, quoted in Sheldon et al. 2003).

5.2.3.3 Slope wetlands

Slope wetlands occur on hill or valley slopes where groundwater "daylights" and begins running along or immediately below the soil surface. Water in these wetlands flows only in one direction (downslope), 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, quoted in Sheldon et al. 2003).

5.2.3.4 Lacustrine fringe wetlands

Lacustrine (lake) fringe wetlands in Washington are found along the edges of deeper bodies of water such as lakes or reservoirs. In eastern Washington, these wetlands occur at the margin of topographic depressions in which surface water covers more than 20 acres (8 hectares) and is deeper than 10 feet (3 meters). 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, quoted in Sheldon et al. 2003).

5.2.3.5 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, quoted in Sheldon et al. 2003).

5.2.4 Subclasses of wetlands in eastern 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 2003) are shown in Table 6. Although the HGM classification for wetlands in the state is not yet complete, the categories listed in Table 6 provide a useful tool to help separate wetlands into different types.

5.2.5 Subclasses and families of wetlands in eastern Washington State

Table 6
Subclasses and families of wetlands in different regions of Washington State (Hruby et al. 1999, 2000, quoted in Sheldon et al. 2003).

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.				

5.3 Overview of Wetland Functions in Eastern Washington

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 assessments and ratings for wetlands in the state (Hruby et al. 1999, 2000, quoted in Sheldon et al. 2003; Hruby 2003). 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. Functions that are currently defined for the state are listed below. The definitions are compiled from Hruby et al. (1999, 2000) (quoted in Sheldon et al. 2003), and Hruby (2003). Not all wetlands in a region, class, or subclass perform all of these functions. 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.

5.3.1 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.

5.3.2 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 major storm or snowmelt, events that would otherwise cause flooding.
- **Decreasing 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 also protect resources from erosion but in a different

way (Jude and Pappas 1992, quoted in Sheldon et al. 2003). For wetlands classed as lacustrine fringe, the function can be called *dissipation of erosive forces*. This is defined as the process by which wetlands reduce wave and current energies, thus decreasing 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.

5.3.3 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 in the upland habitats contiguous to a wetland. Characteristics in a wetland can be quite different and still 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 provide habitat or life resources for species of wetland-associated birds. Wetland-associated bird species are those that depend on aspects of the wetland ecosystem 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 semiaquatic 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 ecosystems through the export and assimilation of the primary productivity of the wetland. This function combines three major ecosystem processes: primary production, secondary production, and export of production.

5.4 How Wetlands Perform Functions in Eastern Washington

Table 7 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 7
Functions performed by wetlands in different HGM classes inWashington

Key to symbols used in table:
P = Functions are performed
N = Functions are not performed
NS = Functions are probably not performed to any significant degree

Functions	Riverine	Depressional	Slope	Lacustrine Fringe	Flats
Improving Water Quality					
Removing Nutrients	P	P	P	P	NS
Removing Sediment	P	P	P	P	NS
Removing Metals/Toxic Organic Compounds	P	P	P	P	NS
Hydrologic					
Reducing Peak Flows	P	P	P	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

Data compiled from Hruby et al. (1999, 2000), Hruby (2003).

5.4.1 Functions that improve water quality

Wetlands greatly influence the quality of water in a watershed. They help improve water quality, including that of drinking water, by intercepting surface runoff and removing or retaining inorganic nutrients, processing organic wastes, and reducing suspended sediments before they reach open water (Sipple 2002, quoted in Sheldon et al. 2003).

5.4.1.1 Removing sediment

Some general properties may be attributed to all wetlands with respect to their ability to remove sediments (Phipps 1986, quoted in Sheldon et al. 2003). Within a given wetland, the deposition of sediment depends on several factors including (Fennessy et al. 1994, Gilliam 1994, Johnston 1991, and Phipps 1986, all quoted in Sheldon et al. 2003):

- the residence time of the water,
- wind and wave action,
- the size and amount of incoming sediment, and
- vegetation.

5.4.1.2 Removal of sediment by wetlands of various classes

The way wetlands remove sediment is not judged to be different in the two major domains of the state (the east and west sides of the Cascades) (Hruby et al. 1999, 2000, quoted in Sheldon et al. 2003). However, the processes by which wetlands in Washington remove sediments does 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 (Brinson 1993a, quoted in Sheldon et al. 2003)

- Wetlands in the depressional class.

  Depressional wetlands that hold back all the surface water coming in (i.e., those without a surface outlet) trap all the sediment they receive (Hruby et al. 1999, 2000, quoted in Sheldon et al. 2003).

- 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. 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, quoted in Sheldon et al. 2003).

- Wetlands in the slope class.

  Slope wetlands, by definition, do not impound surface water (Brinson 1993, quoted in Sheldon et al. 2003). Removing sediment by increasing the residence time of water, therefore, is not a significant factor in this class of wetlands. Slope wetlands in eastern Washington usually have vegetation that is thicker than the vegetation in the surrounding uplands. This vegetation acts like a filter to trap sediments coming from farther upslope, because it provides more resistance to the water flowing down the hillside (Hruby 2003).

- 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, quoted in Sheldon et al. 2003). The efficiency of sediment trapping by riverine wetlands in the Pacific Northwest has not been measured (Phipps 1986, quoted in Sheldon et al. 2003), but the process of trapping sediments is still judged to be an important function on a watershed scale in Washington State. The characteristics of riverine wetlands judged important in removing sediments were as follows (Hruby et al. 1999, quoted in Sheldon et al. 2003):
  - 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, and
  - the amount of constriction in the outlet (if the wetland has an outlet).

5.4.1.3 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, quoted in Sheldon et al. 2003). The major processes by which wetlands keep phosphorus from going farther downstream are (Mitsch and Gosselink 2000, quoted in Sheldon et al. 2003):

- by trapping sediment on which phosphorus is adsorbed, and
- by removing dissolved phosphorus through adsorption to soils that are high in clay content or organic matter.

Wetlands that are effective at trapping sediments, therefore, are also effective at removing phosphorus; the classes of wetlands that are effective at removing sediments also remove phosphorus (Hruby et al. 1999, quoted in Sheldon et al. 2003). 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 and Reddy and Gale 1994, quoted in

Sheldon et al. 2003). In general, however, wetlands are a sink for phosphorus in watersheds.

Other data also show that phosphorus retention in wetlands is highly variable. Whigham et al. (1988, quoted in Sheldon et al. 2003) concluded that wetlands where waters had extensive contact with vegetation and/or organic litter were the most effective at phosphorous 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 phosphorous removal. Johnston et al. (1997) observed that a wetland may remove phosphorus from incoming waters during one part of the year, but may add phosphorus to water leaving the wetland at other times of year. They hypothesized that the release of phosphorus from a wetland is due to the leaching of phosphorus from dying wetland vegetation.

5.4.1.4 Phosphorus removal by wetlands of various classes

The way wetlands remove phosphorus is similar in the wetlands of the two domains of the state (the east and west sides of the Cascades). Wetlands that are effective at trapping sediments are also effective at removing phosphorus (Hruby et al. 1999, 2000, quoted in Sheldon et al. 2003). 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, all quoted in Sheldon et al. 2003) (see previous discussion of sediment removal). Phosphorus entering a wetland in a dissolved form can also be retained because it binds to clay and organic soils. The HGM classification does not separate wetland types by soil content (Brinson 1993a, quoted in Sheldon et al. 2003), so the presence of clay or organic soils is not specific to a particular wetland class. 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 assumed 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.

5.4.1.5 Removing nitrogen

Wetlands in general act as sinks for nitrogen under both nutrient-enriched and unenriched conditions (Adamus et al. 1991, Jansson et al. 1994, quoted in Sheldon et al. 2003). 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, quoted in Sheldon et al. 2003).

5.4.1.6 Nitrogen removal by wetlands of various classes

Wetlands remove nitrogen in similar fashion both east and west of the Cascades (Hruby et al. 1999, 2000, quoted in Sheldon et al. 2003; Hruby 2003). Furthermore, the HGM classification does not separate wetland classes by the amount of oxygen in the soils (Brinson 1993a, quoted in Sheldon et al. 2003). The presence of alternating cycles of anaerobic and aerobic conditions is not specific to

wetland type or region. Therefore, it is not possible to differentiate this function between wetland types and regions.

5.4.1.7 Removing metals and toxic organic compounds

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, plant uptake, and degradation (Adamus et al. 1991, quoted in Sheldon et al. 2003).

- Sedimentation is a major process by which wetlands remove toxic compounds. Wetlands that are effective at removing sediments are also effective at trapping toxicants (Newton 1989, referenced in Sheldon et al. 2003).

- Adsorption of the compounds to the wetland soil is promoted by soils high in clay or organic matter (Adamus et al. 1991, and Mitsch and Gosselink 2000, both quoted in Sheldon et al. 2003). 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, quoted in Sheldon et al. 2003).

- 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, quoted in Sheldon et al. 2003).

- Plant uptake of toxic compounds is maximized when there is significant wetland coverage by emergent plants (Kulzer 1990, quoted in Sheldon et al. 2003).

5.4.1.8 Removal of toxic compounds by wetlands of various classes

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, quoted in Sheldon et al. 2003). This conclusion is based on data showing that some of the toxic compounds entering a wetland are bound to sediment (Mitsch and Gosselink 2000, quoted in Sheldon et al. 2003).

Depressional wetlands and others with certain soil types, however, may perform this function at a higher level than most others. In general, the performance of this function may be better in wetlands with the following characteristics (all quoted in Sheldon et al. 2003):

- wetlands with clay soils (Bluemle 1999),
- wetlands with volcanic ash (Bluemle 1999; Hruby et al. 2000),
- wetlands with organic soils (WDOE 2003), and
- wetlands in the depressional class (Brinson 1993a; North Carolina State University 2002).

5.4.2 Functions related to maintaining the water regime in a watershed (hydrologic functions)

5.4.2.1 Reducing peak flows

Surface water that may otherwise cause flooding is stored to a greater degree in wetlands than in terrestrial environments (Adamus et al. 1991, quoted in Sheldon et al. 2003). As a result, the intensity of peak flows in streams and rivers is inversely related to the total amount of wetlands in the watershed, or to the area of wetlands in the headwaters of the system (National Research Council 1995, quoted in Sheldon et al. 2003). In short, the more wetlands in a watershed, especially in the headwater areas, the lower the peak flood flows will be. 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, quoted in Sheldon et al. 2003).

The function of reducing peak flows as defined in Washington State also includes the process of flood flow desynchronization (Hruby et al. 1999, quoted in Sheldon et al. 2003). 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, quoted in Sheldon et al. 2003). The characteristics of a wetland that indicate a potential to reduce peak flows include (Mitsch and Gosselink 2000, quoted in Sheldon et al. 2003):

- the volume of water storage (depth of water stored, multiplied by wetland area),
- proximity of the wetland to floodwaters,
- location of the wetland (along a river, lake, or stream),
- amount of flooding that would occur without the presence of the wetlands, and
- lack of other upstream storage areas such as ponds, lakes, and reservoirs.

5.4.2.2 Reduction in peak flows by wetlands of various classes wetlands of eastern Washington

In the depressional wetlands of eastern Washington, the characteristics within a 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, quoted in Sheldon et al. 2003). The events that cause flooding in eastern Washington are different than in the western part of the state. For instance, 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." Depressional wetlands with no outlet store all surface waters coming into them and therefore have the greatest potential to reduce peak flows.

In riverine wetlands, the major characteristic that reduces peak flows is the storage provided by overbank areas (Hruby et al. 1999, quoted in Sheldon et al. 2003). 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 riverbank is the most important factor in reducing peak flows. As the floodwaters 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 and Hruby et al. 1999, both quoted in Sheldon et al. 2003).

Wetlands in the lacustrine fringe and slope class have not been analyzed for their ability to reduce peak flows in eastern Washington. The information collected during the calibration of the eastern Washington rating system, however, suggests wetlands in these two classes do provide this function, but not at the same levels as riverine or depressional wetlands (Hruby 2003).

5.4.2.3 Decreasing downstream erosion

The major process by which wetlands reduce downstream erosion is by slowing the velocity of water flowing downstream (Adamus et al. 1991 and Reinelt and Horner 1995, both quoted in Sheldon et al. 2003). The reduction in velocity depends on:

- channel constrictions that slow the flow of water,
- the frictional resistance of the bottom,
- the frictional resistance of vegetation.

5.4.2.4 Reduction of erosion by wetlands of various classes

In the 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, quoted in Sheldon et al. 2003). The events that cause erosion in eastern Washington are different than those in the western part of the state. For example, summer thunderstorms can cause highly erosive flows at times when most depressional wetlands are dry. As a result, the entire storage capacity of the wetland, rather than just the live storage, usually is available to reduce water velocities. 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 2003). Although experts have not developed function assessments, the fieldwork 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.

5.4.2.5 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, quoted in Sheldon et al. 2003) and the expert teams developing the Washington State Wetland Function Assessment Methods (Hruby et al. 1999, 2000, quoted in Sheldon et al. 2003) concluded that the movement of water into the ground primarily depends on:

- the elevation of the wetland relative to the groundwater,
- the mass and pressure of water (pressure head) in the wetland, and
- 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., in a seep), the wetland cannot recharge that groundwater. By definition, recharge occurs only if water from surface runoff infiltrates into groundwater. The little information available on the potential for wetlands to recharge groundwater is contradictory. Adamus et al. (1991, quoted in Sheldon et al. 2003) conclude, from an extensive review of the literature, that four site-specific conditions determine how well a wetland performs this function:

- the 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), and
- evapotranspiration (linked to the pressure head of water in the wetland).

This conclusion about these site-specific conditions was confirmed more recently by Hunt et al. (1996, quoted in Sheldon et al. 2003). Adamus et al. (1991, quoted in Sheldon et al. 2003) 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" (pp. 2–45).

5.4.2.6 Groundwater recharge by wetlands of various classes

The characteristics within a wetland that result in the recharge of groundwater are the same for wetlands in both the eastern and the 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 pressure, or head, 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, quoted in Sheldon et al. 2003).

Groundwater recharge occurs only in a subset of depressional wetlands and in 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, quoted in Sheldon et al. 2003; Hruby 2003).

5.4.2.7 A new perspective on baseflow support

One aspect of groundwater recharge that is often attributed to wetlands in Washington is called base flow 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. In a review of the literature up to 1991, Adamus et al. (1991, quoted in Sheldon et al. 2003) concluded that discharge from wetlands during the dry season is very small, if it exists at all. In fact, Adamus et al. concluded that some wetlands may reduce base flow because of evapotranspiration. Surface outflow from the wetland was not judged to be an important factor in maintaining low flows in streams in Washington State.

5.4.3 Functions related to habitat

5.4.3.1 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 and Sipple 2002, both quoted in Sheldon et al. 2003). As a result, wetlands support numerous species from all of the major groups of organisms—from microbes to mammals. The support they provide for these organisms includes sources of food, shelter, and refugia. All of these aspects are generalized by the term *habitat*. General reviews of wetlands as habitat (Adamus et al. 1991 and Mitsch and Gosselink 2000, both quoted in Sheldon et al. 2003) 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, and
- hydrologic regime (quantity and movement of water).

Wetland-dependent species are those that normally exclusively use wetlands for food and cover throughout most of their range, and which spend most of their lifetime within wetlands, or which would be extirpated from a large region if all wetlands were to be filled (Adamus et al. 1991, quoted in Sheldon et al. 2003).

Wetland users are those 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). Other terms used in the literature to reflect the different types of organisms using wetlands include the term *wetland-associated* (Adamus et al. 1991, quoted in Sheldon et al. 2003).

Four general ecological features contribute to species richness and abundance in a landscape (Knutson and Naef 1997, quoted in Sheldon et al. 2003):

- structural complexity,
- connectivity with other ecosystems,
- abundant food sources and available water, and
- 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.

5.4.3.2 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 percent of the area of the state (Dahl 1990, quoted in Sheldon et al. 2003), over two thirds of all terrestrial vertebrate species in Washington can be considered wetland-dependent or wetland users (Kaufmann et al. 2001 and Knutson and Naef 1997, both quoted in Sheldon et al. 2003).

- **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, quoted in Sheldon et al. 2003).

- **Birds**

Overall, 266 (72 percent) of the 367 species of birds in Oregon and Washington use freshwater, riparian, and wetland habitats. More strikingly, 204 (77 percent) of the 266 species of inland birds that breed in the two states do so in riparian and wetland environments (Kauffman et al. 2001, quoted in Sheldon et al. 2003).

- **Mammals**

Ninety-five of the 147 mammal species (65 percent) in the two states use the riparian/wetland ecosystem (Kauffman et al. 2001, quoted in Sheldon et al. 2003). All the furbearers (e.g., mink, otter, beaver, and raccoon) use this ecosystem, and all but one of the big game animals (e.g., deer, elk, and moose, with bighorn sheep excepted) rely on these areas for part of their habitat requirements.

5.4.3.3 Habitat requirements of some wetland-dependent species in Washington

- **Invertebrates**

Invertebrates have evolved unique adaptations that enable them to occupy most wetland habitats and most parts of the food web. Consequently, wetland invertebrates are considered pivotal components of the food webs in wetlands (Mitsch and Gosselink 2000, quoted in Sheldon et al. 2003). As filter feeders, shredders, and scrapers, insects convert microorganisms and vegetation into biomass, providing significant food that then becomes available to 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 nutrient transfer within aquatic ecosystems (Rosenberg and Danks 1987, quoted in Sheldon et al. 2003).

Several factors are found to influence the distribution, richness, and abundance of invertebrates in wetlands (all quoted in Sheldon et al. 2003).

- Species richness of invertebrates is high in water interspersed with stands of emergent vegetation (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 does a single assemblage (Andrews and Hasler 1943; Balla and Davis 1995; Dvorak and Best 1982; Lodge 1985). 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).
- Permanent flowing water is a habitat feature that supports a unique assemblage of invertebrate species (Needham and Needham 1962; Rolauffs et al. 2001; Wiggins et al. 1980). Furthermore, the invertebrates in flowing permanent channels are an important resource for many other aquatic species such as fish (Needham and Needham 1962).
- Higher invertebrate species richness was found in wetlands that underwent marked seasonal changes in water regime, compared to those that contained permanent water with little water level fluctuation (Balla and Davis 1995).
- Vegetation is a major factor shaping wetland invertebrate communities (Krieger 1992; Wissinger et al. 1999).

~~5.1~~ **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. 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, quoted in Sheldon et al. 2003).

Other information known about amphibians in wetlands includes the following (all quoted in Sheldon et al. 2003):

- The presence of corridors 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 (Beebee 1996; Berven and Grudzien 1990; Heusser 1968). 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 (Richter, pers. comm.), 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 (Pechmann and Wilbur 1994; Sofgren 1991, 1994).
- Conditions in the buffers of a wetland are especially important in providing cover to amphibian females and to newly metamorphosed animals. Female redlegged frogs (*Rana aurora*), Northwestern salamanders (*Ambystoma gracile*) (Richter, pers. comm.), 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*) 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 generally avoid both exposed water and densely vegetated sites, instead selecting habitats with an interspersion of both features (Ildos and Ancona 1994; Strijbosch 1979). Research suggests that most species of amphibians select areas in which exposed water and vegetation are interspersed for laying eggs (Richter, pers. comm.).
- 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, and therefore optimum habitat conditions are those where water levels are stable from spawning through hatching. Although mean water level fluctuations exceeding approximately 8 inches (20 cm) have been correlated to decreased amphibian richness in wetlands (Azous and Richter 1995), their experiments 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.
- Experimental evidence suggests that vegetation structure, particularly plant shape and stem diameter, rather than the species of the plant, is 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**

All sources in the following summary of anadromous fish are quoted in Sheldon et al. (2003).

- Slope and flats wetlands in Washington are the only classes of wetlands that do not have the potential to provide habitat for anadromous fish because, by definition (Brinson 1993a), they do not have ponded or impounded surface water.
- 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 4°F (7°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).
- Overhanging vegetation provides both temperature control and protection from predation. McMahon (1983) reports 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, and
    - 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**

Some of the characteristics in wetlands that provide habitat for resident fish include (quoted in Sheldon et al. 2003):

- 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).

- 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).

5.4.3.4 Wetland-dependent (or -associated) birds

Wetland-dependent bird species are those that depend on aspects of the wetland ecosystem for some part of their life needs: food, shelter, breeding, or resting. Kauffman et al. (2001, quoted in Sheldon et al. 2003) reviewed the literature and found a very high richness and abundance of birds in wetland ecosystems 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.

General characteristics of wetlands that provide good habitat for wetland-dependent birds include the following (all quoted in Sheldon et al. 2003):

- 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 size of the buffer as well as its condition is important. Milligan (1985) concluded that bird species richness in urban wetlands of King County was strongly correlated with a buffer of at least 50 feet (15 meters).
- 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 (Hunter 1996, Gibbs et al. 1991).
- Embayments and peninsulas in a wetland with open water provide microhabitats for certain species that require hiding cover or those seeking security within a more enclosed system (USDI 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 (USDI 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 (USDI 1978).

5.4.3.5 Wetland-dependent (or -associated) mammals

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, quoted in Sheldon et al. 2003). Many mammals use wetlands but do not depend on them for some part of their life needs (food, shelter, breeding, or resting); these mammals are considered wetland users rather than wetland-dependent.

Washington State species usually considered to be wetland-dependent include the beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), river otter (*Lutra canadensis*), and mink (*Mustela vison*) (Hruby et al. 1999, quoted in Sheldon et al. 2003). The following summarizes some general information about the characteristics of wetlands that provide good habitat for mammal species (all sources quoted in Sheldon et al. 2003).

- Wetlands with a relatively undisturbed buffer are important to these four species (and others) because the buffers
  - o minimize disturbance (Allen and Hoffman 1984; Burgess 1978),
  - o provide habitat for prey species and food sources for mammals (Allen 1983; Dunstone 1978; Brenner 1962),
  - o provide cover from predators (Melquist et al. 1981), and
  - o 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, water depth must be sufficient 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 (Tabor, pers. comm.). 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).

- River otters feed primarily on fish (Kauffman et al. 2001). Wetlands with fish, therefore, provide better otter habitat than those without.
- Vegetated corridors leading to and from wetlands are considered an important feature in assessing habitat suitability (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 (e.g., muskrats, water birds, and fish) (King 1983). Food abundance and availability appeared to have the greatest influence on habitat use by river otter in Idaho (Melquist and Hornocker 1983). Classic muskrat studies by Dozier (1953) and Errington (1937) indicate that optimum muskrat habitat is an area where 66 to 80 percent of the wetland is in emergent vegetation with the remainder in open water.

5.4.3.6 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, presence of salt, and water level fluctuations in an environment that is neither fully aquatic nor terrestrial (Mitsch and Gosselink 2000, quoted in Sheldon et al. 2003). 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, quoted in Sheldon et al. 2003).

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 focused on the characteristics of wetlands that affect plant richness, as summarized below (all sources quoted in Sheldon et al. 2003):

- 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 the types of water level fluctuations and the 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.
- Observations show that the distribution of species within a wetland is primarily a function of water depths (Spence 1982, quoted in Van der Valk et al. 1994). As a result, wetlands with a range of water depths tend to have higher richness than those with fewer (Hruby et al. 1999).

5.4.3.7 Supporting food webs (primary production and export)

Wetlands are known for their high primary productivity (production of plant material) and the subsequent export of this organic matter to adjacent aquatic ecosystems. The exported organic matter provides an important source of food for most downstream aquatic ecosystems (Mitsch and Gosselink 2000, quoted in Sheldon et al. 2003).

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. 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, quoted in Sheldon et al. 2003).

The following summarizes the general characteristics of wetlands that have high production and provide excellent support for aquatic food webs (all sources quoted in Sheldon et al. 2003):

- In general, wetlands in which water flows through the system have higher levels of primary production and export than those in which water is impounded without leaving (Mitsch and Gosselink 2000).
- The water level fluctuation as well as the movement of water 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 ecosystems (Hruby et al. 1999).

6.0 ENVIRONMENTAL DISTURBANCES CAUSED BY DIFFERENT HUMAN ACTIVITIES AND USES OF THE LAND (from Sheldon et al. 2003, Chapter 2)

A general conclusion that can be drawn 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 8, sorted 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, 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 percent imperviousness within a basin appears to be the point above which significant impacts on aquatic ecosystems begin to occur, based on research in the Puget Sound Basin (Azous and Horner 2001, quoted in Sheldon et al. 2003).

While the effects of urbanization on water movement have been extensively studied, agriculture also can 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. [Note: this generally applies to ore mining rather than the basalt and gravel mining that more typically occurs in Yakima County.] Logging increases sediments in a watershed and can also change the amount of water and its fluctuations.

Habitat fragmentation of 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 Chapter 3 of Sheldon et al. 2003 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. For the wetland, the source of the sediment is irrelevant—the impact of excess sediments on wetland functions is similar, regardless of the source of sediments.

Table 8 [Note: some disturbances listed belowfor mining may be specific to ore mining and would typically not apply to the basalt and gravel mining that occurs in Yakima County.]

Disturbances resulting from different land use practices that can change the factors that control wetland functions

Key to symbols used in table:

(xx) land use creates a significant disturbance of environmental factors

(x) land use creates a disturbance

(nm) studies on impacts of this land use do not mention this disturbance

(h) literature is lacking but disturbances can be hypothesized based on authors' experience

(?) information lacking

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	nm0	nm

Decreasing the connection between habitats	Landscape scale	xx	xx	h
Other disturbances	Site scale	xx	++	h

7.0 IMPACTS OF HUMAN DISTURBANCES ON THE FUNCTIONS OF WETLANDS (from Sheldon et al. 2003, Chapter 4)

Humans create many different types of disturbances that can affect the environmental factors that control the performance of wetland functions. These disturbances are reviewed in Chapter 3 of Sheldon et al. (2003). Chapter 4 of that document reviewed the information available about how these human disturbances impact wetlands and their functions. The disturbances that have the greatest impact on wetlands include:

- direct changes to the physical structure of wetlands through filling, vegetation removal, tilling of soils, and compaction of soils;
- changes in the amount of water in wetlands;
- changes in how water levels fluctuate (e.g., in frequency, amplitude, or direction of flows);
- changes in the amount of sediment;
- increases in the amount of nutrients;
- increases in the amount of toxic contaminants;
- changes in the amount of acidity;
- increasing concentrations of salts;
- decreasing connections between habitats, and
- other disturbances that are not as well documented, including alteration of soils, construction of roads, noise, recreational access, and invasion of exotic species.

Table 8 reviews how various land use practices create disturbances that can change the environmental factors controlling wetland functions. Table 9 summarizes the effects of each of these disturbances in terms of the wetland functions they may impact. The rating of the impacts in the table represents a synthesis by Sheldon et al. (2003) of all the information presented in Chapter 4. By combining the information in these two tables, it is possible to associate changes in functions of wetlands with general types of human land use, as shown in Table 10.

For example, Table 8 shows that urbanization creates significant disturbances, which change the amount of water, the fluctuations of water levels, and input of sediments, nutrients, and contaminants to wetlands. Table 9 shows that disturbances to water flows, fluctuations of water levels, and input of sediments, nutrients, and contaminants have a significant impact on the wetland functions of providing habitat for plants, invertebrates, and reptiles/amphibians. Table 10, then, synthesizes this information to show that urbanization impacts the habitat for plants, invertebrates, reptiles, and amphibians in wetlands. The human land uses create various disturbances in the environment, and those disturbances in turn

Key to symbols used in table:

(xx) land use creates a significant disturbance of environmental factors

(x) land use creates a disturbance

(nm) studies on impacts of this land use do not mention this disturbance

(h) literature is lacking but disturbances can be hypothesized based on authors' experience

(?) information lacking

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

Table 9 [Note: some disturbances listed belowfor mining may be specific to ore mining and would typically not apply to the basalt and gravel mining that occurs in Yakima County.]

Synthesis of the information reported in the literature on the impact of different human disturbances on wetland functions.

Key to symbols used in table:

++ Significant impacts on specific functions have been documented
+ Some data suggest impacts or impacts could be hypothesized
0 Data indicate that impacts are minimal
? Information is lacking

Disturbance Type	Functions							
	Hydrologic	Water Quality	Plants	Habitat for Invertebrates	Habitat for Amphibians and Reptiles	Habitat for Fish	Habitat for Birds	Habitat for Mammals
Changing the to physical structure of wetland	+	+	++	++	+	+	++	+
Changing the amount of water	+	+	++	++	++	+	+	?
Changing fluctuations of water levels	?	?	++	+	++	+	?	?
Changing amounts of sediment	+	?	++	++	?	?	?	?
Increasing amounts of nutrients	+	+	++	++	++	+	+	+
Increasing amounts of toxic contaminants	?	+	++	++	++	++	++	?
Changing acidity	0	+	+	++	++	+	+	+
Increasing concentrations of salt	0	?	++	++	?	?	+	?
Decreasing connections between habitats	0	?	?	?	++	?	++	+
Other disturbances	?	?	++	+	++	++	++	++

Note: A (++) does not indicate the direction of the impacts to functions. In some cases the disturbance can increase the function or the richness and abundance of species and in other cases it can decrease them. A disturbance can also decrease or increase a function depending on the intensity of the disturbance (e.g., small amounts of nutrients can increase invertebrate richness and abundance, but too much will cause eutrophication).

Table 10 [Note: some impagts listed belowfor mining may be specific to ore mining and would typically not apply to the basalt and gravel mining that occurs in Yakima County.]
Synthesis of the impacts of different land uses on wetland functions.

Key to symbols used in table:

++ Significant impacts on specific functions have been documented
+ Some data suggest impacts or impacts could be hypothesized
? Information is lacking
+? Some impacts have been documented but more information is needed

Land Use	Functions							
	Hydrologic	Water Quality Improvement	Plants	Habitat for Invertebrates	Habitat for Reptiles and Amphibians	Habitat for Fish	Habitat for Birds	Habitat for Mammals
Agriculture	+	+	++	++	++	++	++	+?
Urbanization	+	+	++	++	++	++	++	+?
Mining	?	?	+	++	++	+	+	+?

Note: A (++) does not indicate the direction of the impacts to functions. In some cases the land use can increase the function or the richness and abundance of species and in other cases it can decrease them. A land use can also decrease or increase a function depending on the intensity of the land use.

affect the factors that control wetland functions, ultimately leading to changes in those functions.

The available scientific information indicates that human activities and uses of the land can have significant impacts on wetland functions at both the larger, landscape scale and at the scale of the individual wetland itself. As a result, many different approaches and methods have been developed to try to minimize these impacts. These methods include regulations to control human activities near wetlands, methods to replace the functions, and ways to protect the wetland resource through restoration. The effectiveness of some these tools at actually protecting wetland functions are discussed in Chapters 5 and 6.

8.0 THE SCIENCE AND EFFECTIVENESS OF WETLAND MANAGEMENT TOOLS (from Sheldon et al. 2003, Chapter 5)

Chapter 5 of Sheldon et al. (2003) presents a synthesis of what the current literature reports on four tools currently used to address impacts to wetlands and their functions: wetland definitions, wetland delineation methods, wetland ratings, and buffers. The section on definitions discusses biological versus regulated wetlands (including "prior converted" wetlands), small wetlands, and isolated wetlands. This chapter does not provide language or recommendations for

regulatory or policy language—those will be provided in a separate volume on management options and recommendations (Volume 2).

8.1 Introduction and Background on Regulatory Tools

The regulatory tools discussed in chapter 5 are components of "typical" wetland protection programs. The intent is not to analyze all elements of protection programs and their regulations but to focus on the key science-based elements relating directly to wetland protection and management. Therefore, this chapter focuses on the following four elements:

- wetland definitions,
- wetland delineation methods,
- wetland ratings, and
- buffers.

8.2 How Wetlands are Defined and Delineated

8.2.1 How agencies define wetlands

Several definitions of wetlands have been developed and used by various federal, state, and local agencies and jurisdictions. The effectiveness of current federal or state wetland definitions was not evaluated as part of Sheldon et al. (2003). However, definitions are included here because how a wetland is defined is critical to determining what areas are subject to the provisions of a law or regulation. For the purposes of most laws and regulations, wetlands are usually defined using one of the following two definitions (both quoted in Sheldon et al. 2003):

- "Those areas that are saturated or inundated by surface or groundwater at a frequency and duration sufficient to support, and under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." (USACOE 1987, p. 5-4)
- "*Wetlands* or *wetland areas* means areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas. Wetlands do not include those artificial wetlands intentionally created from non-wetland sites, including, but not limited to, irrigation and drainage ditches, grass-lined swales, canals, detention facilities, wastewater treatment facilities, farm ponds, and landscape amenities, or those wetlands created after July 1, 1990, that were unintentionally created as a result of the construction of a road, street, or highway. Wetlands may include those artificial wetlands intentionally created from nonwetland areas to mitigate the conversion of wetlands." (Washington Administrative Code 173-22-030.)

The Washington State definition is derived from the U.S. Army Corps of Engineers' definition, but it also includes clarifying language that identifies which common human-made or -induced features are not meant to be defined as wetland. The state definition is required by the Growth Management Act (RCW 36.70A.030 [20]) to be used in all local critical area regulations.

8.2.2 Biological versus regulated wetlands

In some jurisdictions, all lands that meet the definition of wetland are regulated. However, it is not unusual for a jurisdiction to differentiate within its regulations between "wetlands" (i.e., biological wetlands) and "regulated wetlands" (i.e., wetlands that they intend to regulate). The definition of what constitutes a regulated wetland may vary from jurisdiction to jurisdiction. A review of the regulatory language from local wetland regulations reveals that the three primary criteria used to differentiate between wetland and regulated wetland are:

- the category or rating of the wetland,
- the size of the wetland, and
- wetland types, such as prior converted croplands and isolated wetlands.

In general, a category or rating system historically has been used in regulatory language to differentiate between wetlands that need different degrees of protection. Rating systems are used by local jurisdictions to group wetlands by physical characteristics and/or by functions that the wetlands may provide, and by how those characteristics or functions are valued.

The criterion of wetland size is usually a minimum, below which the jurisdiction will not regulate a wetland. For example, the jurisdiction may allow no fill in wetlands larger than 10,000 square feet, or they may include language such as "Category 2 wetlands larger than 0.25 acre cannot be altered." The historical rationale for the use of size as a regulatory criterion was the perception that "bigger is better" and the belief that small wetlands were less important and did not provide significant functions. The scientific literature of the last ten years has made it clear that size does matter, but not in the way previously believed. Small wetlands have been shown in multiple studies to contain a significant diversity of plant and animal species.

Additionally, two other wetland types may be exempted from regulation: isolated wetlands and prior converted wetlands. A U.S. Supreme Court decision in 2001 determined that most isolated wetlands are not subject to regulation under Section 404 of the federal Clean Water Act. However, the Court did not define *isolated*, and the federal government has not issued any new guidance or regulations to clarify the situation. In general practice, the U.S. Army Corps of Engineers, the federal agency that administers the Clean Water Act, considers isolated wetlands to be those of any size that have no direct surface water connection to any navigable waters. Washington State has determined that isolated wetlands are regulated by the Department of Ecology under the state Water Pollution Control Act (RCW 90.48). Since some local jurisdictions in Washington fashion their wetland

regulations on the federal or state standards, it is important to consider the implications of not regulating isolated wetlands. Thus, scientific information on isolated wetlands is discussed in Section 5.3.4.

Prior converted wetlands (or prior converted croplands) are another type of wetlands exempt from regulation by the federal government. Prior converted wetlands are those wetlands that were drained or otherwise manipulated prior to December 23, 1985, for the production of commodity crops, where inundation (ponding) does not occur for more than 14 consecutive days during the growing season. However, most of these areas still meet the three criteria for a biological wetland. As with isolated wetlands, the Department of Ecology regulates prior converted wetlands under state law.

No information on areas meeting the definition of prior converted wetland (or cropland) was found in the scientific literature. However, many wetlands meeting these criteria would still provide important functions, given that the criteria for being designated prior converted require only that the wetland has been manipulated for production of commodity crops prior to 1985 and does not pond for more than 14 consecutive days during the growing season. If the agricultural activities were abandoned, the area could revert to a plant community characteristic of wetlands and, without maintenance of the hydrologic modifications, the wetland's water regime might revert to a condition more like that which existed prior to the alteration. Even if they have been maintained for agricultural production, many prior converted wetlands in western Washington pond during the winter and provide significant overwintering habitat for waterfowl (Zeigler, pers. comm., quoted in Sheldon et al. 2003). Prior converted wetlands also may provide important flood storage functions. Further analysis of the functions of areas designated as prior converted wetlands is needed.

No literature was found that discussed the ecological consequences of the legal bifurcation between biological wetlands and regulated wetlands. However, literature was found that discusses the functions and values provided by small wetlands and isolated wetlands, as discussed below.

8.2.3 Small wetlands

Smaller wetlands typically receive lower levels of protection, yet the loss of small wetlands is one of the most common cumulative impacts on wetlands and wildlife (Tiner 2002 and Weller 1988, both quoted in Sheldon et al. 2003). In addition to the obvious loss of habitat for wildlife, fragmentation of habitat increases as small wetlands are removed, resulting in greater distances between wetland patches in the landscape. Semlitsch and Bodie (1998, quoted in Sheldon et al. 2003) found that creating greater distances between wetlands can have a significant effect on the ability of a landscape to support viable populations of amphibians, as juveniles dispersing from a source wetland may not be able to travel far enough to recolonize other surrounding (and now distant) wetlands.

8.2.4 Amphibians and small wetlands

Snodgrass et al. (2000, quoted in Sheldon et al. 2003) determined that amphibian species richness increases with length of hydroperiod. They also concluded that short-hydroperiod wetlands (smaller, temporarily ponded wetlands) are also important in maintaining biological diversity in that they support species not found in larger wetlands with longer hydroperiods. The species they found in small wetlands were not a subset of those in larger wetlands but rather comprised a unique group of species.

High richness occurred in some of the smallest wetlands (Richter and Azous 1995, quoted in Sheldon et al. 2003). The study indicates that small wetlands that are vegetatively simple can serve adequately as breeding habitats as long as favorable nonbreeding habitat is present nearby. Species richness also was not related to persistence of ponding.

8.2.5 Birds and small wetlands

Bird use of wetlands appears to have a stronger relationship to wetland size than that of amphibians. Bird richness was positively correlated with larger wetland size in a Puget Sound study of palustrine wetlands (Richter and Azous 2001b, quoted in Sheldon et al. 2003). This is attributed to the fact that larger wetlands in the study generally had greater structural complexity and a greater number of habitat types.

Martin-Yanny (1992, quoted in Sheldon et al. 2003) also found that bird species richness and abundance in Pacific Northwest wetlands are positively correlated with wetland size. However, they note that habitat heterogeneity was a more important determining factor than wetland area in influencing bird species richness. Wetlands in highly urbanized watersheds had fewer neotropical migrant species, fewer ground-nesting birds, and more edge-tolerant (habitat generalist) species. This is because urbanizing watersheds tend to have smaller wetlands (less than 10 acres [4 hectares]) with more edge habitat, making birds more susceptible to competition, predation, and nest parasitism. However, in eastern Washington, Foster et al. (1984, quoted in Sheldon et al. 2003) found that waterfowl breeding use of wetlands in the Columbia Basin was greatest in smaller wetlands (less than 1 acre [0.4 hectare]).

8.2.6 Mammals and small wetlands

The study that modeled the effects of the loss of small wetlands in Maine showed that local populations of small mammals faced a significant risk of extinction following the loss of small wetlands (Gibbs 1993, quoted in Sheldon et al. 2003). However, in a study of Puget Sound wetlands, Richter and Azous (2001c, quoted in Sheldon et al. 2003) concluded that wetland size alone was not a significant factor in determining mammal richness or abundance. They noted that small-mammal richness was most closely affected by the combined factors of

- wetland size,
- the extent of forest adjacent to the wetland, and
- the quantity of large woody debris within wetland buffers.

8.2.7 Isolated wetlands

Wetlands can be defined as *isolated* based on geographic isolation, ecological isolation, or hydrologic isolation. For this discussion, isolated wetlands are defined by their hydrologic isolation—they do not have a surface outlet, even seasonally, to another water body. Although frequently described as closed depressions (Tiner et al. 2002, quoted in Sheldon et al. 2003), isolated wetlands also can be sloped wetlands where surface water, if present, reenters the shallow groundwater zone at the base of the wetland and is not linked via surface flows to a downstream water body. Isolated wetlands are not necessarily small. They can be large systems with substantial heterogeneity and diverse habitat types (Tiner et al.). Generally, isolated wetlands provide most of the same functions as non-isolated wetlands, and do so for the same reasons: their position in the landscape, the hydrologic regime, and the type of soils and vegetation present.

From an ecological standpoint, isolated wetlands are among the country's most significant biological resources. In some areas, isolation has led to the evolution of endemic species vital for the conservation of biodiversity. In other cases, their isolation and sheer numbers in a given locality have made these wetlands crucial habitats for amphibian breeding and survival (e.g., woodland vernal pools and cypress domes) or for waterfowl and waterbird breeding (e.g., potholes). In arid and semi-arid regions, many isolated wetlands are veritable oases—watering places and habitats vital to many species that use them for breeding, feeding, and resting, or for their primary residence.

8.2.8 Delineation methods

As required by state legislation, the Department of Ecology issued the *Washington State Wetlands Identification and Delineation Manual* in 1996 (WAC 173-22-080). The DOE manual uses the original 1987 Corps of Engineers manual and incorporates changes made by the federal government since 1987. The state manual includes national guidance issued by the Army Corps of Engineers in 1991 and 1992 (which is not used in the 1987 Corps manual), as well as regional guidance issued by the Corps and EPA in 1994. In addition, the state manual eliminated references and examples that were not relevant to Washington State, and added examples and situations relevant to Washington. The 1996 state manual is required by statute (RCW 36.70A.175) to be used by local jurisdictions in implementing the Growth Management Act.

8.3 Wetland Rating Systems

Some freshwater wetlands in Washington are categorized in the Washington State Wetland Rating System based on important characteristics that are not specifically related to functions. These characteristics include rarity on the landscape,

sensitivity to disturbance, and difficulty in restoring or creating such wetlands through mitigation efforts (WSDOE 1991, quoted in Sheldon et al. 2003; Hruby 2003). At present these wetland types have been redefined for eastern Washington (Hruby) and include:

- bogs,
- alkali wetlands,
- mature and old-growth forested wetlands,
- vernal pools, and
- wetlands identified by the Washington State Department of Natural Resources as Natural Heritage wetlands.

8.4 Buffers

Buffers are another common element of wetland regulations. Buffers are vegetated areas adjacent to an aquatic resource that can, through various physical, chemical, and/or biological processes, reduce impacts from adjacent land uses. Buffers also provide the terrestrial habitats necessary for wildlife that use wetlands to meet their life-history needs.

The primary purpose of buffers is to protect and maintain the wide variety of functions and values provided by wetlands (or other aquatic areas). The physical characteristics of buffers—slope, soils, vegetation, and width—determine how well buffers reduce the adverse impacts of human development and provide the habitat needed by wildlife species that use wetlands.

The subject of buffers is well documented in the scientific literature. The research on buffers has occurred worldwide, and this section of Sheldon et al. (2003) includes literature from a variety of regions, when it was found to be relevant. In particular, a variety of literature related to agricultural practices and vegetated filter strips from the north central United States and south central Canada is relevant to some agricultural practices in Washington State, especially east of the Cascades. In addition, studies on buffers in urban and suburban settings conducted in the Pacific Northwest region are clearly relevant.

The majority of research on buffers tends to focus on the processes that buffers provide to filter sediment or take up nutrients (i.e., their influence on water quality). Far fewer studies look at the influence of a buffer's physical characteristics on attenuating surface water flow rates, except as it relates to water quality. The long-term effectiveness of buffers in providing such mechanical and biological processes is not well documented in the literature and may represent a critical need for future research.

The literature on buffers related to wildlife is, in general, less focused. Most studies document the needs of a particular species or guild relative to distances for breeding or other life-history needs, within a radius from aquatic habitats. There is substantial literature on the implications of habitat fragmentation and connectivity, some of it related specifically to agricultural practices, forestry practices, or the

impacts of urbanization. This literature does not specifically address the role of buffers in providing connectivity between wetlands and other parts of the landscape.

8.4.1 Functions provided by buffers

The literature is broadly consistent on the ways in which buffers can provide for the protection and maintenance of wetland functions. These include:

- removing sediment,
- removing excess nutrients (e.g., phosphorous and nitrogen),
- removing toxics (e.g., bacteria, metals, and pesticides),
- influencing the microclimate,
- maintaining adjacent habitat critical for the life needs of many species that use wetlands,
- screening adjacent disturbances (e.g., noise and light), and
- maintaining habitat connectivity.

As noted by Castelle and Johnson (2000, quoted in Sheldon et al. 2003), buffers can be both ecological sources and sinks. They can control or limit the effects of land use upslope from the aquatic resource (act as a sink), and they can contribute biological benefits to the aquatic resource (act as a source). The literature also describes the physical, chemical, and/or biological characteristics of a buffer that determine the functions it provides. The most frequently cited physical characteristics that influence the effectiveness of a buffer are:

- the landscape position of the buffer,
- vegetation characteristics (e.g., composition, density, and roughness),
- the percent slope,
- the soils, and
- the buffer width and length (adjacent to the source of impacts).

Only two of the physical characteristics noted above (vegetation characteristics and buffer width/length) can be easily managed; the others are characteristics that do not lend themselves to manipulation.

By far the issue of greatest interest with respect to buffers is the question of how wide a buffer needs to be in order to be effective in protecting a wetland (or other aquatic resource). While the literature is unanimous in noting that buffers provide important functions that protect wetlands and provide essential habitat for many species, there is wide-ranging discussion about how much buffer is necessary to be effective in providing a particular level of function (Booth 1991; Castelle et al. 1994; Dosskey 2000; McMillan 2000; Norman 1996; Rickerl 2000; and Young 1980, all quoted in Sheldon et al. 2003).

For ease of discussion regarding the effective widths of buffers, the functions of buffers listed above are grouped into two major categories:

- water quality protection, and
- wildlife habitat protection.

8.4.2 Buffers and protection of water quality

Buffers protect the water quality of wetlands through four basic mechanisms:

- they remove sediment (and attached pollutants) from surface water flowing across the buffer;
- they biologically "treat" surface and shallow groundwater through plant uptake or by biological conversion of nutrients and bacteria into less harmful forms;
- they bind dissolved pollutants by adsorption onto clay and humus particles in the soil; and
- they help maintain the water temperatures in the wetland through shading and blocking wind.

Literature describing the different ways that buffers maintain and improve water quality in wetlands and other aquatic areas is abundant. There also is considerable research on the effective widths that provide a relative percentage of removal of sediments, nutrients, and some toxics emanating from various sources. Four categories of water quality improvement, discussed below are:

- removing sediment,
- removing nutrients,
- removing toxics and pathogens, and
- maintaining microclimate.

8.4.3 Removing sediment

A buffer's ability to remove sediment from surface water flows depends upon several physical characteristics of the buffer. Sediment removal occurs when (Castelle et al. 1992, Dillaha and Inamdar 1997, and Phillips 1989, all quoted in Sheldon et al. 2003):

- flows are slowed sufficiently to allow particles to fall out;
- physical filtering by vegetation and roots mechanically removes sediments from the water column;
- the slope of the buffer is of a low enough gradient to preclude formation of rills and scouring;
- there is large woody debris on the ground to create roughness; and
- the infiltration rate of the soils allows water to move through the soils rather than on the surface.

As noted above, the ability of a buffer to remove sediment is based on the condition of the buffer and its slope, as well as on the characteristics of the

incoming sediment. The following variables all contribute to the effectiveness of sediment removal within a buffer:

- the velocity of sediment transport (in surface water),
- the size of sediment particles from the source materials,
- the density of the vegetation present,
- the presence and extent of large woody debris, and
- the surface roughness within the buffer.

However, the relationship between the width of the buffer and its effectiveness is nonlinear. The largest particles and the greatest percentage of particles are dropped in the outer portions of the buffer (closest to the source of sediment). In these outer areas, the rate of surface flow begins to diminish as the water is slowed by vegetation and woody debris. Slower water movement allows particles to drop out of the water column.

In 1982, Wong and McCuen derived a formula to model a buffer's ability to remove sediments based on sediment particle size, the slope within the buffer, the rate of surface runoff, and the amount of vegetation and woody debris (roughness) in the buffer (Castelle et al. 1994, quoted in Sheldon et al. 2003). The model predicted that there would be a point of relative diminishing returns for function vs. width. For example, "If the sediment removal design criteria were increased from 90 to 95% on a 2% slope, then the buffer widths would have to be doubled from 30.5 to 61 m (100 to 200 ft)" (p. 5-28).

In other words, the model predicted that the width of the buffer would have to double to achieve an additional 5 percent removal of sediment after 90 percent of it had already been removed from the water column. Desbonnet et al. (1994, quoted in Sheldon et al. 2003) determined that a small buffer (7 feet [2 meters]) could effectively remove up to 60 percent of suspended sediment, while a buffer of up to 82 feet (25 meters) would be needed to remove 80 percent.

8.4.4 Removing nutrients

The primary nutrients of concern are nitrogen and phosphorous. Buffers remove nitrogen and phosphorous through a variety of mechanisms similar to the mechanisms present within the wetland itself, as described in Chapter 2 of Sheldon et al. (2003).

It is difficult to compare studies of buffer width and effectiveness at removing nutrients because the basic parameters of the studies differ greatly. Some studies were conducted in field settings while others occurred in experimentally designed plots. There were differences in the loading rate of nutrients, the types of soils, and the vegetation in the buffers. Some studies examined only nitrogen or phosphorous removal, whereas others combined different nutrients. The result is that reported effectiveness of buffer widths for removing nutrients ranges from a few meters to hundreds of meters. Studies are listed in Table 11

In a synthesis of research on nitrogen removal, McMillan (2000, quoted in Sheldon et al. 2003) found that nitrogen can be effectively removed in buffer strips ranging from 20 to 98 feet (6 to 30 meters) wide. McMillan cites work by two research groups (Daniels and Gilliam 1996; Patty et al. 1997) that found 47 to 99 percent removal of nitrogen can be achieved in buffers ranging from 20 to 66 feet (6 to 20 meters) wide. This is not totally consistent with synthesis results presented by Desbonnet et al. (1994, quoted in Sheldon et al. 2003) that "well configured" buffers (with ideal slope, soils, and vegetation) as small as 30 feet (9 meters) could reduce as much as 60 percent of nitrogen, while 197-foot (60-meter) buffers would be necessary for 80 percent nitrogen removal.

Table 11
Summary of studies on sediment control provided by buffers of various widths.

Author(s)	Date	Buffer Width	Comments
Broderson	1973	200 feet (61 m)	Effective sediment control "even on steep slopes" as cited by Castelle and Johnson (2000)
Desbonnet et al.	1994	6.6 – 82 feet (2 – 25 m)	60% removal in 6.6 feet (2 m); 80% removal required 80 feet (25 m)
Desbonnet et al.	1994	16 – 49 feet (5 – 15 m)	On grassy buffers on slopes with less than 5% slope, removed all but the finest particles. Cited by McMillan (2000)
Ghaffarzadeh et al.	1992	16 – 49 feet (5 – 15 m)	Found 85% removal in 30-foot (9.1 m) buffers as cited by Castelle and Johnson (2000)
Horner and Mar	1982	200 feet (61 m)	80% of sediments. As cited by Castelle and Johnson (2000)
Lynch, Corbett, and Mussallem	1985	98 feet (30 m)	75 to 80% removal of sediment from logging activities into wetlands. As cited by Castelle and Johnson (2000)
Norman	1996	9.8 feet (3 m): sands 49.9 feet (15.2 m): silts 400 feet (122 m): clays	Distances required for effective removal of progressively smaller particle sizes
Wong and McCuen	1982	100 – 200 feet (30.5 – 61 m)	90% at 100 feet (30 m), need 200 feet (61 m) to obtain 95% removal effectiveness. Cited by Castelle et al. (1994)
Young	1980	80 feet (24.4 m)	92% sediment removal rate from feedlot through vegetated buffer strip. Cited by Castelle et al. 1994

The literature also describes a range of buffer widths necessary for phosphorus removal. Studies of buffers as small as 13 feet (4 meters) wide, and as large as 279 feet (85 m) wide, found phosphorus removal rates of 50 percent to over 90 percent (see Table 12).

Table 12
Summary of studies on nutrient removal provided by buffers of various widths.

Author(s)	Date	Width	Comments
Daniels and Gilliam	1996	20 – 66 feet (6 – 20 m)	47-99% removal of nitrogen, cited by McMillan (2000)
Desbonnet et al.	1994	30 feet (9 m): 60% removal 197 feet (60 m): 80% removal	Small buffers could have effective removal rates for nitrogen; much larger buffers are necessary for a significant increase in effectiveness
Desbonnet et al.	1994	Averages: 39 feet (12 m): 60% 279 feet (85 m): 80%	When all the findings from the literature synthesis were averaged, the average removal efficiencies were non-linear: larger buffers were needed for increases in effectiveness
Dillaha	1993	15 feet (4.6 m): 70% 30 feet (9.1 m): 84 %	Percent removal of suspended solids and their associated nutrients with vegetated filter strips. As cited in Todd (2000)
Dillaha	1993	15 feet (4.6 m): 61 % 30 feet (9.1 m): 79 %	Removal of phosphorus with vegetated filter strips. As cited by Todd (2000)
Dillaha	1993	15 feet (4.6 m): 54% 30 feet (9.1 m): 73%	Removal of nitrogen with vegetated filter strips. As cited by Todd (20000)
Doyle, Stanton and Wolf	1977	12.5 feet (3.8 m) forested 13.1 feet (4 m) grass	Reduced nitrogen, phosphorus, and potassium levels. Cited by Castelle and Johnson (2000), McMillan (2000)
Edwards et al.	1983	98 feet (30 m)	50% removal rate of phosphorus. As cited by McMillan (2000)
Lowrance et al.	1992	23 feet (7 m)	Forested buffer zones were effective at removing nitrate through plant uptake and microbial denitrification
Lynch, Corbett and Mussallem	1985	98 feet (30 m)	Forested buffers reduced soluble nutrient levels from logging activities to "appropriate" levels. Cited by Castelle and Johnson (2000)
Patty et al.	1997	20 – 66 feet (6 – 20 m)	47 - 99% removal of nitrogen, as cited by McMillan (2000)
Peterjohn and Correll	1984	164 feet (50 m)	Forested buffer strips provided "dramatic reductions in nutrient loads from crops" as cited by Belt and O'Laughlin (1994)

(Table 12, cont.)

Author(s)	Date	Width	Comments
Shisler, Jordan, and Wargo	1987	62 feet (19 m)	Forested riparian buffers effectively removed up to 80% and 89% of phosphorus and nitrogen, respectively. Cited by Castelle and Johnson (2000)
Thomson et al.	1978	39 – 118 feet (12 – 36 m)	Found a range of removal effectiveness of 44 to 70%. As cited by McMillan (2000)
Vanderholm and Dickey	1978	> 853 feet (260 m)	Removal of 80% of nutrients, solids, and BOD from feedlot runoff with shallow (<0.5%) buffer slopes. Cited in Castelle et al. (1998)
Young et al.	1980	69 feet (21 m): 67% removal 89 feet (27 m): 88% removal	Removal of phosphorus, as cited by McMillan (2000)
Xu, Gillam, and Daniels	1992	33 feet (10 m)	Significant reductions in nitrate through a mixed herbaceous and forested buffer strip. As cited by Castelle and Johnson (2000)

8.4.5 Removing toxics and pathogens

A buffer's ability to remove toxics and pathogens is one of the least thoroughly studied areas in the literature. At this time, it represents a significant data gap. Castelle and Johnson (2000, quoted in Sheldon et al. 2003) note the lack of research on pathogens such as fecal coliform bacteria and toxics such as pesticides. Many of the studies they examined are quite old, but little recent research was found to supplement these older studies. Therefore, the conclusions presented from the synthesis of the previous work are provided here (see Table 13).

Toxics (pesticides and metals) can be removed by buffers through sedimentation, biological uptake by vegetation, adsorption onto clay or humus particles in the soil of the buffer, or degradation of the toxics through biochemical processes (McMillan 2000 and Patty et al. 1997, quoted in Sheldon et al. 2003).

Table 13
Summary of studies on pathogen control provided by buffers of various widths.

Author(s)	Date	Width	Comments
Doyle, Stanton and Wolf	1977	12.5-foot (3.8 m) forested buffers 13.1-foot (4 m) grass buffers	Reduction in fecal coliform bacteria levels as cited by Castelle and Johnson (2000)
Grismer	1981	98-foot (30 m) grass filter strip	Removal of 60% of fecal coliform bacteria as cited by McMillan (2000)
Young et al.	1980	115-foot (35 m) grass buffer	Reduced microorganisms to acceptable levels. Cited by McMillan (2000)

8.4.6 Maintaining microclimate

The influence of buffers on microclimate is most often thought of in the context of shading for maintaining water temperature. This is well documented in the literature, in relation to the effects on streams (Belt and O'Laughlin 1994, Castelle and Johnson 2000, Johnson and Stypula 1993, and McMillan 2000, all quoted in Sheldon et al. 2003). In those documents, literature focusing on streams and their buffers is almost exclusively relied upon to discuss the influences of buffers on water temperature (see Table 14). No literature was found that specifically examines the influence of buffers on the water temperatures and microclimates within wetlands.

Table 14
Summary of studies on the influence of microclimate provided by buffers of various widths.

Author(s)	Date	Width	Comments
Harper and MacDonald	2001	Approx. 131 feet (40 m)	Influence of large aquatic systems on adjacent upland forest composition and structural complexity

8.4.7 Buffers and wildlife habitat

Wetland buffers are essential to maintaining viable wildlife habitat because they perform three overlapping functions:

- Buffers can provide an ecologically rich and diverse transition zone between aquatic and terrestrial habitats, including necessary terrestrial habitats for many wildlife species that use wetlands.

- Buffers can screen wetland habitat from the disturbances of adjacent human development.
- Buffers may provide connectivity between otherwise isolated habitat areas.

In regard to wildlife, most of the scientific research is not directly focused on the effectiveness of buffers for maintaining individuals or populations of species that use wetlands. Some of the research simply documents use of upland habitats adjacent to wetlands by wildlife to meet their life-history needs. For example, a substantial body of research identifies the distances that amphibians may be found away from a wetland edge, but what is not well documented are the implications to amphibian populations of providing buffers smaller than those identified ranges.

8.4.8 Maintaining terrestrial habitat adjacent to wetlands

Buffers provide a transition between aquatic and terrestrial environments and are a critical component of the habitat of wildlife that uses wetlands. The specific habitat functions provided by wetland buffers include:

- sites for wildlife foraging, breeding, and nesting;
- cover for escape from predators or adverse weather;
- sources of organic matter that provide habitat structure and food; and
- areas for dispersal and migration related to both individuals and populations (buffers may connect or be part of corridors).

As defined previously, buffers are predominantly upland habitat communities that lie adjacent to aquatic habitats. They are a different habitat type than the wetland, and their presence increases habitat heterogeneity by providing niches for more species. First described by Leopold (1933, quoted in Sheldon et al. 2003) as the "edge effect," this phenomenon features the higher use of transition zones by wildlife, particularly between aquatic and terrestrial habitats. It has been demonstrated in studies of birds (Beecher 1942; McElveen 1977), mammals (Bider 1968), and amphibians (Bury 1988). The same pattern has been demonstrated in the Pacific Northwest, in studies by Cross (1988), Knight (1988), and Oakley et al. (1985) (all quoted in Sheldon et al. 2003). Research conducted in the Puget Sound lowlands confirmed the relationship between habitat diversity and species richness when the greatest species richness of birds and small mammals was found within the first 1,640 feet (500 meters) adjacent to a wetland boundary (Richter and Azous 2001b, 2001c, quoted in Sheldon et al. 2003).

Protection of upland areas adjacent to wetlands is critical to helping ensure that wetland-dependent wildlife populations have access to the habitat features necessary to meet their survival requirements. Wetland-dependent species, such as many amphibians, aquatic invertebrates, waterfowl, and some mammals, require access to wetlands for critical stages of their life-history. Many more species use wetlands—as well as other aquatic systems such as streams, lakes, or rivers—to meet various life-history needs. Research shows that species that were assumed to be dependent upon wetlands also depend upon adequate and appropriate upland

habitats to maintain viable populations (Bury 1988, Castelle et al. 1992, and Foster et al. 1984, quoted in Sheldon et al. 2003).

8.4.9 Buffer width and effectiveness in protecting wetland habitat and providing habitat in adjacent uplands

This section summarizes the literature that identifies ranges of widths of uplands that protect wetland habitat and/or that provide adjacent upland habitat for wildlife species that use wetlands. The literature presents findings in a variety of ways. Some studies identify the distances that target species range from a wetland source, while other researchers identify the distances that species travel between wetlands. Synthesis documents outlined recommendations for buffer widths based on a review of research findings. Some of the literature identified use of habitats by broad categories of wildlife guilds, while other studies focused on limited guilds or even on individual species.

It is important to understand that the range of buffer widths identified and discussed in the literature is a reflection of many variables, including the objectives of the research, the species/guilds studied and their varied life-history needs, and the methods of the research. Thus, it is not appropriate to choose a single study or buffer dimension to justify any buffer dimension, whether large or small. It is critical to incorporate the life-history requirements of the range of targeted species when considering buffer dimensions. Synthesis documents clarify that a range of upland habitat buffer dimensions may be appropriate, depending upon site considerations, landscape context, and targeted species.

- **Birds**

The research on birds ranges from studies in individual species to summaries on bird species richness. A tremendous amount of research on waterfowl exists, with the majority being conducted in the prairie pothole region of the United States. This section focuses on studies or syntheses that are relevant to the Pacific Northwest.

In eastern Washington, Foster et al. (1984, quoted in Sheldon et al. 2003) determined that 68 percent of waterfowl nests were in upland areas within 98 feet (30 meters) of the wetland edge, whereas it would take a 312-foot (95-meter) buffer to encompass 95 percent of the nesting sites.

- **Amphibians**

The research on amphibians and buffers in relation to their habitat needs comes both from studies in the Pacific Northwest and from literature summaries from around the United States. Findings are rather consistent in that amphibians range substantial distances from breeding locations in a wetland to fulfill their life-history needs. On the west side of the Cascades there appears to be a preference for forested habitats adjacent to breeding sites, and urban uses near breeding sites seem to have a negative influence on amphibian abundance.

- **Reptiles**

Research on reptiles and buffers in the Pacific Northwest was not found. Research on freshwater turtles in North Carolina found that turtles used a wide area for nesting and terrestrial hibernation in uplands surrounding the ponds where breeding occurred (Burke and Gibbons 1995, quoted in Sheldon et al. 2003). Burke and Gibbons found that a 902-foot (275-meter) buffer was required to protect 100 percent of the nest and hibernation sites. Protecting 90 percent of the sites required a 240-foot (73-meter) buffer. The authors concluded that most buffer requirements are inadequate to protect turtle habitat for all stages of their life history.

- **Mammals**

Use of wetlands by mammals depends upon adjacent uplands. The literature indicates that even a wetland-dependent mammal such as a beaver uses upland habitats an average of 100 feet (30 meters) from the wetland edge, in eastern Washington, and over 300 feet (100 meters) distant in western Washington (Castelle et al. 1992, quoted in Sheldon et al. 2003). Research on small mammals found the greatest concentration of species near riparian corridors, with some species found within that riparian corridor that were not found farther away in upland habitats (Cross 1985, quoted in Sheldon et al. 2003). Azous (2001c, quoted in Sheldon et al. 2003) found that the highest richness of small mammals was in wetlands in which at least 60 percent of the first 1,640 feet (500 meters) of buffer included forest cover. Other findings of this program include:

- The preservation of large woody debris within the wetland and adjacent upland forest is important for maintaining small-mammal habitat.
- Small-mammal richness was best associated with the combined factors of wetland size, adjacent forest, and the quantity of large, coarse woody debris within the wetland and its buffer.
- In southwestern Oregon, Cross conducted research on small mammals in "leave-strips" adjacent to streams, within zones of forest that had been harvested. He found that the richness of small-mammal species was highest in the riparian zone closest to the stream, intermediate in the transition zone, and lowest in the upland zone. (The zones were defined by vegetation composition, not by dimension.) Because riparian habitats provide more niches for species, it is expected that such habitats would maintain greater species richness (Cross 1985, quoted in Sheldon et al. 2003).

It is difficult to synthesize the findings of the research on wildlife and buffer widths into simple generalizations that can be readily applied. When looking at life-history needs (e.g., nesting sites and foraging ranges) the distances presented in the literature range from 98 feet (30 meters) (Castelle et al. 1992; Foster et al. 1984) to 3,280 feet (1,000 meters) (Richter 1997, all quoted in Sheldon et al. 2003). These are distances from a wetland edge, measured in the field, that species ranged, nested, or foraged (see Table 15).

Table 15
Summary of studies on wildlife habitat provided by buffers.

Author(s)	Date	Width	Comments
Allen	1982	328 – 590 feet (100 – 180 m)	Mink use: generally concentrated within 330 feet (100 m) of water but will use upland habitats up to 590 feet (180 m) distant
Burke and Gibbons	1995	240 feet (73 m): 90% 902 feet (275 m): 100%	Buffer to encompass % nesting and hibernation of turtles in North Carolina
Castelle et al.	1992	197 – 295 feet (60 – 90 m): Western Washington 98 – 197 feet (30 – 60 m): Eastern Washington	Range for all species they noted. Range for all species they noted.
Castelle et al.	1992	263 feet (80 m) avg. - 590 feet (180 m)	Wood duck nesting locations from wetland edge (non-Washington data)
Castelle et al.	1992	98 feet (30 m): Eastern Washington 328 feet (100 m): Western Washington	Distance of beaver use of upland habitats from water edge
Chase et al.	1995	98 feet (30 m) or more	100 feet (30 m) would be "adequate"; buffers larger than 100 feet needed to meet habitat needs, including breeding for birds and some mammals
Cross	1985	220 feet (67 m)	Forested "leave-strips" for small mammal richness adjacent to streams in SW Oregon
Desbonnet et al.	1994	49 – 98 feet (15 – 30 m): low intensity 98 – 328 feet (30 – 100 m): high intensity	Variable buffer widths using adjacent land uses as decision-making criteria
Fischer et al.	2000	98 feet (30 m) minimum	Literature review; majority of literature cited recommends buffer widths of 330 feet (100 m) for reptiles, amphibians, birds, and mammals

(continued on next page)

Author(s)	Date	Width	Comments
Foster et al.	1984	98 feet (30 m): 68% of nests) 312 feet (95 m): 95% of nests	Waterfowl breeding use of wetlands in the Columbia Basin greatest in smaller (<1 acre [0.4 ha]) wetlands; 68% of waterfowl nests within 100 feet (30 m) of wetland edge; to encompass 95% of waterfowl nests would require 310 feet (95 m) of buffer
Groffman et al.	1991	197 - 328 feet (60 - 100 m)	For most wildlife needs
Groffman et al.	1991	328 feet (100 m)	Neotropical migratory bird species
Howard and Allen	1989	197 feet (60 m)	For most wildlife needs
McMillan	2000	98 – 328 feet (30 – 100 m)	Based on a synthesis of literature
Milligan	1985	49 feet (15 m)	Bird species diversity strongly correlated with the percentage of the wetland boundary buffered by at least 50 feet (15 m) of tree and shrub vegetation
Norman	1996	164 feet (50 m)	To protect wetland functions; more buffer may be required for "sensitive wildlife species"
Ostergaard	2001	3,280 feet (1,000 m)	Forested habitat surrounding stormwater ponds, related to native amphibian richness
Richter	1996	3,280 feet (1,000 m)	Literature review and synthesis
Richter	1996	3,280 feet (1,000 m)	Native amphibian use
Richter and Azous	2001b	1,680 feet (512 m)	Distance from wetland edge necessary to include all bird richness in Puget Sound lowland wetlands
Richter and Azous	2001c	1,640 feet (500 m): 60%	Highest small-mammal richness when 60% of first 1,640 feet (500 m) of buffer was forest habitat
Semlitsch	1998	1,969 feet (600 m)	Salamanders
Semlitsch	1998	228 – 411 feet (69.6 - 125.3 m) 539 feet (164.3 m) for 95% of all species	Six species of adult salamanders and two species of juveniles; mean distance from wetland edge was 228 feet (juveniles) – 411 feet (adults). To incorporate 95% of all species, buffer mean would have to be 539 feet
Short and Cooper	1985	164 – 328 feet (50 – 100 m)	164 feet (50 m) for foraging
Temple and Cary	1988	> 656 feet (200 m): 70% success 328 – 656 feet (100 – 200 m): 58% success < 328 feet (100 m): 18% success	Nesting success rates for interior-dwelling forest birds related to distance into the interior of a forest from the forest edge

8.4.10 Screening adjacent disturbances

Wetland buffers screen wildlife from human activities. Disturbance from humans can come in the form of noise and light (indirect effects) or from human presence/movement (direct effects). Noise and light can disrupt feeding, breeding, and sleeping habits of wildlife. Many wildlife species in wetlands are disturbed by unscreened human activity within 200 feet (61 meters). Dense shrubs and trees in a wetland buffer can limit intrusion and screen out noise, light, and movement from adjacent human development (Castelle et al. 1992, quoted in Sheldon et al. 2003). In addition, domestic pets such as dogs and cats can adversely affect wetland wildlife by preying on some wildlife species, and domestic animals are particularly damaging to ground-nesting species (Churcher 1989, quoted in Sheldon et al. 2003). Groffman et al. (1991, quoted in Sheldon et al. 2003) determined that 105 feet (32 meters) of dense forested buffer was necessary to reduce commercial area noise to background noise levels. Shisler et al. (1987, quoted in Sheldon et al. 2003) differentiate between the impacts of low-intensity land uses (e.g., agriculture, recreation, or low-density housing) and high-intensity land uses (e.g., high-density residential or commercial/industrial use). They found that low-intensity land uses can be effectively screened with vegetated buffers of 49 to 98 feet (15 to 30 meters), while high-intensity land uses require buffers of 98 to 164 feet (30 to 50 meters).

Direct sighting of approaching humans was found to disrupt birds (i.e., to change their behavior or to cause flushing) between 46 and 164 feet (14 to 50 meters) (Josselyn et al. 1989, Rodgers and Smith 1997, and Shisler 1987, all quoted in Sheldon et al. 2003). Looking specifically at great blue herons, Short and Cooper (1985, quoted in Sheldon et al. 2003) documented that they would flush from their nests if humans approached within 328 feet (100 meters). Buffers between 46 and 164 feet (14 to 50 meters) may be required to screen wildlife from direct observation of humans, while larger buffers (328 feet or 100 meters) were documented as necessary to screen nesting herons.

8.4.11 Maintaining habitat connections

Increased isolation of wetlands and the fragmentation of habitats directly result from human conversion of habitats to other uses. Buffers can play a role in reducing habitat fragmentation by serving as upland habitat directly adjacent to a wetland, or by providing an area that connects, or is part of a corridor that connects, wetlands with upland habitats or other water bodies. Generally, buffers applied in a regulatory context rarely are designed to provide these connections. Typical buffer widths generally are insufficient to link wetlands to other habitats. In addition, maintaining linkages from one habitat type to another on distinct parcels is often not a consideration when properties are reviewed case by case (see Table 16).

Table 16
Summary of studies on screening provided by buffers.

Author(s)	Date	Width	Comments
Castelle et al.	1992	200 feet (61 m)	General wildlife considerations
Cooke	1992	50 feet (15 m)	Analyzed 21 sites in King County. Buffers less than 50 feet were often disturbed by human activities and were not effective at screening "human effects". Cited in Castelle et al. (1992)
Groffman et al.	1991	105 feet (32 m)	Dense forest to filter sound from commercial land uses to natural background levels
Josselyn et al.	1989	49 – 164 feet (15 – 50 m)	Unscreened human activity within 50 – 164 feet was disruptive to waterbirds in San Francisco Bay area
Rodgers and Smith	1997	46 to 112 feet (14 –34 m) 61 to 78 feet (18.5 – 24 m)	Waterbirds in Florida: flushing distance from walkers 46 – 112 feet; flushing distance from autos 61 – 78 feet. Nature observation had greatest impact of human walking activities. Nesting birds tolerated closer human approach than birds that were perching/foraging
Shisler et al.	1987	50 - 100 feet (15 – 30 m) 100 – 164 feet (30 – 50 m)	Low-intensity land uses (agriculture, recreation, and low density residential): 50 - 100 feet High-density residential housing and commercial/industrial: 100 - 164 feet Most effective buffers had steep slopes, dense shrubs
Short and Cooper	1985	328 feet (100 m)	328 feet to buffer nesting great blue herons from human disturbance

8.4.12 Buffer maintenance and effectiveness over time

8.4.12.1 Human alteration to buffers

Human activities are the most common mechanism for altering buffers over time. Buffer functions can be reduced if vegetation is cut or trampled, if soils are compacted, if sediment loading surpasses the filtering capability of the vegetation, or if surface water flows create channels and subsequent erosion. Cooke (in Castelle et al. 1992, quoted in Sheldon et al. 2003) analyzed 21 wetland sites in western Washington and concluded that buffers less than 50 feet (15 meters) wide were more susceptible to being reduced over time by human disturbance. Nearly all of the studied buffers less than 50 feet (15 meters) in width were significantly reduced in the few years the buffers had been present on the back of private lots.

Some of the buffers were found to have been eliminated through complete clearing of native vegetation. Of the buffers wider than 50 feet (15 m), most still had some portion intact, and overall they showed fewer signs of human disturbance.

8.4.12.2 Loss of trees to blowdown

Pollock and Kennard (1998, quoted in Sheldon et al. 2003) concluded that trees in narrow forested buffers (less than 76 feet [23 meters] wide) have a much higher probability of suffering significant mortality from windthrow and blowdown than do trees in wider buffers. They concluded that buffers in the range of 76 to 115 feet (23 to 35 meters), created when the surrounding forest is cut, are the minimum width that can be expected to withstand the effects of wind in the long term

8.4.12.3 Reduced capacity for sediment/nutrient removal

Many of the studies described earlier assess the effectiveness of buffers in removing sediments and nutrients for short durations (on the order of one to two years, if the time period was discernable in the methods sections of the literature). One study that assessed water quality improvement over longer periods found that effectiveness diminished as the outer margins of the buffers became saturated with sediment (Dillaha and Inamdar 1997, quoted in Sheldon et al. 2003). Their findings suggest that buffers have a limited carrying capacity for sediment removal, and that larger buffers and other methods may be required to ensure long-term control of sediment. Similarly, Todd (2000, quoted in Sheldon et al. 2003) cites work by Dillaha in 1993 that found less than 10 percent of grass filter strips were effective after three to five years. The grass filter strips became channelized, and surface flows were no longer passing through as sheet flow that would allow contact with vegetation to remove sediments and nutrients. Todd emphasizes that, for buffers to be effective, they have to be sustainable over time, and this must be a factor when determining buffer widths.

8.4.13 Summary of buffer ranges and characteristics from the literature

Several references (Castelle et al. 1992, Desbonnet 1994, McMillan 2000, Norman 1996, and Todd 2000, all quoted in Sheldon et al. 2003) identify four criteria that should be considered in determining the width of a buffer:

- the value of the aquatic resource to be protected by the buffer;
- the characteristics of the aquatic resource in question, of the watershed contributing to the aquatic resource, and of the buffer itself;
- the intensity of the adjacent land use (or proposed land use); and
- the specific functions that the buffer is supposed to provide, including the targeted species to be managed for and an understanding of their life-history needs.

Table 17 presents a summary of the buffer ranges recommended by the authors who conducted literature reviews or syntheses on buffer effectiveness. Minimums ranged from 25 feet (8 meters) to 197 feet (60 meters). Maximums ranged from 98

feet (30 meters) for some land uses to 350 feet (107 meters). Table 18 outlines the general effectiveness of different buffer widths at removing pollutants and providing habitat (Desbonnet et al. 1994).

Table 17
Summary of recommendations for buffer dimensions from the literature

Author(s)	Date	Minimum Buffer	Maximum Buffer	Comments
Castelle et al.	1994	25 feet (8 m)	98 feet (30 m)	"Adequate under most circumstances"
Desbonnet et al.	1994	49 feet (15 m)	98 feet (30 m)	Low-intensity land uses (agriculture, recreation, and low density residential)
		98 (30 m)	164 feet (50 m)	High-density residential housing and commercial/industrial
Fischer	2000	98 feet (30 m)	328 feet (100 m)	Larger buffer for reptiles, amphibians, birds and mammals
Groffman et al.	1991a	197 feet (60 m)	328 feet (100 m)	For most wildlife needs
Howard and Allen	1989	197 feet (60 m)		For most wildlife needs
McMillan	2000	25 feet (8 m)	350 feet (107 m)	Case by case, using a rating system and the intensity of proposed or existing land use
Norman	1996	164 feet (50 m)		To protect wetland functions; more may be required to protect more "sensitive wildlife species"

Castelle et al. (1994, quoted in Sheldon et al. 2003), summarizing research conducted primarily before 1990, concludes, "buffers necessary to protect wetlands and streams should be a minimum of 49 to 98 feet (15 to 30 meters) in width under most circumstances" (p. 5-49). They note that the lower end of the spectrum is the minimum necessary to maintain physical and chemical processes, while the upper end of the spectrum may be necessary to maintain biological processes. This work appears to contradict the findings of Desbonnet et al. (1994, quoted in Sheldon et al. 2003). However, the language in the Castelle et al. report of 1994 states that the buffers should be a *minimum* of 49 to 98 feet; the report does not identify appropriate maximums. The report is most often quoted to imply that the full range of buffers should be *between* 49 and 98 feet.

In urban settings, larger buffer widths are often prescribed in anticipation of future impacts from adjacent land use and activity upstream in the watershed. The most important criterion for determining buffer width is identification of the various

functions the buffer is expected to provide (Todd 2000, quoted in Sheldon et al. 2003).

Table 18
General effectiveness of different buffer widths at removing pollutants and providing habitat (Desbonnet et al. 1994).

Buffer Width in Feet (m)	Pollutant Removal Effectiveness	Wildlife Habitat Value
16 feet (5 m)	Approximately 50% or greater sediment and pollutant removal	Poor habitat value; useful for temporary activities of wildlife
32 feet (10 m)	Approximately 60% or greater sediment and pollutant removal	Minimally protects stream habitat; poor habitat value; useful for temporary activities of wildlife
49 feet (15 m)	Greater than 60% sediment and pollutant removal	Minimal general wildlife and avian habitat value
66 feet (20 m)	Greater than 70% sediment and pollutant removal	Minimal wildlife habitat value; some value as avian habitat
98 feet (30 m)	Approximately 70% or greater sediment and pollutant removal	May have use as a wildlife travel corridor as well as general avian habitat
164 feet (50 m)	Approximately 75% or greater sediment and pollutant removal	Minimal general wildlife habitat value
246 feet (75 m)	Approximately 80% or greater sediment and pollutant removal	Fair to good general wildlife and avian habitat value
328 feet (100 m)	Approximately 80% or greater sediment and pollutant removal	Good general wildlife habitat value; may protect significant wildlife habitat
656 feet (200 m)	Approximately 90% or greater sediment and pollutant removal	Excellent general wildlife value; likely to support a diverse community
1,968 feet (600 m)	Approximately 99% or greater sediment and pollutant removal	Excellent general wildlife value; supports a diverse community; protection of significant species

In agricultural lands, Welsch (1991, quoted in Sheldon et al. 2003) identifies a three-zone approach for establishing buffers.

- **Zone 1**—consists of riparian-type trees and shrubs immediately adjacent to the stream, water body, or wetland. It should be a minimum 13 feet (4 meters) wide, or adjusted to include the entire riparian area (the area with year-long or seasonal soil-moisture regime influenced by the stream or water body). Minimum length should be the length of the proposed disturbance outside the riparian management zones, or "the longest distance possible."
- **Zone 2**—extends upslope from Zone 1 and consists of vegetation that may be periodically harvested as it matures. A minimum distance of 20 feet (6 meters) should be allowed for this zone for small streams or waterbodies; for larger

streams or waterbodies, the total of Zones 1 and 2 can be increased up to 98 feet (30 meters) or 30 percent of the geomorphic floodplain (whichever is less). Minimum length should match that of Zone 1. Zone 2 can be an active harvest zone, but trees and vegetation need to be left to provide soil-holding and filtering capacity.

- **Zone 3**—is added upslope of Zone 2 if adjacent land (away from the aquatic resource) is cultivated cropland or another land use with the potential for erosion or sediment production. Zone 3 is a vegetated filter strip and should be wide enough to control "concentrated flow erosion from cultivated cropland." Zone 3 vegetation should be established prior to the establishment of Zones 1 and 2.

9.0 THE SCIENCE AND EFFECTIVENESS OF WETLAND MITIGATION (from Sheldon et al. 2003, Chapter 6)

Wetland compensatory mitigation has been studied in Washington and elsewhere in the United States for the past 15 years. Considerable data are available to evaluate the effectiveness of compensatory mitigation. The majority of compensatory wetland mitigation projects described in the literature are neither fully successful nor complete failures, but rather are somewhere between. While most compensatory mitigation projects were installed, compliance of the projects with permit requirements was generally low, due to shortfalls of wetland acreage, failure to achieve performance standards, and a lack of monitoring and maintenance. The few studies that examined the effect of regulatory follow-up suggest that it had a positive influence on the level of compliance and success for compensatory wetland mitigation projects.

There is a general lack of information about the relative effectiveness of the various types of compensation (e.g., restoration, creation, or enhancement). Creation is generally the most frequently used type of compensation, but studies of its effectiveness produced mixed results. Enhancement of wetlands also was frequently used, but few studies examined its effectiveness. Limited studies from Washington indicate a low level of success among enhanced wetlands, primarily due to a minimal gain in functions. However, it may simply take longer for a gain in functions to appear (i.e., 15 to 20 years, rather than 5 to 10 years). Restoring wetlands was noted as a high priority, but as a type of compensation it is not frequently used. This could be due to the fact that restoration is most cost-effective for large projects, while most compensation projects tend to be relatively small.

Preservation and a mixture of compensation types appear to be used occasionally. Studies provide limited information on the effectiveness of these types. Two studies from Washington indicated that mixed compensation projects had a higher level of compliance than creation or enhancement, and all mixed projects were moderately successful. The lack of data regarding the effectiveness of preservation is problematic, since one of the only studies to look at its effectiveness determined that one large site was predominantly upland habitat. On the other hand, if a site can be confirmed as wetland, or if a mosaic of wetland and upland is determined to

be acceptable, preservation of existing wetlands offers no risk of failure and no temporal loss of wetland functions, which are inherent in the other types of compensation. Preservation does, however, result in a net loss of wetland area and possibly of wetland functions.

Replacement ratios equalize the trade-off between the wetland being lost and the wetland being provided as compensation, by accounting for the risk of failure and temporal loss of functions. Required replacement ratios vary from one state to another, based on the type of compensation proposed and on project-specific circumstances. Replacement ratios actually achieved through compensation were less than what was required, which is to be expected since the ratios are meant to encompass a certain level of failure.

However, in some cases this resulted in less than 1:1 acreage replacement. While on paper, studies indicated that permitting programs have improved over time in terms of wetland acreage required for compensation, studies in the field indicate that compensatory wetland mitigation has resulted in a loss of wetland acreage. Functions performed and characteristics produced by created and restored wetlands differed from those performed and produced by reference wetlands—except in the case of water quality functions, which appeared to be performed in a similar capacity. None of the studies compared the functions provided by compensation wetlands with the functions provided by the wetlands that were lost.

For the most part, reference wetlands provided habitat for a greater diversity or abundance of wildlife than created or restored wetlands. Birds were an exception since half of the studies found no difference between created/restored sites and reference wetlands, particularly for ducks. Created and restored wetlands have different vegetative characteristics and plant communities than reference wetlands. Certain plant communities, such as sedge meadows, may require many years to develop, if at all.

The common finding that wetland compensation sites have greater vegetation species richness is probably linked to the broad range of niches created on a new site. A newly created or restored site is a blank slate upon which species will be planted, species from the previous habitat on the site will reemerge, and species adapted to disturbance will colonize. Over time the site will stabilize and mature, and only the species adapted to the resulting conditions will remain. However, research on restored, created, or enhanced sites that have stabilized is currently lacking. This indicates that sites are probably not studied for a long enough time, due either to the relatively short regulatory time frame or to the decades or lifetimes necessary to achieve stabilization and maturity.

Researchers observed that created, restored, and enhanced wetlands had less organic matter than reference wetlands. This could be due to the excavation of surface soil layers during project construction. Studies also indicated that organic matter at compensation wetlands did not appear to accumulate over time. Therefore, plant establishment at compensation wetlands could be hindered by low

organic content in conjunction with soils that were found to be sandier, more compacted, and lower in nitrogen.

Compensatory mitigation is producing more acreage of open water wetlands than was lost. The ability of compensatory mitigation projects to produce other Cowardin classes varied. Some compensatory mitigation wetlands have produced significantly different HGM classes than were present in the reference wetlands. This has resulted in wetlands that have more inundation for a longer period than reference systems.

Some unique types of wetlands, such as bogs, fens, and mature forested wetlands, may not be reproducible, especially not within current regulatory time frames. Other wetland types, such as vernal pools, may be reproducible given the right conditions. The literature provides numerous suggestions on virtually every aspect of the mitigation process. Key suggestions include:

- improving regulatory guidance on a variety of topics, such as measurable, meaningful, and enforceable performance standards for compensatory mitigation;
- finding better sites that provide increased benefits due to their location within a watershed;
- monitoring compensatory mitigation wetlands more effectively; and
- implementing measures to increase regulatory follow-up of compensation projects.

The literature suggests that some improvements have been made in compensatory mitigation over the past two decades, particularly in terms of what is required. However, overall success and permit compliance have not noticeably improved. Most studies indicate that created and restored wetlands do not provide the same characteristics or level of functions as reference wetlands (water quality functions may be the exception).

Though older created and restored wetlands generally exhibit vegetation characteristics that lead to improved habitat for wildlife, soils and hydroperiods may remain so modified that they will not replicate reference systems in the foreseeable future. Since the effectiveness of compensatory mitigation remains highly variable and somewhat questionable, it is increasingly important to understand the cumulative effects of the continuing loss of wetland acreage and functions. This is addressed in chapter 7 of Sheldon et al. (2003).

10.0 CUMULATIVE IMPACTS ON WETLANDS (from Sheldon et al. 2003, Chapter 7)

The majority of wetland management decisions in Washington State are based on case-by-case actions related to specific projects, without any opportunity to consider landscape-scale processes or consequences. This pattern is a result of the current structure of programs at local, state, and federal regulatory agencies. The

results of the research on case-by-case permitting processes are clear: consistent wetland losses, both regionally and statewide.

In spite of regulatory programs at federal, state, and local levels, wetland impacts continue to occur. These impacts are often the result of cumulative and synergistic impacts across the landscape.

The benefits and anticipated consequences of managing natural resources within a landscape context are well documented. In the case of wetland resources, a landscape-scale management program has not been implemented in Washington State. However, examples from Oregon and elsewhere in the nation provide approaches that may help address cumulative impacts in Washington. The literature reviewed for this synthesis did not focus on the reasons for the lack of landscape-scale strategies, but some impediments can be assumed:

- costs of analysis, inventories, assessments, and rankings;
- costs of implementing a landscape-scale program relative to existing project-driven programs, which often are funded by applicant fees;
- inconsistent mandates driving the agendas and priorities of regulatory agencies;
- lack of examples of successful tools for interagency collaboration and implementation;
- lack of awareness and understanding, on the part of both the public and the staff of implementing agencies, of the ecological consequences of existing regulatory programs; and
- lack of support for local jurisdictions in tackling the process of identifying and prioritizing aquatic resources for long-term protection and/or potential alteration.

Volume 2 of the two-volume document (Sheldon et al. 2003) will build on the foundation of scientific information in this synthesis, to construct options and recommendations for the protection and management of wetlands and their functions at the site- and landscape scales.

11.0 EASTERN WASHINGTON WETLAND RATING SYSTEM

The following sections are a summary of *Washington State Wetland Rating System for Eastern Washington—Revised* (Hruby 2003).

11.1 Overview

The Eastern Washington Wetland Rating System currently is in the process of being revised from the original document published in 1991. The need to revise the original version became apparent as wetland scientists learned more about how wetlands function and what is needed to protect them in Washington State.

The Eastern Washington Wetland Rating System is designed to differentiate between wetlands based on their sensitivity to disturbance, their significance, their

rarity, the ability to replace them, and the functions they provide. The rating system, however, does not replace a full assessment of wetland functions that may be necessary to plan and monitor a project of compensatory mitigation.

The rating categories are intended to be used as the basis for developing standards for protecting and managing the wetlands to minimize further loss of their resource value. Some management decisions that can be made based on the rating include the width of buffers necessary to protect the wetland from adjacent development, the ratios needed to compensate for impacts to the wetland, and permitted uses in the wetland. The Department of Ecology is developing recommendations for such protective standards, and these will be available in a companion document, *Managing and Protecting Wetlands in Eastern Washington Using the Wetland Rating System.*

Wetlands in eastern Washington differ widely in their functions and values. Some wetland types are widespread, while others are uncommon. Some are disturbed, while others are relatively pristine. All wetlands, however, provide some functions and resources that are valued. These may be ecological, economic, recreational, or aesthetic. Managers, planners, and citizens need tools to understand the resource value of individual wetlands, in order to protect them effectively.

There are many ways to understand the resource value of wetlands. The methods range from detailed scientific analyses that may require many years to complete, to the judgments of individual resource experts done during one visit to the wetland. Management of our wetland resources faces a dilemma: scientific rigor is often time-consuming and costly. Tools are needed to provide information on the functions and values of wetlands in a time- and cost-effective way. One way to accomplish this is with an analytical tool that categorizes wetlands by their important attributes or characteristics based on the collective judgment of regional experts. Such methods are relatively rapid but still provide some scientific rigor (Hruby 1999, quoted in Hruby 2003).

The rating system is designed to differentiate between wetlands based on their sensitivity to disturbance, their rarity, the functions they provide, and whether they can be replaced. The emphasis is on rating highly those wetlands:

- where our ability to replace is low,
- that are sensitive to adjacent disturbance,
- that are rare in the landscape,
- that perform many functions well, and
- that are important in maintaining biodiversity.

The rating method identifies a category for vegetated wetlands and is primarily intended for use with wetlands identified using the State of Washington delineation method (WAC 173-22-035). It also is consistent with the definition of wetlands used in the Federal Clean Water Act. Thus, it does not characterize many streambeds, riparian areas, and other valuable aquatic resources.

The following description summarizes the rationale for including different wetland types in each category. As a general principle, it is important to note that wetlands of all categories have valuable functions in the landscape, and all are worthy of inclusion in programs for wetland protection.

11.2 Category I Wetlands

Category I wetlands are those that:

- represent a unique or rare wetland type,
- are more sensitive to disturbance than most wetlands,
- are relatively undisturbed and contain ecological attributes that are impossible to replace within a human lifetime, or
- provide a high level of functions.

We cannot afford the risk of any degradation to these wetlands. Generally, these wetlands are not common and make up only a small percentage of the wetlands in the region. In eastern Washington the following types of wetlands are Category I:

- alkali wetlands,
- natural heritage wetlands,
- bogs,
- mature and old-growth forested wetlands with slow growing trees, and
- wetlands that perform many functions very well.

11.2.1 Alkali wetlands

Alkali wetlands are characterized by the occurrence of shallow saline water. In eastern Washington these wetlands contain surface water with specific conductance that exceeds 3000 micromhos per cm. These wetlands provide the primary habitat for several species of migrant shorebirds and are also heavily used by migrant waterfowl. They also have unique plants and animals that are not found anywhere else in eastern Washington. For example, the small alkali bee that is used to pollinate alfalfa and onion for seed production lives in alkali systems. It is a valuable natural resource for agriculture in the western United States, and especially in eastern Washington (Delaplane and Mayer 2000, quoted in Sheldon et al. 2003). The bees ordinarily used to pollinate fruits and vegetables generally are too large to pollinate the small flowers of these other commercially important plants.

The salt concentrations in these wetlands have resulted from a relatively long-term process of groundwater surfacing and evaporating. These conditions cannot be easily reproduced through compensatory mitigation because the balance of salts, evaporation, and water inflows are hard to reproduce, and to our knowledge has never been tried. Alkali wetlands are also rare in the landscape of eastern Washington. Of the several hundred wetlands that were surveyed and visited as part of the function assessment project and the revisions to the rating system, only nine could be classified as alkali.

Alkali wetlands are placed into Category I because they probably cannot be reproduced through compensatory mitigation and are relatively rare in the landscape. No information was found on any attempts to create or restore alkali wetlands. Any impacts to alkali wetlands will, therefore, probably result in a net loss of their functions and values.

11.2.2 Natural Heritage wetlands

Scientists of the DNR Natural Heritage Program (NHP) identify natural heritage wetlands as high-quality, relatively undisturbed wetlands, or as wetlands that support state threatened or endangered plant species. Extremely high-quality, relatively undisturbed examples of wetlands are very uncommon in eastern Washington. By categorizing these wetlands as Category I, we are providing a high level of protection for the undisturbed character of these remaining high-quality wetlands. Examples of undisturbed wetlands help us to understand natural wetland processes. Furthermore, the presence of rare plants in a wetland indicates unique habitat that might otherwise not be identified through the rating system. Rare plant populations are also sensitive to disturbance, particularly to activities that result in the spread of invasive species. The DNR's NHP has identified important natural plant communities and species that are very sensitive to disturbance or are threatened by human activities, and maintains a database of these sites. A list of state threatened or endangered plant species can be found on the DNR NHP web site, at http://www.dnr.wa.gov/nhp/index.html.

11.2.3 Bogs

Relatively undisturbed bogs are Category I wetlands because they are sensitive to disturbance and impossible to re-create through compensatory mitigation. Bogs are low-nutrient, acidic wetlands that have organic soils, and whose water regime is based on precipitation. They are rare, sensitive habitats with an irregular distribution in eastern Washington. The chemistry of bogs is such that changes to the water regime or water quality of the wetland can easily alter their ecosystems. The plants and animals that grow in bogs are specifically adapted to such conditions and do not tolerate changes. Immediate changes in the composition of the plant community often occur after water regime changes. Minor changes in the water regime or nutrient levels in these systems can have major adverse impacts on the plant and animal communities (Grigal and Brooks, 1997, quoted in Hruby 2003).

In addition to being sensitive to disturbance, bogs are not easy to re-create through compensatory mitigation. Researchers in Northern Europe and Canada have found that restoring bogs is difficult, specifically in regard to plant communities (Bolscher 1995; Grosvermier et al. 1995; Schouwenaars 1995; Schrautzer et al. 1996), water regime (Grootjans and van Diggelen 1995; Schouwenaars 1995) and/or water chemistry (Wind-Mulder and Vitt 2000) (all quoted in Hruby 2003). In fact, restoration may be impossible because of changes in biotic and abiotic properties (Schrautzer et al.; Shouwenaars).

Furthermore, bogs form extremely slowly, with organic soils forming at a rate of about one inch per 50 years in eastern Washington (Rigg 1958). The majority of the

bogs/fens observed in Washington have been degraded through modification of their water regime and reductions in species diversity and integrity. All remaining relatively undisturbed bogs need a high level of protection. Nutrient-poor wetlands, such as bogs, have higher species richness, many more rare species, and a greater range of plant communities than nutrient-rich wetlands (Adamus and Brandt 1990, quoted in Hruby 2003). They are, therefore, more important than would be accounted for using a simple assessment of wetland functions (Moore et al. 1989, quoted in Hruby 2003).

11.2.4 Mature and old-growth forested wetlands with slow-growing trees

Mature and old-growth forested wetlands over one quarter acre in size and dominated by slow-growing native trees are rated as Category I because these wetlands cannot be easily replaced through compensatory mitigation. A mature forest of slow-growing trees may require a century or more to develop, and the full range of functions performed by these wetlands may take even longer.

These forested wetlands are also important because they represent a second *priority habitat*, as defined by the state Department of Fish and Wildlife: "Priority habitats are those habitat types or elements with unique or significant value to a diverse assemblage of species" (quoted in Sheldon et al., p. 7).

Wetland species considered to be slow-growing and native in eastern Washington are western red cedar (*Thuja plicata*), Alaska yellow cedar (*Chamaecyparis nootkatensis*), pine spp. (mostly white pine [*Pinus monticola*]), western hemlock (*Tsuga heterophylla*), Oregon white oak (*Quercus garryana*), and Englemann spruce (*Picea engelmannii*).

11.2.5 Wetlands that perform many functions very well

Wetlands scoring 70 points or more (out of 100) on the questions related to functions are rated Category I wetlands. Not all wetlands function equally well, especially across the suite of functions performed. A field questionnaire was developed to provide a method by which wetlands can be categorized based on their relative performance of different functions. Wetlands scoring 70 points or more were judged to have the highest levels of function. Wetlands that provide high levels of all three types of functions (water quality improvement, hydrologic functions, and habitat) are also relatively rare. Of the 90 wetlands used to calibrate the rating system in eastern Washington, only 12 (13 percent) scored 70 points or higher. The questionnaire on wetland functions is based on the six-year effort to develop detailed methods for assessing wetland functions in both eastern and western Washington. These methods currently represent the best available science in rapid assessments of wetland functions.

11.3 Category II Wetlands

Category II wetlands are

- forested wetlands in the flood plains of rivers,
- mature forested wetlands containing fast-growing trees,
- relatively undisturbed vernal pools present within a mosaic of other wetlands,
- wetlands with a moderately high level of functions, or
- a wetland identified by the state DNR as containing sensitive plant species.

These wetlands are difficult, though not impossible, to replace, and provide high levels of some functions. These wetlands occur more commonly than Category I wetlands, but still need a relatively high level of protection. Thirty-six out of 90 wetlands were listed as Category II during the field-testing and calibration of this rating system.

11.3.1 Forested wetlands in the floodplains of rivers

Forested wetlands are an important resource in the floodplains of rivers, especially in the areas through which the river may flow regularly (often called the channel migration zone). These wetlands are rated Category II, at a minimum, because the questionnaire on functions does not adequately capture their unique role in the ecosystem. Trees in the floodplains are critical to the proper functioning and dynamic natural processes of rivers. Please note, however, that many forested wetlands with high habitat heterogeneity in floodplains may actually be a Category I, based on the functions.

Trees in floodplains "are a primary factor influencing channel form, creating the pools, riffles and side channels that are essential habitat for many fish and other aquatic species. Erosion is buffered by tree roots and large organic debris introduced into channels through erosion and windfall. Large woody debris forms stable associations when trapped within side channels, and functions to minimize bank erosion, dissipate channel energy, meter flow down the side channels, create localized rearing and flood refuge areas, and contribute to the stabilization of the main river channel" (Gorsline 2002, quoted in Hruby 2003, p. 8).

11.3.2 Mature and old-growth forested wetlands with fast-growing trees

Mature and old-growth forested wetlands over one quarter acre in size and dominated by fast-growing native trees are rated as Category II because they are hard to replace within the time frame of most regulatory activities. The time needed to replace them is shorter than for forests with slow-growing trees, but still is significant. These forested wetlands are also important because they represent a second priority habitat, as defined by the Washington State Department of Fish and Wildlife.

Native fast-growing wetland trees are:

- **alders**—red (*Alnus rubra*) and thin-leaf (*A. tenuifolia*);

- **cottonwoods**—narrow-leaf (*Populus angustifolia*) and black (*P. balsamifera*);
- **willows**—peach-leaf (*Salix amygdaloides*), Sitka (*S. sitchensis*), and Pacific (*S. lasiandra*); and
- **aspen** (*Populus tremuloides*).

11.3.3 Vernal pools

Vernal pools, or rain pools, located in a landscape with other wetlands and relatively undisturbed during the early spring are rated Category II because the questionnaire on functions does not adequately capture their unique role in the ecosystem.

Vernal pool ecosystems are formed when small depressions in the scabrock or in shallow soils fill with snowmelt or spring rains. They retain water until the late spring, when reduced precipitation and increased evapotranspiration lead to a complete drying out. The wetlands hold water long enough throughout the year to allow some strictly aquatic organisms to flourish, but not long enough for the development of a typical wetland environment (Zedler 1987, quoted in Hruby 2003).

The Washington Natural Heritage Program (WNHP) has recognized the vernal pool ecosystem as an important component of Washington's Natural Area System. Vernal pools in the scablands are the first to melt in the early spring. This open water provides areas where migrating waterfowl can find food while other, larger waterbodies are still frozen. Furthermore, the open water provides areas for pair bonding in waterfowl (R. Friesz, WDFW, pers. comm., quoted in Hruby 2003). Thus, vernal pools in a landscape with other wetlands provide an important habitat function for waterfowl, which requires a relatively high level of protection. This is the reason why relatively undisturbed vernal pools in a mosaic of other wetlands are Category II, and an isolated undisturbed vernal pool is a Category III.

11.3.4 Natural Heritage wetlands

Wetlands that are identified by the Washington Natural Heritage Program as wetlands that support state sensitive plant species are rated a Category II. The presence of rare plants in a wetland suggests unique habitat qualities that otherwise might not be identified through the rating system. Rare plant populations are also sensitive to disturbance, particularly to activities that result in the spread of invasive species.

11.3.5 Wetlands that perform many functions well

Wetlands scoring between 51 and 69 points (out of 100) on the questions related to the functions present are Category II wetlands. Such wetlands were judged to have relatively high levels of function for most functions, or performed one group of functions very well and the other two moderately well.

11.4 Category III Wetlands

Category III wetlands are:

- isolated vernal pools, and
- wetlands with a moderate level of functions (scores between 30 and 50 points).

Wetlands scoring between 30 and 50 points generally have been disturbed in some ways, and are often smaller, less diverse, and/or more isolated in the landscape than Category II wetlands.

11.5 Category IV Wetlands

Category IV wetlands have the lowest level of functions (scores less than 30 points) and are often heavily disturbed. These are wetlands that we should be able to replace, and in some cases may be able to improve. However, experience has shown that replacement cannot be guaranteed in any specific case. These wetlands may provide some important functions, and should to some degree be protected.

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CHAPTER 4: A REVIEW OF THE BEST AVAILABLE SCIENCE REGARDING UPLAND HABITAT PROTECTION AND THE IDENTIFICATION OF HABITAT CONSERVATION AREAS

1.0 INTRODUCTION

The Growth Management Act requires Yakima County to designate and protect Critical Areas, among which are wildlife habitat conservation areas. The Washington Administrative Code (WAC) defines wildlife habitat conservation as land management for maintaining species in suitable habitats within their natural geographic distribution so that isolated subpopulations are not created. WAC 365-190(5)(a) further describes those habitat areas as follows:

"Fish and wildlife habitat conservation areas include:

- areas with which endangered, threatened, and sensitive species have a primary association;
- habitats and species of local importance;
- commercial and recreational shellfish areas;
- kelp and eelgrass beds;
- herring and smelt spawning areas;
- naturally occurring ponds under twenty acres and their submerged aquatic beds that provide fish or wildlife habitat;
- waters of the state;
- lakes, ponds, streams, and rivers planted with game fish by a governmental or tribal entity; or
- state natural area preserves and natural resource conservation areas."

Yakima County currently protects wildlife habitat in an indirect manner. The current Critical Areas Ordinance protects habitat associated with stream corridors and wetlands. Additionally, current requirements under the State Environmental Policy Act (SEPA) require an environmental review of governmental actions, such as permits, that may have a significant environmental impact; this includes impacts to fish and wildlife habitat. Many smaller projects, however, are exempt from the environmental review process. Projects that are subject to SEPA are evaluated for their possible impacts, while the exempted projects are not.

The Yakima County Comprehensive Plan 2015 currently addresses these requirements through adopted goals and policies to protect fish and wildlife habitat. Those goals and policies are as follows:

- **Goal NS 17**—Provide for the maintenance and protection of habitat areas for fish and wildlife.

- **Policy NS 17.1**—Encourage the protection of fish and wildlife habitat from a regionwide perspective, to ensure that the best representation and distribution

of habitats remain, and to protect the natural values and functions of those habitats. Fish and wildlife habitat protection considerations should include:

- the physical and hydrological connections between different habitat types, to prevent isolation of those habitats;
- a diversity of habitat types on both a local and a regional scale;
- large tracts of fish and wildlife habitat;
- areas of high species diversity;
- locally or regionally unique and rare habitats; and
- winter ranges and migratory bird habitat of seasonal importance.

- **Policy NS 17.6**—Protect the habitat of Washington State listed species of concern, and of priority habitats and species, in order to maintain their populations within Yakima County.

The addition of a wildlife habitat conservation area to the Critical Areas Ordinance will allow for habitat protection relative to all land use proposals. In implementing the stated comprehensive plan goals and policies, it is important to understand that a diverse inventory of naturally occurring vegetation will ensure maximum richness of species within the County. Yakima County is home to several significant classifications of habitat that account for our diverse wildlife population. Some of the more predominant among these habitats are old growth and mature forests, shrub-steppe and riparian areas, and Oregon white oak woodlands. It is also important to understand what management practices are necessary to preserve the habitat and the wildlife they protect.

The wildlife habitat conservation area that has been mapped for the Critical Areas Update considers species that occur within Yakima County in areas of high species concentration, and connects these areas with naturally occurring riparian vegetative corridors, as well as with other natural features that provide for the migration of mammals, birds, reptiles, and amphibians. The following paragraphs discuss the importance of various types of habitat, what habitat is the most important, how much is needed to ensure the adequate protection of the entire range of wildlife that occurs, and how this habitat was mapped.

2.0 HABITAT EVALUATION

This evaluation addresses upland habitat only. Fish habitat is considered in the stream corridor best available science report (Chapter 2).

The ultimate aim of planning for habitats is the conservation of associated wildlife species. Three main elements determine whether species are conserved: the availability of habitat, the behavior of individual animal species, and the dynamics of populations. Availability of habitat determines what resources and environments are accessible. Behavior establishes how animals select their resources and interact with the environment. Population dynamics dictate how the habitats are occupied. To maintain viable populations of wildlife species, there must be adequate

environmental conditions for reproduction, foraging, resting, cover, and dispersal of animals at a variety of scales across the landscape.

One important aspect of habitat that has a significant effect on species persistence is fragmentation, or the increase in isolation and decrease in the size of habitat areas. No single factor has been a greater cause of declines in wildlife populations than loss of habitat, and no one aspect of change of habitat conditions has been more insidious and difficult to understand than fragmentation. Fragmentation affects quality of habitat of a given species in numerous ways. It alters the quality and type of the food base. It changes microclimates by altering temperature and moisture regimes. It alters the availability of cover and brings species together that normally would have little interaction, and thus may increase the rate of nest parasitism, competition, and predation. It can also increase contact with and exploitation by humans.

The size of a habitat area, however, is not the only important factor. Other key factors affecting habitat quality include the presence of essential resources such as food, water, nest building materials, the complexity of the environment, and the presence or absence of predator species and diseases. These factors are often influenced by elements outside the habitat area (Kagen, Morgan, and Blakely 2000; Morrison, Marcot and Mannon 1992).

As a method of linking large habitat areas, migration corridors offer a means to connect publicly protected lands and other intact habitat areas. Riparian corridors offer a natural system of linkages between these large habitat areas. The value of riparian corridors varies from species to species, depending on the available width. This width ranges from several hundred feet in width for the migration of large mammals down to widths less than 50 feet for various amphibian and reptile species. In semi-arid regions such as Yakima County, riparian corridors not only offer migratory linkages between large habitat areas, but also offer important refuge and habitat for numerous species that rely on the riparian areas for their existence. Of the more than 300 vertebrate species known to occur within Yakima County, approximately 57 percent of them use the riparian corridors as their primary habitat. Species that use riparian areas for some portion of their life cycle represent up to 80 percent of all species (Kagen, Morgan, and Blakely 2000; Morrison, Marcot, and Mannon 1992).

In addition to riparian corridors, cliffs, steep slope areas, and ravines can add to the inventory of corridors available for species movement and in some cases can also effectively add to the width of relatively narrow riparian areas adjacent to them. These non-riparian corridors are essential to connecting some of the shrub-steppe habitat areas in the eastern portion of the county (Morrison, Marcot, and Mannon 1992).

In providing for adequate distribution of habitat within and across landscapes, a clear understanding of the elements that change the landscape is necessary. Some of these elements include loss of vegetative cover, erosion, and the alteration or disruption of a water supply, to name just a few. Assessing the cumulative effects

of activities both on- and offsite is important when planning for specific habitat amounts and configurations. Managing a natural landscape for both human presence and ecological objectives depends on keeping human activity inversely proportional to the sensitivity of landscape elements, protecting the areas of major animal movement, and maintaining natural disturbance regimes. Managing a remnant of a natural landscape focuses on these same three objectives, plus two more: minimizing isolation and minimizing human impacts on the surrounding matrix (Morrison, Marcot, and Mannon 1992).

3.0 YAKIMA COUNTY VEGETATIVE MATRIX

The available vegetative habitat within Yakima County is extremely diverse and offers habitat for a wide variety of vertebrate species. This habitat ranges from the permanent snow and alpine areas in the upper Cascades to the arid steppe regions in the eastern half of the county. Although much of this varying landscape and its wide range of species habitat still survives to a significant degree, much is threatened by nonnative plant species or by incompatible land uses. Johnson and O'Neil (2003) provide detailed information regarding the description, extent, condition, and species of major habitat vegetation classifications in this area. Habitat vegetation for Yakima County includes the following.

3.1 Alpine Grasslands and Shrublands

Alpine grassland and shrubland habitat always occurs above the upper tree line in the mountains, or a short distance below it. Typically, it occurs adjacent to or in a mosaic with *subalpine parkland*. The GAP vegetation classifications within this habitat include *alpine* and *permanent snow/ice*. This habitat is naturally very limited in extent. Most of this habitat is still in good condition and is dominated by native species. Some vertebrate species that are known to occur within this vegetation class include:

- **Mammals**

broad-footed mole
American pika
yellow-pine chipmunk
yellow-bellied marmot
hoary marmot
Olympic marmot
Belding's ground squirrel
Columbian ground squirrel
Cascade golden-mantled ground squirrel
Douglas' squirrel
northern pocket gopher
deer mouse
bushy-tailed woodrat
southern red-backed vole
heather vole
long-tailed vole
creeping vole
water vole
western jumping mouse
Pacific jumping mouse
coyote
red fox
black bear
American marten
long-tailed weasel
mountain lion
bobcat
black-tailed deer
mule deer
mountain goat
bighorn sheep

- **Amphibians and reptiles**

long-toed salamander
western toad
Pacific chorus (tree) frog
common garter snake

- **Birds**

turkey vulture
mallard
green-winged teal
Barrow's goldeneye
northern harrier
sharp-shinned hawk
Cooper's hawk
golden eagle
American kestrel
prairie falcon
white-tailed ptarmigan
blue grouse
spotted sandpiper
great horned owl
rufous hummingbird
gray jay
Clark's nutcracker
common raven
horned lark
violet-green swallow
black-capped chickadee
mountain chickadee
chestnut-back chickadee
red-breasted nuthatch
canyon wren
winter wren
golden-crowned kinglet
ruby-crowned kinglet
hermit thrush
varied thrush
European starling
American pipit
cedar waxwing
Nashville warbler
yellow-rumped warbler
Macgillivray's warbler
Wilson's warbler
chipping sparrow
vesper sparrow
savannah sparrow
fox sparrow
song sparrow
white-crowned sparrow
dark-eyed junco
brewer's blackbird
pine grosbeak
red crossbill
pine siskin
evening grosbeak

3.2 Subalpine Parkland

The *subalpine parkland* habitat lies above the *mixed montane conifer forest* or *lodgepole pine forest* habitats and below the *alpine grassland* and *shrubland* habitats, between 5,000 and 8,000 feet elevation. The GAP vegetation zones that fall within this category include *alpine parkland* and *subalpine fir*. Wind blasting by ice and snow plays a critical role in this zone. Shifts in climate factors, such as drought, snow pack depth, or duration either allow tree invasions into meadows and shrublands or retards tree growth. Land uses within this zone include recreation and grazing. This habitat is generally considered fairly stable with some possible future impacts associated with warming. Some species that are known to occur within this vegetation class include:

- **Mammals**

masked shrew
Trowbridge's shrew
shrew-mole
Yuma myotis
little brown myotis
long-legged myotis
long-eared myotis
Townsend's big-eared bat
American pika
snowshoe hare
Townsend's chipmunk
yellow-bellied marmot
hoary marmot
golden-mantled ground squirrel
northern pocket gopher
American beaver
deer mouse
bushy-tailed woodrat
heather vole
long-tailed vole
creeping vole
Pacific jumping mouse
common porcupine
coyote
red fox
black bear

American marten
ermine
long-tailed weasel
mountain lion
bobcat
mule deer
mountain goat
bighorn sheep

- **Amphibians and reptiles**

common garter snake
northwestern salamander
long-toed salamander
Cope's giant salamander
Pacific giant salamander
rough-skinned newt
western toad
Pacific chorus (tree) frog
Cascades frog
Columbia spotted frog

- **Birds**

turkey vulture
mallard
Barrow's goldeneye
osprey
northern harrier
sharp-shinned hawk
Cooper's hawk
northern goshawk
golden eagle
American kestrel
prairie falcon
ruffed grouse
spruce grouse
blue grouse
spotted sandpiper
band-tailed pigeon
great horned owl
northern pygmy owl
vaux's swift
black-chinned hummingbird
calliope hummingbird
rufous hummingbird
Lewis's woodpecker
Williamson's sapsucker
red-naped sapsucker
three-toed woodpecker
black-backed woodpecker
northern flicker
olive-sided flycatcher
dusky flycatcher
gray jay
Steller's jay
Clark's nutcracker
black-billed magpie
American crow
common raven
horned lark
violet-green swallow
barn swallow
black-capped chickadee
mountain chickadee
red-breasted nuthatch
canyon wren
winter wren
American dipper
golden-crowned kinglet
ruby-crowned kinglet
western bluebird
Townsend's solitaire
Swainson's thrush
hermit thrush
American robin
varied thrush
European starling
American pipit
cedar waxwing
orange-crowned warbler
Nashville warbler
yellow-rumped warbler
Townsend's warbler
hermit warbler
Macgillivray's warbler
western tanager
chipping sparrow
vesper sparrow
savannah sparrow
fox sparrow
song sparrow
Lincoln's sparrow
golden-crowned sparrow
dark-eyed junco
brown-headed cowbird
pine grosbeak
purple finch
Cassin's finch
white-winged crossbill
pine siskin
evening grosbeak

3.3 Montane Mixed Conifer Forest

The *montane mixed conifer forest* habitat is typified by a moderate-to-deep winter snow pack that persists for 3 to 9 months. On the east side of the Cascade Range it occupies a narrow zone of about 1,500 vertical feet. The topography is generally mountainous. The GAP vegetation classifications within this habitat include *mountain hemlock, interior Douglas fir, grand fir* and *subalpine fir*. The typical land use is forestry or recreation. Most of this vegetation type is found on public lands managed for timber values, and much of it has been harvested in a dispersed-patch pattern. There has probably been little or no decline in the extent of this type over time. Large areas of this habitat are relatively undisturbed by human impacts and include significant old-growth stands, while other areas have been extensively affected by logging, especially clear-cut areas. Some species that are known to occur within this vegetation class include:

- **Mammals**

masked shrew
vagrant shrew
montane shrew
Trowbridge's shrew
shrew-mole
coast mole
California myotis
Yuma myotis
little brown myotis
long-legged myotis
fringed myotis
long-eared myotis
silver-haired bat
big brown bat
hoary bat
Townsend's big-eared bat
American pika
snowshoe hare
mountain beaver
yellow-pine chipmunk
Townsend's chipmunk
golden-mantled ground squirrel
Douglas' squirrel
northern flying squirrel
northern pocket gopher
American beaver
deer mouse
bushy-tailed woodrat
heather vole
montane vole
long-tailed vole
creeping vole
Pacific jumping mouse
common porcupine
coyote
black bear
American marten
ermine
long-tailed weasel
mink
mountain lion
bobcat
mule deer
white-tailed deer
mountain goat

- **Amphibians and reptiles**

northwestern salamander
long-toed salamander
Pacific giant salamander
Olympic torrent salamander
Columbia torrent salamander
southern torrent salamander
Cascade torrent salamander
rough-skinned newt
Dunn's salamander
*Larch Mountain salamander
Van Dyke's salamander
western red-backed salamander
Del Norte salamander
Siskiyou mountains salamander
ensatina
clouded salamander
California slender salamander
tailed frog
western toad
Pacific chorus (tree) frog
red-legged frog
Cascades frog

Oregon spotted frog
Columbia spotted frog

northern alligator lizard
western skink

rubber boa
common garter snake

- **Birds**

turkey vulture
Barrow's goldeneye
osprey
*bald eagle
sharp-shinned hawk
Cooper's hawk
northern goshawk
red-tailed hawk
golden eagle
American kestrel
prairie falcon
ruffed grouse
blue grouse
killdeer
band-tailed pigeon
flammulated owl
great horned owl
northern pygmy-owl
*spotted owl
long-eared owl
northern saw-whet owl
common nighthawk
Vaux's swift
rufous hummingbird
Lewis's woodpecker
Williamson's sapsucker
red-naped sapsucker
red-breasted sapsucker
hairy woodpecker
three-toed woodpecker
black-backed woodpecker
northern flicker
pileated woodpecker
olive-sided flycatcher
western wood-pewee
willow flycatcher
Hammond's flycatcher
dusky flycatcher
Pacific-slope flycatcher
warbling vireo
gray jay
Steller's jay
Clark's nutcracker
common raven
tree swallow
violet-green swallow
northern winged swallow
barn swallow
mountain chickadee
chestnut-backed chickadee
red-breasted nuthatch
brown creeper
canyon wren
house wren
golden-crowned kinglet
ruby-crowned kinglet
western bluebird
mountain bluebird
Townsend's solitaire
Swainson's thrush
hermit thrush
American robin
varied thrush
European starling
cedar waxwing
orange-crowned warbler
Nashville warbler
yellow-rumped warbler
Townsend's warbler
hermit warbler
Macgillivray's warbler
Wilson's warbler
western tanager
chipping sparrow
fox sparrow
song sparrow
white-crowned sparrow
dark-eyed junco
brown-headed cowbird
pine grosbeak
purple finch
Cassin's finch
red crossbill
pine siskin
evening grosbeak

*On state or federal list of threatened or endangered species

3.4 Eastside Mixed Conifer Forest

The *eastside mixed conifer forest* habitat is primarily mid-montane, with an elevation range mostly between 3,000 and 5,500 feet. Eastside mixed conifer habitats are montane forests and woodlands. This habitat contains various GAP vegetation classifications including *interior Douglas fir*, *ponderosa pine*, *whitebark pine*, *grand fir*, *western hemlock* and *subalpine fir*. Stand canopy structure is

generally diverse, although single-layer forest canopies are currently more common than multilayered forests with snags and large woody debris. The tree layer varies from closed forests to more open-canopy forests or woodlands. This habitat may include very open stands. The undergrowth is complex and diverse. Tall shrubs, low shrubs, forbs, or any combination may dominate stands. Deciduous shrubs typify shrub layers. Prolonged canopy closure may lead to development of sparsely vegetated undergrowth. Roads, timber harvest, periodic grazing, and fire suppression have compromised these forests. Even though this habitat is more extensive than it was previously to 1900, natural processes and functions have been modified enough to alter its natural status as functional habitat for many species. Some species known to occur within this vegetation class include:

- **Mammals**

masked shrew
vagrant shrew
montane shrew
Trowbridge's shrew
shrew-mole
coast mole
California myotis
Yuma myotis
little brown myotis
long-legged myotis
long-eared myotis
silver-haired bat
big brown bat
hoary bat
Townsend's big-eared bat
snowshoe hare
yellow-pine chipmunk
Townsend's chipmunk
yellow-bellied marmot
golden-mantled ground squirrel
Douglas' squirrel
northern flying squirrel
northern pocket gopher
American beaver
deer mouse
bushy-tailed woodrat
heather vole
montane vole
long-tailed vole
Pacific jumping mouse
common porcupine
coyote
black bear
American marten
ermine
long-tailed weasel
mink
American badger
striped skunk
mountain lion
bobcat
mule deer
white-tailed deer
bighorn sheep

- **Amphibians and reptiles**

northwestern salamander
long-toed salamander
Pacific giant salamander
rough-skinned newt
tailed frog
great basin spadefoot
western toad
Pacific chorus (tree) frog
red-legged frog
Cascades frog
Columbia spotted frog

- **Birds**

turkey vulture
osprey
*bald eagle
sharp-shinned hawk
Cooper's hawk
northern goshawk
red-tailed hawk
golden eagle
American kestrel
prairie falcon
ruffed grouse
blue grouse
wild turkey
killdeer
band-tailed pigeon
flammulated owl
western screech-owl
great horned owl
northern pygmy-owl
*spotted owl
barred owl
long-eared owl
northern saw-whet owl
common nighthawk

white-throated swift
rufous hummingbird
Lewis's woodpecker
Williamson's sapsucker
red-naped sapsucker
hairy woodpecker
white-headed woodpecker
three-toed woodpecker
black-backed woodpecker
northern flicker
pileated woodpecker
olive-sided flycatcher
western wood-pewee
willow flycatcher
Hammond's flycatcher
dusky flycatcher
warbling vireo
gray jay
Steller's jay
Clark's nutcracker
common raven
violet-green swallow
northern rough-winged swallow
bank swallow
cliff swallow
barn swallow
mountain chickadee
chestnut-backed chickadee
red-breasted nuthatch
brown creeper
canyon wren
house wren
winter wren
golden-crowned kinglet
ruby-crowned kinglet
western bluebird
mountain bluebird
Townsend's solitaire
Swainson's thrush
hermit thrush
American robin
varied thrush
European starling
orange-crowned warbler
Nashville warbler
yellow-rumped warbler
black-throated gray warbler
Townsend's warbler
hermit warbler
Macgillivray's warbler
Wilson's warbler
western tanager
spotted towhee
chipping sparrow
fox sparrow
song sparrow
white-crowned sparrow
dark-eyed junco
black-headed grosbeak
pine grosbeak
purple finch
Cassin's finch
red crossbill
pine siskin
American goldfinch
evening grosbeak

*On state or federal list of threatened or endangered species

3.5 Ponderosa Pine Forest and Woodlands

The *ponderosa pine forest* habitat generally occurs on the driest sites supporting conifers. It is widespread and variable, appearing on moderate-to-steep slopes in canyons, foothills, and on plateaus or plains near mountains. This habitat represents the lower tree line zone, forming a transition with the *eastside mixed conifer forest* habitat. Tall ponderosa pine over Oregon white oak trees form stands along part of the east Cascades. Oregon white oak dominates limited areas of open woodlands. This habitat generally is degraded because of increased numbers of exotic plants and decreased native bunchgrasses. One third of Pacific Northwest Oregon white oak, ponderosa pine, and dry Douglas fir or grand fir community types listed in the National Vegetation Classification are considered imperiled or critically imperiled. Some species known to occur within this vegetation class include:

- **Mammals**

masked shrew
vagrant shrew
Trowbridge's shrew
coast mole
California myotis
Yuma myotis
little brown myotis
long-legged myotis
long-eared myotis
silver-haired bat
big brown bat
hoary bat
spotted bat
Townsend's big-eared bat
pallid bat
snowshoe hare
least chipmunk
yellow-pine chipmunk
yellow-bellied marmot
golden-mantled ground squirrel
*western gray squirrel
Douglas' squirrel
northern flying squirrel
northern pocket gopher
American beaver
deer mouse
montane vole
long-tailed vole
Pacific jumping mouse
common porcupine
coyote
black bear
ermine
long-tailed weasel
mink
American badger
striped skunk
mountain lion
bobcat
mule deer
white-tailed deer
bighorn sheep

- **Amphibians and reptiles**

long-toed salamander
rough-skinned newt
*Larch Mountain salamander
ensatina
tailed frog
Great Basin spadefoot
western toad
Pacific tree frog
Columbia spotted frog
bullfrog
painted turtle
northern alligator lizard
southern alligator lizard
short-horned lizard
sagebrush lizard
western fence lizard
western skink
rubber boa
racer
sharptail snake
ringneck snake
night snake
striped whipsnake
western terrestrial garter snake
northwestern garter snake
common garter snake
western rattlesnake

- **Birds**

turkey vulture
osprey
*bald eagle
sharp-shinned hawk
Cooper's hawk
northern goshawk
red-tailed hawk
golden eagle
American kestrel
merlin
prairie falcon
ring-necked pheasant
ruffed grouse
blue grouse
wild turkey
California quail
killdeer
band-tailed pigeon
mourning dove
flammulated owl
western screech-owl
great horned owl
northern pygmy-owl
*spotted owl
barred owl
long-eared owl
northern saw-whet owl
common nighthawk
rufous hummingbird
Lewis's woodpecker
Williamson's sapsucker
red-naped sapsucker
hairy woodpecker
white-headed woodpecker
three-toed woodpecker
black-backed woodpecker
northern flicker
pileated woodpecker
olive-sided flycatcher
western wood-pewee
willow flycatcher
Hammond's flycatcher
gray flycatcher

dusky flycatcher
say's phoebe
ash-throated flycatcher
western kingbird
eastern kingbird
warbling vireo
gray jay
Steller's jay
Clark's nutcracker
black-billed magpie
common raven
violet-green swallow
northern rough-winged swallow
cliff swallow
barn swallow
mountain chickadee
red-breasted nuthatch
white-breasted nuthatch
pygmy nuthatch
brown creeper
rock wren
canyon wren
house wren
golden-crowned kinglet
ruby-crowned kinglet
western bluebird
mountain bluebird
Townsend's solitaire
hermit thrush
American robin
varied thrush
European starling
cedar waxwing
orange-crowned warbler
Nashville warbler
yellow-rumped warbler
black-throated gray warbler
Townsend's warbler
Macgillivray's warbler
Wilson's warbler
western tanager
spotted towhee
chipping sparrow
lark sparrow
fox sparrow
song sparrow
white-crowned sparrow
dark-eyed junco
black-headed grosbeak
lazuli bunting
purple finch
Cassin's finch
house finch
red crossbill
pine siskin
American goldfinch
evening grosbeak

*On state or federal list of threatened or endangered species

3.6 Eastside Riparian—Wetlands

Riparian habitats appear along perennial and intermittent rivers and streams. This habitat also appears in impounded wetlands and along lakes and ponds. The riparian and wetland areas usually are in fairly narrow bands along valley streams. The most typical stand is limited to 100 to 200 feet from streams. Approximately 40 percent of riparian shrublands occurred above 3,280 feet in elevation previous to 1900; now nearly 80 percent is found above that elevation. This change reflects losses to agricultural development, roads, and dams and other flood-control activities. Riparian habitat is located within all GAP vegetation zones. Some species known to occur within the riparian areas include:

- **Mammals**

masked shrew
vagrant shrew
montane shrew
Trowbridge's shrew
shrew-mole
coast mole
California myotis
Uuma myotis
little brown myotis
long-legged myotis
long-eared myotis
silver-haired bat
western pipistrelle
big brown bat
hoary bat
spotted bat
Townsend's big-eared bat
pallid bat
snowshoe hare
white-tailed jackrabbit
yellow-pine chipmunk
yellow-bellied marmot
northern flying squirrel
northern pocket gopher
American beaver
western harvest mouse
deer mouse

bushy-tailed woodrat
heather vole
montane vole
long-tailed vole
creeping vole
muskrat
Pacific jumping mouse

common porcupine
coyote
black bear
raccoon
American marten
long-tailed weasel
mink

American badger
mountain lion
bobcat
mule deer
white-tailed deer

- **Amphibians and reptiles**

northwestern salamander
long-toed salamander
rough-skinned newt
tailed frog
Great Basin spadefoot
western toad

Woodhouse's toad
Pacific tree frog
red-legged frog
Cascades frog
Columbia spotted frog
bullfrog
painted turtle
northern alligator lizard

rubber boa
racer
sharptail snake
western terrestrial garter snake
common garter snake
western rattlesnake

- **Birds**

pied-billed grebe
great blue heron
black-crowned night-heron
turkey vulture
wood duck
mallard
green-winged teal
ring-necked duck
harlequin duck
hooded merganser
common merganser
osprey
*bald eagle
northern harrier
Cooper's hawk
northern goshawk
Swainson's hawk
red-tailed hawk
golden eagle
American kestrel
prairie falcon
chukar
ring-necked pheasant
ruffed grouse
blue grouse
wild turkey

California quail
*sandhill crane
killdeer
spotted sandpiper
band-tailed pigeon
mourning dove
barn owl
flammulated owl
western screech-owl
great horned owl
northern pygmy-owl
barred owl
long-eared owl
northern saw-whet owl
common nighthawk
calliope hummingbird
rufous hummingbird
belted kingfisher
Lewis's woodpecker
red-naped sapsucker
red-breasted sapsucker
downy woodpecker
hairy woodpecker
three-toed woodpecker
black-backed woodpecker
northern flicker
pileated woodpecker

olive-sided flycatcher
western wood-pewee
willow flycatcher
dusky flycatcher
Say's phoebe
eastern kingbird
Cassin's vireo
warbling vireo
gray jay
Steller's jay
black-billed magpie
common raven
tree swallow
violet-green swallow
northern rough-winged swallow
bank swallow
cliff swallow
barn swallow
black-capped chickadee
mountain chickadee
red-breasted nuthatch
white-breasted nuthatch
pygmy nuthatch

brown creeper
canyon wren
house wren
winter wren
American dipper
golden-crowned kinglet
ruby-crowned kinglet
western bluebird
mountain bluebird
Townsend's solitaire
veery
Swainson's thrush
hermit thrush
American robin
gray catbird
European starling
cedar waxwing
orange-crowned warbler
Nashville warbler
yellow warbler
yellow-rumped warbler
Macgillivray's warbler
common yellowthroat
Wilson's warbler
yellow-breasted chat
western tanager
spotted towhee
American tree sparrow
chipping sparrow
savannah sparrow
fox sparrow
song sparrow
Lincoln's sparrow
white-crowned sparrow
golden-crowned sparrow
dark-eyed junco
black-headed grosbeak
lazuli bunting
bobolink
red-winged blackbird
brewer's blackbird
brown-headed cowbird
Bullock's oriole
Cassin's finch
house finch
pine siskin
American goldfinch
evening grosbeak

*On state or federal list of threatened or endangered species

3.7 Shrub-Steppe

Shrub-steppe habitat can appear in large landscape patches. *Three-tip sage*, *bitterbrush*, and *central arid steppe* are three GAP vegetation classifications that fall into this broad vegetation class. Livestock grazing is the primary land use in the shrub-steppe, although much has been converted to irrigation or dryland agriculture. Large areas occur within the Army Firing Center and wildlife refuges. Burrowing animals and their predators likely play important roles in creating small-scale patch patterns. The shrub-steppe habitat has seen an increase in exotic plant importance and a decrease in native bunchgrasses. More than half of the Pacific Northwest shrub-steppe habitat community types listed in the National Vegetation Classification are considered imperiled or critically imperiled. Some species that are known to occur within this vegetation class include:

- **Mammals**

California myotis
Yuma myotis
little brown myotis
long-legged myotis
long-eared myotis
big brown bat
spotted bat
Townsend's big-eared bat
pallid bat
black-tailed jackrabbit
least chipmunk
Townsend's ground squirrel
Great Basin pocket mouse
western harvest mouse
deer mouse
northern grasshopper mouse
bushy-tailed woodrat
montane vole
sagebrush vole
coyote
mule deer

- **Amphibians and reptiles**

rough-skinned newt
Great Basin spadefoot
western toad
Woodhouse's toad
Columbia spotted frog
bullfrog
painted turtle
short-horned lizard
sagebrush lizard
western fence lizard
side-blotched lizard
western skink
rubber boa
racer
ringneck snake
night snake
striped whipsnake
western terrestrial garter snake
common garter snake
western rattlesnake

- **Birds**

turkey vulture
mallard
Barrow's goldeneye
osprey
*bald eagle
northern harrier
sharp-shinned hawk
Cooper's hawk
northern goshawk
Swainson's hawk
red-tailed hawk
*ferruginous hawk
golden eagle
American kestrel
prairie falcon
chukar
gray partridge
ring-necked pheasant
*sage grouse
blue grouse
California quail
killdeer
black-necked stilt
American avocet
spotted sandpiper
long-billed curlew
rock dove
mourning dove
barn owl
great horned owl
burrowing owl
long-eared owl
short-eared owl
common nighthawk
common poorwill
white-throated swift
black-chinned hummingbird
northern flicker
gray flycatcher
Say's phoebe
western kingbird
eastern kingbird
loggerhead shrike
black-billed magpie
common raven
horned lark
northern rough-winged swallow
bank swallow
cliff swallow
barn swallow
rock wren
canyon wren
Townsend's solitaire
American robin
sage thrasher
European starling
Nashville warbler
chipping sparrow
Brewer's sparrow
vesper sparrow
lark sparrow
sage sparrow
savannah sparrow
grasshopper sparrow
white-crowned sparrow
western meadowlark
Brewer's blackbird
brown-headed cowbird
American goldfinch

*On state or federal list of threatened or endangered species

4.0 HABITAT METHODOLOGY

The primary objective in selecting a methodology for determining the appropriate wildlife conservation area is to prevent human encroachment into those habitats needed for wildlife species, and at the same time allow for development needed for the economic health of the county. The ideal scenario, to the extent possible, is to locate habitat areas that are far removed from areas appropriate for future

development. This is possible to a certain extent, but larger riparian corridors associated with the larger bodies of water (i.e., the Yakima and Naches Rivers) important for connecting habitat areas represent some level of conflict.

In determining the appropriate methodology for identifying the location, size, and shape of the county's wildlife conservation areas, a comprehensive list of priorities is necessary. Habitat areas should (Morrison, Marcot, and Mannon 1992; Scott et al. 1993; Tarlock 1994):

- be large and geographically separated from human population centers,
- contain the highest species richness possible,
- represent all native species known to occur within Yakima County,
- include those areas that support priority species, and
- be connected by linkages capable of providing migratory corridors for wildlife.

A thorough search was conducted of recent methodologies that list biodiversity as the priority in establishing wildlife conservation areas. Several examples of subbasin and ecoregional habitat planning efforts were examined but discarded, due to the species-specific methodology used or the introduction of invertebrates and plant species into the analysis, which would add more complexity to the evaluation process. Another issue was the time-intensive effort of evaluating habitat and species information on a broad, countywide scale. For these reasons, the Washington State GAP analysis program offered the most thorough and realistically achievable process. Not only does the GAP program offer species habitat range data, but also provides vegetative information that can later be effectively linked to efforts throughout the state. Johnson and O'Neil (2003) indicate that there are inherent strengths and weaknesses associated with this methodology.

4.1 Methodology Strengths

GAP methodology strengths include a distribution prediction for all vertebrates, regardless of their protective status. The combination of richness, representation, and connectivity ensures protection for all species, before they are allowed to become threatened. This methodology is particularly beneficial to land-use planning efforts because the large-scale analysis of vegetation and species habitat patterns are observed where they otherwise would not be noticeable. Finally, this method represents an opportunity to manage larger areas for biodiversity. Creating a larger, connected system of habitat areas enhances the aesthetic qualities of the landscape, raises property values, and can create new recreational opportunities.

4.2 Methodology Weaknesses

GAP methodology weaknesses include the large-scale aspect of the analytical process within the GAP program. The data is based on satellite imagery collected in 1991, and substantial changes may have occurred in the past 12 years. This coarse scale of data necessitates a large amount of pre-analysis collaboration to ensure an acceptable level of accuracy.

The GAP analysis process is described below (Marcot et al. 2002; Porter and Salvesen 1995; Scheeler et al. 2003; Stevenson 1998; Wisdom et al. 2003).

5.0 APPLYING WASHINGTON GAP ANALYSIS TO YAKIMA COUNTY

Gap analysis, developed in the late 1980s and early 1990s by the U.S. Geological Survey, is a scientific method for identifying the degree to which native animal species and natural communities are represented in our present-day mix of conservation lands. Those species and communities not adequately represented in the existing network of conservation lands constitute conservation "gaps." The purpose of the Gap Analysis Program (GAP) is to provide broad geographic information on the status of ordinary species (those not threatened with extinction or not naturally rare) and their habitats in order to provide land managers, planners, scientists, and policy makers with the information they need to make better-informed decisions. In the process, vegetation is mapped using satellite imagery. Native animal species ranges are mapped by using museum and agency specimen collection records in conjunction with known general ranges and an animal's affiliation with the previously mapped vegetation types and other physical characteristics.

This collected data is then used to predict the distribution of wildlife species throughout the county using a Geographic Information System (GIS). It also provides information that can be applied to landscapes and regions, in order to ensure that land management and land use plans more effectively incorporate the protection of biodiversity. This nationwide program has been exported to each state, to provide for localized analysis. The Washington State GAP project (WAGAP) has been funded by the U.S. Geological Survey (USGS) Biological Resources Division, through the Washington Cooperative Fish and Wildlife Research Unit at the University of Washington.

Although the data from WAGAP has been summarized and analyzed at the statewide level, the analysis was conducted using ecoregions and vegetation zones. This approach to interpreting the data is useful for many applications; however, with regard to county land-use planning, ecologically determined units do not translate well to political boundaries. The WAGAP data was therefore significantly manipulated, analyzed, and reinterpreted before being applied to the county land-use planning process. The methodologies described in this paper were originally developed through a pilot implementation project for Spokane County and were created in an effort to link biological knowledge to the county's Critical Areas Ordinance and its comprehensive plan. The GAP program has so far undergone two review processes, one by a panel of peers (Zube et al. 1995) and another by the forest products industry (Flather et al. 1994).

Yakima County currently is engaged in updating its Critical Areas Ordinance as required by the Washington Growth Management Act (RCW 36.70A). The revised ordinance is required to include best available science in the formulation of the

various Critical Areas as well as in the regulatory requirements enacted to protect them. Among the Critical Areas required are fish and wildlife habitat conservation areas. The main distinction between fish and wildlife habitat is that fish habitat is aquatic-based, while wildlife is terrestrial-based. The WAGAP implementation project represents a proven methodology to identify the terrestrial priority species and habitat areas within the county and to develop a map that can be used to provide for a maximum of biological diversity in areas removed from high human densities and intense land uses. The Washington Growth Management Act also requires the identification of aquatic habitats. Aquatic habitats have already been identified in the existing GIS data covering the county's lakes and perennial streams and their associated riparian areas.

6.0 MAPPING METHODOLOGY

The protection of biodiversity was chosen as the design strategy for locating and delineating wildlife conservation areas, corridors, and landscape linkages in Yakima County because it is the most effective way to ensure the realization of the comprehensive plan goals and policies dealing with fish and wildlife in the Critical Areas Ordinance. Furthermore, planning for biodiversity before species become endangered can help to prevent confrontational governmental sanctions as human activity continues to expand into previously undeveloped areas. To accomplish such planning, richness and representation were the two parameters chosen to capture biodiversity at the scale of the entire county. Within this analysis, *richness* refers to the concentration of species within a specific area. *Representation* means the level of inclusion of the species known to occur within Yakima County (Jennings 1995; Tarlock 1994).

6.1 Species Representation

The purpose of achieving representation is to ensure that every species predicted to occur in the county is recognized at least once within the selected set of polygons. Representation does not necessarily mean that the entire life history of any given species can be accommodated within the representative set of polygons, but it does guarantee that all species predicted to occur in the county are included within the representative subset of polygons. Figure 14 shows a sample map, using mammals. Redundancy is built into the process, as the groups used in the analysis (mammals, birds, reptiles, and amphibians) are combined after representation is established for each individual group. Representation was determined through a series of queries to identify areas where all species occurred at the highest level of richness, using the WAGAP species distribution data (exemplified in Figure 14). This approach resulted in the map shown in Figure 15, the representative set for all terrestrial vertebrates modeled by WAGAP (Stevenson, 1998).

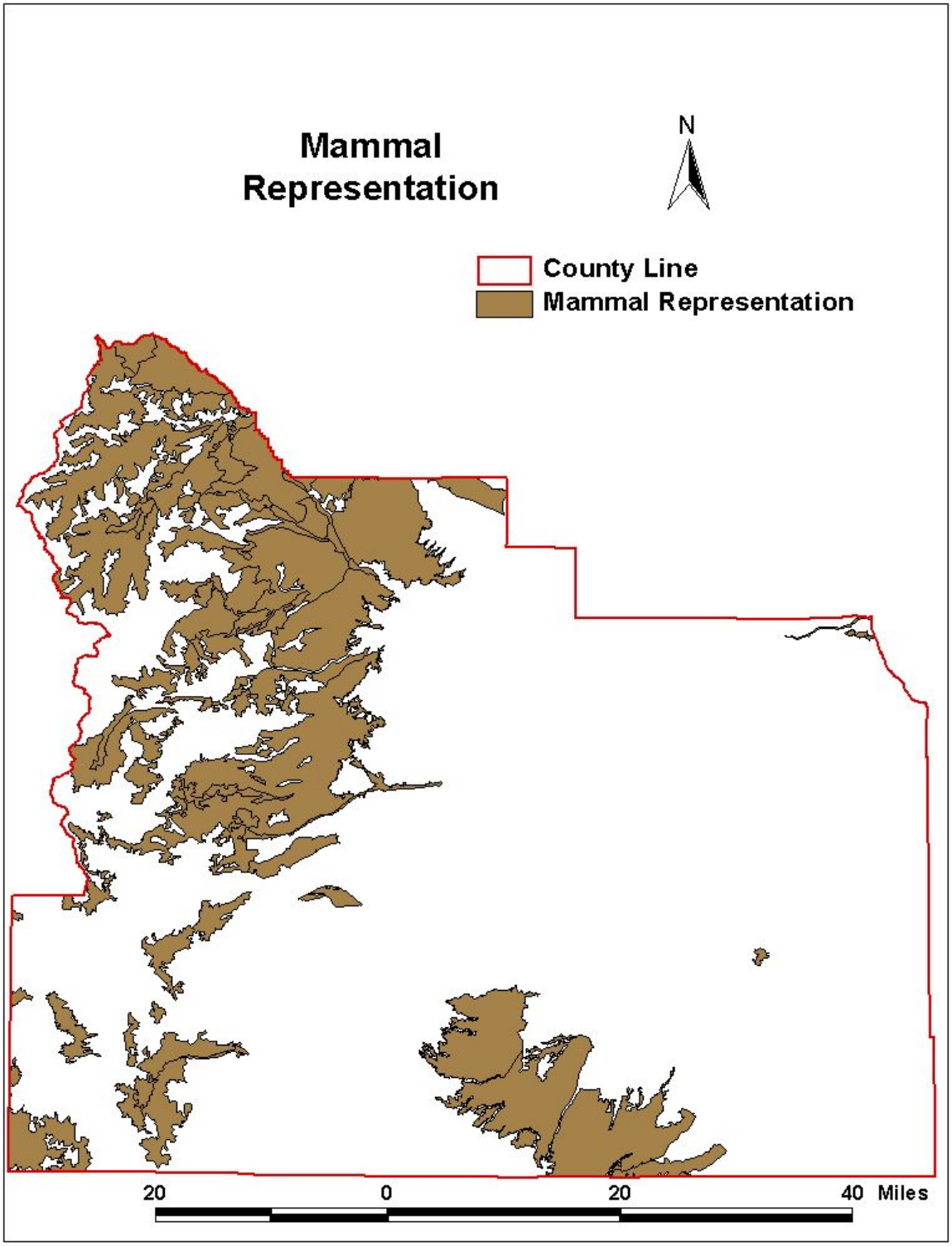

Figure 14. Sample species representation map.

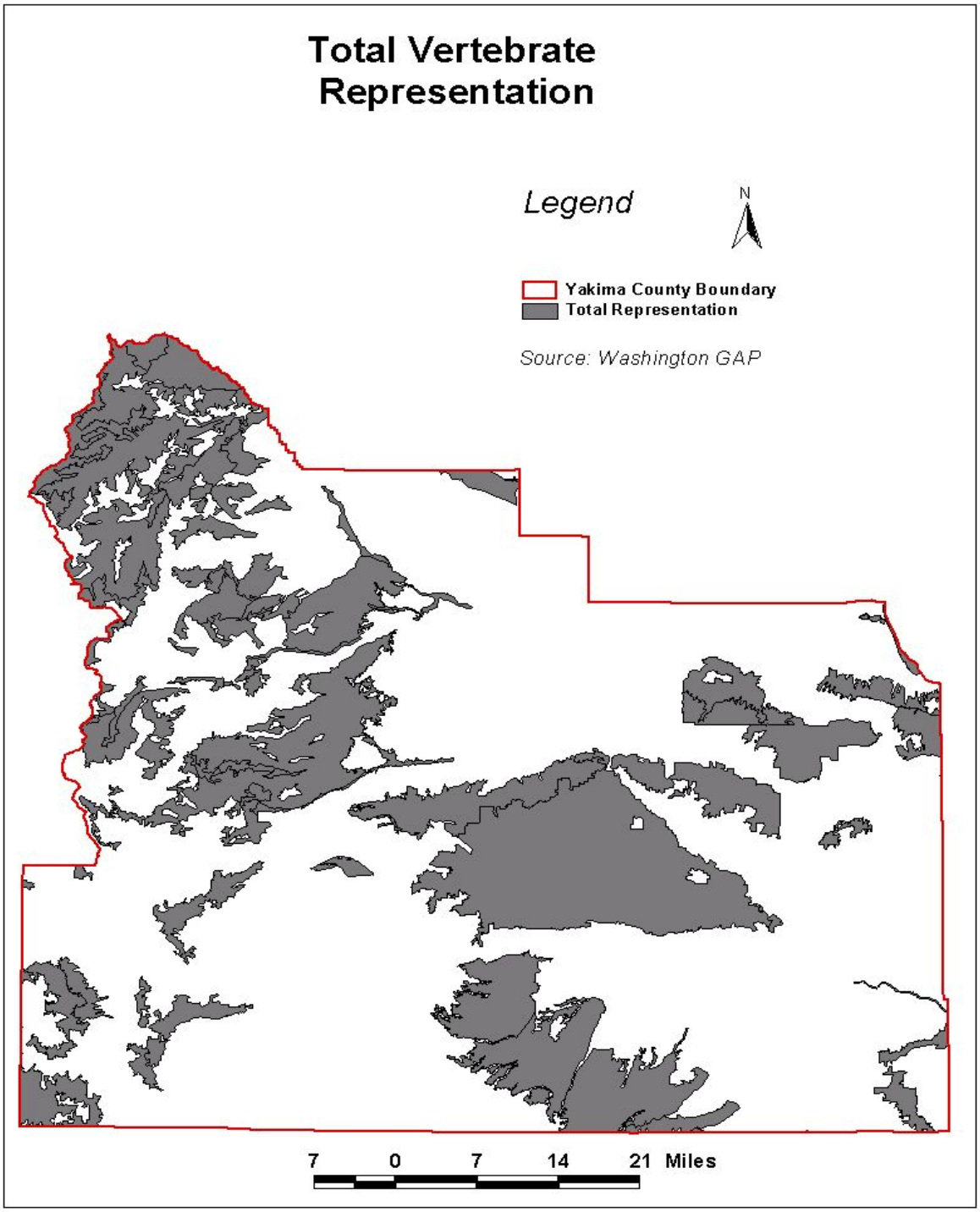

Figure 15. Representative set for all terrestrial vertebrates modeled by WAGAP (Stevenson, 1998)

6.2 Species Richness

Establishing species richness thresholds for birds, mammals and, reptiles was necessary before areas of high species richness could be identified as potential locations for habitat conservation. This process entailed the creation of a decision rule for which polygons should be selected or "turned on," based upon the number of species predicted to be present in each. For this analysis, threshold levels were set at 75 percent of possible richness for mammals and birds and 50 percent of possible richness for reptiles and amphibians. A lower threshold inclusion rule was set for reptiles and amphibians, since their populations are distributed primarily within spatially concentrated habitats such as wetlands, streams corridors, and lakes. A higher threshold inclusion rule was used for birds and mammals due to their wide distribution across a variety of habitats. All polygons with high species richness, as indicated by the application of the inclusion rule, initially were considered for habitat reserve area designation. This is illustrated in Figure 16. The ideal polygons for potential habitat reserves are large polygons with high species richness, containing natural land cover, low internal and adjacent human development, and high levels of agreement with other wildlife distribution databases in adjacent counties and federal reserves. Identified potential habitat reserves for all three species groups are reflected in Figure 17.

6.3 Habitat Corridors

Connections between habitat reserves and other high-representation areas were made by identifying and selecting polygons with high species richness and natural land cover. Those areas of high species richness and representation, which represent the potential connection areas for corridors, were combined to produce Figure 18, the raw material from which a potential wildlife corridor and landscape linkage system might be created. Approximately 43 percent (1,151,504 acres) of Yakima County is indicated in Figure 18 as being important for protecting biodiversity—a tremendous amount of land. In order to refine the areas developed through the additive process described above, it was necessary to utilize additional sources of information, providing a greater level of detail. Existing county data sets used to evaluate potential habitat linkages and corridors included a high-definition aerial photo of the Urban Growth Area surrounding the City of Yakima and its suburbs; contour lines, publicly owned parcels; highways; rivers and streams; and unique topographical features. With the exception of the aerial photos, these coverages are shown in Figure 19 (Stevenson, 1998).

The final result of the additive process, described above, determining the combined representation and richness areas, and the reductive process of identifying appropriate corridors and further refining the result is shown in Figure 20. The reductive process consists of the elimination of areas of high parcelization, most agricultural lands, and lands with high road density. As much forested area as possible was kept for its high potential for species movement. For Yakima County, these connections are made possible by using the primary stream riparian corridors as well as some adjacent steep slopes.

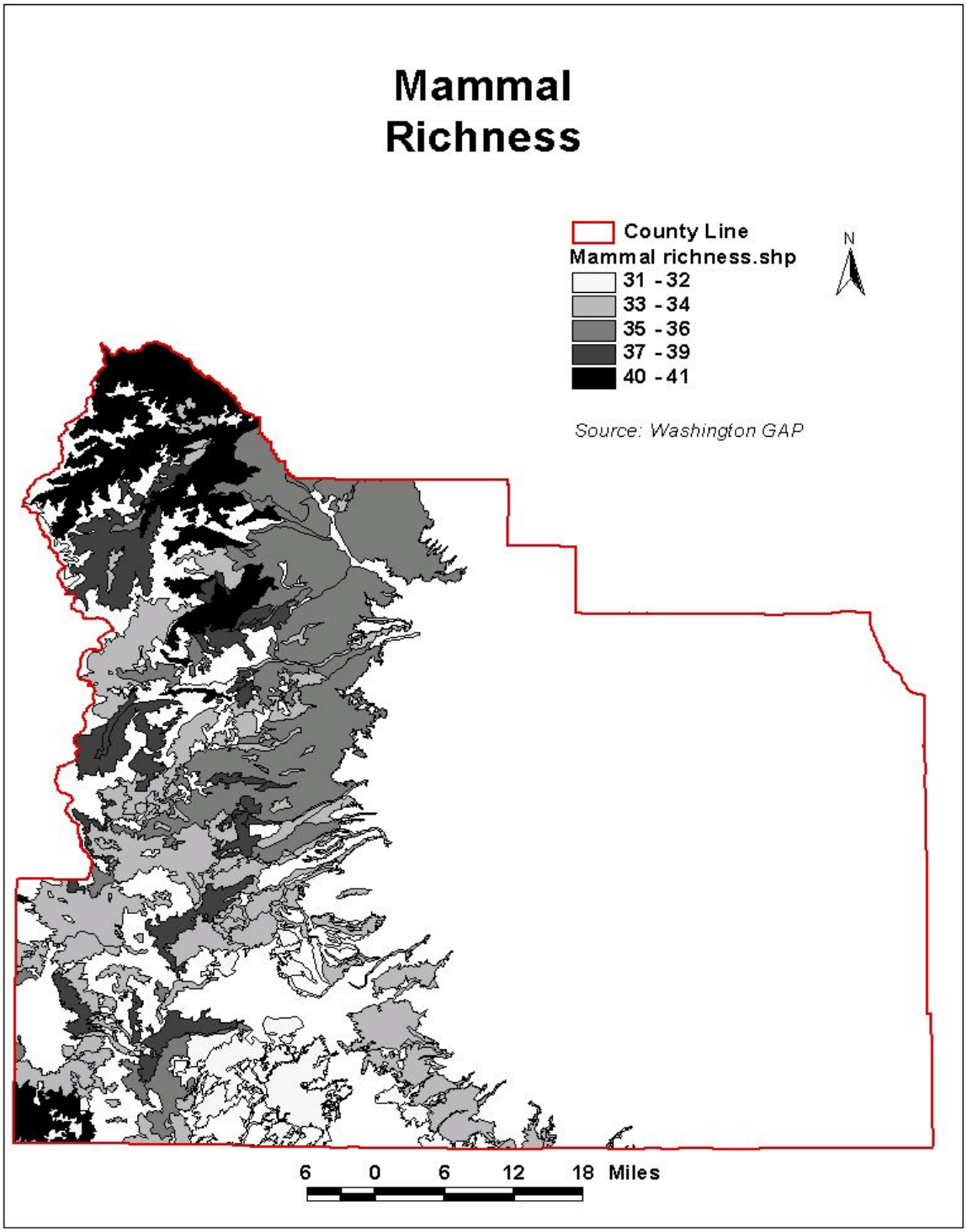

Figure 16. Polygons with high species richness, as indicated by the application of the inclusion rule.

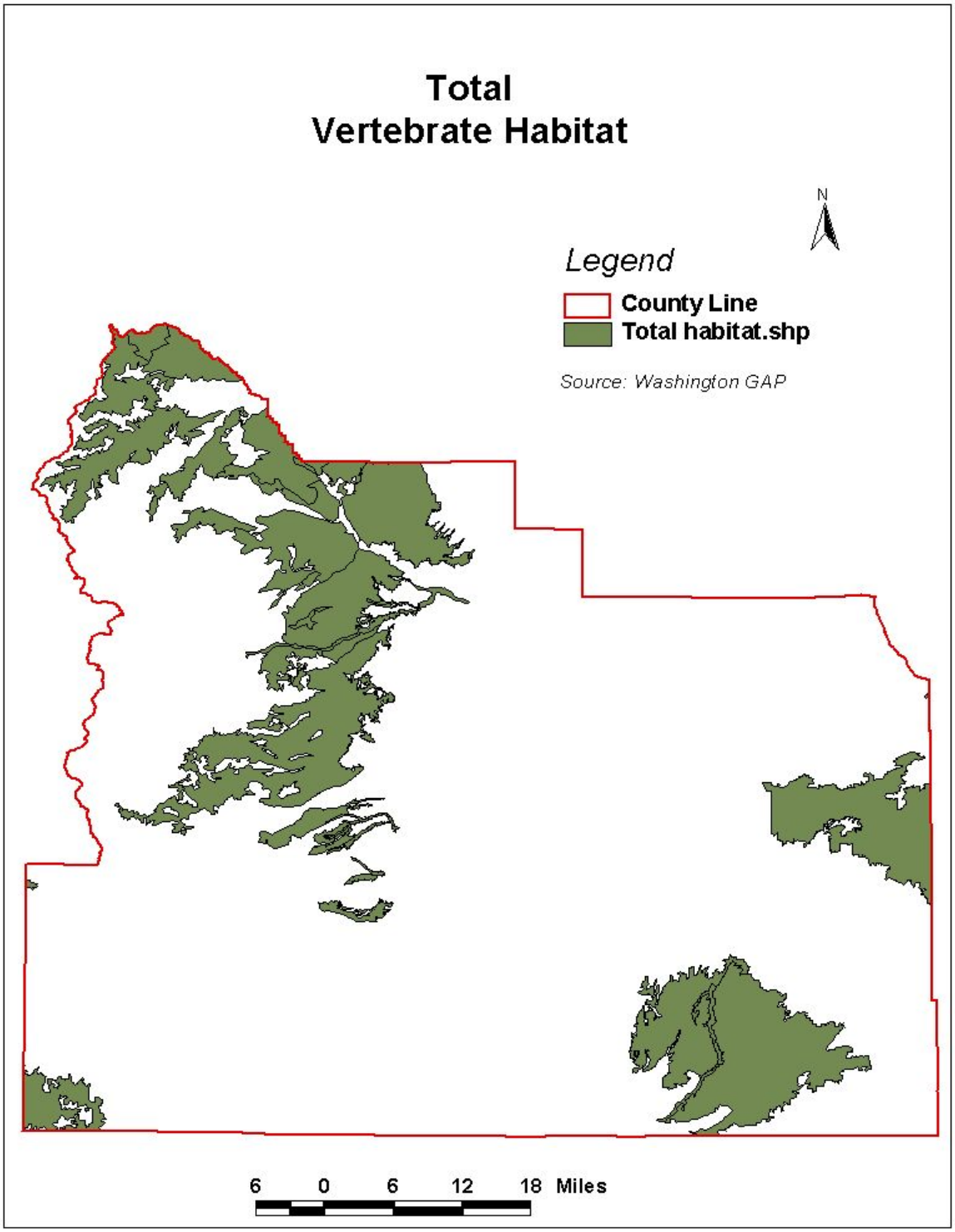

Figure 17. Identified potential habitat reserves for all three species groups

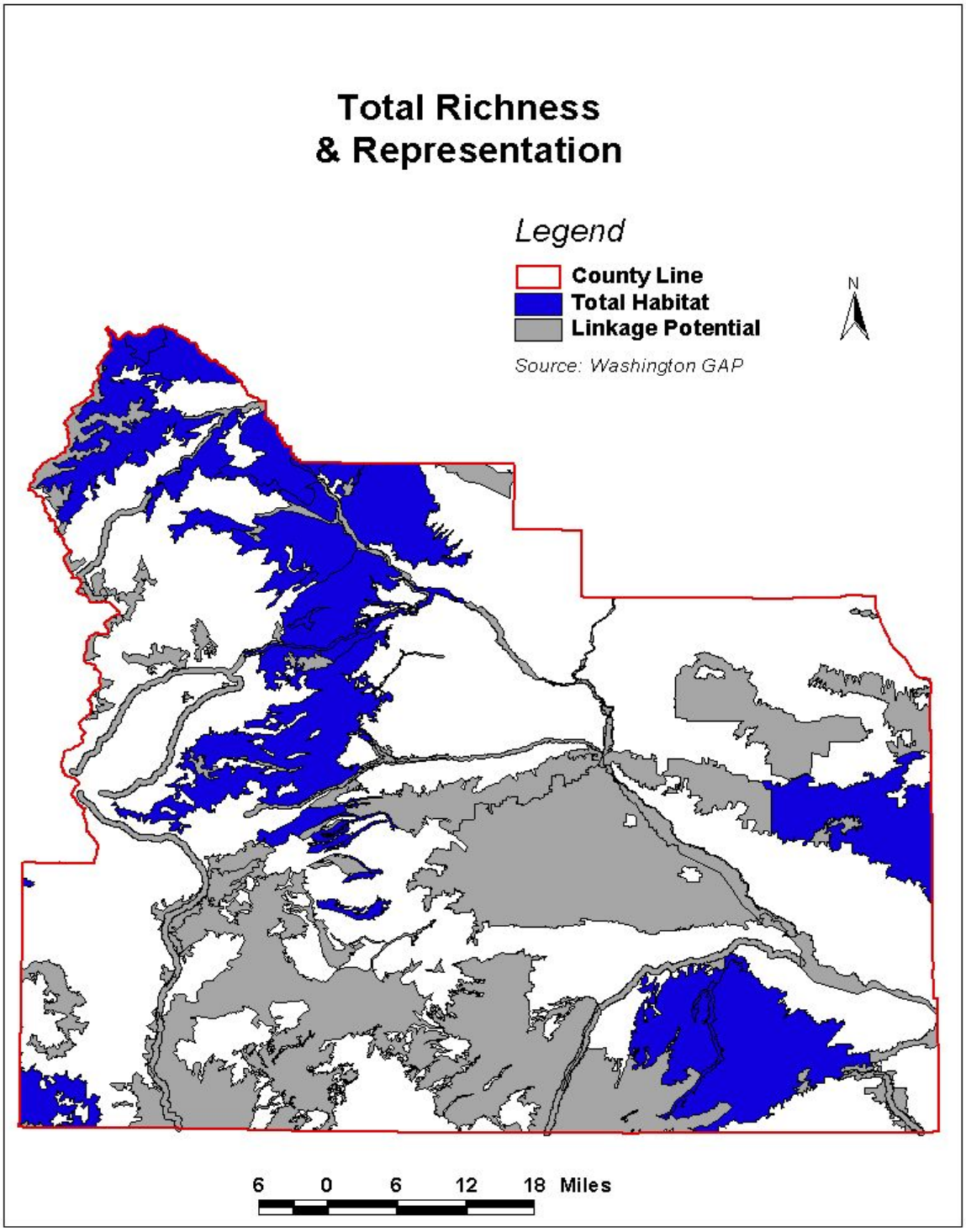

Figure 18. Areas of high species richness and representation, representing the potential connection areas for corridors.

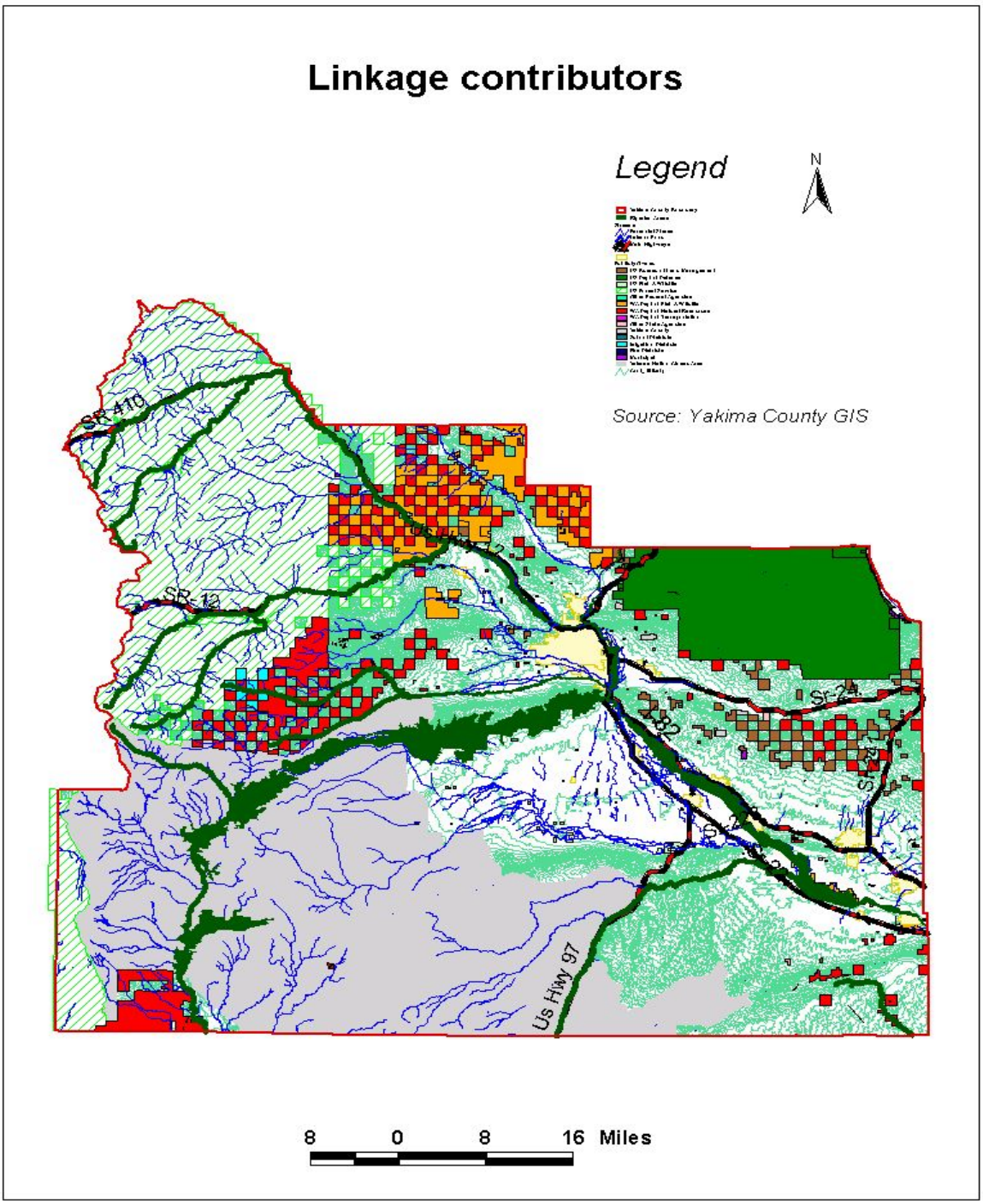

Figure 19. Coverages used to evaluate potential habitat linkages and corridors, including contour lines, publicly owned parcels, highways, rivers and streams, and unique topographical features (Stevenson, 1998).

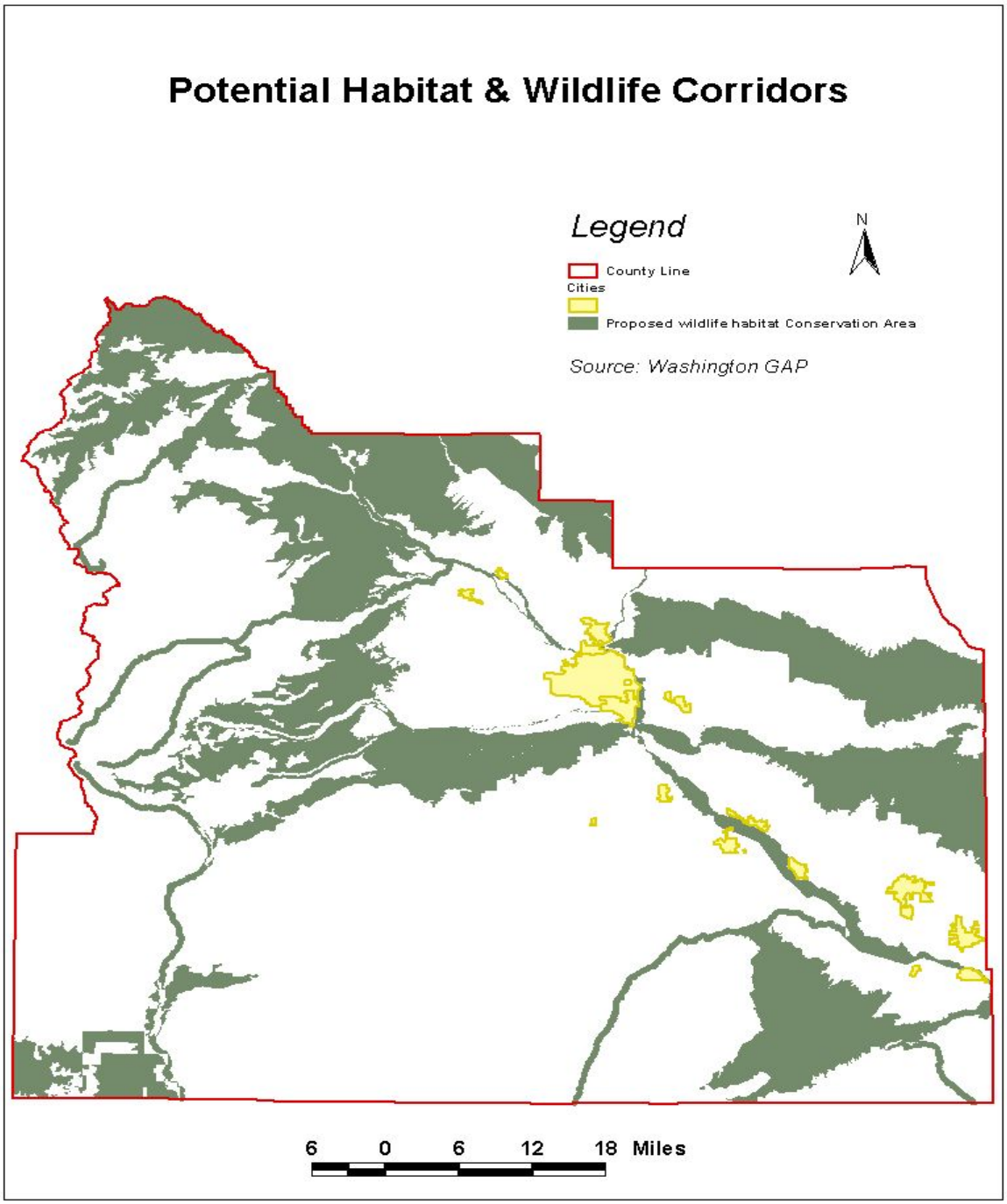

Figure 20. Final result of the additive process (determining combined representation and richness areas) and the reductive process (identifying appropriate corridors and further refining the result).

Existing publicly owned habitat reserves were evaluated for inclusion, and information from the Wildlife Heritage Foundation database was studied for the known location of any species of interest (see Table 19). The known ranges of all priority species were evaluated and the extent of the coverage was modified to ensure the maximum amount of these species habitats as possible were included. On average, this meant approximately 90 percent of any particular priority habitat area was included within the final conservation area. Finally, the Washington State Department of Fish and Wildlife priority habitats and species polygons and species point locations were used, to further modify the potential areas for corridors and reserves. This final proposed system comprises approximately 25.7 percent of the county, a substantial reduction from the initial 43 percent indicated at the end of the additive process. This final system of habitat areas and linkage corridors was also evaluated against adjacent counties to ensure continuity of the various habitat areas throughout the greater area (Stevenson, 1998).

6.4 Results

If the system of wildlife habitat reserves and corridors shown in Figure 20 were implemented with no substantial modifications, all vegetation zones within the county would have a percentage of their area protected. The largest zone within the county, the central arid steppe, would realize an area of protection amounting to 27 percent of the entire zone. A breakdown of the amount of the various vegetative areas protected is as follows:

Table 19
Protected habitats by acreage

Vegetative type	Total county acreage	Acreage protected	% protected
Three-tip sage	143,341	8,389	6%
Central arid steppe	1,348,197	362,163	27%
Oak	100,568	44,915	45%
Ponderosa pine	379,478	181,661	48%
Interior Douglas fir	168,738	38,165	23%
Grand fir	168,902	101,542	60%
Interior western red	84,679	27,965	33%
Subalpine fir	267,150	13,760	5%
Mountain hemlock	14,863	17	<1%
Alpine	62,773	1,929	3%
Permanent snow/ice	12,868	406	3%

It should also be noted that the above figures do not account for the significant amount of additional acreage under federal or tribal ownership, which is also receiving a degree of protection.

7.0 MANAGEMENT TECHNIQUES

Management of the various habitats within the wildlife conservation area will mostly be broad in nature, to ensure the viability of the wide range of species occurring within Yakima County. The Oregon white oak regions of the county are home to a very wide range of animal life. The preservation of this valuable habitat will in turn ensure the survival of all the plant and animal life within it. These broad management techniques may include but are not necessarily limited to (Knutson and Naef 1997; Larson 1997, 1998, 2000):

- minimizing the allowable development density;
- managing nonnative vegetative species;
- managing existing Oregon white oak stands;
- maintaining fallen wood debris and leaf litter for foraging, nesting, and denning sites;
- minimizing vegetative clearing associated with allowed development; and
- requiring vegetative screening adjacent to development in elk winter range areas.

More specific management techniques would be used in the protection of listed federal and state endangered and threatened species, and species of concern. These techniques would be specific to the species identified, but only in cases where species occurrence has been confirmed. Although an attempt has been made to ensure an overwhelming percentage of the areas identified as priority species habitat have been included within the conservation area, when discovered and confirmed, threatened, endangered, or species of concern should be protected regardless of their location within the county. In general, these protection measures may include (Braun 1998; Knutson and Naef 1997):

- setting specific avoidance distances from confirmed nesting areas;
- preventing disturbance during breeding season;
- removing fencing within nesting areas (unless essential for livestock grazing);
- avoiding sagebrush removal;
- minimizing the conversion of shrub-steppe areas;
- using controlled burns as a means of suppressing wildfire destruction of essential habitat; and
- preventing nonnative predator species and plants.

8.0 SUMMARY

This analytical process identifies a significant amount of known habitat for species within Yakima County. It accomplishes this identification in a manner that minimizes conflict with areas likely to develop in the future (see Figure 21 for comparison to zoning), while ensuring large habitat areas remain connected to the greatest extent possible. To successfully utilize the findings from this analysis, the county (and any other municipalities or counties interested in conducting similar analyses) will have to employ a wide variety of tools. There is no single mechanism

by which the biologically significant lands in Yakima County can be instantly and unilaterally protected in perpetuity; indeed, even if there were, it might not be desirable to protect biodiversity in this manner. Rather, a combination of regulatory provisions and nonregulatory incentives, regulations, and acquisitions is an approach most likely to achieve the goals established in Yakima County's comprehensive plan.

The intent is for Yakima County to use the results of this analysis to create wildlife habitat GIS data coverage during the update of the Critical Areas Ordinance. Additionally, the information will be used to analyze and evaluate properties for possible protection through the use of conservation easements and other nonregulatory mechanisms.

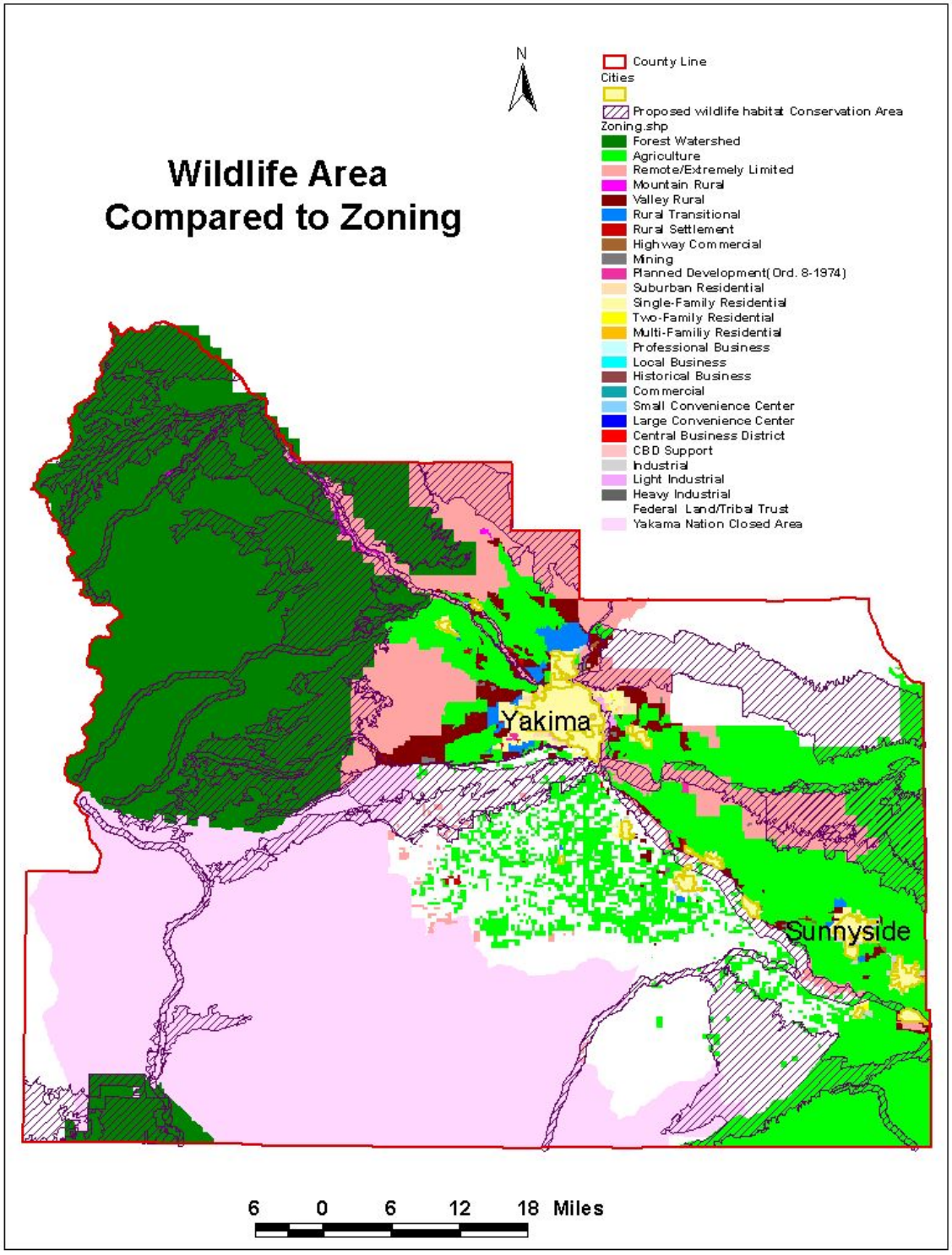

Figure 21. Known habitat for species within Yakima County compared to zoning

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DRAFT

CHAPTER 5: A REVIEW OF THE BEST AVAILABLE SCIENCE REGARDING CRITICAL AQUIFER RECHARGE AREA (CARA) IDENTIFICATION

1.0 INTRODUCTION

The Washington Administrative Code (WAC) defines critical aquifer recharge areas as "areas where an aquifer that is a source of drinking water is vulnerable to contamination that would affect the potability of the water." WAC 365-190-080(2)(a) indicates factors that may be considered in determining the location of critical aquifer recharge areas:

- depth to groundwater;
- aquifer properties such as hydraulic conductivity and gradients;
- soil (texture, permeability, and contaminant-attenuation properties);
- characteristics of the vadose zone, including permeability and attenuation properties; and
- other relevant factors.

WAC 365-190-080(2)(b) indicates factors that may be considered to evaluate the contaminant loading potential:

- general land use,
- waste disposal sites,
- agricultural activities,
- well logs and water quality test results, and
- other information about the potential for contamination.

The code also says,

> Classification strategy for recharge areas should be to maintain the quality of the groundwater, with particular attention to recharge areas of high susceptibility. In recharge areas that are highly vulnerable, studies should be initiated to determine if groundwater contamination has occurred. Classification of these areas should include consideration of the degree to which the aquifer is used as a potable water source, feasibility of protective measures to preclude further degradation, availability of treatment measures to maintain potability, and availability of alternative potable water sources. [WAC 365-190-080(2)(c)]

WAC 365-190-080(2)(d) lists examples of areas with a critical recharging effect on aquifers used for potable water:

- Sole source aquifer recharge areas designated pursuant to the Federal Safe Drinking Water Act.

- Areas established for special protection pursuant to a groundwater management program, chapters 90.44, 90.48, and 90.54 RCW, and chapters 173-100 and 173-200 WAC.
- Areas designated for wellhead protection pursuant to the Federal Safe Drinking Water Act.
- Other areas meeting the definition of "areas with a critical recharging effect on aquifers used for potable water" in these guidelines.

There currently are specific goals and policies within the Yakima County Comprehensive Plan 2015 that list the protection of groundwater as a priority.

- **Goal NS 8**—Maintain and manage the quality of the groundwater resources in Yakima County as nearly as possible to their natural condition and in compliance with state water quality standards.
- **Policy NS 8.1**—Identify and map important aquifers, aquifer recharge areas, and surface waters.
- **Policy NS 8.2**—Develop performance standards and regulate uses for activities that adversely impact water quantity and quality in aquifers, wetlands, watersheds, and surface waters.
- **Policy NS 8.3**—Evaluate the potential impact of development proposals on groundwater quality and require alternative site designs to reduce contaminant loading where site conditions indicate that the proposed action will measurably degrade groundwater quality.
- **Policy NS 8.4**—Continue data collection and evaluation efforts to better understand the county's groundwater system and its vulnerability to contamination.
- **Policy NS 8.5**—Encourage the retention of natural open spaces in development proposals overlying areas highly susceptible for contaminating groundwater resources.

This paper focuses on the identified best available science relevant to determining the extent of and protecting critical aquifer recharge areas (CARA), and Yakima County's efforts to establish critical aquifer recharge area protection standards necessary to protect groundwater quality and to ensure the groundwater's continued use as a potable water source. The U.S. Department of the Interior's Interim Comprehensive Basin Operating Plan for the Yakima Project (2002) and Campbell's (1998) report on the geology of the Yakima accurately describe the hydrogeology and geology of the Yakima area. The following paragraphs summarize its characterization.

1.1 Geologic Setting

The geologic history of the Yakima Basin includes a sequence of geological processes that created a basin, characterized by numerous alluvial valleys separated by relatively short bedrock canyon reaches. In the semi-arid lowlands, these geological controls, along with the distribution of surface water delivered from the upper watershed, determine the timing and location of most groundwater recharge and discharge. Geologic structures such as folds and faults alter the

groundwater flow pattern in the Yakima River Basin. Folded ridges and troughs dominate the topography in the lower basin. The uplift of the ridges occurred slowly enough to allow the Yakima River to maintain its course across structures such as Union Gap. The bedrock folds determine flow patterns and form hydrologic boundaries.

Yakima River Basin geology and hydrogeology fall into two main regions: the Cascade upland region, with an assortment of rock types with low permeability but no water availability, and the Columbia Plateau lowland and ridges, where a thick sequence of basaltic lava flows and overlying sediments covers the older rocks. Within this lower region, there are several aquifers that are used as sources of potable water. These aquifers include:

- **Alluvial aquifer**—Gravel, sand, and silt deposited by the Yakima River during uplift and glaciation. Recharge to this aquifer is from rainfall, irrigation, and streams. This unconfined aquifer provides water for domestic and irrigation wells in the Yakima Basin.
- **Ellensburg formation/post basalt aquifer**—This aquifer consists of volcanically produced sedimentary deposits from extinct volcanoes and is composed of sand, clay, and conglomerate. The lower sand zones within the Ellensburg formation supply all or most municipal drinking water. Recharge comes from the overlying stream alluvium and possibly from the underlying basalt.
- **Tieton andesite aquifer**—This aquifer consists of young volcanic rock erupted in the upper Tieton drainage, which descended the Tieton Canyon and currently covers the Naches Heights area. This aquifer represents the source of domestic well water in the Naches Heights area.
- **Yakima basalt aquifer**—Hydraulic activity is greatest within the interflow zones. In contrast with the relatively flat terrain east of the Columbia River, the western part of the plateau was folded into east-west ridges and broad valleys. This strongly influences groundwater flow patterns. Recharge to these interflow zones is from surface precipitation and irrigation seepage when the zones come in contact with surface streams. Water from these interflows is sometimes used for domestic wells, particularly where the interflow is tilted, as in an anticline.

1.2 Hydrogeologic Setting

The flow of groundwater and the interactions between it and surface waters in the Yakima River Basin are strongly influenced by the local topography and geology. The Yakima River drains the eastern slope of the Cascade Range and flows through 150 miles of semi-arid lowland valleys and canyons before joining the Columbia River. A strong rain shadow effect reduces annual precipitation within the lower Yakima Basin to less than 10 inches of rainfall annually. Consequently, precipitation-generated recharge is low or nonexistent. Seventy-five percent of our precipitation comes between October and April, with a dry season running between late spring and the end of summer, and less than 5 percent of annual precipitation occurring between July and August. River flow is primarily sustained by snowpack, which provides runoff that lasts well into the summer. This natural system of

recharge peaks around April to June and declines to lows in September and October.

A sequence of geologic processes created a basin characterized by numerous alluvial valleys separated by relatively short bedrock canyon reaches. In the semi-arid lowlands, these geologic controls, along with the distribution of surface water from the upper watershed, determine the timing and location of most groundwater recharge and discharge.

Groundwater recharge sources include precipitation and the application of irrigation. The strong rain shadow effect causes an uneven distribution of precipitation-induced recharge. Runoff rather than infiltration dominates in the Cascades due to the degree of impermeability. Under predevelopment conditions, stream flow provided recharge to alluvial aquifers; most precipitation in the unirrigated semi-arid areas of the basin left as evapotranspiration. Under development conditions, the application of irrigation water has caused increases in recharge by a factor of 50 in the lower valley.

2.0 DETERMINING AQUIFER SUSCEPTIBILITY

Evans (1999), in his dissertation on assessing the vulnerability of groundwater, indicates that methods for determining aquifer susceptibility to contamination fall into three broad categories. These categories include:

- overlay and index methods,
- methods employing process-based simulation models, and
- statistical models.

2.1 Overlay and Index Methods

Overlay and index methods combine maps of parameters considered to be influential in contaminant transport. Each parameter has a range of possible values, indicating the degree to which it represents a level of susceptibility to groundwater contamination. Depth to groundwater normally is common to most of them. The simplest overlay systems identify areas where the different parameters indicating high susceptibility coincide. More sophisticated systems assign numerical scores to each of the variables based on the level of their contribution to overall susceptibility. Generally, such systems include variables related to groundwater recharge rates, depth to groundwater, and soil and aquifer properties.

2.2 Mathematical Models

Mathematical models can predict with remarkable accuracy the fate and transport of contaminants from known sources in a localized area, by applying fundamental physical principals to predict the flow of water in porous media and the behavior of chemicals carried by water. Although mathematical models offer the most sophisticated and potentially the most accurate predictions of water quality, they

are not widely used for regional groundwater susceptibility analysis due to the need for site-specific data.

2.3 Statistical Models

Statistical models are the least common susceptibility assessment methods. Although they are used as tests for other methods, very few susceptibility assessment methods are based on statistical methodology. These models have the great advantage of being based on sound principles, but this does little to enhance their value for use at a regional level. They require more expertise and more detailed data than can be provided for regional-scale analysis.

For the purpose of determining the Yakima County critical aquifer recharge area with the highest level of potential for contamination, the decision was made to use an overlay and index method. This decision was driven primarily by data availability, time, and cost. Although mathematical and statistical models are more accurate, they are unrealistic candidates for use when time and the cost and availability of data collection are significant issues.

2.4 Washington State Department of Ecology Methodology

The methodology outlined in the Department of Ecology's (2000) *Guidance Document for the Establishment of Critical Aquifer Recharge Areas* is an overlay and index method that contains those variables listed within the Washington Administrative Code for use in determining hydrogeologic susceptibility. Consequently, the decision was made to use the Department of Ecology methodology, which is described in the following paragraphs. Any departure from the Department of Ecology methodology is disclosed within the methodology description.

All groundwater is vulnerable to contamination to some extent; however, hydrogeologic conditions in certain areas create a greater potential to convey contamination from points of recharge to points of use. To protect groundwater within these susceptible areas, it is necessary to determine first where such areas exist. The determination of an aquifer's vulnerability is based on aquifer susceptibility combined with a contaminant's ability to enter and move within the aquifer media. Aquifer vulnerability, therefore, is based on known or assumed conditions that are difficult to determine. There are virtually hundreds of contaminants that have potential for reaching groundwater. Any analysis must consequently be separated from the attributes of any specific contaminant. If it is assumed that contaminants are neither retarded nor degraded as they pass from the surface down to the aquifer, then the extent of the critical aquifer recharge area can be established by determining susceptibility, independently from the attributes assigned to any specific contaminant.

Aquifer susceptibility studies within Washington, Oregon, and Idaho indicate that while there are numerous factors that may be considered in determining aquifer susceptibility, there are three that generally dominate the determination:

- the overall permeability of the vadose material, comprising the soil as well as the underlying geologic material;
- the thickness of the vadose zone, which would also indicate the depth to groundwater; and
- the amount of recharge available.

The Department of Ecology manual provides a formula by which to calculate susceptibility using the above factors. This formula combines scores for soil permeability, geologic material permeability, infiltration, and depth to groundwater to produce a total susceptibility score. We have opted to use data related to net recharge, rather than to infiltration as called for in the Department of Ecology methodology.

2.4.1 Permeability of the vadose zone

The success of any rating system will depend on its usability, the availability of information or data, the scale at which it is applied, and the weight given to the various components of the system. The vadose zone is made up of both the soils and the geologic material underlying the soils. Although the overlay formula described in the Department of Ecology manual for the establishment of critical aquifer recharge areas includes the primary elements that affect aquifer susceptibility, obtaining the data in a workable format was found at different steps to be problematic, requiring a manipulation of the data prior to use, or in some cases, the use of proxy data. These requirements and concerns are described in the following methodology description.

2.4.2 Soil permeability

Soil permeability can be determined by using the *Soil Survey of Yakima County* (USDA 1985), which gives the permeability for each soil type listed in the number of inches per hour that available water will move through the various portions of the soil layer. Soil permeability was calculated for each layer of soil relative to its thickness within the soil layer, and an overall permeability was then determined by adding the individual layers. This analysis of soil permeability was conducted using soil survey information for the county as well as that of the Yakama Nation. Figure 22 shows the results of the analysis and the areas of highest soil permeability. The area of analysis was limited by the extent of the soil survey data available.

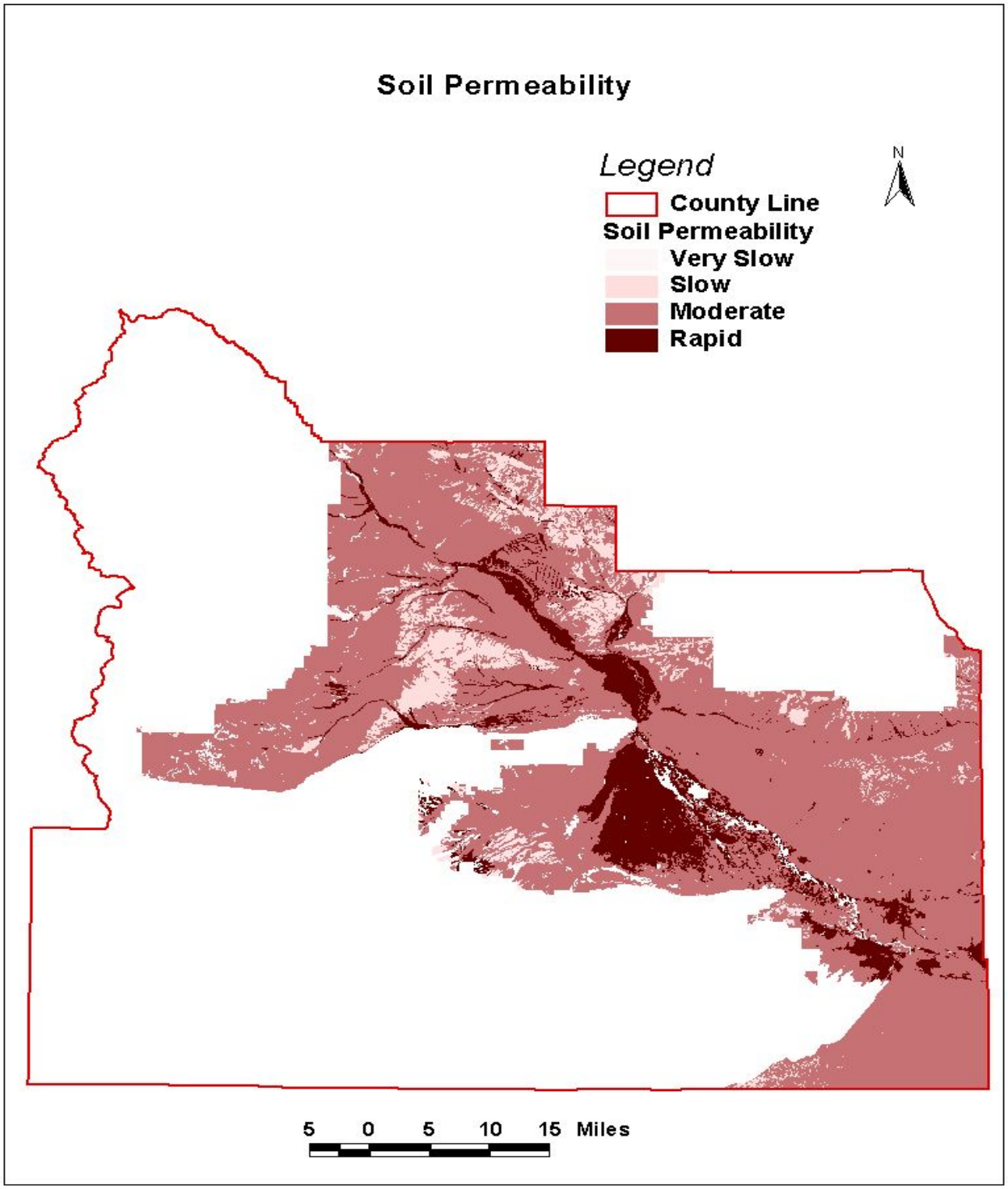

Figure 22. Results of soil permeability analysis, and the areas of highest soil permeability.

The permeability data contained in the *Soil Survey of Yakima County* (USDA 1985) shows different ranges of permeability for each layer within each soil type listed. To allow computations with the permeability values, the midpoints of each range were used. One level of permeability was required for any given soil type. To derive an overall permeability for a given soil type, it was necessary to compute the individual permeability for each soil layer within it. It was also necessary to determine the importance of the various soil layers and to assign a value based on their thickness relative to the overall soil thickness. Once the soil layer's permeability and relative importance were determined, all layers could be averaged to compute permeability for each soil type. Thus:

$$\text{Individual Soil Layer Permeability} \times \frac{\text{Soil Layer Thickness}}{\text{Total Soil Thickness}} = \text{Individual Soil Layer Relative Permeability}$$

The relative individual permeability ratings for each identified layer were expressed as a percentage of the total and were then simply added up, to determine the total soil permeability for the entire soil layer. This total soil permeability was then rated *very slow, slow, moderate, or rapid* based on thresholds outlined in the *Soil Survey of Yakima County* (USDA 1985) as follows:

Soil survey description	Permeability (in./hr)	Rating
Very slow	< 0.06	0
Slow	0.06 to 0.60	1
Moderate	0.60 to 6.0	2
Rapid	> 6.0	3

2.4.3 Geologic material permeability

A determination of the permeability of the underlying geologic material is more problematic. The Department of Ecology CARA manual calls for using well logs to determine the underlying geologic material permeability. The size of the county, as well as the lack of the well log data in digital format, makes that prospect unrealistic due to the number of well logs required to review (two or three per square mile), and the amount of time required to interpret the nonstandardized geologic descriptions on the individual well logs, to digitize the data, and to conduct the analysis. After consulting with local Department of Ecology hydrogeologists, as well as with members of the science advisory group, it was determined that surficial geology information from the USGS maps would be a good proxy for the description of the geologic underlying materials. This information was interpreted into one of the four permeability classifications, as indicated in the Department of Ecology manual. These four classifications are depicted in Table 20.

Table 20
Department of Ecology permeability classifications

Classification	Geologic matrix description	Permeability rating
Very slow	Described as unfractured, igneous, or metamorphic bedrock or shale, marine clay, clay, dense sandstone, or hardpan	0
Slow	Described as Loess, glacial till, fractured igneous or metamorphic bedrock, silt, clayey sands, weathered basalt	1
Moderate	Described as silty sands, fine sands, permeable basalt, clean sands, or Karst limestone	2
Rapid	Described as sand and gravel or plain gravel	3

The permeability rating assigned to the resultant range of the underlying geologic material permeability (Figure 23) was then entered into the database.

2.4.4 Combined permeability

The next step was to combine the permeability of the soil with the permeability of the underlying geologic material, to determine the permeability of the entire vadose zone. This was done by joining the geologic permeability GIS coverage with the soils permeability GIS coverage and then adding the two separate permeability values. The resultant combined permeability is shown in Figure 24.

Soil permeability + Geologic material permeability = Total permeability

2.4.5 Recharge

The Department of Ecology (2000) defines *infiltration* as the degree to which water moves through the vadose zone into the uppermost aquifer. The same document defines *recharge* as the process involved in the absorption and addition of water to groundwater. This ambiguity between infiltration and recharge led us to search other sources to determine the correct relationship. Freeze and Cherry (1979, quoted in WSDOE 2000) define infiltration as the entry into the soil of water made available at the ground surface, together with the associated flow away from the ground surface within the unsaturated (vadose) zone. Recharge is defined as the entry into the saturated (groundwater) zone of water made available at the water table surface, together with the associated flow away from the water table surface within the saturated zone.

In other words, infiltration is that water that lies within the vadose zone, or unsaturated area, and recharge is that water that makes it into the aquifer. Recharge, then, is the key element that must be considered when evaluating water

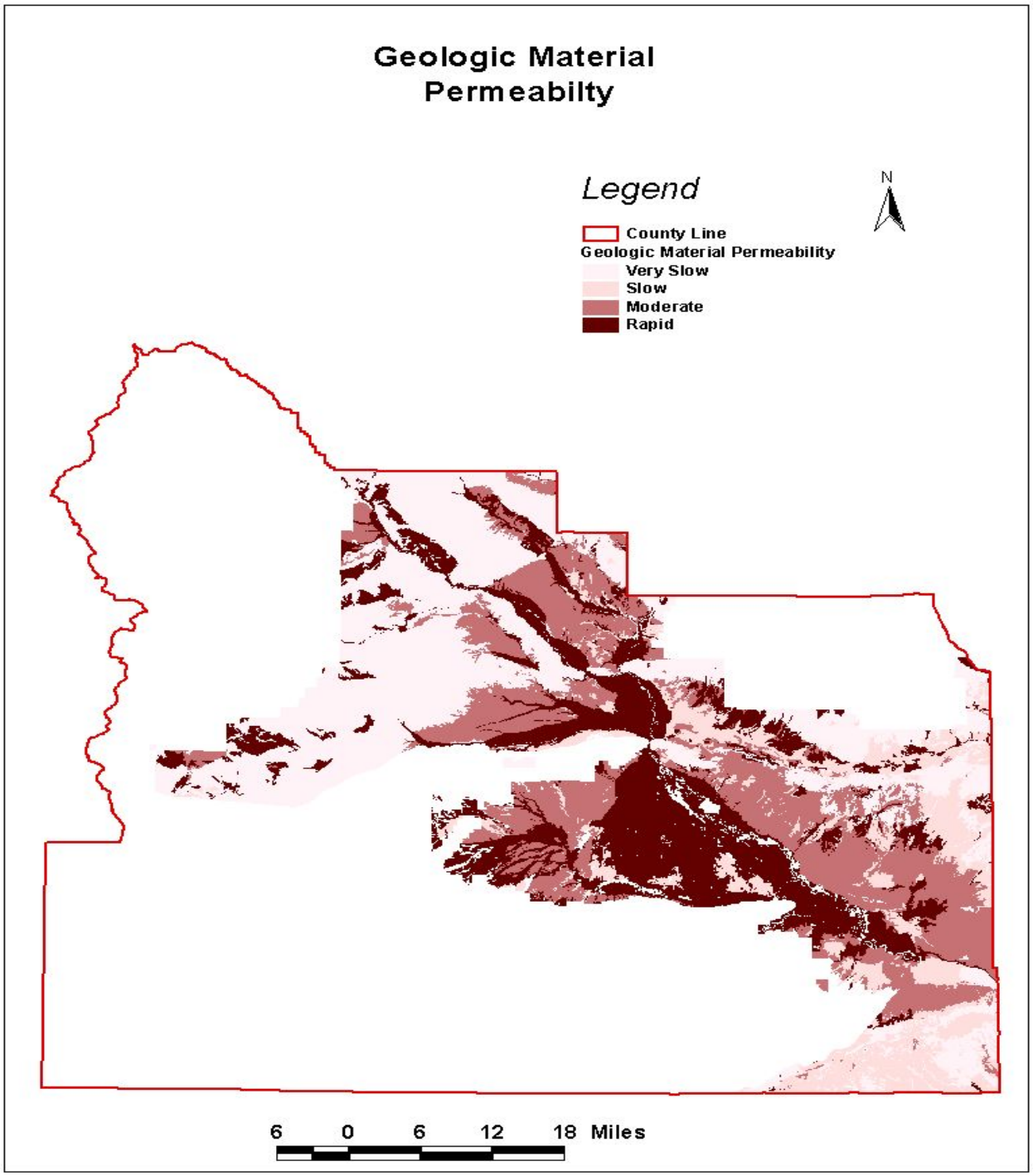

Figure 23. Rating assigned to the range of underlying geologic material permeability.

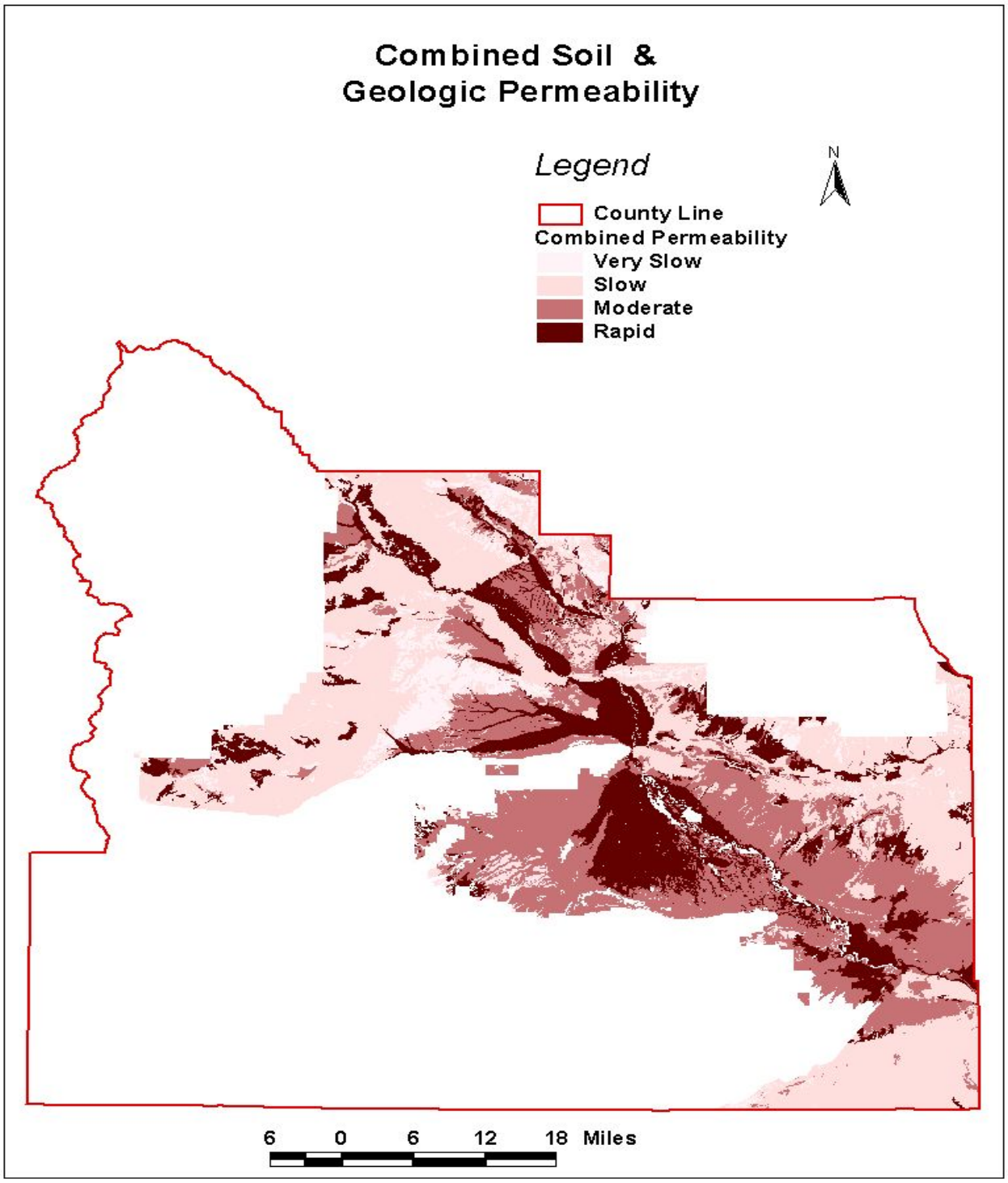

Figure 24. Combined permeability obtained by adding the geologic permeability GIS coverage to the soils permeability GIS coverage.

passing through the vadose zone and entering groundwater. Regardless of the use of the terms, the Department of Ecology methodology was found to be too broad-based to be of any use in our attempt at a countywide analysis. In the DOE methodology, infiltration is calculated by subtracting the potential evapotranspiration (PET) from the total precipitation.

The Department of Ecology manual includes a table that lists precipitation and PET listings for most counties in the state, but no information related to irrigation rates. Since the DOE manual indicates that irrigation levels must be included for the central portions of the state where precipitation levels are relatively low and where irrigation is significant, an alternative source of data was needed. Research disclosed recharge data within a USGS study for the Columbia Plateau regional aquifer system, which includes parts of Washington, Oregon, and Idaho. This study (Bauer and Vaccaro 1988) includes average irrigation rates in the overall recharge calculations. This recharge calculation considered numerous variables—including precipitation, temperature, stream flow, soils, land use, and altitude data—to determine transpiration, soil evaporation, snow accumulation, snowmelt, sublimation, and evaporation of intercepted moisture. Although the resulting recharge information is relatively broad, it does have considerably more detailed value than the countywide infiltration estimate, recommended within the Department of Ecology methodology with regards to understanding total susceptibility. This recharge data was obtained in digital format from the author of the study and was added to the formula as *total recharge*. Recharge data was broken into four distinct categories, shown in Table 21. Total recharge is shown in Figure 25.

Table 21
Four distinct categories of recharge data

Net recharge (inches)	Rating
0–1	0
1–3	1
3–9	2
> 9	3

2.4.6 Depth to groundwater

Depth to groundwater is the distance between the land surface and the uppermost aquifer, which also defines the vadose zone. The uppermost aquifer in most parts of the county is the alluvial aquifer, which the research described earlier indicates is where most domestic wells obtain potable water. The Department of Ecology manual advises using depth to groundwater data from existing well logs. As stated earlier, well log data is not available in digital format and thus is not usable for a timely analysis. Additionally, well logs have been found to be inconsistent in their descriptions of the geologic matrix and the identification of the depth to the potable water aquifer.

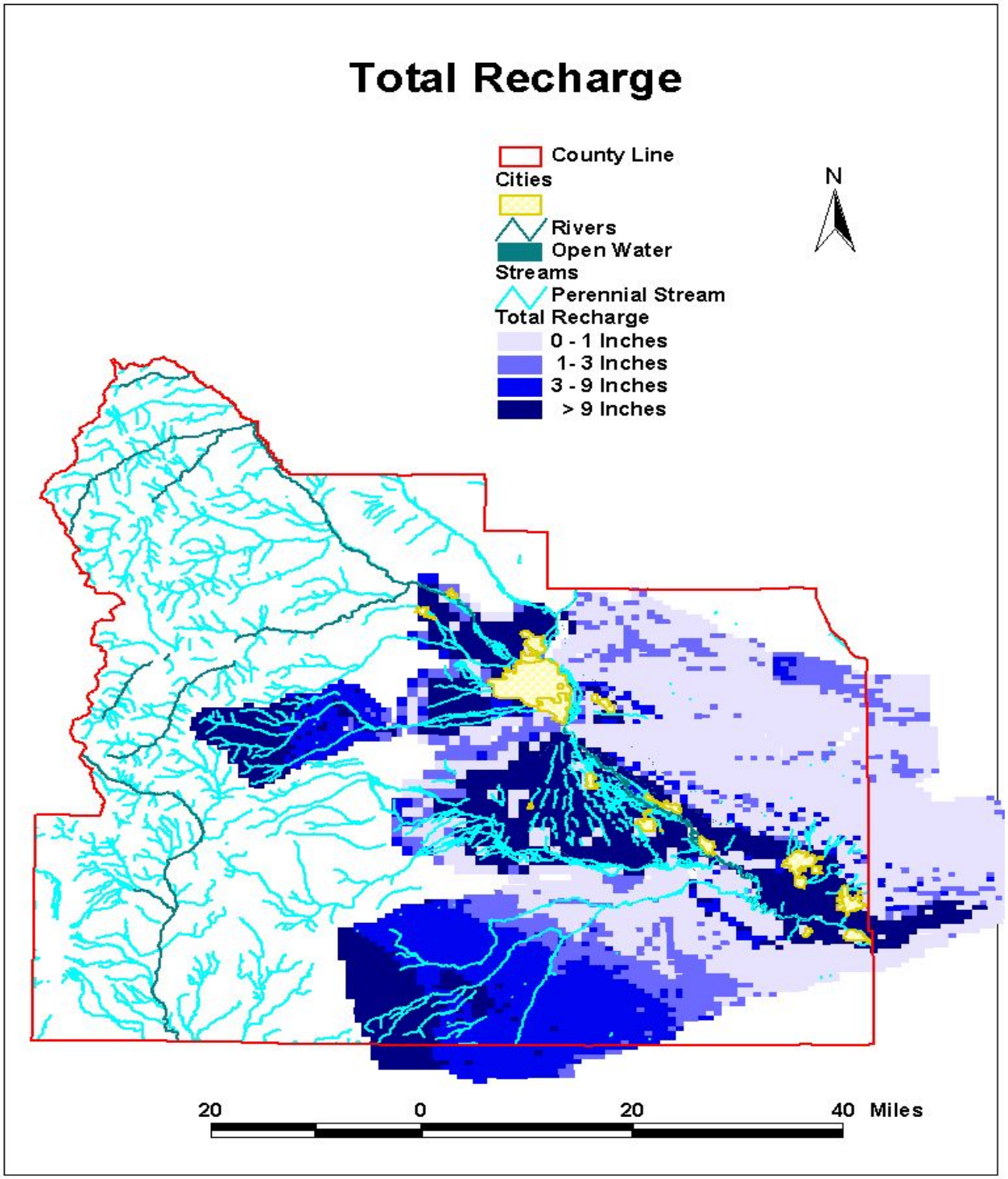

Figure 25. Total recharge.

As a proxy for depth to water, data relating to areas of shallow groundwater (less than six feet), reported in the *Soil Survey of Yakima County* (USDA 1985) has been included. The locations of these areas of shallow groundwater are shown in Figure 26. In the absence of a rating for seasonal high groundwater, it was simply determined to exist or not to exist, and 3 points are added to the overall score if seasonal high groundwater exists; a zero is added if it doesn't exist. While this does not provide a scaled rating for various depths to groundwater throughout the county, it does identify the areas of shallow groundwater most susceptible to contamination.

2.4.7 Combining the score

The final step in determining the overall level of susceptibility is to combine soil permeability, underlying geology permeability, recharge, and high groundwater information. The specific values assigned to each of these variables is added and mapped by GIS into three classifications of susceptibility: low, moderate, and high.

Low susceptibility	Moderate susceptibility	High susceptibility
0–4	5-8	9-12

This combined rating is shown in Figure 27. The full calculation process is illustrated in Figure 28.

2.4.8 Wellhead Protection

The final element of the critical aquifer recharge coverage pertains to adequate wellhead protection. The County completed its wellhead protection plan in October 2000. The purpose of this plan is to identify existing potential sources of contamination near wells within the system, to implement management strategies to prevent contamination, and to devise a contingency plan in the event groundwater contamination does occur.

Wellhead susceptibility to groundwater contamination has been calculated for periods of six months, one year, five years, and ten years, using an analytical model. The analytical model makes use of existing groundwater flow equations to provide for an accurate delineation. The direction of groundwater flow and the time for groundwater to travel a specific distance were used to determine the areas within which contaminants represent possible impacts to water quality. Each well has been assigned an appropriate level of susceptibility, outlined in the wellhead protection plan. The levels of susceptibility for each wellhead protection area should be incorporated into the general CARA coverage. Wellhead protection zones are shown in relation to the general CARA susceptibility areas in Figure 29.

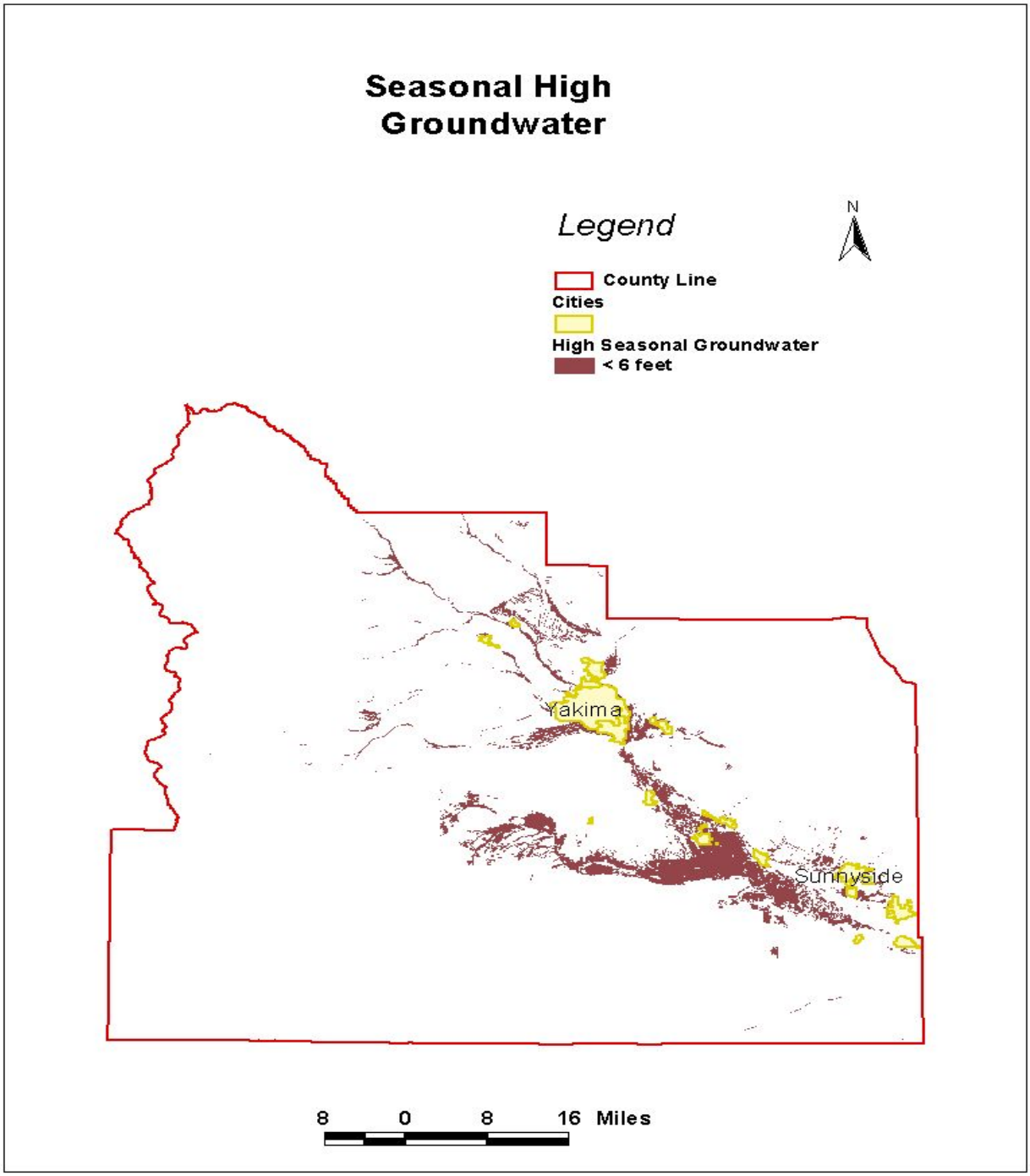

Figure 26. Seasonal high groundwater, showing locations of areas of shallow groundwater.

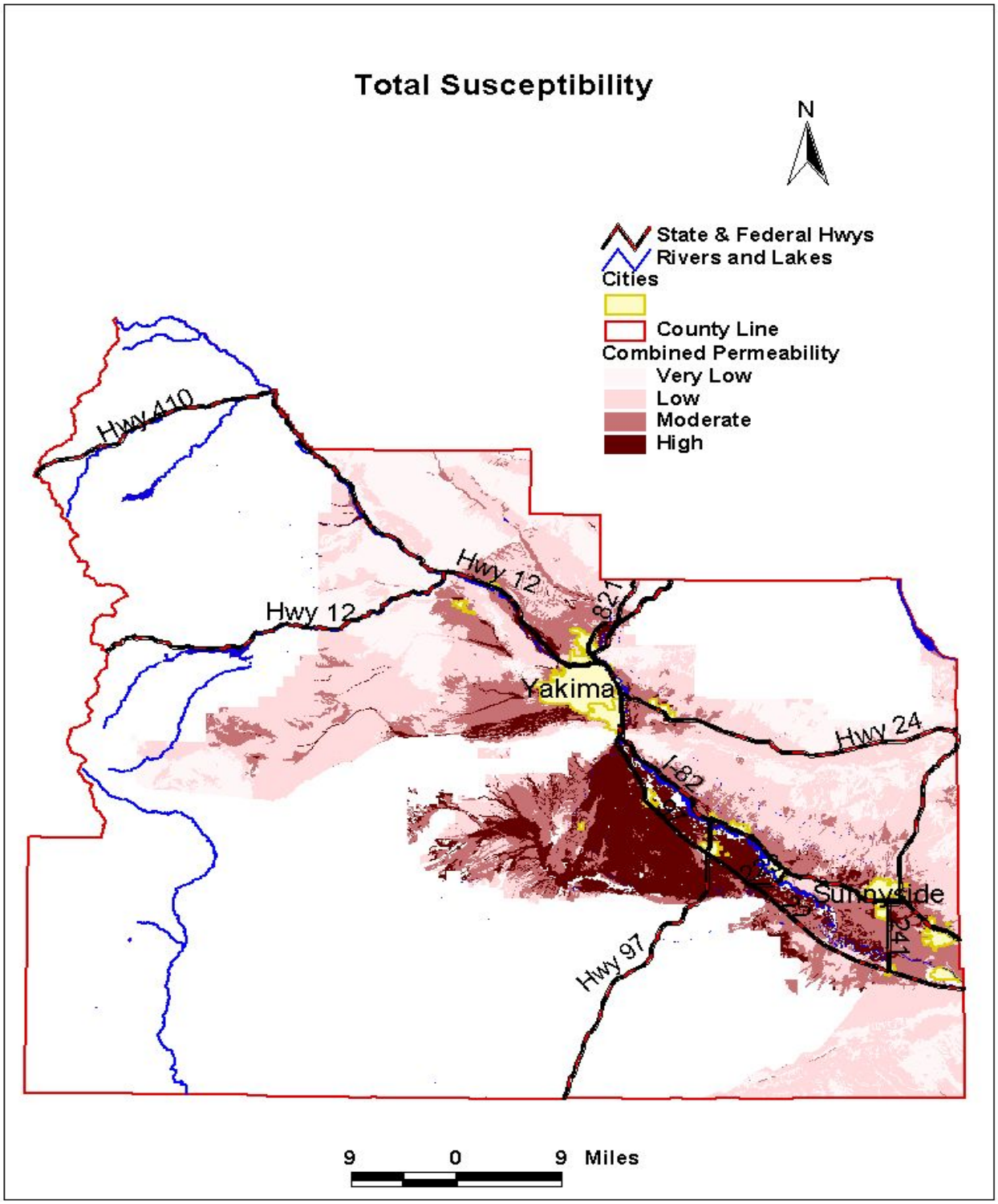

Figure 27. Total susceptibility determined by combining soil permeability, underlying geology permeability, recharge, and high groundwater information.

Total Susceptibility = Soil Permeability + Geologic Permeability + Seasonal High Groundwater + Infiltration

Soil Permeability

< 0.06	=	0
0.06 – 0.60	=	1
0.60 – 6.0	=	2
> 6.0	=	3

Geologic Permeability **(rating is based on description of the geologic material)**

Unfractured igneous or metamorphic bedrock, shale, marine clay, clay, dense sandstone, hardpan	=	0
Loess, glacial till, fractured Igneous or metamorphic Bedrock, silt, clayey sands, Weathered basalt	=	1
Silty sands, fine sands, Permeable basalt, clean Sands, karst limestone	=	2
Sand, gravel	=	3

Seasonal High Groundwater

> 6 feet	=	0
< 6 feet	=	3

Infiltration

0 – 1 inches	=	0
1 – 3 inches	=	1
3 – 9 inches	=	2
> 9 inches	=	3
Total Poss. Score	=	12

Total Susceptibility

Low	=	0 – 4
Moderate	=	5 – 8
High	=	9 – 12

Figure 28. Total susceptibility calculation.

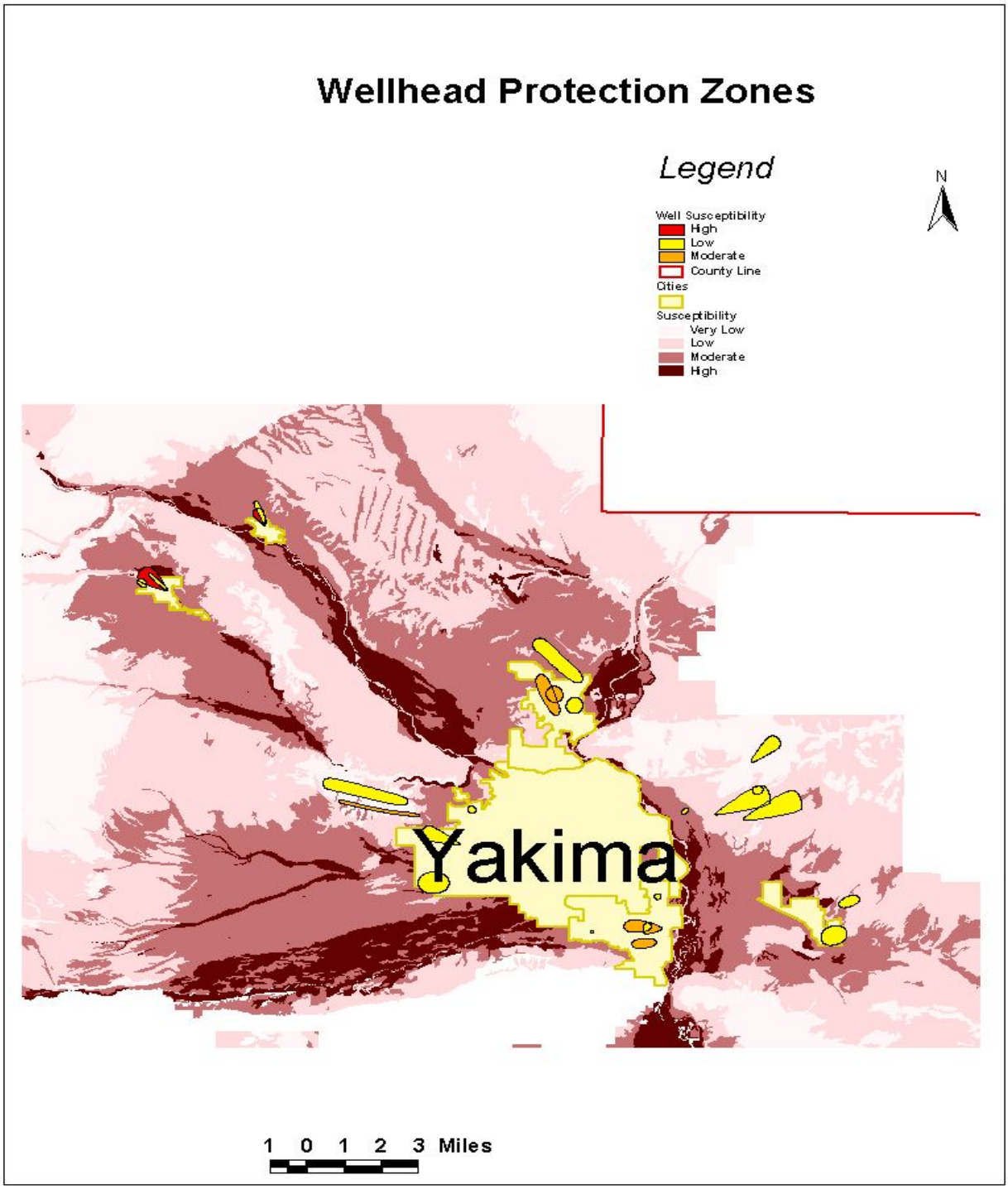

Figure 29. Wellhead protection zones shown in relation to the general CARA susceptibility areas.

3.0 GROUNDWATER CONTAMINATION

The presence of substances in groundwater, and the understanding of how, why, and where they are present, directly relates to their use and/or disposition. The United States Congressional Office of Technology Assessment (1984) published an exhaustive study related to the protection of groundwater as a potable water source, and outlined those uses that represent potential for contamination. Many substances found in groundwater are widely used by industry, agriculture, commerce, and residential households. Potential contaminants can thus enter groundwater at numerous points. Many of these substances can cause biological injury, disease, or death under certain conditions of exposure. Listed below are some of the more common contaminants sources described in the study. Some of the potential contaminants and their associated uses are listed in Figure 30 and illustrated in Figure 31.

3.1 Subsurface Percolation: Septic Tanks and Cesspools

Septic tank systems consist of a buried tank and drainage system designed to collect waterborne wastes, remove settle-able solids from the liquid by gravity separation, and permit percolation into the soil of clarified effluent. They are best suited for small volumes and periodic flows. Of all the sources known to contribute to groundwater contamination, septic tank systems and cesspools directly discharge the largest volume of wastewater into the subsurface. Major factors affecting the potential of septic systems to contaminate groundwater in general are the density of systems per unit area, and hydrogeological conditions. Areas with a density of more than 40 systems per square mile are considered regions with potential for contamination.

3.2 Land Application

Land application of treated wastewater and wastewater byproducts (i.e., sewage sludge) is often used in place of more costly disposal processes. The primary goal of such application is the biodegradation, immobilization, and/or stabilization of various chemicals, and the beneficial use of nutrients contained in the wastewater or sludge. The wastewater itself is applied primarily by spray irrigation. Sludge is applied on agricultural or forested lands, used as commercial compost, disposed of in landfills, and applied in land reclamation projects. Sludge is also disposed of by incineration and by ocean dumping. Groundwater contamination can occur when substances in sludge are leached by precipitation after the sludge is applied to the land. The substances of most concern include nitrogen, phosphorus, and heavy metals.

Contaminant	Concentration[a]	Standard[b]	Examples of uses[c]	Carcinogenic potency[d,e]	Noncarcinogenic toxicity[d,e]
Aromatic hydrocarbons	(parts per billion)				
Acetanilide-	—		Intermediate manufacturing, pharmaceuticals, dyestuffs		
Alkyl benzene sulfonates		•	Detergents		
Aniline			Dyestuffs, intermediate, photographic chemicals, pharmaceuticals, herbicides, fungicides, petroleum refining, explosives		
Anthracene	1.8[h]		Dyestuffs, intermediate, semiconductor research		
Benzene	0.6-20,230	•	Detergents, intermediate, solvents, antiknock gasoline	Low	
Benzidine			Dyestuffs, reagent, stiffening agent in rubber compounding	High	
Benzyl alcohol			Solvent, perfumes and flavors, photographic developer inks, dyestuffs, intermediate		
Butoxymethylbenzene			NA[i]		
Chrysene	10		Organic synthesis		
Creosote mixture			Wood preservatives, disinfectants		
Diben[a,h]anthracene			NA[i]		
Di-butyl-p-benzoquinone			NA[i]		
Dihydrotrimethylquinoline			Rubber antioxidant		
4,4-Dinitrosodiphenylamine			NA[i]		
Ethyl benzene	0.9-4,000	•	Intermediate, solvent		Low
Fluoranthene	31	•	NA[i]		
Fluorene			Resinous products, dyestuffs, insecticides		
Fluorescein			Dyestuffs		
Isopropyl benzene	290		Solvent, chemical manufacturing		
4,4'-Methylene-bis-2-chloroaniline (MOCA)			Curing agent for polyurethanes and epoxy resins	Low	
Methylthiobenzothiazole			—		
Naphthalene	6.7-82	•	Solvent, lubricant, explosives, preservatives, intermediate, fungicide, moth repellant		Low
o-Nitroaniline			Dyestuffs, intermediate, interior paint pigments, chemical manufacturing		
Nitrobenzene			Solvent, polishes, chemical manufacturing		Moderate
4-Nitrophenol			Chemical manufacturing		
n-Nitrosodiphenylamine			Pesticides, retarder of vulcanization of rubber		
Phenanthrene	18-471[h]		Dyestuffs, explosives, synthesis of drugs, biochemical research		
n-Propylbenzene			Dyestuffs, solvent		
Pyrene	48		Biochemical research		Low
Styrene (vinyl benzene)		•	Plastics, resins, protective coatings, intermediate		Low
Toluene	0.1-6,400	•	Adhesive solvent in plastics, solvent, aviation and high octane blending stock, dilutent and thinner, chemicals, explosives, detergents		
1,2,4-Trimethylbenzene			Manufacture of dyestuffs, pharmaceuticals, chemical manufacturing		
Xylenes (m,o,p)	0.07-300	•	Aviation gasoline, protective coatings, solvent, synthesis of organic chemicals		Low
Oxygenated hydrocarbons					
Acetic acid			Food additives, plastics, dyestuffs, pharamaceuticals photographic chemicals, insecticides		Low
Oxygenated hydrocarbons (cent'd)	(parts per billion)				
Acetone	10-3,000		Dyestuffs, solvent, chemical manufacturing, cleaning and drying of precision equipment		Low
Benzophenone			Organic synthesis, odor fixative, flavoring, pharmaceuticals		Low
Butyl acetate			Solvent		
n-Butyl-benzylphthalate	10-38		Plastics, intermediate		
Di-n-butyl phthalate	470	•	Plasticizer, solvent, adhesives, insecticides, safety glass, inks, paper coatings		Low
Diethyl ether			Chemical manufacturing, solvent, analytical chemistry, anesthetic, perfumes		
Diethyl phthalate		•	Plastics, explosives, solvent, insecticides, perfumes		
Diisopropyl ether	20-34		Solvent, rubber cements, paint and varnish removers		
2,4-Dimethyl-3-hexanol			Intermediate, solvent, lubricant		
2,4-Dimethyl phenol			Pharmaceuticals, plastics, disinfectants, solvent, dyestuffs, insecticides, fungicides, additives to lubricants and gasolines		
Di-n-octyl phthalate	23		Plasticizer for polyvinyl chloride and other vinyls		
1,4-Dioxane	2,100		Solvent, lacquers, paints, varnishes, cleaning and detergent preparations, fumigants, paint and varnish removers, wetting agent, cosmetics		
Ethyl acrylate			Polymers, acrylic paints, intermediate		
Formic acid			Dyeing and finishing, chemicals, manufacture of fumigants, insecticides, solvents, plastics, refrigerants		
Methanol (methyl alcohol)			Chemical manufacturing, solvents, automotive antifreeze, fuels		High
Methylcyclohexanone			Solvent, lacquers		
Methyl ethyl ketone			Solvent, paint removers, cements and adhesives, cleaning fluids, printing, acrylic coatings		
Methylphenyl acetamide			Na		
Phenols (e.g., p-Tert-butylphenol)	10-234,000	•	Resins, solvent, pharmaceuticals, reagent, dyestuffs and indicators, germicidal paints		
Phthalic acid			Dyestuffs, medicine, perfumes, reagent		
2-Propanol			Chemical manufacturing, solvent, deicing agent, pharmaceuticals, perfumes, lacquers, dehydrating agent, preservatives		
2-Propyl-1-heptanol			Solvent		
Tetrahydrofuran			Solvent		
Varsol			Paint and varnish thinner		
Hydrocarbons with specific elements (e.g., with N, P,S,Cl,Br,I,F)					
Acetyl chloride			Dyestuffs, pharmaceuticals, organic preparations		
Alachlor (Lasso)	190-1,700	•	Herbicides		Moderate
Aldicarb (sulfoxide and sulfone; Temik)	38-405	•	Insecticide, nematocide		High
Aldrin		•	Insecticides	High	
Atrazine		•	Herbicides, plant growth regulator, weed control agent		Moderate
Benzoyl chloride		•	Medicine, intermediate		
Bromacil	72-110		Herbicides		Moderate
Bromobenzene	1.9-5.8		Solvent, motor oils, organic synthesis		Moderate

Figure 30. A list of some of the potential contaminants and their associated uses (U.S. Congress Office of Technology Assessment 1984)

Figure 30 (continued)

Contaminant	Concentration[b]	Standard[c]	Examples of uses[d]	Carcinogenic potency[e,f]	Noncarcinogenic toxicity[e,g]
Hydrocarbons with specific elements					
(e:g., with N,P,S,Cl,B;,I,F) (cent'd)	(parts per billion)				
Bromochloromethane	—		Fire extinguishers, organic synthesis		Low
Bromodichloromethane	1.4-110	•	Solvent, fire extinguisher fluid, mineral and salt separations		
Bromoform	2.4-110		Solvent, intermediate		Moderate
Carbofuran	4-160	•	Insecticide, nematocide		Moderate
Carbon tetrachloride	0.3-18,700	•	Degreasers, refrigerants and propellants, fumigants, chemical manufacturing	Moderate	
Chlordane		•	Insecticides, oil emulsions		
Chlorobenzene	2.7-41	•	Solvent, pesticides, chemical manufacturing		Moderate
Chloroform	1.4-1,890	•	Plastics, fumigants, insecticides, refrigerants and propellants		
Chlorohexane	—		NA[i]		
Chloromethane (methyl chloride)	44		Refrigerants, medicine, propellants, herbicide, organic synthesis		Low
Chloromethyl sulfide			NA[i]		
2-Chloronaphthalene	83		Oil: plasticizer, solvent for dyestuffs, varnish gums and resins, waxes wax: moisture-, flame-, acid-, and insect-proofing of fibrous materials; moisture- and flame-proofing of electrical cable; solvent (see oil)		
Chlorpyrifos			NA[i]		
Chlorthal-methyl (DCPA, or Dacthal)			Herbicide		
o-Chlorotoluene	2.4		Solvent, intermediate		
p-Chlorotoluene	—		Solvent, intermediate		
Dibromochloromethane	2.1-55		Organic synthesis		
Dibromochloropropane (DBCP)	1-137	•	Fumigant, nematocide		
Dibromodichloroethylene	—		NA[i]		
Dibromoethane (ethylene dibromide, EDB)	35-300	•	Fumigant, nematocide, solvent, waterproofing preparations, organic synthesis		
Dibromomethane	44.9		Organic synthesis, solvent		
Dichlofenthion (DCFT)	—		Pesticides		
o-Dichlorobenzene	2.7	•	Solvent, fumigants, dyestuffs, insecticides, degreasers, polishes, industrial odor control		Moderate
p-Dichlorobenzene	0.6-0.7	•	Insecticides, moth repellant, germicide, space odorant, intermediate, fumigants		Moderate
Dichlorobenzidine			Intermediate, curing agent for resins	Moderate	
Dichlorocyclooctadiene			Pesticides		
Dichlorodiphenyldichloroethane (DDD, TDE)			Insecticides		Low
Dichlorodiphenyldichloroethylene (DDE)	0.01-0.8		Degradation product of DDT, found as an impurity in DDT residues		
Dichlorodiphenyltrichloroethane (DDT)	0.05-0.22	•	Pesticides	High	
1,1-Dichloroethane	0.5-11.330		Solvent, fumigants, medicine		Low

3.3 Landfills

Solid wastes deposited in landfills are generally classified either as hazardous or as nonhazardous. Considerations in the design of municipal landfills include the location, the area to be served, and plans for different stages in the filling process (e.g., land use upon completion of the fill). Groundwater contamination can be minimized by proper design, construction, and operation and maintenance of a facility. Abandoned landfills (the locations of which are not usually known to regulatory authorities) often pose a threat to groundwater quality because geologic and hydrologic characteristics were not considered in the original site selection; the same may be true for some active landfills.

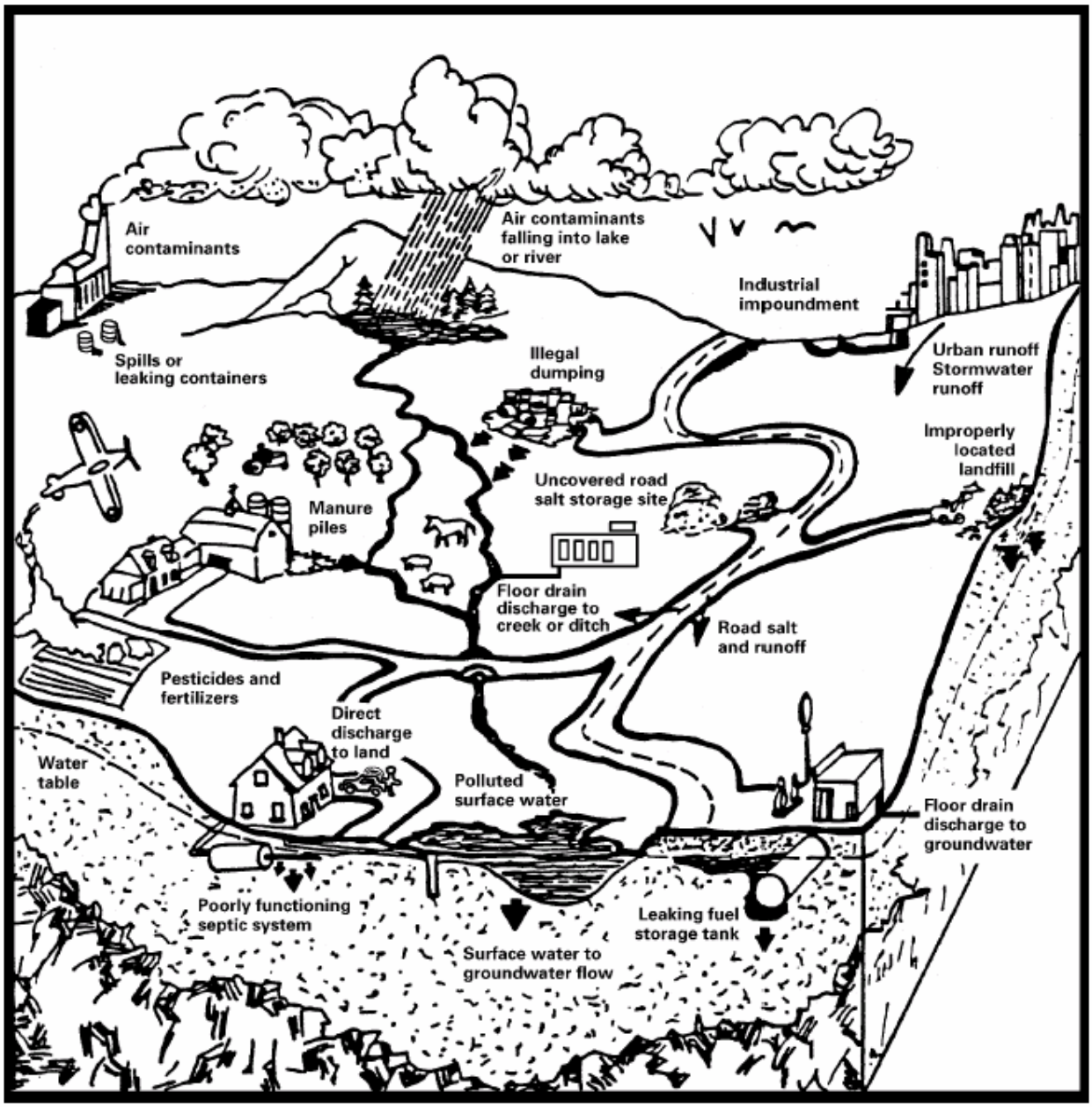

Figure 31. Preventing groundwater contamination (Michigan Department of Environmental Quality 1999).

3.4 Surface Impoundments

Surface impoundments are used by industries, agriculture, and municipalities for the retention, treatment, and/or disposal of both hazardous and nonhazardous liquid wastes. They can be either natural depressions or artificial holding areas

(e.g., excavations or dikes). The term *pit* is commonly applied to a small impoundment used by industries, municipalities, agricultural operations, or households for special purposes (e.g., farm waste storage, industrial wastewater storage, and sludge disposal). The wastewater in impoundments is treated by chemical coagulation and precipitation, by pH adjustment, by biological oxidation, by separation of suspended solids from liquids, and by reduction in water temperature.

Surface impoundments operate under one of two schemes: discharging and nondischarging. Discharging impoundments are designed to release their liquid contents either periodically or continuously into streams, lakes, bays, or the ocean. Nondischarging impoundments lose their liquid by evaporation and/or seepage. Impoundments that rely on evaporation are usually lined with low-permeability materials to prevent seepage, and are most effective in arid areas. Municipal impoundments are located at landfills and water- and waste-treatment facilities; about 33,000 are located at sewage treatment plants. Agricultural impoundments are used in crop production, animal husbandry, and other farming operations; most of them are associated with feedlot waste operations.

3.5 Materials Stockpiles

Problems associated with materials stockpiles are much the same as those associated with waste piles, the major difference being that materials stockpiles are not waste. But for all, the concern is the ultimate disposition of the soluble substances. Water percolating through stockpiles can carry soluble substances to the groundwater. Chemical reactions within coal piles, for example, can produce sulfuric acid and ferric sulfate, which can then be carried down to the groundwater by precipitation percolating through the pile.

3.6 Graveyards

Decomposing bodies in graveyards produce fluids that can leak to underlying groundwater, especially if non-leakproof caskets are used. The potential for graveyards to contaminate groundwater depends on several factors. Groundwater contamination is primarily a function of soils and depth to groundwater. Areas with high rainfall and high underlying water tables are most vulnerable to contamination from graveyards. Studies of individual cemeteries indicate that, in all cases, soil contamination occurred in immediate proximity to the graves, but not all graveyards actually contaminated groundwater. Although the contamination potential cannot be accurately quantified, the magnitude of contamination appears to be highly localized and is probably much less than that from other sources.

3.7 Animal Burial

Animal burial procedures have become increasingly sophisticated. Mass burial, less common than individual burials, occurs near large concentrations of livestock and in local landfills or open dumps. Individual burials are most likely to take place within sections of municipal landfills or in residential backyards. There are no data to

assess the potential contribution of this source to groundwater contamination. It is highly site-specific and depends on disposal practices, the surface and subsurface hydrology, the proximity of the site to water sources, the nature and amount of the disposed material, and the cause of death.

3.8 Aboveground Storage Tanks

Aboveground storage tanks for a large variety of chemicals are used in industrial, commercial, and agricultural operations, and at individual residences. No systematic information is available regarding numbers, sizes, and locations of these tanks or of the chemicals stored in them.

3.9 Underground Storage Tanks

Underground storage tanks are used by industries, commercial establishments, and individual residences for storage and treatment of products or raw materials, for waste storage and treatment, and for piping systems. Industrial use is primarily for fuel storage but also for storage of a wide range of other substances, including acids, metals, industrial solvents, technical-grade chemicals, and chemical wastes. Commercial businesses and individual homeowners use underground storage almost exclusively for fuel storage. The most numerous underground storage tanks are those used for gasoline at service stations and for fuel oil at residences.

Underground storage tanks are known to have caused many cases of groundwater contamination. In particular, old corroded gasoline storage tanks are frequently cited as sources of contamination. Such corrosion can be caused by impurities in the backfill, by faulty installation involving surface abrasions and failure to remove shoring, and by certain soil conditions. Many companies have installed new tanks near old ones. When they do, a new tank often acts as a sacrificial anode (i.e., metallic ions flow from the new tank to the old tank) and it rusts faster. In addition, dispensing pumps can develop leaks in couplings and hoses, and delivery lines can corrode or break. Although new underground tanks are usually coated with a protective or corrosion-resistant material if they are steel, or are made from relatively corrosion-resistant materials (e.g., fiberglass), they still are subject to corrosion-induced leakage. Fiberglass tanks can crack if installed incorrectly, and the polyester resins in fiberglass may be weakened by some alcohol-blend gasoline.

3.10 Containers

Containers are storage barrels and drums for various waste and nonwaste products. They can be moved around with relative ease, and although they may be buried, they are not specifically designed to be. Very little information is available about containers because they are not covered by any federal water quality regulations.

3.11 Pipelines

Pipelines are used to transport, collect, and/or distribute both wastes and nonwaste products. The wastes are primarily municipal sewage, most often located in densely populated areas. The primary nonwastes are petroleum products and natural gas, but ammonia, coal, sulfur, and anhydrous ammonia are also transported. Nonwaste pipelines are located throughout the nation; maps of major pipeline networks are available from the Federal Energy Administration. Although pipelines are designed to retain their contents and thus to pose no threat to groundwater, in reality they have leakage contamination potential. The major causes of leaks are ruptures, external and internal corrosion, incorrect operating procedures, and defective welds or pipes. Other causes were surges of fluid in pipelines, breakage or heaving of lines by tree roots or earthquakes, loss of foundation support, and rupture due to other loads.

3.12 Pesticide Applications

Pesticides are chemicals used for control of insects, fungi, and other undesirable organisms and weeds. Agricultural operations (including but not limited to those on irrigated lands) account for most pesticide use (69 to 72 percent), government agencies and industrial/commercial organizations account for 21 percent, and home and garden uses account for the remainder.

3.13 Fertilizer Applications

Farmers used 54 million tons of commercial fertilizers in 1980-1981, 48.7 million tons in 1981-1982, and 42.3 million tons in 1982-1983 (USDA 1983d, quoted in Office of Technology Assessment 1984). The areas covered are likely the same as those covered by pesticides and are spread throughout much of the country. The potential for fertilizers to contaminate groundwater depends on the rate of application in relation to crop uptake.

3.14 Animal Feeding Operations

Animal feeding operations can adversely affect groundwater if leachate enters the subsurface, either directly from the feedlots or from waste piles and wastewater impoundments (see *surface impoundments,* above). The most important potential contaminant in manure is nitrogen, but bacteria, viruses, and phosphates are also of concern. The potential for groundwater contamination is greatest in areas with high densities of animals and a shallow water table. Data are insufficient to estimate the volume of leachate and runoff that actually reaches the water table from large feedlots. In any case, because manure piles and feedlots often are near rural homes, domestic water supply wells are vulnerable.

3.15 Mining and Mine Drainage

Excavation and operation of both surface and underground mines can disrupt the natural positioning of aquifers, and hence of groundwater flow.

3.16 Urban (Stormwater) Runoff

Urbanization necessarily expands the areas that are impervious to rainfall and thus increases the amount and rate of surface runoff. The runoff, in turn, is channeled by extensive drainage networks and carries with it the contaminants associated with urban activities (e.g., automobile emissions, litter, deposited atmospheric pollutants, and sediments). The potential for groundwater contamination from urban runoff depends on where the runoff is discharged, its proximity to aquifers, and various hydrogeologic factors. A major source of contaminants is automobile emissions, which may contribute contaminants to surface runoff in some areas. The contaminants of most concern are suspended solids and toxic substances, especially heavy metals and hydrocarbons. Runoff can also contain bacteria, nutrients, and other oxygen-demanding loads, and petroleum residues.

4.0 CONTAMINATION PREVENTION

Very few uses are recommended for absolute prohibition within areas rated as highly susceptible to groundwater contamination. Those uses that are mostly consist of uses that involve subsurface disturbances, such as landfills, underground injection wells, and mining. Most other uses that represent a potential for groundwater contamination are conditioned upon various means of containing the contaminant in such a way as to ensure against any inadvertent introduction into the soil. Some examples of prevention include:

- **Fertilization**
  - Ensure that all fertilizers are applied at agronomic rates.
  - Provide adequate setback from open water and residential wells.

- **Paints and chemicals**
  - Store on an impervious surface with a perimeter barrier capable of containing the amount of liquid being stored.
  - Reuse spent cleaning solvents and/or send to a tank for periodic pumping. Do not allow to run down floor drains.

- **Underground storage tanks**
  - Backfill with noncorrosive materials.
  - Construct with noncorrosive materials.
  - Reinforce the base of tank area to support the entire weight of the tank when full.

- **Vehicle maintenance and repair shops**
  - Collect all used fluids for recycling.
  - Use non–solvent-based cleaners.
  - Use drip pans to avoid contamination from leaks.

The above list is only a sample of some of the ways contaminants can be prevented from entering groundwater and contaminating drinking water supply. Each use must be evaluated for its unique potential for groundwater contamination, and conditioned accordingly if necessary. The Washington Administrative Code lists guidelines for various uses that represent potential for groundwater contamination as follows:

Activity	**Statute–Regulation–Guidance**
Above ground storage tanks	WAC 173-303-640
Animal Feedlots	WAC 173-216, WAC 173-220
Automobile washes	WAC 173-216
BMP's for Vehicle and Equipment Discharges	WDOE WQ-R-95-56
Below ground storage tanks	WAC 173-360
Chemical treatment/storage facilities	WAC 173-303-182
Hazardous waste generator	WAC 173-303
Injection Wells	WAC 173-218
Junk yards & Salvage yards	WAC 173-304
Oil & Gas drilling	WAC 332-12-450
On-site sewage systems	WAC 173-240
Pesticide storage and use	RCW 15.54; 17.21
Sawmills	WAC 173-303, 304; WDOE 95-53
Solid waste handling & recycling	WAC 173-304
Surface Mining	WAC 332-18-015
Wastewater application to land surface	WAC 173-200 & 216

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CHAPTER 6: A REVIEW OF THE BEST AVAILABLE SCIENCE REGARDING GEOLOGIC HAZARDS IN YAKIMA COUNTY

1.0 INTRODUCTION

Geologically hazardous areas include areas susceptible to erosion, sliding, earthquake, or other geological events. They pose a threat to the health and safety of citizens when incompatible commercial, residential, or industrial development is sited in areas of significant hazard. Some geological hazards can be reduced or mitigated by engineering, design, or modified construction or mining practices, so that risks to health and safety are acceptable. When technology cannot reduce risks to acceptable levels, building in geologically hazardous areas is best avoided. Areas in Yakima County that are susceptible to one or more of the following types of hazards shall be classified as a geologically hazardous area (WAC 365-190-080):

- earthquake hazards;
- slope failure hazards, which include
  - erosion hazards,
  - landslide hazards, and
  - avalanche hazards; and
- stream corridor hazards, which include
  - flooding hazards,
  - channel migration/avulsion hazards,
  - debris flow hazards, and
  - alluvial fan hazards.

2.0 GEOLOGIC OVERVIEW OF YAKIMA COUNTY

The geology of Yakima County falls in two main regions: the southern Cascade Range to the west, with a variety of older rocks; and the Columbia Plateau to the east, that is made up of a thick series of basaltic lava flows and overlying sediments (Ring and Watson 1999) (see Figure 32). Campbell's (1998) succinct synthesis of the Columbia Plateau geology is summarized below.

The Columbia Plateau comprises a series of lava flows called the Columbia River Basalt Group (CRBG). The CRBG extends from Idaho to the Pacific Ocean, with an average total thickness of 1500 meters. The CRBG originated from fissures in the earth that discharged large volumes of molten lava. These fissures were located somewhere around southeastern Washington and northeastern Oregon. These eruptions occurred from about 17 million years ago to approximately 8 million years ago. Some of the less viscous lava flows spread to the Pacific Ocean by way of the ancestral Columbia River.

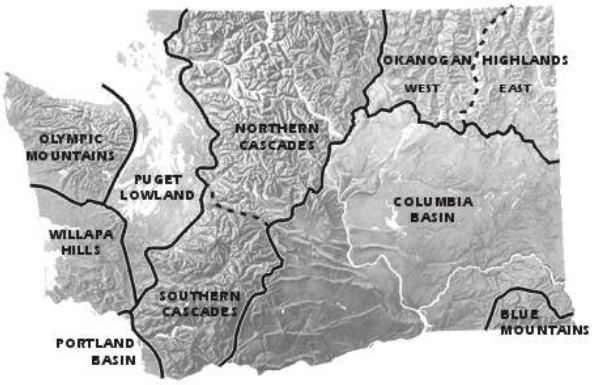


Figure 32. Geology of Washington State (Walsh et al. 2001).

The Tieton andesite formation is a lava flow in Yakima County that is not part of the CRBG. The Tieton flow originated from volcanoes in the Goat Rocks area, west of Yakima, approximately 1 million years ago. These volcanoes erupted liquid lava similar to the CRBG, which flowed down the Tieton River canyon and pooled to form the Naches Heights.

In between these flows, ancient soils formed and additional sediments were deposited. These layers are known as interbeds. Some of these interbeds were deposited as the Cascade Range was being constructed by volcanics, and consist of pumice, ash, and mud flows. Interbeds and some of the overlying sediments are known as the Ellensburg formation. The Ellensburg formation generally consists of gravel, sand, silt, and clay. The Cascade Range volcanoes responsible for the Ellensburg formation were active from about 11 to 4 million years ago. These volcanoes originally constructed cones of erodible material and no longer exist.

Additional sedimentary deposits found in Yakima County are ancestral Columbia River gravels (ACRGs), Thorp gravels, Touchet beds, loess, and Yakima River and side stream deposits. Geologic evidence indicates that the ancient Columbia River once flowed through what is now Selah, through the lower Yakima Valley as far east as Harrah, and cut across what is now Satus Pass. The ACRGs are found near the base of the Ellensburg formation and consist of quartzite-rich gravels originating from the Rocky Mountains. Deposits can be seen along the south face of Snipes Mountain and the east end of Toppenish Ridge. Uplift of the ridges and the formation of the Cascade Range forced the Columbia River to the east.

The Thorp gravels consist of ancient Yakima River terrace deposits and are generally found above the Ellensburg formation, but the exact contact is unclear. The deposits under the Terrace Heights golf course consist of Thorp gravels. The Thorp gravels were deposited approximately 3.7 to 4.9 million years ago. The Thorp formation is important to note because its base represents the time when the ridges began to rapidly rise.

The Touchet beds are slackwater lake deposits formed during the Missoula floods. The Missoula floods occurred approximately 13,000 years ago, during the last ice age, as a lobe of the continental ice sheet dammed the Clark Fork River in northern Idaho. This dam created a huge lake called Glacial Lake Missoula. The ice dam eventually failed, producing a catastrophic flood that poured across the Columbia Basin. Recent evidence indicates that as many as forty such events may have occurred over a 30,000-year time period. These large flood events were so large and erosive that they created such landforms as Dry Falls and Moses Coulee. The resulting landscape of coulees and dry channels is known as the channeled scablands of eastern Washington. Floodwaters ponded behind Wallula Gap, near the Tri-Cities, and created another lake that backed up into the Yakima Valley as far north as Moxee. Fine glacial sediment settled out of the lake, forming deposits in excess of 20 meters in some locations. The Touchet beds can be seen along the north side of I-82 near Zillah.

Loess is the main constituent of the soils found in Yakima County. During the last glacial period, winds from the southwest picked up significant amounts of fine sediment and deposited them across the Columbia Basin. The thickest deposits are found in the Palouse region of eastern Washington and western Idaho. The majority of loess deposits in Yakima County are found on the north side of the ridges, and in canyons and gullies.

The east-west trending ridges in Yakima County are known as the Yakima fold belt. This formation is caused by folding of the CRBG and interbeds into anticlinal ridges and synclinal valleys. Folding occurred in a north-south direction in association with tectonic activity and Cascade volcanism. Uplift of the ridges began approximately 15 million years ago but was most active 4 to 5 million years ago. Evidence suggests that some of the ridges may still be active. Stream sediment deposition and erosion of the ridges has filled the bottom of the synclines, forming flat-bottomed valleys. The north-south direction of compression generally created asymmetrical anticlines that have steeper north faces and gentle south faces (see Figure 33).

The ancient Yakima River cut through the ridges as they rose, to form the Yakima Canyon, Selah Gap, and Union Gap. Alpine glaciers in the Cascades, and eroded sediments from the uplifted ridges, delivered large volumes of gravel to the alluvial basins formed between the ridges. These deposits and other overlying sediments, in addition to the CRBG and interbeds, form a regionally important aquifer system. The alluvial aquifers are generally quite permeable, while Cascade Range rocks store and transmit little water (Ring and Watson 1999).

Four types of faults are commonly associated with the Yakima fold belt: thrust, normal, high-angle reverse, and strike slip. Thrust and normal faulting generally occur parallel to the ridge, along the flanks near the valley floor, while high-angle faulting occurs near the ridge crest. Strike slip faults in Yakima County run in a north to northwest direction under the ridges.

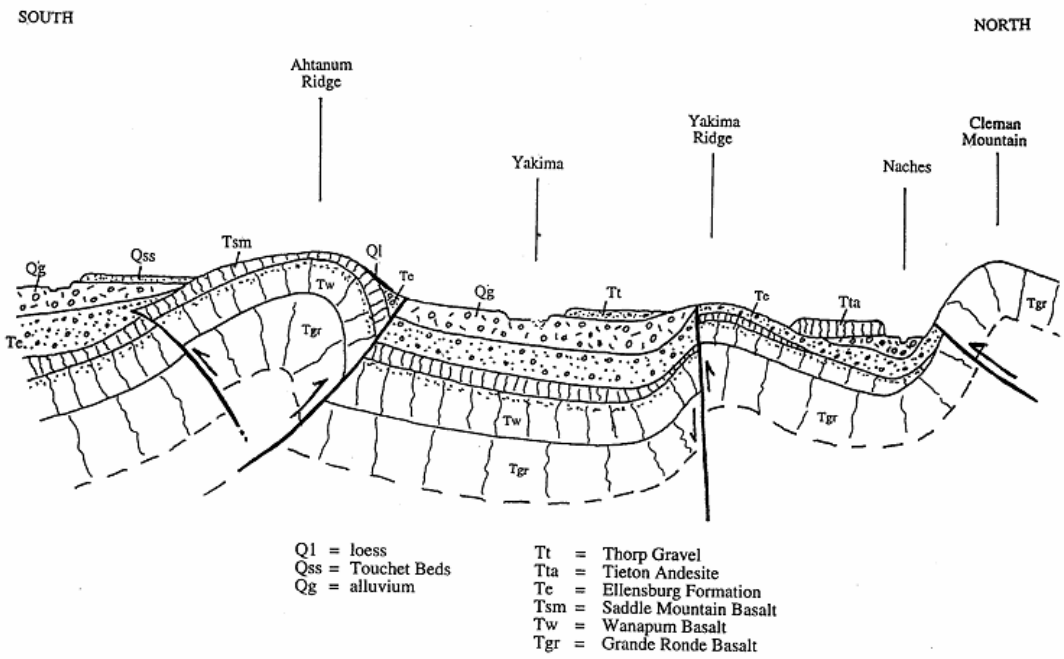


Figure 33. Cross section of the Yakima area, looking west (from Campbell 1998).

Two regional fault systems affect the local geology, the Leavenworth and the Naches. The Leavenworth system begins northwest of the city of Leavenworth, runs under the CRBG, and ends somewhere south of Rattlesnake Ridge. The crest of this system creates a north-south anticline in the basalt called the Naneum Ridge-Hog Ranch axis. The Naches system begins around Enumclaw, west of the Cascades. The Naches fault system crosses the Cascades near Naches Pass and generally follows the Naches River. The fault runs under the CRBG in a southeast direction, creating offsets in the ridges at Twin Bridges, Konowac Pass, and Snipes Mountain. A third regional fault system known as the Olympic Wallowa lineament runs under Manastash Ridge in Kittitas County and most likely has no effect on Yakima County geology.

The Washington Department of Natural Resources synthesized the geology of the southern Cascades region from Lasmanis (1991), summarized below.

The southern Cascade region consists mostly of volcanic rocks and associated deposits. Small amounts of CRBG are found along the eastern margins. The southern Cascade region is bounded by the Puget lowlands to the west and is

severed by the Columbia River Gorge to the south. Southern Cascades geology is less complex than the geology of the northern Cascades, although a small amount of highly deformed sedimentary and volcanic rock is exposed in the vicinity of Rimrock Lake, along State Highway 12.

Southern Cascades mountain building was initiated by basalt and andesite volcanism approximately 33 million years ago. Columbia River basalts flowed up against the eastern flanks of the Cascades, which later were arched upward with uplift and mountain building, initiated approximately 23 million years ago.

The southern Cascades contain three large volcanoes: Mount Rainer, Mount Saint Helens, and Mount Adams. Mount Adams is the only volcano located within Yakima County and is the second highest peak in the Pacific Northwest, at 12,276 feet above sea level. Mount Adams was built up of andesite flows emanating from a cluster of vents. Mount Adams is a relatively young volcano, having developed during the last 1.8 million years. There was repeated volcanic activity from 275,000 to 2,500 years ago, interspersed with periods of glaciation. Large debris flows and rock falls have been described for Mount Adams. Thermal activity, evidenced by fumaroles, has altered the andesite and deposited sulfur near the summit.

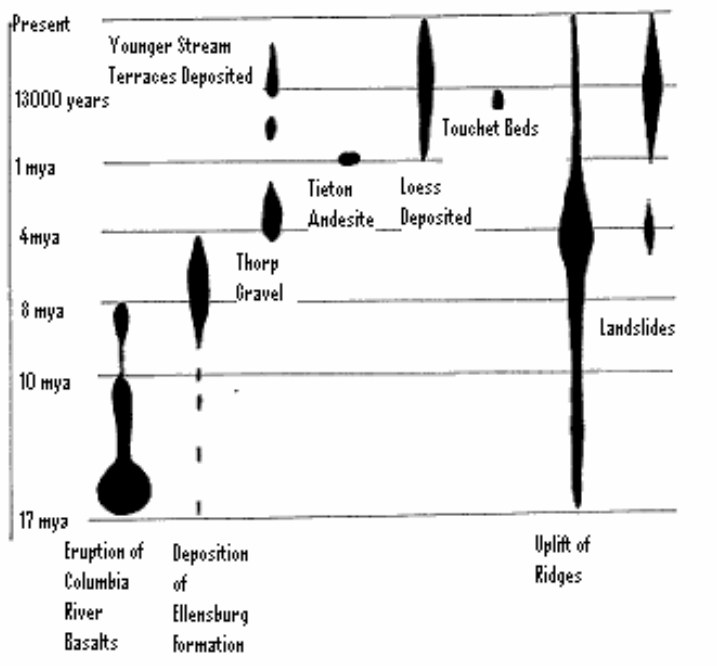


Figure 34. Sequence of events involved in the geologic history of the Yakima area. The greater the intensity of the geologic event, the thicker the line (Campbell 1998).

3.0 VOLCANIC HAZARDS

The GMA (WAC 365-190-080) defines the minimum standards for identifying volcanic hazard areas as "areas subject to pyroclastic flows, lava flows, debris avalanche, inundation by debris flows, mudflows, or related flooding resulting from volcanic activity." While Yakima County contains a portion of Mount Adams and is in close proximity to Mount Rainer and Mount Saint Helens, the threat of volcanic hazards is minimal and limited to ash deposition. The more devastating effects of volcanic activity, such as lava flows and lahars, are not possible due to intervening ridges (Campbell 1998).

4.0 EARTHQUAKE HAZARDS

4.1 Introduction

The GMA (WAC 365-190-080) defines the minimum standards for identifying seismic hazard areas as

> areas subject to severe risk of damage as a result of earthquake induced ground shaking, slope failure, settlement, soil liquefaction, or surface faulting. One indicator of potential for future earthquake damage is a record of earthquake damage in the past. Ground shaking is the primary cause of earthquake damage in Washington.
>
> The strength of ground shaking is primarily affected by
> - the magnitude of an earthquake,
> - the distance from the source of an earthquake,
> - the type and thickness of geologic materials at the surface, and
> - the type of subsurface geologic structure.
>
> Settlement and soil liquefaction conditions occur in areas underlain by cohesionless soils of low density, typically in association with a shallow ground water table.

The remainder of this section is summarized from Shedlock, Kaye, and Pakiser (1994).

An earthquake is an abrupt movement of the Earth's crust, caused by a sudden release of energy that has accumulated over time. Energy can be generated by a sudden dislocation of segments of the crust, by a volcanic eruption, or by human-made explosions. Dislocations of the crust cause the most destructive quakes. The crust may first bend and then, when the stress exceeds the strength of the rocks, break and snap to a new position. In the process of breaking, vibrations called seismic waves are generated. These waves travel outward from the source of the earthquake, along the surface and through the Earth at varying speeds, depending on the material through which they move.

The focal depth of an earthquake is the depth from the Earth's surface to the region where an earthquake's energy originates (the focus). Earthquakes with focal depths from the surface to about 70 kilometers (43.5 miles) are classified as *shallow*. Earthquakes with focal depths from 70 to 300 kilometers (43.5 to 186 miles) are classified as *intermediate*. The focus of deep earthquakes may reach depths of more than 700 kilometers (435 miles). The focuses of most earthquakes are concentrated in the crust and upper mantle. The epicenter of an earthquake is the point on the Earth's surface directly above the focus. The location of an earthquake is commonly described by the geographic position of its epicenter and by its focal depth.

The vibrations produced by earthquakes are detected, recorded, and measured by instruments call seismographs. The zigzag line made by a seismograph, called a seismogram, reflects the changing intensity of the vibrations by responding to the motion of the ground surface beneath the instrument. From the data expressed in seismograms, scientists can determine the time, the epicenter, the focal depth, and the type of faulting of an earthquake, and can estimate how much energy was released.

The two general types of vibrations produced by earthquakes are surface waves, which travel along the Earth's surface, and body waves, which travel through the Earth. Surface waves usually have the strongest vibrations and probably cause most of the damage done by earthquakes. Body waves are of two types, compressional and shear. Both types pass through the Earth's interior from the focus of an earthquake to distant points on the surface, but only compressional waves travel through the Earth's molten core.

The magnitude of an earthquake, usually expressed using the Richter scale, is a measure of the amplitude of the seismic waves. The moment magnitude of an earthquake is a measure of the amount of energy released—an amount that can be estimated from seismograph readings. The intensity, as expressed by the modified Mercalli scale, is a subjective measure that describes how strong a shock was felt at a particular location.

The Richter scale is logarithmic, so that a recording of 7.0, for example, indicates a disturbance with ground motion 10 times as large as a recording of 6.0. A quake of magnitude 2.0 is the smallest quake normally felt by people. Earthquakes with a Richter value of 6.0 or more are commonly considered major; great earthquakes have magnitude of 8.0 or more on the Richter scale.

The modified Mercalli scale expresses the intensity of an earthquake's effects in a given locality in values ranging from I to XII. The most commonly used adaptation covers the range of intensity from the condition of

- I—Not felt except by a very few under especially favorable conditions, to
- XII—damage total. Lines of sight and level are distorted. Objects are thrown upward into the air.

4.2 How Earthquakes Cause Damage

The chief mechanisms by which earthquakes cause damage are through ground shaking, and through the secondary effects of ground failures (e.g., surface faulting, ground cracking, landslides, liquefaction, and subsidence). The intensity of ground shaking (strong motion) usually decreases with distance from the earthquake source (attenuation). Ground shaking can be more intense in other areas due to amplification (an increase in strength of shaking for some range of frequencies), while at the same time there is a decrease, or deamplification, in strength of shaking for other frequencies. Amplification takes place where earthquake waves pass from bedrock into softer geologic materials such as sediments. Strong shaking of long duration is one of the most damaging characteristics of great subduction-zone earthquakes. Strong shaking is a hazard both near the epicenter of an earthquake and in areas where amplification occurs (Walsh, Gerstel, Pringle, and Palmer 2001).

Ground failures associated with earthquakes include surface faulting, ground cracking, subsidence, liquefaction, and landslides. Surface faulting occurs as offsets of the ground surface and is limited to the immediate area of the fault. Other ground failures can cover a wide area and have multiple causes. Earthquakes have caused landslides, including debris avalanches from volcanoes. Earthquake-induced acceleration can produce additional downslope force, causing otherwise stable or marginally stable slopes to fail. Rockfalls can be triggered at great distances from earthquake epicenters (Walsh, Gerstel, Pringle, and Palmer 2001).

Liquefaction is a phenomenon in which strong earthquake shaking causes a soil to rapidly lose its strength and to behave like quicksand. Liquefaction typically occurs in loose sandy soils saturated with water, such as those found at lakeshores and in river valleys. The basic idea is that earthquake waves pass more slowly through soil than through the underlying rock of the earth's crust, and it is this difference in wave speed that causes the shaking at the ground surface to be amplified. Generally, the greater the wave velocity difference, the greater the amplification of ground surface shaking. Consequently, ground shaking in areas of soft soils underlain by stiffer soils or rock is generally stronger than in areas where there is little or no variation in seismic velocity between the surface and subsurface (Palmer et al. 2003).

Soil liquefaction occurs in four different forms (NRC 1985):

- flow slides from slopes;
- loss of foundation bearing capacity, leading to large settlement and/or tilting of structures;
- lateral spreading, or a movement of gradually sloping ground toward low points;
- ground oscillation, where ground overlying saturated soil breaks up into jostling plates.

Flow slides and a loss of bearing capacity are dramatic but less common. While the remaining forms are less spectacular, they are much more common (NRC 1985).

4.3 Earthquakes in Washington

The following sections are summarized from Walsh, Gerstel, Pringle, and Palmer's (2001) pamphlet *Earthquakes in Washington.*

Washington is situated at a convergent continental margin, the collisional boundary, between two tectonic plates. The Cascadia subduction zone, which is the convergent boundary between the North America plate and the Juan de Fuca plate, lies offshore of Washington, Oregon, and northern California. The two plates are converging at a rate of about 3 to 4 centimeters (2 inches) per year; in addition, the northward-moving Pacific plate is pushing the Juan de Fuca plate north, causing complex seismic strain to accumulate. Earthquakes are caused by the abrupt release of this slowly accumulated strain (Figure 35).

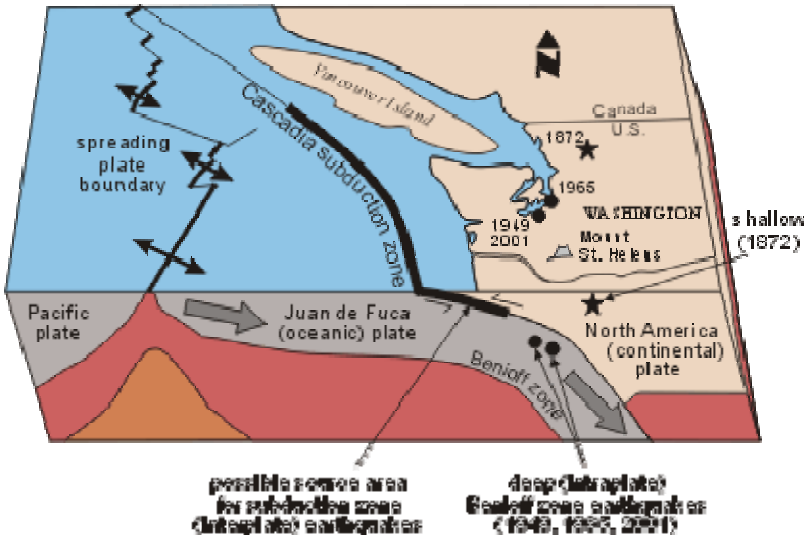


Figure 35. The Cascadia subduction zone (Walsh et al. 2001).

There are three types of earthquakes found in Washington:

- intraplate or Benioff-zone earthquakes,
- shallow crustal earthquakes, and
- subduction zone (interplate) earthquakes.

Intraplate or Benioff-zone earthquakes occur in the subducting Juan de Fuca plate at depths of 25 to 100 kilometers. As the Juan de Fuca plate subducts under the North America plate, earthquakes are caused by the abrupt release of slowly accumulated strain. Benioff-zone ruptures usually have dip-slip or normal faulting and produce no large aftershocks. These earthquakes are caused by mineral changes as the plate moves deeper into the mantle. Temperatures and pressure increase, and the minerals making up the plate alter to denser forms that are more stable at the increased temperature and pressure. The plate shrinks and stresses build up that pull the plate apart.

Shallow crustal earthquakes occur within about 30 kilometers of the surface. Shallow crustal earthquakes are the primary mechanism for earthquakes in Yakima County.

Subduction zone (interplate) earthquakes occur along the interface, between tectonic plates. Compelling evidence for great-magnitude earthquakes along the Cascadia subduction zone has recently been discovered. These earthquakes were potentially devastating (magnitude 8.0 to 9.0+) and recurred on average every 550 years. The recurrence interval, however, has apparently been irregular, as short as about 100 years and as long as about 1,100 years. The last of these great earthquakes occurred in Washington about 300 years ago.

4.4 Earthquakes in Yakima County

Repasky, Campbell, and Busacca (1997) conducted a National Earthquake Hazard Reduction Program (NEHRP) study that found a potential for moderate to strong seismic activity in the Yakima area. There have been at least three and possibly five earthquakes up to magnitude 7.1 on Toppenish Ridge in the past 165,000 years, and three or more seismic events of up to magnitude 6.0 on Rattlesnake Hills/Ahtanum Ridge in the past 109,000 years. Both fault systems are considered active and capable of further movement.

Repasky, Campbell, and Busacca (1997) found that the strongest event (~7.1) likely occurred between 5,000 and 7,000 years ago. Fieldwork conducted on the Union Gap fault on Rattlesnake Hills/Ahtanum Ridge uncovered clear evidence for at least three seismic events in the past 109,000 years. The latest event most likely occurred about 15,000 years ago. The short length of the Union Gap fault (8 km) and the 3 meter offset in the graben suggests an event of less than 6.0.

The Union Gap fault zone consists of a series of grabens and thrust faults located south of the city of Yakima. At Union Gap, the faults cross onto the north limb of Ahtanum Ridge anticline. The faults cannot be traced beyond 2 kilometers west of Union Gap, due to ground surface disruption by development and agricultural land use. The present known length of the fault zone is 8 kilometers.

The active faults and graben (informally called the Union Gap fault) are close to population centers. Even small events could cause some damage. Several old landslides are visible on the north side of the ridge—one trailer court and several

homes are built on slide debris. A second trailer court is built directly on the graben. Many homes in the town of Union Gap and nearby Yakima are built on stream alluvium that may become unstable during an earthquake event.

Geomatrix (1996) conducted predictive modeling to determine the seismicity of the Columbia Basin for the Hanford Nuclear Reservation. Geomatrix reported that earthquake activity in the Columbia Basin is attributed to three separate source regions:

- thrust and reverse fault sources at the surface in the Yakima fold system,
- shallow sources in the Columbia River Basalt Group that is not associated with the Yakima fold system, and
- a crystalline basement source region below the CRBG.

Geomatrix (1996) determined earthquake probability for the Yakima fold ridges in the Columbia Basin and found that Toppenish Ridge has a high probability, with the remainder of the ridges assessed a relatively low probability. Geomatrix also assessed the potential for a coupled earthquake source, which consists of a fault underlying a fold, which extends from the surface or near the surface within the basalts, down into the basement through the entire width of the crust. The Toppenish Ridge was assigned a high level of coupling due to evidence of large earthquake events with relatively large degrees of displacement. The Toppenish Ridge may be more active than the rest of the Columbia Basin because it sits in a structural setting that appears to be more influenced by Cascade Range tectonic activity. The Horse Heaven Hills were also assessed a high level of coupling, based on similarities to Toppenish Ridge orientation, deformation style, and location, but they do not display recent evidence of faulting. The remainder of Yakima fold ridges were assessed a low potential for coupling. Geomatrix then computed a potential maximum earthquake magnitude for Yakima fold ridges (Table 22) and determined a 5,000-year recurrence frequency of events with a magnitude ≥ 6.0.

Table 22
Potential maximum earthquake magnitude for Yakima fold ridges (Geomatrix 1996)

Ridge	**Potential Maximum Magnitude Range**
Umtanum	6.5-7.8
Rattlesnake	6.7-7.7
Manastash	7.0-7.6
Saddle Mount	6.8-7.7
Horse Heaven Hills	7.0-7.9
Yakima Ridge	7.0-7.6
Frenchman Hills	7.0-7.5
Toppenish	6.8-7.6
Hog Ranch	7.0-7.6

4.5 Earthquake Hazards and Building Codes

In the mid 1990s a simplified method for characterizing the ground-motion amplifying effects of soft soils was developed by Roger Borcherdt of the U.S. Geological Survey, based on data collected from the Loma Prieta and Northridge earthquakes in California. His empirical study related the average shear-wave velocity in the upper 100 feet of the soil-rock column to the amplification of shaking at ground surface (Borcherdt 1994, quoted in Palmer et al. 2003). Shear waves are the earthquake waves that create the strongest horizontal shaking and are the most damaging to buildings and structures.

A modification of Borcherdt's empirical method was implemented by the Building Seismic Safety Council and the Federal Emergency Management Agency in the 1994 edition of the NEHRP's *Recommended Provisions for Seismic Regulations for New Buildings and Other Structures.* In 1997, this modified method of accounting for soil-column amplification effects was adopted by the International Council of Building Officials into the Uniform Building Code (UBC). The 1997 version of the UBC was approved by the Washington State Legislature as the statewide building code (Palmer et al. 2003).

The 1997 edition of the UBC is the current governing publication describing the minimum design requirements for structures built within Washington State. The 1997 UBC, with appropriate amendments, was adopted by the state in the summer of 1997, and enforcement began in the summer of 1998. It will remain in force until the summer of 2004, when the 2003 IBC, adopted by Washington State in the summer of 2003, will be enforced as the governing publication describing the minimum design requirements for Washington State structures.

With regard to the UBC, seismic (earthquake) design was codified in the first edition of the UBC following the 1925 Santa Barbara earthquake. Seismic design became mandatory following the 1933 Long Beach 6.2 Richter scale earthquake. The early editions of the UBC were written by the Pacific Coast Building Officials Conference, an organization that later became the International Conference of Building Officials (ICBO).

From the first seismic designs to today's seismic designs, several milestone changes have been implemented to improve the design process. Most early changes were regarding the recognition of distinct zones of seismic activity and definitions of seismic structure weight. In 1957, a committee of the Structural Engineers Association of California (SEAOC) began the development of the Uniform Seismic Code for California, also known as the Blue Book. The Blue Book remained a driving force behind UBC seismic code design provisions and received input from several scientific and professional organizations.

Several design factors or modifiers have been incorporated in seismic design including more specific seismic zones (recognizing seismic activity zones and magnitudes); importance factors (recognizing the need for certain essential structures to perform well in seismic events); K or R factors (recognizing the response to seismic events of various types of structure types and

configurations); and others. Another factor or modifiers that has been incorporated into seismic design is the C, or C and S factor(s), which recognizes the effects of site-specific soil conditions and fundamental building response periods to structure seismic performance.

The last version of the UBC (1997) was very specific with regards to site-specific soil factors (Ca, Cv, and Nv) and R factors. The 1997 UBC incorporated into its seismic design the best available resources, most notably the most recent NEHRP methodology. This edition of the UBC, like the previous editions, underwent the ICBO code development process prior to publication (Tate 2004, pers. comm.)

In 1985, the Building Seismic Safety Council (BSSC) published the NEHRP *Recommended Provisions for the Development of Seismic Regulations for Buildings*. FEMA funded the development of the NEHRP document. The NEHRP documents are, at this time, the definitive publication for recommended seismic design within the United States.

The 2003 edition of the International Building Code references many standards and documents, and will be enforced within Washington Slate beginning in the summer of 2004. One such document is the American Society of Civil Engineers (ASCE) Publication 7, *Minimum Design Loads for Buildings and Other Structures* (ASCE 2002). Chapter nine describes the minimum design seismic (earthquake) loads, and is essentially the recommendations taken from the 2002 Edition of the NEHRP documents. This NEHRP document, like the previous editions, was published by the BSSC and is a benchmark document in seismic design. The 2003 IBC, like the 2000 IBC before it, underwent the ICC code development process, much the same as the UBC's code processes under the ICBO. It is expected that future codes will adhere to the NEHRP documents for seismic design and will undergo the typical code development processes and amendments (Tate 2004, per. comm.).

5.0 SLOPE FAILURE HAZARDS

There are five general ways that slope failure can occur under the forces of gravity (NRC 1985):

- material may fall freely through the air from a cliff;
- it may topple or tilt over a pivot point;
- it may slide downward along an identifiable surface or narrow zone that either is curved or spoon-shaped (rotational slide or slump) or is relatively planar (translation slide);
- it may spread laterally across a slope; or
- it may flow as a thick fluid, sometimes very rapidly (debris flow), sometimes so slowly as to be barely perceptible (creep).

Slope movements involving two or more of these types of movements are termed *complex*.

5.1 Erosion Hazards

The GMA (WAC 365-190-080) defines the minimum standards for identifying erosion hazards as "At least those areas identified by the United States Department of Agriculture Soil Conservation Service as having a severe rilland inter-rill erosion hazard." The USDA Soil Survey of Yakima County (1985) describes erosion characteristics associated with each soil type, indicating the soil's level of probability for erosion. Figure 36 shows those soils with severe and very severe levels of erosion hazard.

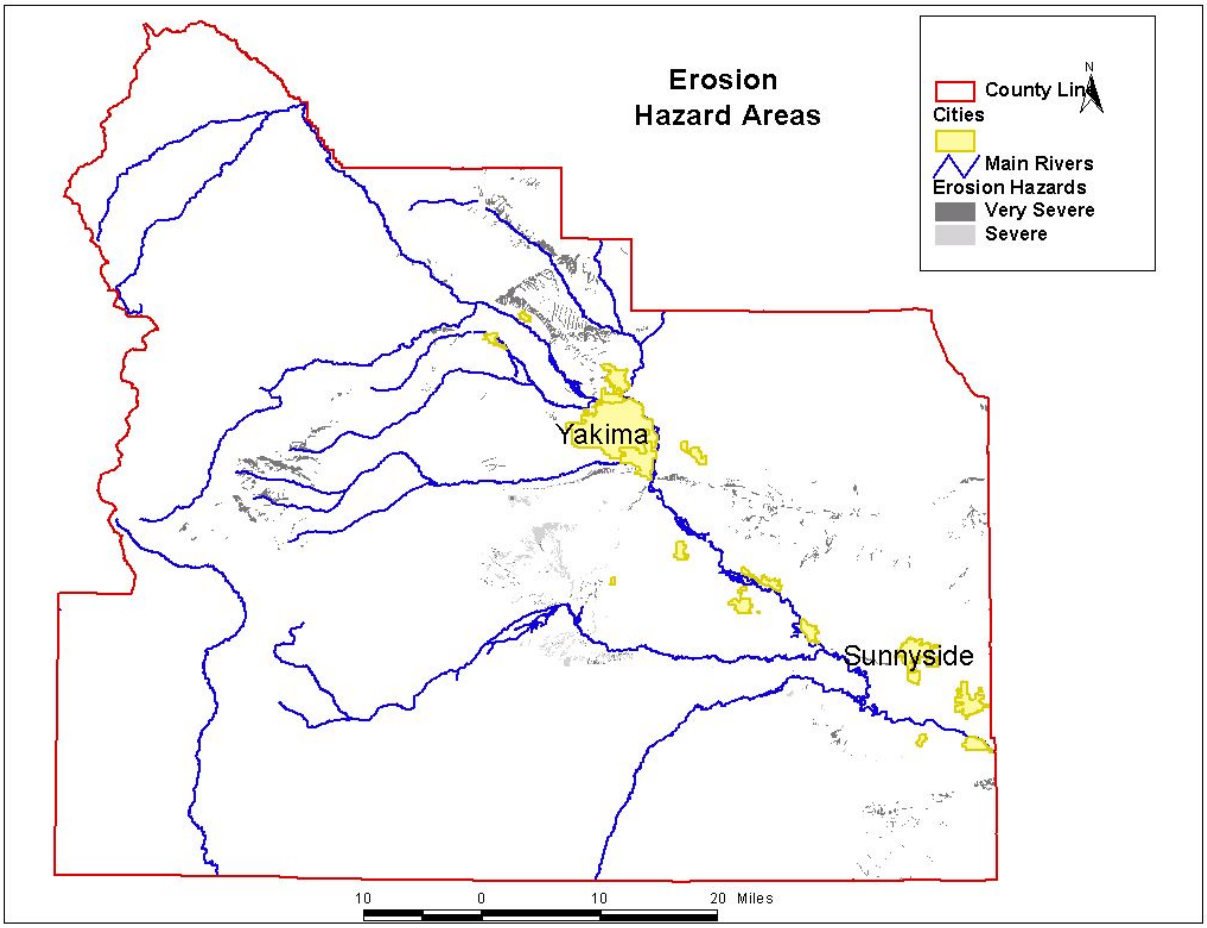


Figure 36. Soils with severe and very severe levels of erosion hazard.

5.2 Landslide Hazards

The GMA (WAC 365-190-080) defines the minimum standards for identifying landslide hazard areas as follows.

Landslide hazard areas shall include areas potentially subject to landslides based on a combination of geologic, topographic, and hydrologic factors. They include any areas susceptible because of any combination of bedrock, soil, slope (gradient), slope aspect, structure, hydrology, or other factors. Example of these may include, but are not limited to the following:

- Areas of historic failures, such as
  - Those areas delineated by the United States Department of Agriculture Soil Conservation Service as having a "severe" limitation for building site development; or
  - areas designated as quaternary slumps, earth-flows, mudflows, lahars, or landslides on maps published as the United States Geological Survey or department of natural resources division of geology and earth resources.
- Areas with all three of the following characteristics:
  - slopes steeper than fifteen percent, and
  - hillsides intersecting geologic contacts with a relatively permeable sediment overlying a relatively impermeable sediment or bedrock, and
  - springs or groundwater seepage.
- Areas that have shown movement during the Holocene epoch (from ten thousand years ago to the present) or which are underlain or covered by mass wastage debris of that epoch.
- Slopes that are parallel or subparallel to planes of weakness (such as bedding planes, joint systems, and fault planes) in subsurface materials.
- Slopes having gradients steeper than eighty percent subject to rockfall during seismic shaking.
- Any area with a slope of forty percent or steeper and with a vertical relief of ten or more feet, except areas composed of consolidated rock. A slope is delineated by establishing its toe and top and measured by averaging the inclination over at least ten feet of vertical relief.

Other landslides occur when layers of bedrock, usually basalt flows, slide along planes of weakness. This is usually the result of undercutting along the flank of an anticlinal ridge where basalt and weakly resistant interbeds are tilted at a steep angle (Campbell 1998).

Although gravity acting on and over steepened slope is the primary reason for a landslide, there are other contributing factors (USGS 2002).

- Erosion by rivers or glaciers creates oversteepened slopes.
- Rock and soil slopes are weakened through saturation by snowmelt or heavy rains.
- Earthquakes create stresses that make weak slopes fail.
- Earthquakes of magnitude 4.0 and greater have been known to trigger landslides.
- Volcanic eruptions produce loose ash deposits, heavy rain, and debris flows.

- Excess weight from accumulation of rain or snow, stockpiling of rock or ore, from waste piles, or from human-made structures may stress weak slopes to failure.

Lillquist (2001) found that mass-wasting events (landslides) are common along the Columbia River Basalts in eastern Washington. Analysis discovered that slope failures covered approximately 38 percent of the Swauk watershed in Kittitas County. Translational slides were the most numerous, but complex slide-flows cover the most area. Slope failures were placed into four categories based on age: active, inactive-young, inactive-mature, and inactive-old. The majority of slope failures were found to be inactive-mature (> 6,880 years ago), with a minority of inactive-young (< 5,930 years ago). Rockfall deposits cover ~29 percent of the watershed, range from inactive to active, and are typically found on top of previous slope failures in well-jointed Columbia River Basalts. Slope failures are typically associated with steep slopes, inclined beds, incompetent geologic units, stream-cuts, road-cuts, and clear-cuts. In addition, extreme climatic events such as rain-on-snow events can activate slopes which previously were stable.

5.3 Avalanche Hazards

The GMA (WAC 365-190-080) defines the minimum standards for identifying avalanche hazard areas as "areas that show evidence of or are at risk from snow avalanches." The National Research Council (1990) synthesized the science of avalanches, and this information is summarized below.

A snow avalanche is a type of slope failure that can occur whenever snow is deposited on slopes steeper than about 20 to 30 degrees. Avalanche-prone areas can be delineated with some accuracy, since under normal circumstances avalanches tend to run down the same paths year after year, although exceptional weather conditions can produce avalanches that overrun normal path boundaries or create new paths.

There are two basic types of snow avalanches: point release and slab. A point release avalanche is the result of a small amount of cohesionless snow slipping out of place, moving downslope, and encountering additional cohesionless snow, such that the failure progresses and spreads out into a characteristic inverted V-shaped pattern. Point release events typically occur either within the cohesionless near-surface layers of newly fallen snow or within the wet surface snow resulting from melt conditions. Point release events usually involve small volumes and generally present a small degree of hazard.

Slab avalanches initiated within cohesive snow cover on slopes steeper than 25 degrees present the majority of avalanche hazards and are the main focus of defense and control measures. Failures occur when the shear load parallel to the slope exceeds the shear strength of supporting layers, and where the layer of cohesive snow, poorly anchored underneath, fractures as a continuous single unit. With relatively homogeneous snow properties, the fracture may spread for a great distance across a slope and may include a large volume of snow. Fractures may

extend as much as several meters into the snow cover. Prediction of slab avalanches is difficult because the location of initial failure is frequently well below the surface, within the layers that accumulated weeks or months earlier. Slab avalanches present a significant hazard due to difficulty of prediction, in addition to their potential for release over large areas. The hazard to activity and structures in the avalanche run-out zone is high due to the large volumes of snow that can be activated by a slab release. Wet snow avalanches present additional problems due to their high mobility and erratic run-out style. Also important is the rapid mass movement of water-saturated snow, known as a slush flow.

Point release avalanches occur when cohesionless snow rests on a slope that is steeper than the snow's natural angle of repose. In contrast, slab release occurs when a cohesive cover of snow rests above a layer of lesser strength, along which the eventual sliding failure occurs when shear stress exceeds shear resistance. Slab release typically results from a complex series of events, often originating within a snow cover creeping downslope. Direct loads due to falling cornices, passage of humans through the starting zone, rockfalls, rain-on-snow events, or elastic waves from blasting or earthquakes can trigger avalanches.

6.0 STREAM CORRIDOR HAZARDS

The GMA (WAC 365-190-080) defines the minimum standards for identifying stream corridor hazards: "Areas potentially unstable as a result of rapid stream incision or stream bank erosion. Areas located in a canyon or on an active alluvial fan, presently or potentially subject to inundation by debris flows or catastrophic flooding".

Stream corridors are areas of natural disturbance that can be hazardous to life and property. Stream corridor hazards within Yakima County include:

- flooding,
- channel migration,
- channel avulsion,
- debris flows, and
- alluvial fans.

While it is important to protect the functions and values of stream corridors for water quality, quantity, and wildlife habitat, it is also important to protect life and property from the natural hazards found within the stream corridor.

6.1 Flooding

Flooding of the stream corridor generally occurs in three different ways (Kinnison and Sceva, 1963; USACOE 1972):

- the more severe, but less frequent winter flood resulting from warm Chinook winds or rain-on-snow,

- the spring flood resulting from rapid snow melt, or
- short, intense thunderstorms that cause localized flooding and debris flows.

Flooding in eastern Washington typically occurs when stormwater runoff reaches the stream channel quickly, usually within a day or so of falling on the ground. Stormwater occurs when the amount of precipitation exceeds the soil's ability to absorb it, causing the excess to run into the stream corridor as sheet or channelized flow. Stormwater in eastern Washington is caused by intense precipitation over a short time period, shallow soils, and sparse vegetation. Vegetation functions to intercept precipitation before it reaches the soil. Vegetation also uses groundwater during photosynthesis; this allows for more water capacity in the soil. Winter flooding events can occur when the soil is frozen and cannot absorb any rainfall. Another flooding process occurs when stormwater percolates into the soil, charging the shallow groundwater. As the water table rises and saturates the soil, new stormwater cannot infiltrate and ponding occurs (Booth 1991).

Winter floods, expected from October to March, are historically more destructive than spring floods, but tend to have to have a lower total volume due to their shorter duration. Spring floods, expected in April through June, typically have a larger total volume but are less destructive and last for a longer time period (Tetra Tech/KCM 2003; USACOE 1975).

The Yakima River has exceeded flood stage 45 times since 1894. Yakima County has been declared a federal disaster area nine times since 1970, which includes the most recent flooding in 1995 and 1996. The largest flood on record occurred in December 1933, with flows estimated at 67,000 cubic feet per second (cfs) at the Kiona gauging station; the average annual discharge at Kiona is 3,700 cfs. The February 1996 flood is the second largest flood on record, with flows recorded at 57,500 cfs at Parker Dam and an estimated total damage cost exceeding $17 million (KCM 1998). For more information on flood history in Yakima County, see the *Upper Yakima River Comprehensive Flood Hazard Management Plan*, which was written in 1998 to identify flooding issues and gain an understanding of flood hazard management options.

6.2 Channel Migration and Avulsion

Channel migration can be either a slow, predictable pattern or a quick, catastrophic event. Channel avulsions are usually unpredictable, erosive events that occur during high flood flows. Channel avulsions generally occur when the existing channel cannot transport all of the water and sediment supplied to it (O'Connor and Watson 1998). Sediment transport and deposition during a flood is dependant upon water velocity, depth of flow, and the size of the segment in the channel and the floodplain. Deep, high-velocity floodwaters can move large quantities of sediment, causing severe erosion of the bed and banks (Tetra Tech/KCM 2003).

In natural stream systems, the ability of the stream to erode, mobilize, transport, and deposit sediment are the main functions that influence channel migration and

avulsion (Tetra Tech/KCM 2003). The natural meander patterns of stream channels are the result of the dissipation of the energy of flowing water and the transportation of sediment (Rosgen 1994). The bed of a stream channel may rise (aggrade) and fall (incise) as it reacts to changes in woody debris, sediment, and flooding activity.

Activities that initiate aggradation and increase avulsion hazards include log/ice jams, landslides, human-made constrictions such as dams and bridges, and reduction in the erosion resistance of the floodplain (e.g., removal of riparian vegetation). As a channel aggrades, flooding patterns and depths change, reactivating inactive stream corridor features.

Stream channel incision causes a channel to abandon portions of its floodplain, which diminishes avulsion hazards. If the incised segment is below an aggraded one, it may increase avulsion risk. This occurs when flood flows return to the channel in the incised segment, causing headcutting across the floodplain, and potentially, avulsion. Incised channels may still be unstable, given that incision often initiates a period of channel widening as unstable banks collapse.

Constrictions in the stream channel, whether natural or artificial, reduce the stream's capacity to transport water and sediment upstream of the constriction, which promotes channel instability. Alternately, incision caused by channelization reduces the channel migration potential. Natural, unregulated systems can encounter fluctuations between incision and aggradation in response to naturally occurring changes in sediment supply and amounts of woody debris. Alternatively, regulated and channelized streams are susceptible to increased sediment inputs (aggradation), due to high levels of erosion and mass wasting, and are susceptible to irreversible long-term incision, due to corresponding increases in discharge and decreases in channel roughness and sediment inputs (Rapp and Abbe 2003).

Rosgen (1994) developed a stream classification system that utilizes an entrenchment ratio (ER). The ER is the ratio of the width of the flood-prone area to the width of the stream channel, and is used to illustrate the relationship of the stream channel to the valley it is positioned in. Streams with a ratio of:

- **1.0 to 1.4**—are entrenched with no floodplain;
- **1.41 to 2.2**—are moderately entrenched with little or no floodplain; and
- **2.2 or greater**—are slightly entrenched with well-developed floodplains.

O'Connor and Watson (1998) developed a system to predict the potential of channel migration and avulsion using ER and slope (Table 23). Slightly entrenched channels (ER greater than 2.2) with a low gradient (less than 1.5 percent) have the greatest potential for channel migration, while entrenched channels (ER less than 1.41) with a high gradient (4 to 8 percent) have the least potential. It is important to recognize that forced morphologies can occur anywhere within the stream corridor. Forced morphologies are caused by flow obstruction, like a logjam, that enhances sediment storage in an otherwise sediment-limited reach (Rapp and Abbe 2003).

CMZ potential generally depends on whether the amount of sediment is in balance with or greater than the stream's ability to transport sediment. When the amount of sediment exceeds the stream's ability to transport it, the stream channel will aggrade or raise its bed elevation. Aggraded channels tend to form multiple or braided channels in order to deposit sediment. If the amount of sediment is reduced or cut off, or if stream flow increases, channels will incise and become entrenched. Increased entrenchment can cause the channel to abandon former floodplains, which become terraces that are seldom flooded or entirely isolated from the stream, although abandoned floodplains are still at risk from channel migration.

6.3 Debris Flows

Debris flows, often called mudslides, mudflows, lahars, or debris avalanches, are common types of fast-moving landslides. Debris flow volume depends on the amount of water supplied by a cloudburst, rain-on-snow, lake outburst, or volcanic eruption. The consistency of the debris flow must have a high sediment-to-water ratio so that the mixture has a low permeability—the water cannot separate and the sediment cannot drop out. Debris flows can comprise a variety of sediment sizes. Flows with a high proportion of fine material have a high internal strength. Flows with a high internal strength are capable of transporting large objects such as boulders, trees, or cars (Highland, Stephenson, Christian, and Brown 1997; Schumm et al. 1996).

Steep (greater than 30 percent) source reaches are sediment storage sites subject to debris flows. Montgomery and Buffington (1993) describe source reaches as one of two valley types:

- unchanneled colluvial, and
- channeled colluvial.

Unchanneled colluvial valleys, also known as hollows or swales, lack sufficient stream flow to maintain a consistent, defined channel. Hollows function as sediment storage sites that collect sediment from the surrounding landscape. The depth of colluvial sediment is dependant upon the rate at which material is delivered and the time since deposits began accumulating. Intense precipitation events initiate debris flows that flush the collected colluvium down slope. After a debris flow, the valley may become channelized or eroded to bedrock, and may refill with sediment over time. Debris flows tend to occur in concave depressions on a slope, but can also form on the convex face of a slope (Montgomery and Buffington 1993).

Channeled colluvial valleys are located either downslope from unchanneled valleys, at the upper ends of the stream system in low-gradient systems, or where there is an abrupt change in transport capacity. Channeled valleys are basically similar to unchanneled, except that there is sufficient stream flow to maintain a constant channel (Montgomery and Buffington 1993).

Table 23
CMZ potential (O'Connor and Watson 1998)

Confinement or Entrenchment	Low Gradient < 1.5 % Channel Slope	Moderate Gradient 1 - 6 % Channel Slope	High Gradient 4 - 8 % Channel Slope
Confined/ Entrenched (ER ≤ 1.4)	Uncommon channel type; no hypotheses regarding channel migration processes	Channel migration unlikely	Channel migration unlikely
Moderately Confined/ Moderately Entrenched (1.4 < ER ≤ 2.2)	Uncommon channel type; no hypotheses regarding channel migration processes	**CMZ (3-6%)** Channel migration by avulsion is not uncommon, but is likely to be spatially-discontinuous, depending on local variation in valley slope and width and disturbance regime	**CMZ** Channel migration by avulsion is uncommon, and is likely related to debris flows and torrents; may be locally significant depending on local variation in valley slope and width and disturbance regime
Unconfined or Slightly Entrenched (ER > 2.2)	**CMZ (<1.5%)** Channel migration by gradual erosion of meander bends is common; avulsions may also occur. Areas of potential migration are spatially continuous and include much or all of the floodplain.	**CMZ (1-3.5%)** Channel migration by avulsion may be common. Areas of potential migration are spatially discontinuous and include much or all of the floodplain.	**CMZ** Channel migration by avulsion may be common, and is likely to be related to alluvial fan and debris flow fan processes. Process may be spatially discontinuous continuous, or localized, depending on fan-building processes.

The arid and semi-arid areas of eastern Washington are especially susceptible to debris flow events. The Yakima River Canyon was subject to such an event on July 3, 1998. Precipitation data from a weather recorder on Manastash Ridge indicated that 3 inches of rain fell within less than one hour (Kaatz 2001). Kaatz found that flow depths exceeded 6 feet in depth, mobilizing basalt boulders of 1 foot or more

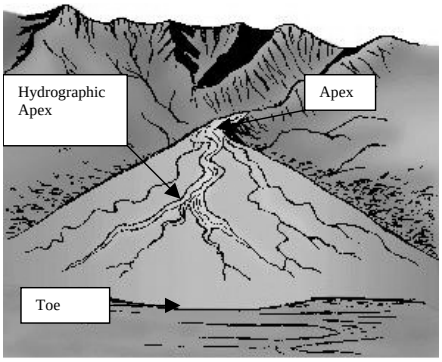
in diameter. Eight sections of State Route 821 were covered in debris fans exceeding 15 feet in depth. Six debris fans extended well into the river, filling approximately 60 percent of the stream channel width.

6.4 Alluvial Fans

Schumm et al. (1996) define an alluvial fan as "a sedimentary deposit located at a topographic break, such as the base of a mountain front, escarpment, or valley side, that is composed of fluvial and/or debris flow sediments and which has the shape of a fan either fully or partially extended" (p. 6). Alluvial fans are constructed by:

- stream flow,
- debris flow, or
- a composite of the two.

Alluvial fans typically form where a stream exits a steep canyon; the point where the fan begins is called the apex. The apex forms a major break in gradient that drastically affects the stream's ability to transport sediment. Lateral channel movement at the mouth of the canyon progressively deposits sediment, building the fan into a cone shaped feature (Figure 37). Two or more fans that coalesce together are known as a bajada. Arid and semi-arid areas are particularly prone to alluvial fan formation due to a lack of substantial vegetation and high sediment loading (Schumm et al. 1996).



An Alluvial Fan from Merriam-Websters online Collegiate Dictionary.

Figure 37. Alluvial fan (source Merriam-Webster's dictionary, online).

Stream flow depositional fans usually consist of braided or multiple distributary channels radiating from the apex. Deposition typically occurs within the channel as bars. Bar formation within the channel promotes lateral migration as the bank opposite bar formation is eroded, in a process similar to cut-and-fill alluviation in floodplains. Large amounts of sediment within the channel can reduce transport

capacity and force overbank flooding. High velocity overbank flows can avulse or erode a new channel or may occupy an older channel.

Channels generally braid and become smaller as they flow down fan. Due to the convex cone shape of the fan, distributary channels diverge and usually do not reconnect. Stream flow–dominated fans constructed during different climates, or in which tectonics have caused uplift, can become entrenched and relatively stable. Entrenched channels may be incised deeply below the fan surface, where flooding and avulsion are rare or nonexistent in the current climate. Separation of flow into multiple channels is thereby reversed and channel complexity is diminished. Channel banks can be colonized by vegetation that adds additional strength. Fans that are no longer accumulating sediment can be considered stable in whole or in part. Entrenched channels can emerge downfan, a point called the hydrographic apex, and again take on stream flow characteristics (Schumm et al. 1996).

Debris flow–dominated fans occur on very steep reaches, where there is a high and constant accumulation of colluvium, or where there is a high concentration of flow. Debris flows with high internal strength are capable of coming to rest at steep gradients near the apex. Such deposits can block fluvial channels formed between debris flow events. Blocked channels cause overbank flooding with a high potential for avulsion. Debris flow–dominated fans typically have coarser sediment near the apex with progressively finer sediment size downfan. Some fans are blocked with boulders near the apex and do not exhibit stream or debris flow, but instead are dominated by sheet flow (Schumm et al. 1996).

Composite fans are formed by both stream and debris flow. Some fans may be divided, with debris flow dominating near the apex and stream flow at the hydrographic apex to the toe.

FEMA (2000) outlines the most common flooding processes found on alluvial fans. The prediction of flooding on alluvial fans is extremely difficult to impossible, due to channel migration and avulsion. Flooding processes are not strictly reserved for a single fan. One fan may possess all four processes along its profile. FEMA has defined alluvial fan flooding processes as:

- stable channel flow,
- unstable channel flow,
- sheet flow, and
- debris flow.

Stable channel flow occurs in entrenched channels or in channel networks formed in different climatic or tectonic conditions. Channels consisting of large sediment typically are more stable than fans with fine or gravelly sediment. Channels are established and not prone to severe erosion or deposition that would decrease channel transport capacity. Stable channels tend to have established vegetation that increases stability.

Unstable channel flow occurs on fans with multiple or braided channels and with a high likelihood of avulsion. Fans with fine to gravelly sediment are more prone to the erosion and deposition that promotes lateral channel movement. Recently formed or actively eroded channels lack stabilizing vegetation.

Sheet flow occurs in broad sheets unconfined by channel banks. Sheet flow can develop from stormwater or overbank flooding on a stable fan surface that does not erode to form a new channel. Sheet flow may occur where multiple channels come together near the toe, where the gradient is low and the flows merge.

Debris flow dominated fans are discussed above.

6.5 Summary

Yakima County contains a number of significant flood hazards. These natural disturbance regimes, while destructive in the short term, are beneficial to the overall function of the stream corridor. Streams function to move water and sediment. Alluvial fans and debris flows provide sediment to downstream reaches. Channel migration and avulsion are natural mechanisms for sediment transport and storage. Overbank flooding deposits beneficial sediments and exchanges nutrients on the floodplain, in addition to recharging the groundwater. While it is important to protect the functions and values of stream corridors for water quality, quantity, and wildlife habitat, it is also important to protect life and property from the natural hazards found within the stream corridor.

7.0 MAPPING AND INVENTORY METHODOLOGY

7.1 Yakima County Geologic Hazards Inventory

In 1991, Yakima County contracted geology professor Newell Campbell (1991) to inventory and map geologic hazards per WAC 365-190-080. The geologic hazards inventory consists of areas of the county susceptible to hazardous geologic events. The inventory does not address stream and river flood or erosion hazards, which are shown in other studies. Mine-working hazards and hazards from volcanic activity are not considered a problem in Yakima County and are omitted. The final products of the original inventory were hard copy mylar figures that were converted to digital GIS layers at an unknown date. After a review and comparison of the digital layers to the original mylars, it was determined that there were large gaps and errors, and the mylars were redigitized and geographically corrected for accuracy.

Geologic hazards are subdivided on the basis of risk. The categories used are *high risk*, *intermediate risk*, *low risk*, *suspected risk*, and *unknown risk.* A description of how each geologic hazard is subdivided into risk type appears below. The following hazards are depicted in the inventory:

- **Landslides (LS)**
  Areas designated landslide areas include places where landslides, debris flows, or slumps have already occurred. Sliding presumed to be holocene in age (10,000 years or less) is shown as *high risk* (LS3) on the map. Slides thought to be older than holocene (plus some stabilized holocene slides) but still capable of movement are shown as *intermediate risk* (LS2). Areas where slides are absent are unlabeled and are combined with other low risk areas.

- **Oversteepened slopes (OS)**
  These include areas with slopes steep enough to create potential problems. High risk areas (OS3) include slopes greater than 40 percent, areas of rockfall and -creep, and places underlain with unstable materials. Intermediate risk areas (0S2) are less likely to fail but still are potentially hazardous. This category also includes some slopes between 15 and 40 percent. Low risk areas, unlikely to fail, are unlabeled and are combined with other low risk categories.

- **Stream undercutting (SU)**
  These areas are confined to banks near main streams and rivers, where undercutting of soft materials may result. High risk areas (SU3) include steep banks of soft material adjacent to present stream courses. Intermediate risk areas (SU2) are banks along the edge of a floodplain but away from the present river course. Low risk areas (unlabeled) are combined with other low risk areas on the maps.

- **Alluvial fans/flash flooding (AF)**
  These are areas where flash flooding can occur, often associated with inundation by debris from flooding. They include alluvial fans, canyons, gullies, and small streams where catastrophic flooding can occur. Such flooding may also occur in larger streams and rivers, but these areas are depicted on the Yakima County Flood Insurance Rate map. High risk areas (AF3) are those most likely to experience flooding. These areas usually involve larger drainage areas, easily eroded sediment, and steeper gradients. Intermediate risk areas (AF2) have some potential for flash flooding but involve smaller drainages and flatter slopes. Low risk areas (unlabeled), where flash flooding is unlikely, are combined with other low risk areas on the map.

- **Avalanche risk (AR)**
  Areas of avalanche hazards are limited (within the mapped boundaries) to areas near the Cascade Crest. High risk areas (AF3) are those in areas of high snowfall where avalanche scars are visible and slopes are steep to moderately steep. These areas could also be rated OS3. Intermediate risk areas (AF2) are usually adjacent to AF3 areas, but with vegetation still in place and moderate slopes. AF2 and AF3 areas are mapped on the basis of aerial photography and observed scars. Climatic data (e.g., snowfall and wind direction) are necessary for more detailed mapping. Low risk areas (unlabeled), where avalanches are unlikely, are combined with other low risk geologic hazards.

- **Earthquake activity (EA)**
  Recorded earthquake activity in Yakima County is mostly marked by low-magnitude events and thus low seismic risk. One exception is an area along Toppenish Ridge and Ahtanum/Rattlesnake Ridge, where holocene faulting may have produced earthquakes of as much as magnitude 7.0. Zones of surficial fault scarps are shown as high risk areas (EA3), while areas adjacent to the scarps are assigned *intermediate risk* (EA2). The rest of the county is low risk (unlabeled) and combined with other low risk hazards.

7.2 Soil Liquefaction Analysis in Yakima County

The Washington Department of Natural Resources (Palmer 2003) recently produced *Preliminary Liquefaction Susceptibility and NEHRP Soil Type Maps for Washington State.* A liquefaction susceptibility map presents an estimate of the susceptibility of the soils to liquefy as a result of earthquake shaking. The susceptibility is a measure of the physical characteristics of a soil column, such as grain texture, compaction, and depth of groundwater, which determines the propensity of the soil to liquefy during earthquake shaking. A liquefaction susceptibility map depicts the relative hazard in terms of high, moderate, or low liquefaction susceptibility, and cannot be used to directly predict the severity of permanent ground deformation resulting from liquefaction. Assessment of ground failure effects depends on local site conditions (e.g., slope steepness or the presence of free faces).

The preliminary versions of the liquefaction susceptibility and NEHRP soil type maps are based on 1:100,000-scale geologic mapping. Existing detailed liquefaction susceptibility maps will be incorporated into a future, final susceptibility map. The liquefaction susceptibility and NEHRP soil type maps released are very preliminary, and will be superseded by final versions in Fall 2004.

The liquefaction susceptibility and NEHRP soil type maps are meant only as a general guide to delineate areas based on their potential for enhanced ground shaking. It is not a substitute for site-specific investigation to assess the actual ground conditions and potential for amplified ground shaking, as measured by the NEHRP soil type or other more quantitative analyses. Because the data used in producing this NEHRP soil type map is based on regional geologic mapping, this map cannot be used to make a final determination at any specific locality.

After review by the Yakima County science advisory group, a determination was made to coordinate with the WDNR to acquire more relevant data on which to base susceptibility modeling. Yakima County will wait to review a more final version of the maps, to determine applicability to Critical Areas regulations.

7.3 Landslide Hazard Mapping

The Washington Department of Natural Resources recently developed a statewide, GIS-based landslide inventory. This inventory is the first major step in Washington State's development of a landslide hazard zonation database. The first public draft of the landslide inventory is a compilation of the individual efforts of many timber,

tribal, state, and federal agents. The inventory contains detailed information on both deep-seated and shallow landslides. Further updates to this data are ongoing through the Landslide Hazard Zonation Project.

7.4 Stream Corridor Inventory

See the Stream Corridor BAS report (Chapter 2) for analysis of the inventory methodology within the stream corridor, which includes:

- Critical areas pilot study
  - Bankfull channel
  - Channel migration zone (CMZ)
  - Frequently flooded areas
  - Hydric/aquic soils overlay
  - Holocene floodplain
  - Stream accuracy conditions
  - Setland accuracy conditions
- Shoreline inventory and characterization

8.0 GENERAL MANAGEMENT RECOMMENDATIONS

Geologically hazardous areas pose a threat to the health and safety of Yakima County citizens when incompatible commercial, residential, or industrial development is sited in areas of significant hazard. Some geological hazards can be reduced or mitigated by engineering, design, or modified construction or mining practices, so that risks to health and safety are acceptable. When technology cannot reduce risks to acceptable levels, building in geologically hazardous areas is best avoided (WAC 365-190-080).

Booth and Bethel (1998) outline several components necessary for any regulatory effort designed to mitigate a geologic hazard:

- definition of the hazard,
- characterization of a set of hazardous site conditions,
- delineation of the hazards, and
- screening of proposed developments in hazardous areas.

Definitions, characterizations, and delineation methodologies of geologically hazardous areas are contained within this report. Screening of proposed developments identified in hazardous areas may determine an appropriate review procedure, as follows (Booth and Bethel 1998):

- **No concern is warranted**—e.g., kitchen remodel without any structural change.
- **No concern is warranted**—e.g., mapping error determined by a site evaluation.

- **Concern is warranted**—The project lies in a geologically hazardous area, but the concerns are addressed in solving other, more severe site constraints, e.g., an active landslide threat.
- **Concern is warranted**—The hazard is significant and requires specific mitigation or avoidance determined by a qualified, professional third party.

8.1 Volcanic Hazards

While Yakima County contains a portion of Mount Adams and is in close proximity to Mount Rainer, and Mount Saint Helens, the threat of volcanic hazards is minimal and limited to ash deposition. The more devastating effects of volcanic activity, such as lava flows and lahars, are not possible due to intervening ridges (Campbell 1998). Therefore, Yakima County proposes no management recommendation for volcanic hazards.

8.2 Earthquake Hazards

Basic risk reduction strategies in seismically hazardous areas are intended either to limit the intensity of land use or to apply more stringent building requirements to development. If the seismic risk is high and cannot be reduced, then development may be prohibited or limited through zoning or other land-use regulations. If the risk is minor, or can be mitigated to that level, then development with appropriate conditions may be allowed (Booth and Bethel 1998).

8.3 Slope Failure Hazards

8.3.1 Erosion hazards

Projects proposed to be located on soils shown to possess a high risk for erosion should be required to comply with the appropriate best management practices (BMP) as outlined by the *Model Municipal Stormwater Program for Eastern Washington* (2003).

8.3.2 Landslide hazards

Campbell (1998) identifies several means of preventing landslides from occurring:

- prevent building above or on the hazard area, to prevent overweighting or lubricating the hazard area;
- avoid grading into the old slide material or into areas with sliding tendencies; and
- do not develop at the base of cliffs or steep slopes prone to rock falls.

8.3.3 Avalanche hazards

Defense against avalanche risk is simply one of avoidance. Structures should not be located within the risk zones or immediately downslope from them. Avalanche control can be accomplished through structural engineering or by artificial release

of built-up snow accumulations. Engineering techniques such as snow sheds and wedges can be applied to modify terrain so as to divert moving snow from facilities, and various fence structures have been designed to stabilize snow on mountainsides. Artificial release techniques focus on the frequent release of small avalanches to inhibit the formation of large avalanches, and employ explosive charges (NRC 1990).

8.4 Stream Corridor Hazards

8.4.1 Flooding, channel migration and avulsion

Restrict or limit development within the floodplain, the channel migration, and the avulsion hazard areas. In some instances, where multiple Critical Areas are present, it may be necessary to protect the entire width of the floodplain. This area provides essential spawning and rearing habitat for threatened and endangered fish and important year-round habitat for semiaquatic and terrestrial wildlife. Therefore, the area necessary to maintain the functions and values of the Critical Areas may include the extent of the 100-year floodplain, and should be wide enough to permit natural channel migration (Knutson and Naef 1997; Portland Metro 2002; Snyder and Stanford 2001; Stanford et al. 2002; Ward and Stanford 1995).

8.4.2 Debris flows and alluvial fans

Defense against debris flow risk is simply one of avoidance. Structures should not be located within or near the observable channel on an associated active alluvial fan. Flood hazard determinations should be made in accordance with the Federal Emergency Management Agency's (2000) *Guidelines for Determining Flood Hazards on Alluvial Fans*.

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APPENDIX A: RIPARIAN BUFFER WIDTH TABLES

Metro's Technical Report for Goal 5. 2002. Portland Metro 600 NE Grand Ave., Portland, OR 97232-2736 (503) 797-1700
http://www.metro-region.org/article.cfm?ArticleID=1047

Table 7: Range of functional riparian area widths for fish and wildlife habitat

AQUATIC HABITAT			
Function		Reference	Functional width *(each side of stream)*
Temperature regulation and shade	Shade	FEMAT 1993	100 ft
	Shade	Castelle et al. 1994	50-100 ft
	Shade	Spence et al. 1996	98 ft
	Shade	May 2000	98 ft
	Shade	Osborne and Kovacic 1993	33-98 ft
	Shade/reduce solar radiation	Brosofske et al. 1997	250 ft
	Control temperature by shading	Johnson and Ryba 1992	39-141 ft
Bank stabilization and sediment control	Bank stabilization	Spence et al. 1996	170 ft
	Sediment removal and erosion control	May 2000	98 ft
	Ephemeral streams	Clinnick et al. 1985	66 ft
	Bank stabilization	FEMAT 1993	_ SPTH
	Sediment control	Erman et al. 1977	100 ft
	Sediment control	Moring 1982	98 ft
	Sediment removal	Johnson and Ryba 1992	10 ft (sand) – 400 ft (clay)
	High mass wasting area	Cederholm 1994	125 ft
Pollutant removal	Nitrogen	Wenger 1999	50-100 ft
	General pollutant removal	May 2000	98 ft
	Filter metals and nutrients	Castelle et al. 1994	100 ft
	Pesticides	Wenger 1999	>49 ft
	Nutrient removal	Johnson and Ryba 1992	33 – 141 ft
Large woody debris and organic litter	Large woody debris	Spence et al. 1996	1 SPTH
	Large woody debris	Wenger 1999	1 SPTH
	Large woody debris	May 2000	262 ft
	Large woody debris	McDade et al. 1990	150 ft
	Small woody debris	Pollock and Kennard 1998	100 ft
	Organic litterfall	FEMAT 1993	_ SPTH
	Organic litterfall	Erman et al. 1977	100 ft
	Organic litterfall	Spence et al. 1996	170 ft
Aquatic wildlife	Cutthroat trout	Hickman and Raleigh 1982	98 ft
	Brook trout	Raleigh 1982	98 ft
	Chinook salmon	Raleigh et al. 1986	98 ft
	Rainbow trout	Raleigh et al. 1984	98 ft
	Cutthroat trout, rainbow trout and steelhead	Knutson and Naef 1997	50 – 200 ft
	Maintenance of benthic communities (aquatic insects)	Erman et al. 1977	100 ft
	Shannon index of macroinvertebrate diversity.	Gregory et al. 1987	100 ft
	Trout and salmon influence zone (Western Washington)	Castelle et al. 1992	200 ft

Table 7 (continued) - TERRESTRIAL HABITAT			
Function		Reference	Recommended width *(each side of stream)*
Wildlife needs	Willow flycatcher nesting	Knutson and Naef 1997	123 ft
	Full complement of herpetofauna	Rudolph and Dickson 1990	>100 ft
	Belted Kingfisher roosts	USFWS HEP Model	100 – 200 ft
	Smaller mammals	Allen 1983	214 – 297 ft
	Birds	Jones et al. 1988	246 – 656 ft
	Minimum distance needed to support area-sensitive Neotropical migratory birds	Hodges and Krementz 1996	328 ft
	Western pond turtle nests	Knutson and Naef 1997	330 ft
	Pileated woodpecker	Castelle et al. 1992	450 ft
	Bald eagle nest, roost, perch Nesting ducks, heron rookery and sandhill cranes	Castelle et al. 1992	600 ft
	Pileated woodpecker nesting	Small 1982	328 ft
	Mule deer fawning	Knutson and Naef 1997	600 ft
	Rufous-sided towhee breeding populations	Knutson and Naef 1997	656 ft
	General wildlife habitat	FEMAT 1993	100-300 ft
	General wildlife habitat	Todd 2000	100-325 ft
	General wildlife habitat	May 2000	328 ft
Edge effect	Interior bird species	Tassone 1981	164 ft
	Neotropical migrants	Keller et al. 1993	328 ft
	Effect of increased predation	Wilcove et al. 1986	2,000 ft
	Noise reduction of a mature evergreen buffer	Harris 1985	20 ft
	Reduce commercial noise	Groffman et al. 1990	100 ft
LWD and structural complexity	Snags and downed wood	FEMAT 1993	1 SPTH outside the buffer
	Width necessary to minimize non-native vegetation	Hennings 2001	650 ft
Movement corridors	Travel corridor for red fox and marten	Small 1982	328 ft
	Minimum to allow for interior habitat species movement	Environment Canada 1998	164 ft
Microclimate	Maintain microclimate	May 2000	328 ft
	Prevent wind damage	Pollock and Kennard 1998	75 ft
	Approximate natural conditions	Brosofske et al. 1997	250 ft
	Maintain microclimate	Knutson and Naef 1997	200-525 ft
	Maintain humidity and soil temperature	Chen et al. 1995	98 – 787 ft

Acronyms:
SPTH: site potential tree height
NMFS: National Marine Fisheries Service
NRCS: National Resource Conservation Service
USFWS: U.S. Fish and Wildlife Service
FEMAT: Forest Ecosystem Management Assessment Team

Knutson, K. L. and Naef, V. L. 1997. Management recommendations for Washington's priority habitats: Riparian. Washington Department of Fish and Wildlife. 181 pp.

Appendix B. Riparian habitat functions or specific wildlife uses, organized by riparian habitat width (perpendicular distance from stream). Appendix C contains this information organized by riparian function.

Perpendicular distance from stream in meters (feet)	Riparian habitat function/parameter observed	Source
4 (13)	Nutrient reduction	Doyle et al. 1977
6 (20)	Noise reduced by an equivalent of tripling of distance from noise to receiver	Johnson and Ryba 1992
10 (33)	Minimum needed for nutrient reduction	Petersen et al. 1992
11-31 (35-100)	Distance needed for shade retention, an important habitat component for Cascade torrent, Columbia torrent, Dunn's, and Van Dyke's salamanders	Brown and Krygier 1970, Brazier and Brown 1973, Steinblums et al. 1984
11-38 (35-125)	Buffer that provides 60-80% shade on stream surface; crucial to water temperature control	Brazier and Brown 1973, Steinblums et al. 1984, Johnson and Ryba 1992
12 (39)	Control of water temperature	Corbett and Lynch 1985
12-70 (39-230)	Riparian buffer capable of supporting small mammal communities comparable to undisturbed sites	Cross 1985
15 (50)	Minimum mean width supporting breeding populations of downy woodpeckers	Cross 1985
15 (50)	Minimum mean width supporting breeding populations of black-capped chickadees	Cross 1985
15 (50)	Sufficient width for mourning doves	Mudd 1975
15 (50)	80% of coarse woody debris input in a multiple canopy forest	Van Sickle and Gregory 1990
15-23 (50-75)	Some edge/mature forest adapted birds retained in clearcut landscape; neotropical migrant birds and pileated woodpeckers lost	Triquet et al. 1990
15 (50)	Median distance of coarse woody debris travel	Harmon et al. 1986
15 (50)	Minimum needed for nutrient reduction	Castelle et al. 1992
15-30 (50-98)	Control of water temperature	Hewlett and Fortson 1982
15-30 (50-98)	Provides minimal maintenance of most functions	Johnson and Ryba 1992
16 (52)	Nutrient reduction	Jacobs and Gilliam 1985
16-137 (52-137)	Edge effect on forest structure: the distance from an edge into a forest where its structure (e.g., stocking density, tree mortality) is affected by the adjacent open environment	Chen et al. 1992
17 (57)	Minimum mean width supporting a breeding population of white-breasted nuthatches	Stauffer and Best 1980

Appendix B. Continued.

Perpendicular distance from stream in meters (feet)	Riparian habitat function/parameter observed	Source
18 (59)	Maintains stream temperature in a logged watershed (but does not fully mitigate changes in sediment, dissolved oxygen, or increased streamflow)	Moring 1975
18-38 (60-125)	Provides 50-100% shading	U.S. For. Serv. et al. 1993
20 (66)	10% mortality of instream mosquito larvae after application of permethrin	Payne et al. 1988
20 (66)	Nutrient removal using the multi-species riparian buffer strip system described by the authors	Schultz et al. 1995
23 (75)	Needed for maximum populations of pheasant, quail, and deer	Mudd 1975
20-50 (66-164)	Width of riparian vegetation	Strong and Bock 1990
25 (82)	Species sensitive to disturbance did not occur unless an undisturbed corridor this wide was present	Croonquist and Brooks 1993
25-50 (82-164)	Width of riparian vegetation	Medin and Clary 1991
30 (100)	Minimum width of riparian buffer to avoid affecting food supply of benthic invertebrates	Erman et al. 1977
30 (100)	Protects aquatic insect communities from sedimentation	Erman et al. 1977
30 (100)	Reduces fecal coliforms	Grismer 1981
30 (100)	Minimum width of riparian buffer that maintained invertebrate populations equal to those in control areas with no logging	Erman et al. 1977, Roby et al. 1977, Newbold et al. 1980
30+ (100+)	Large woody debris use by loafing harlequin ducks	Murphy and Koski 1989
≥30 (≥100)	Full complement of herpetofauna	Rudolph and Dickson 1990
30 (100)	Recommended buffer to control erosion of undercut banks for cutthroat, rainbow, and brown trout; and chinook salmon	Raleigh et al. 1986
30 (100)	Buffers incoming nutrient pollution when buffer contains trees (600 ft required when buffer is herbaceous or cropland)	Terrell and Perfetti 1989
30 (100)	80% of large woody debris input (coniferous riparian)	Van Sickle and Gregory 1990
30 (100)	Buffer provides same stream temperature as old growth	Beschta et al. 1987
30 (100)	90% sediment removal at 2% grade	Johnson and Ryba 1992

Appendix B. Continued.

Perpendicular distance from stream in meters (feet)	Riparian habitat function/parameter observed	Source
30 (100)	75-80% of suspended sediment removed from stormwater in logged areas; less effective where surface flows are channelized than where runoff is in sheets	Johnson and Ryba 1992
30 (100)	Removed nitrates, exceeding drinking water standards	Johnson and Ryba 1992
30 (100)	Stream temperatures maintained within 1° of baseline	Johnson and Ryba 1992
30-60 (100-200)	Belted kingfisher roosts	Prose 1985
30-95)100-312)	Amphibians and reptiles more numerous with buffer width in mature vegetation	Rudolph and Dickson 1990
30 (100)	Shannon index of macroinvertebrate diversity same as control with buffer of this size	Gregory et al. 1987
30-100 (100-328)	30m=90% foraging distance for beaver; 100m=maximum foraging distance (but 200m has been reported)	Allen 1983, Hall 1970
30 (100)	99% of large organic debris recruitment	Murphy and Koski 1989
30 (100)	Macroinvertebrate density begins to increase with buffer this size	Newbold et al. 1980
30 (100)	Nutrient reduction	Lynch et al. 1985
30-43 (100-141)	Nutrient reduction	Jones et al. 1988
30 (100)	Sediment removal	Erman et al. 1977, Moring 1982, Lynch et al. 1985
30 (100)	Water temperature control	Lynch et al. 1985
30-43 (100-141)	Water temperature control	Jones et al. 1988
30-38 (100-125)	75% of sediments removed	Karr and Schlosser 1977
30 (100)	Maintains fish habitat for cutthroat, brook and rainbow trout, and chinook salmon	Hickman and Raleigh 1982, Raleigh 1982, Raleigh et al. 1984, Raleigh et al. 1986
31-55 (100-180)	Distance needed for woody debris recruitment, an important habitat component for Cascade torrent, Columbia torrent, Dunn's, and Van Dyke's salamanders	Bottom et al. 1983, Harmon et al. 1986, Murphy and Koski 1989, McDade et al. 1990, Van Sickle and Gregory 1990
31-88 (100-289)	Distance needed for sediment control, important to maintaining habitat quality for Cascade torrent, Columbia torrent, Dunn's, and Van Dyke's salamanders	Erman et al. 1977, Lynch et al. 1985, Terrell and Perfetti 1989, Johnson and Ryba 1992
31 (102)	Contribution of woody debris to stream structure within this distance	Bottom et al. 1983
36 (118)	Nutrient reduction	Young et al. 1980

Appendix B. Continued.

Perpendicular distance from stream in meters (feet)	Riparian habitat function/parameter observed	Source
40 (133)	Minimum mean width supporting breeding populations of hairy woodpeckers	Stauffer and Best 1980
40 (133)	Minimum mean width supporting breeding populations of red-eyed vireos	Stauffer and Best 1980
45 (148)	Maximum distance of tree-fall (source of coarse woody debris)	Harmon et al. 1986
46 (151)	Maintains large woody debris	McDade et al. 1990, Robison and Beschta 1990
46 (151)	Provides travel corridors for marten when buffers are on both sides of streams in mature uncut basins	Freel 1991
46 (151)	Buffer width provides 80% shading of streams at minimum flow	Steinblums et al. 1984
50 (164)	Most bald eagles perch within this distance of water during daylight hours	Stalmaster 1980
50 (164)	Stream buffer needed to maintain harlequin nests	Cassirer and Groves 1990
50 (164)	Lesser scaup prefer nesting habitat within this distance in emergent vegetation	Allen 1986
50 (164)	Forest interior birds only occurred in corridors greater than 50m	Tassone 1981
50 (164)	100% of coarse woody debris input	Van Sickle and Gregory 1990
55 (180)	Maintains large woody debris	U.S. For. Serv. et al. 1993, Thomas et al. 1993
75-200 (246-656)	Recommended buffer for birds	Jones et al. 1988
75-100 (246-328)	Recommended leave strip for bald eagles along shoreline of major feeding areas	Stalmaster 1980
50-100 (164-328)	Riparian vegetation width in shrub-steppe	Medin and Clary 1991
60 (200)	Marten food/cover -- recommend no harvest	Spencer 1981
60 (200)	Adequate buffer to remove sediment as a result of logging -- buffer measured from edge of floodplain	Broderson 1973
60 (200)	Minimum riparian width needed to sustain forest-dwelling birds	Darveau et al. 1995
60-91 (200-300)	Effective buffer strip width to control non-channelized sediment flow	Belt et al. 1992
60-120 (200-399)	Microclimate edge effects into forest patches: light penetration, increased tree mortality, soil desiccation, temperature effects	Chen et al. 1990
61 (200)	Recommended no-cut zone around osprey nest	Zarn 1974, Westall 1986
61 (200)	Buffering distance for sediment from cropland, animal waste across ungrazed buffers, pesticides	Terrell and Perfetti 1989

Appendix B. Continued.

Perpendicular distance from stream in meters (feet)	Riparian habitat function/parameter observed	Source
61 (200)	Deer and elk -- distance hiding cover needed at 90% vegetative cover	Mudd 1975
63-88 (207-289)	Riparian width in Blue Mountains	Bull and Skovlin 1982
67 (220)	No small mammal species lost	Cross 1985
67-93 (220-305)	Recommended buffer for small mammals	Jones et al. 1988
75-100 (246-328)	Recommended leave strip along shorelines of major bald eagle feeding areas	Stalmaster 1980
80 (262)	Average distance of wood duck nests from water	Gilmer et al. 1978
90 (295)	Average distance of warbling vireo nests from water	Gilmer et al. 1978
91 (300)	Needed on each side of stream to provide a 600 ft travel corridor in mature uncut basins for fisher or a travel corridor between clearcuts for marten	Freel 1991
91 (300)	Recommended hiking trail buffer near osprey nests	Zarn 1994
91 (300)	Buffer required by yellow-billed cuckoo	Gaines and Laymon 1984
100 (328)	Recommended buffer for large mammals	Jones et al. 1988
100 (328)	Majority of beaver foraging	Allen 1983
100 (328)	Minimum distance needed to support area-sensitive neotropical migrants in forest/agricultural areas	Keller et al. 1993
100 (328)	Distance needed to maintain functional assemblages of common neotropical migratory birds	Hodges and Krementz 1996
100 (328)	Mink dens/cover/forage	Melquist et al. 1981, Allen 1986
100 (328)	Recommended disturbance free zone around great blue heron feeding areas	Short and Cooper 1985
100 (328)	Area of optimum mink cover and forage habitat	Allen 1986
100 (328)	Vegetation within this distance used by red fox and marten as travel corridors and habitat	Small 1982
100 (328)	Pileated woodpecker nests within this distance	Small 1982
100 (328)	Bald eagles nest within this distance	Small 1982
100 (328)	45% reduction in birds in agricultural areas if no fencerows within this distance of stream	Croonquist and Brooks 1993
100 (328)	Red fox and fisher use	Small 1982
100 (328)	Eagles nest within this distance of water	Small 1982
100 (328)	Buffer width that reduces nest predation	Temple 1986
100 (328)	Minimum buffer to provide adequate large woody debris in streams	K. Koski, pers. comm.

Appendix B. Continued.

Perpendicular distance from stream in meters (feet)	Riparian habitat function/parameter observed	Source
124 (407)	Northern flicker avoided isolated forest patches farther than this distance from water	Gutzwiler and Anderson 1987
100x300 (328x984)	Minimum riparian dimensions for yellow-billed cuckoo	Gaines 1974
119 (396)	Average distance of successful bald eagle nests from human disturbance	Grubb 1980
125 (410)	Size of naturally vegetated buffer needed to retain full complement of birds	Croonquist and Brooks 1993
127 (417)	Avian richness declines after this point in cottonwood floodplains	Sedgewick and Knopf 1986
133 (443)	Average distance from snowmobile traffic that elicited a locomotor avoidance response in mule deer	Freddy et al. 1986
150 (492)	Most pileated woodpeckers nest within this distance	Conner et al. 1975, Schroeder 1983
160 (525)	Distance microclimatic changes occur within a forest, due to disturbance created edges	Harris 1984, Franklin and Forman 1987
180 (590)	Slopes greater than 15% used as Rocky Mt. mule deer fawning habitat	Thomas et al. 1976
183 (600)	Distance needed on both sides of stream to provide travel corridor for fisher in clearcut landscapes	Freel 1991
183 (600)	Food and cover for dusky shrews	Clothier 1955
183 (600)	Wood duck nesting distance	Grice and Rogers 1965
183 (600)	Wood duck nesting where woody/herbaceous cover is between 50-75%	Sousa and Farmer 1983
183 (600)	Distance needed to filter confined animal waste	Terrell and Perfetti 1989
191 (636)	Average distance from foot traffic that elicited a locomotor avoidance response in mule deer	Freddy et al. 1986
200 (656)	Limit of mink use	Melquist et al. 1981
200 (656)	Minimum mean width to support breeding populations of American redstarts	Stauffer and Best 1980
200 (656)	Minimum mean width to support breeding populations of spotted towhees	Stauffer and Best 1980
200 (656)	Red-winged blackbird foraging distance from nests in wetlands	Short 1985
200 (656)	Distance from human activity at which feeding eagles are disturbed	Skagen 1980
200 (656)	Wood ducks nest within this distance	Lowney and Hill 1989
240 (787)	Distance brown-headed cowbirds penetrate from stream opening	Gates and Giffin 1991

Appendix B. Continued.

Perpendicular distance from stream in meters (feet)	Riparian habitat function/parameter observed	Source
250 (820)	Great blue herons nest within this distance; disturbance-free zone around nests is recommended	Short and Cooper 1985
250-300 (820-984)	Minimum buffer zone around peripheries of great blue heron colonies	Bowman and Siderius 1984, Kelsall 1989, Vos et al. 1985
250-300 (820-984)	Recommended buffer for eagle perch areas with little screening	Stalmaster 1987
305 (1,000)	Elk calving grounds are usually within this distance of water	Thomas 1979
350 (1,148)	Maximum distance from water where wood ducks will nest	Gilmer et al. 1978
400 (1,312)	Avoid road and foot travel within this distance of sandhill crane nests	Schlorff et al. 1983
800 (2,624)	During breeding season (March-August), avoid logging within this distance of sandhill crane nests	Schlorff et al. 1983

Function	Range Of Effective Buffer Widths (Ft)
Water Temperature	35 - 151
Pollutant Removal	13 - 600
Large Woody Debris	100 - 200
Erosion Control	100 - 125
Wildlife Habitat	25 - 984
Sediment filtration	26 - 300
Microclimate	200 - 525

Portland Bureau of Planning. 2001. Streamside Science and an Inventory of Significant Riparian and Wetland Resources. City of Portland Oregon.

Table 3. General riparian buffer recommendations.

	Study	Minimum width[4]
General	Johnson and Ryba 1992	50-100 ft
General	Castelle et al. 1994	50-100 ft
General	Erman et al. 1977	100 ft
General	Fischer et al. 2000	50-325 ft
General	Spence et al. 1996	100-170 ft
General	May et al. 1997	100-326 ft
Perennial streams	Pollock and Kennard 1998	250 ft
Perennial streams	Knutson and Naef 1997	150-200 ft
Seasonal streams	Pollock and Kennard 1998	120 ft
Seasonal streams	Knutson and Naef 1997	150-225 ft
General	Metro 1997	50-200 ft
Headwater/ mid-section streams	Metro 1999	150 ft
General	Schueler 1995	100 ft
General	Oregon Division of State Lands, 1998	20-120 ft
General	FEMAT 1993	150-300ft
	Range of width	*50-326 ft*

Table 2. Summary of literature: minimum riparian buffer width recommendation

	RIPARIAN FUNCTION	STUDY	MINIMUM WIDTH[1]
Organic Inputs-food web	Organic material	FEMAT 1993	100 ft or .5 SPTH[2]
	Organic litter	Spence et al. 1996	170 ft
	Benthic communities	Erman et al. 1977	100 ft
	Benthic communities	FEMAT 1993*	100 ft
		Range of width for function	*100-170 ft*
Channel Dynamics and Morphology	Large wood [3]	Budd et al. 1987 (Citing Bottom et al. 1983)	100 ft
	Large wood	Pollock and Kennard 1998*	1 SPTH or 105-250 ft
	Large wood	Van Sickle and Gregory 1990	164 ft
	Large wood	Spence et al. 1996	170 ft
	Bank stability	Spence et al. 1996	170 ft
	Channel morphology	Johnson and Ryba 1992	65-100 ft
	Channel migration zone	Pollock and Kennard 1998*	100-year floodplain
		Range of width for function	*65-200 ft / 100-yr floodplain*
Water Quality	Water quality	Budd et al. 1987	100 ft
	Water quality	FEMAT 1993	12-860 ft
	Water quality	Metro 1997*	50-200 ft
	Nutrient regulation	Spence et al. 1996	170 ft
	Nutrient removal	Todd 2000*	33-98 ft
	Filter metals and nutrients	Castelle et al. 1994 *	100 ft
	Filter sediment	FEMAT 1993	200 ft
	Filter sediments	Johnson and Ryba 1992 citing Wilson 1967*	10-400 ft
	Filter sediments	Budd et al. 1987 (Citing Bottom et al. 1983)	100 ft
		Range of width for function	*10-860 ft*
Microclimate	Shade	Johnson and Ryba 1992(based, in part, on Steinblums et al 1994)	.75 SPTH or 100 ft
	Shade	Castelle et al. 1994*	50-100 ft
	Shade	FEMAT 1993	100 ft
	Shade	Spence 1996	100 ft
	Shade-Water temperature	Castelle et al. 1994*	76 ft
	Shade-Water temperature	Todd 2000*	15-33 ft
	Shade-Water temperature	Barton et al. 1985	33 ft
	Microclimate	Knutson and Naef 1997*	200-525 ft
	Microclimate	FEMAT	.5-3 SPTH
	Microclimate	Pollock and Kennard 1998*	250 ft
		Range of width for function	*33-525 ft*
Wildlife Habitat	Wildlife habitat	FEMAT 1993 (citing Roderick and Milner 1991)	100-600 ft
	Wildlife habitat	Knutson and Naef 1997 (citing others)	25-984 ft
	Wildlife habitat	Castelle et al. 1994*	10-350 ft
	Wildlife habitat	Todd 2000*	100-325 ft
	Wildlife habitat and migration corridors	Fischer et al. 2000*	325 ft
	Biodiversity	Pollock and Kennard 1998*	200 ft
		Range of width for function	*10-984 ft*

[1] Refers to the width on each side of the stream.

[2] See page 19 for definition of SPTH.

* Based on author's review of literature

[3] Large wood also contributes organic material and nutrients to riparian systems

Wenger, Seth. 1999. A Review of the Scientific Literature on Riparian Buffer Width, Extent and Vegetation. Office of Public Service and Outreach, Institute of Ecology, University of Georgia, Athens Georgia, 30602-2205

Article	Widths Studied (m)	Min. Width Recommendation (m)
Hodges and Krementz (1996)	36-2088	100
Keller et al (1993)	25-800	100
Kilgo et al (1998)	25-500	both narrow and wide
Kinley & Newhouse (1997)	14-70	70
Smith & Schaefer (1992)	20-150	no recommendation
Spackman and Hughes (1995)	25-200	150-175
Thurmond et al (1995)	15-50	15
Triquet et al (1990)	15-23	no recommendation

Table 6. Riparian Buffer Recommendations from Avian Studies.

The recommendations of the literature on riparian corridor widths for birds are summarized here. The second column shows the range of buffer widths studied by the authors. The third column shows the authors' recommendations for the minimum corridor widths necessary to support bird populations.

King County
Table 3. Riparian Buffer Functions and Appropriate Widths Identified by May, C. W. 2000. Protection of stream-riparian ecosystems: a review of best available science. Office of the Natural Resources Coordinator, Kitsap County, Washington.

Function	Range of Effective Buffer Widths	Minimum Recommended	Notes On Function
Sediment Removal/Erosion Control	26 - 600 ft (8 – 183 m)	98 ft (30 m)	For 80% sediment removal
Pollutant Removal	13 - 860 ft (4 - 262 m)	98 ft (30 m)	For 80% nutrient removal
Large Woody Debris	33-328 ft (10 –100 m)	262 ft (80 m)	1 SPTH based on long-term natural levels
Water Temperature	36 - 141 ft (11 – 43 m)	98 ft (30 m)	Based on adequate shade
Wildlife Habitat	33 - 656 ft (10 – 200 m)	328 ft (100 m)	Coverage not inclusive
Microclimate[2]	148 - 656 ft (45 – 200 m)	328 ft (100 m)	Optimum long-term support

APPENDIX B: YAKIMA COUNTY CRITICAL AREAS SCIENCE ADVISORY GROUP

Active Participation

The Science advisory Group was integral in identifying and reviewing the best available science. While the group has been divided based on individual expertise, round table discussion and review of documents were done as a group, with many members participating across the different scientific disciplines.

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APPENDIX C: CRITICAL AREAS / SHORELINES UPDATE BEST AVAILABLE SCIENCE BIBLIOGRAPHY

The Critical Areas/Shorelines Update bibliography is adapted from the Washington State Office of Community Development (OCD) *Citations of the Recommended Sources of Best Available Science*. It has been tailored to include relevant citations pertaining to the geography of Yakima County. Citations noted with an asterisk (*) were reviewed and synthesized into *Yakima County's Review of the Best Available Science for Inclusion in the Critical Areas Ordinance Update*. The remainder of the citations were reviewed, but were not utilized in the report due to relevancy, applicability, redundancy, etc. Hyperlinks have been added for ease of use, but may be out of date and will not be updated; highlighted citations are available in digital format from the Yakima County Planning Department. Most of the other citations are available in hard copy from the Yakima County Planning Department, although some citations were borrowed or checked out from individuals or libraries and would need to be acquired from the source.

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Appendix D Additional BAS Review

Below are additional BAS citations submitted for review to the Planning Commission and Planning Division after the March 2004 Draft BAS Report public release. Staff has reviewed the citations to determined whether they meet the statutory requirements established in WAC 365-195-905, and provided a brief review of the findings. The citations below are listed by the group or individual that submitted them. Some citations were submitted by multiple groups or individuals, but are only reviewed once.

BAS Submissions provided by the Yakima Association of Realtors

Alsea Valley vs. Oregon Natural Resources

> ***Abstract:*** *a legal opinion in an ongoing case which argues that hatchery raised fish should be counted when determining ESA listing status.*
> ***Staff Review:*** *This does not meet the statutory requirements for BAS.*

Grewell, Bishop J. No Date. Farming for the Future: Agriculture's Next Generation. PERC Policy Series. Political Economy Research Center, 2048 Analysis Dr., Suite A, Bozeman, MT, 59718

> ***Abstract:*** *This is an opinion paper that reviews the history of agriculture and the impacts on society and the environment. The new "ecological agrarian", or today's modern farmer has more of an incentive to protect the environment through advanced BMP's. In addition, the authors argue that institutions (laws and regulations) are counter productive toward sustainable agriculture. The two examples used as institutions that hinder sustainable agriculture are the Estate Tax, and the agricultural subsidies. Institutions that foster sustainable agriculture are strong protections of property rights. Policies that encourage voluntary efforts and flexibility are more effective than mandates.*
> ***Staff Review:*** *This does not meet the statutory requirements for BAS.*

Landry, Clay, J. 1998. Saving our Streams Through Water Markets, A Practical Guide. Political Economy Research Center, 2048 Analysis Dr., Suite A, Bozeman, MT, 59718

> ***Abstract:*** *This is an opinion paper that gives some background on western water law and ways to fix the controversy. The proposal is to implement water markets as an economic solution to western water problems.*
> ***Staff Review:*** *This does not meet the statutory requirements for BAS.*

Leal, Donald R., DeAlessi, Micheal., Emerson, Pete. 2003. Overcoming Three Hurdles to IFQ's in the U.S. Fisheries: A Guide for Federal Policy Makers. Political Economy Research Center, 2048 Analysis Dr., Suite A, Bozeman, MT, 59718

> ***Abstract:*** *This is an opinion paper of the deficiencies of ocean fishing regulations. The opinion of the authors is that Individual Fishing Quotas (IFQ) can solve the problems with the current system of regulating ocean fishing.*
> ***Staff Review:*** *This does not meet the statutory requirements for BAS.*

Makie, Alexander, W. 2004. Protection of Critical Areas and the Mythology of Buffers. Prepared for Wetlands in Washington. CLE. Presented by Law Seminar International, Seattle, WA, October 25-26.

Abstract: *This is a legal opinion paper based on Western Washington Critical Areas issues in the urban or built environment, and an argument against "big buffers".*

Staff Review: *This opinion paper quotes numerous scientific findings for the functions of buffers, but lacks any bibliographic references in support. This does not meet the statutory requirements for BAS.*

Mackie, Alexander, W. 2002. Critical Area Review 2002 and Best Available Science: Guide to Effective Participation. Prepared by Perkins Coie LLP. Presented by the Washington Association of Realtors.

Abstract: *This is an opinion paper and guidebook that addresses BAS issues and the affects of increasing buffer widths through CAO updates. It gives guidance to local realtors on how to participate in a CAO update, and issues that should be closely monitored. It gives some background on GMA and Critical Areas, and an analysis of case law.*

Staff Review: *This does not meet the statutory requirements for BAS.*

Meiners, Roger E., Kosnik, Lea-Rachel. 2003. Restoring Harmony in the Kalamath Basin. Issue Number PS-27. Political Economy Research Center, 2048 Analysis Dr., Suite A, Bozeman, MT, 59718

Abstract: *This is an opinion paper that reviews western water law, and the history behind the controversy in the Klamath River Basin. The authors suggest how to resolve the issues, which generally address fixing state water laws, getting the federal government to clarify water claims, and establishing water markets.*

Staff Review: *This does not meet the statutory requirements for BAS.*

Morse, Chandler, C., Parson, Marrolyn PhD., Dilks, David PhD. 2004. The TMDL Tool Kit. National Association of Builders. 1201 15th. St. Washington, D.C., 20005

Abstract: *This is a general overview of the TMDL process and its relation to the Clean Water Act, and stormwater standards. This is a guide for the home building industry to participate in the public process of developing TMDL plans to ensure they do not unnecessarily impinge on development.*

Staff Review: *This does not meet the statutory requirements for BAS.*

Norton, Seth, W. 2002 Population Growth, Economic Freedon and the Rule of Law. Issue Number PS-24. Political Economy Research Center, 2048 Analysis Dr., Suite A, Bozeman, MT, 59718

Abstract: *This is an essay and economic analysis that supports a position where economic freedom, which includes protection of property rights and the rule of law, are more important in determining the quality of human life and the environment than is population growth. The author then suggests that global institutional reform will improve the quality of life and the environment better than population control.*

Staff Review: *This meets the statutory requirements for BAS, but has no applicability to the CAO update.*

Pizzimenti, John, J. PhD. 2002. Efficacy and Economics of Riparian Buffers on Agricultural Lands. GEI Consultants, Inc. 6950 S. Potomac St. Suite 200, Englewood, CO, 80112. In association with Pacific Northwest Project and Mason Bruce & Girard, Inc. Submitted to the Washington Hop Growers Association, Ag Caucus, and Multi Agricultural Caucus.

Abstract: *This is a science synthesis report developed for the agricultural industry to counter proposed state and federal mandated, fixed width 300 foot buffers on existing agricultural land to protect ESA listed anadromous fish. State and federal resource agencies supplied 15 scientific documents as the basis for their recommendation; this report analyzes those documents and conducts an additional scientific synthesis for riparian buffer on agricultural lands. This report has two main objectives: to review the science on buffers associated with agriculture and to evaluate the economic effects of potential state and federal mandated buffers on agricultural land. The report initially introduces six primary functions and values associated with riparian areas, but focuses its analysis on functions they determined are associated with agriculture; sediment retention, pollutant filtering, streambank stabilization, and stormwater treatment. Agricultural impacts are broadly identified as; soil erosion and sedimentation, pesticides and fertilizers, animal wastes, irrigation/water withdrawal, and grazing. The analysis purposely under analyzes large woody debris contribution, organic inputs, wildlife habitat, and floodplain processes, with the justification that these functions are not applicable to agricultural lands, and that they are not necessary to recover ESA listed fish. The report neglects to analyze riparian areas functional contributions to microclimate, hyporheic zone interactions, and aquifer recharge/discharge. The report indicates that it is not intended to be exhaustive, but focused on the minimum buffer width that could reduce known impacts to water quality and salmon on existing agricultural lands. The report also indicates that it is a work in progress, and that other literature will be assessed if identified. The report found the following general conclusions associated with buffers on agricultural land:*

- *Buffer widths developed for forestry are not applicable to agriculture;*
- *Buffers between **5 to 30 meters (16-98 feet)** function adequately for water filtration, sediment reduction, animal exclusion, shade, nutrient removal, and streambank stabilization on agricultural lands;*
- *Buffers wider than **100 feet** are consistent with accommodation for large woody debris recruitment and for terrestrial wildlife;*
- *Agricultural impacts can be effectively managed with Best Management Practices (BMPs);*
- *Performance and effectiveness of buffers on agricultural land is highly variable and both site specific and function specific;*
- *A quantitative approach to buffer width is inadvisable without site-specific data;*

Staff Review: *This meets the statutory requirements for BAS. This report is valuable in justifying the current, and proposed stream buffer widths. The current range of buffer widths in the CAO is* ***0-100 feet****, and the proposed range in the revised CAO is* ***15-100 feet****. This matches almost exactly the range proposed in the Pizzimenti report of* ***5 to 30 meters (16-98 feet).*** *This report was reviewed in the first draft of the BAS Report, and can be reviewed in Chapter 2, section 7.4.3, page 73 and listed in the bibliography on page 93. Yakima County believes that the economic analysis is not applicable to the CAO/SMP update project, since it is based on mandatory, statewide, fixed-width, 300 foot buffers on agricultural lands. The report references the economic impacts to agriculture without a concurrent review of the economic impacts of salmon, or tourism for example. The CAO is a development based regulation that does not mandate buffers on existing land uses.*

Washington Association of Realtors. 2004. A Citizens Guide to Critical Areas Ordinances, How to Understand and Influence the Adoption of Critical Areas Ordinance under the Washington State Growth Management Act.

Abstract: *This is a general guide on GMA and critical areas, which contains some case law, some background on the interaction between the SMA and GMA, some suggested ordinance language, and the permitting process.*
Staff Review: *Yakima County will take these concerns into consideration when drafting the updated ordinance. This does not meet the statutory requirements for BAS.*

Washington Research Council. 2001. Impact of Government Regulations and Fees on Housing Costs. ePB 01-18

Abstract: *This is a report on the impacts to housing costs in the Seattle-Bellevue-Everett metropolitan area. The report identifies the following as increasing housing costs:*

- *Impact fees;*
- *Park set asides;*
- *Open space lands and critical areas;*
- *Federal requirements;*
- *Local permitting process;*
- *Multi-jurisdictional authorities and conflicts.*

Staff Review: *This does not meet the statutory requirements for BAS.*

Zueger-Nikel, Manuel. 2003. Saving Salmon the American Indian Way**.** Issue Number PS-29. Political Economy Research Center, 2048 Analysis Dr., Suite A, Bozeman, MT, 59718

Abstract: *This is an opinion paper that analyzes the anthropologic record of Native American property rights and draws a comparison with current institutions to strengthen property rights that encourage stewardship of ocean fisheries.*
Staff Review: *This does not meet the statutory requirements for BAS.*

BAS Submission provided by Frank Hendrix, WSU Co-Operative Extension.

Larsen, Royce., Kruger, William., Barrington, Mack., Buckhouse, John., George, Melvin., Johnson Douglas. 1996. Livestock Influences on Riparian Zones and Fish Habitat; A Bibliography. EM 8660 Oregon State University

Abstract: *The following review is a synopsis of the authors review, and not staff's review of the literature:*

The purpose of this bibliographic review was to determine the state of knowledge base and to evaluate the quality of the literature relating to the influences of livestock on fish habitat, riparian zones, and streams. This report contains a bibliography and assesses the quality of the literature. There were three levels of literature search and acquisition:

- *An attempt to find all literature relating to grazing impacts to streams, riparian areas, and fish;*
- *Sufficient fish habitat literature to define key habitat requirements, and;*
- *Literature that related to other riparian parameters not exclusive to grazing.*

This bibliography consists of 1,521 citations, with 428 (28%) of them relating directly to grazing impacts on riparian areas and fish habitat. This portion of the bibliography is based largely on documented case histories or observation and comment. Some have data associated, but about 1/3 (~143) are largely observational. ***Only 89 citations (21%) of the grazing impact citations, or 6% (~91) of the total, are classified as experimental, or hard science.*** *Of these 89 citations, most are riparian plant community studies, while only three are studies of stream morphology. The experimentally based (true science) citations usually lack some necessary components of a sound range science experiment, and do not always come to the same conclusion. [Emphasis added]*

A review of this literature exposed several inherent problems with studies that relate to livestock influences on riparian zones and fishery habitat. These problems included:

- *Inadequate description of grazing management practices;*
  -Grazing management descriptions were often so vague, it was impossible to reconstruct the grazing practice prevailing during the study.
- *Lack of pretreatment data;*
  -Descriptions of historical land use practices are crucial to interpretation of study results, but are almost never explained.
- *Non-uniform stream reaches used as experimental units;*
  -Use of non-uniform stream reaches results in large experimental errors, and consequently, studies often show different results from similar treatments.
- *Differential fisheries management considerations;*
  -The complexities of physical and biologic interactions make it difficult to predict effects of grazing practices.

- *Undefined spatiotemporal scale;*
- *Riparian and stream systems are highly variable both in space and time, which complicate analysis.*
- *Inadequate Sample size;*
  -There is a relationship between sample size, accuracy, and uncertainty.
- *Questionable statistical reliability.*

All of the factors listed above yield results that often are not statistically reliable. Data often are reported with no analysis and are assumed to be accurate. Data that have no statistical analysis do not separate effects and cannot be used to make meaningful predictions. A high percentage of the work reviewed did not meet the standards of being statistically reliable by the authors.

Staff Review: *This meets the statutory requirements for BAS. Most of the individual citations are not directly available, so the synthesis was reviewed on its own in similar fashion to other synthesis documents. Even with the conflicting results associated with the varied literature base, a few broad generalizations can be made:*

- *Livestock grazing can be compatible with sustainable riparian systems;*
- *Vegetation response is highly variable, and no single grazing strategy will work everywhere;*
- *Ecosystems are highly variable and grazing strategies need to consider all of the factors.*

DelCurto, Timothy. No Date. Season of Use and Off-stream Water as Management Strategies to Manipulate Beef Cattle Distribution Patterns and Vegetation Use on Mixed-conifer Rangelands (abstract only). Easter Oregon Agriculture Research Center, 327 S. Tenth St., Union OR, 97883

Abstract: *A two year study that evaluated grazing distribution with access to off-stream water versus in-stream water. In general, grazing distribution displays strong diurnal patterns.*

Staff Review: *This meets the statutory requirements for BAS. In summary, grazing distribution, on existing grazing land, can be managed with off-stream water and changing the season of use.*

Borman, Michael M. 1998. Grazing Management for Riparian Areas. The Grazier, No. 296. Oregon State University Extension Service. Corvallis OR, 97331

Abstract: *Water quality impacts are closely related to soil erosion, which can be associated with inappropriate livestock use. Grazing management must be compatible with achieving or maintaining "proper functioning condition" to be considered sustainable. There may be situations where temporary exclusion of live stock can accelerate initiation of riparian area recovery. Free-standing water is the principal focus around which cattle orient their foraging. Passive, continuous grazing rarely improves a degraded riparian area or maintains a riparian area in good condition. Grazing management must provide an adequate cover and height of*

vegetation on the banks and overflow zones to promote natural stream functions. Use of streams as pasture boundaries is not advisable.
Staff Review: *This meets the statutory requirements for BAS. This study found that no single grazing management system has resulted in consistent recovery of degraded riparian areas. Grazing management for an area should be tailored to site-specific situations.*

Council for Agricultural Science and Technology. 1996. Grazing on Public Lands.
Staff Review: *This meets the statutory requirements for BAS. Improper livestock grazing can damage riparian areas. Most riparian areas, however, can be grazed safely if stocking rate, season, and length of grazing are proper.*

Allen-Diaz, Barbra, Jackson, Randall D., Bartolome, James W., Tate, Kenneth W., Oates, Lawrence G. 2004. Long-term Grazing Study in Spring–fed Wetlands Reveals Management Tradeoffs. California Agriculture, Volume 58, Number 3.
Abstract: *A 10-year (long term) and 3-year (paired plot) experiments on existing grazing lands in California to better understand grazing management effects. A study of spring ecosystem responses in plant composition, diversity and cover; channel morphology; water quality; aquatic insects; and green house gasses. Lightly and moderately grazed wetlands exhibited lower insect family richness than ungrazed springs. Plant cover was maintained for the first 7 years of grazing, and plant diversity was not significantly affected. At the same time, removal of grazing decreased emissions of methane, and increased nitrate levels in spring waters. The results reveal important tradeoffs relative to key response variables. In general, light grazing at springs appears to be desirable from an ecosystem function perspective. Spring systems are highly variable, making it difficult to predict responses to management. All sites studied had historically similar fall-winter-spring grazing histories that left approximately 600 to 700 pounds per acre residual dry matter (RDM) or aboveground biomass in the uplands. Implications for management are that species composition can be manipulated by altering the grazing intensity along creeks. In springs however, species composition is controlled by the vagaries of climate, not by grazing. No significant differences in the total number of species were observed at any of the wetland sites. Lightly grazed wetlands maintained greater species evenness and diversity relative to 1992 pretreatment values than either ungrazed or moderately grazed plots. At creek wetlands, moderately grazed plots maintained greater total species, evenness, and diversity than ungrazed or lightly grazed plots. Their results indicate that light grazing on spring-fed wetlands and moderate grazing on down slope creeks maintained current diversity. After 7 years, there were no significant differences in herbaceous cover among grazing intensities, however, by 2002, moderate grazing resulted in significant decrease in plant cover. Sustained grazing at moderate or higher intensities is not desirable from an ecosystem conservation perspective. After five years, no changes in channel morphology due to grazing were observed. After five years, there were no significant differences among grazing intensity toward water quality. The*

removal of grazing impaired the ability of the spring to retain nitrate, by allowing dead plant material to accumulate, and inhibiting plant production. Lightly grazed and moderately grazed wetlands exhibited lower family richness for aquatic insects than ungrazed springs. Grazing removal significantly decreased methane emissions.
Staff Review: *This meets the statutory requirements for BAS. Most riparian areas and spring systems can be grazed safely if stocking rate, season, and length of grazing are closely managed.*

Johnson, D.E., Harris, N.R., du Plessis S., Tibbs, T.M. No Date. Mapping and Analysis of Catherine Creek Using Remote Sensing and Geographic Information Systems (GIS). Oregon State University, Department of Rangeland Resources. Corvallis, OR, 97331

Abstract: *A two year study to quantify the surface hydrology of Catherine Creek in northeastern Oregon as it relates to existing livestock grazing and salmon spawning. Most of the spawning sites for salmon occurred in grazed portions of the stream. Overall, there were an average of 4.68 redds per enclosed plots compared to 7.41 redds per grazed plots.*
Staff Review: *This meets the statutory requirements for BAS. The study found that it was difficult to separate livestock effects on the stream because excluded areas are relatively small and closely associated with grazed parcels. The findings indicate that this is a preliminary study, and that more questions remain unanswered.*

BAS submissions provided by Marie Zuroske, South Yakima Conservation District

Fuhrer, G.J., Morace, J.L., Johnson, H.M., Rinella, J.F., Ebbert, J.C., Embrey, S.S., Waite, I.R., Carpenter, K.D., Wise, D.R., and Hughes, C.A. 2004, Water Quality in the Yakima River Basin, Washington, 1999-2000: U.S. Geological Survy Circular 1237, 34p.

Abstract: *A review of the surface water quality in the Yakima River Basin for the National Water Quality Assessment Program (NAWQA). Nitrate and orthophosphate were dominant forms of nitrogen and phosphorous found in the Yakima River. Concentrations of total phosphouous have begun to decrease, but still frequently exceed EPA goals. The combination of BMPs and TMDL assessments have reduced concentrations of sediments and sediment-sorbed contaminants. The majority of the agricultural streams and drains sampled exceeded WDOE fecal-coliform bacteria standards, but none from the Yakima River exceeded. Concentrations of fecal-coliform bacteria in the Yakima River and at the mouths of major tributaries increased with increasing suspended sediment, turbidity, nutrients, and specific conductivity. Arsenic was detected in agricultural drains at elevated concentrations during non-irrigation season when ground water is the primary source of stream flow, which is a cause for concern due to the high use of groundwater for domestic purposes. Historically used oranochloride insecticides were frequently detected, two of which exceeded EPA chronic water quality criteria for the protection of aquatic life. Concentrations of*

DDT have decreased since 1991, due to decreases in suspended sediment and sorbed DDT resulted from agricultural erosion control. Concentrations of an orchard insecticide routinely exceeded EPA chronic toxicity criterion for the protection of aquatic life. Shallow ground water underlying agricultural areas contributes soluble pesticides to streams all year. The types of pesticides in streams reflect the types of crops grown in the areas they drain. Transport of a pesticide to a stream depends on its tendency to dissolve in water or adhere to soil. Pesticides that strongly adhere to soil were detected at lower frequency, and the opposite for pesticides that weakly adhere to soil. As overall stream conditions decline, benthic macroinvertabrate assemblages are less diverse. Algal assemblages are increasingly dominated by species indicative of high concentrations of nutrients. Algal biomass was limited by light from high turbidity, or by herbicides.

Staff Review: *This meets the statutory requirements for BAS. This is part of an ongoing study to assess the water quality in the Yakima River Basin. The irrigation system greatly controls water quality and aquatic health. Generally, some parameters of water quality still exceed acceptable levels, some remain unchanged, and some have decreased, but the general trend in water quality is improving due to management of agricultural practices.*

Zuroske, Marie. 2004. Conservation Practices and Water Quality Trends in Sulphur Creek Wasteway and Granger Drain Watersheds, 1997-2002. South Yakima Conservation District in collaboration with the Roza-Sunnyside Board of Joint Control.

Abstract: *This report evaluates changes in water quality and conservation practices from 1997-2002. Factors suggesting that improved conservation practices were responsible for the improvements in water quality include:*

- *The simultaneous reduction in loads and concentrations, with no know concurrent systematic changes in hydrology, suggest that source reduction effort, and improved on-farm irrigation water management best explain the improvements;*
- *Yields of all parameters have decreased, indicative of wide-ranging changes;*
- *Concentrations of suspended sediment, nutrients, and bacteria decreased even in years of abundant water supply.*

Water quality improvements varied between sub-basins and years. This variability did not correspond to the varying implementation rates of government funded BMPs. The lack of correlation is likely due to widespread BMP implementation, confounding the attempts to quantify the relationship between these two factors. Private landowners were largely responsible for the water quality improvements.

Staff Review: *This meets the statutory requirements for BAS. Overall, water quality has improved in terms of decreasing concentrations, loads, and yields of suspended sediment, nutrients and fecal coliforms due to on-farm conservation BMPs.*

BAS submissions provided by David Taylor, Taylor Consulting Group

Henri, C.J., Waller, A. 2004. Economics of Riparian Restoration on selected Stillaguamish Farms. Prepared by Resource Consulting. Prepared for the Stillaguamish Implementation Review Committee, WA Department of Agriculture Contract #03-02-01, US Fish and Wildlife Service Contract # 134102J010.;

> ***Abstract:*** *The purpose of this project was to develop tools that agricultural landowners could use to evaluate the economic impacts of riparian restoration. This report on the application of the tool to several case studies, and the impacts of installing riparian buffers on farm net income.*
> ***Staff Comment:*** *On page v of the executive summary and on page 2 of the introduction, the document states that a case study approach was chosen over a statistical analysis of impacts of riparian buffers based on limited availability of financial resources and limited access to data. Because the results reported in this project document do not represent a statistical sample they cannot be applied to the greater farm community at large (page v Executive Summary and pg. 2 Introduction). It should also be noted that this project is not a full scale economic impact analysis for the watershed, which would include a much broader assessment of the direct and secondary impacts on output, employment, and income; not only for the entire agricultural sector, but for related industries and the local economy at large. Nor is it a cost-benefit-analysis of buffers, which would include a much broader discussion of social benefits and costs. (Page 2 Introduction). This does not meet the statutory requirements for BAS.*

Washington State University, Co-Operative Extension. No Date. Pesticide Trapping by Buffers/Maintenance of Buffers.

> ***Abstract:*** *Typical buffer widths of about 50 feet can be effective in reducing pesticide runoff by 50% or more if sheet flow occurs.*
> ***Staff Comment:*** *This document is actually part of a nine chapter online document. The two sections provided are very helpful in describing science related to conservation buffers, agricultural impacts and protection of water quality. This document only analyzes agricultural impacts to water quality, and does not address other land uses or other riparian functions. The recommendations found in this document fit within the range of science reviewed in the Draft BAS Report. This meets the statutory requirements for BAS.*

Pizzimenti, John, J. PhD. 2002. Efficacy and Economics of Riparian Buffers on Agricultural Lands. GEI Consultants, Inc. 6950 S. Potomac St. Suite 200, Englewood, CO, 80112. In association with Pacific Northwest Project and Mason Bruce & Girard, Inc. Submitted to the Washington Hop Growers Association, Ag Caucus, and Multi Agricultural Caucus.

> ***Staff Review:*** *The Report cited above was reviewed in the first draft of the BAS Report, and can be reviewed in Chapter 2, section 7.4.3, page 73 and listed in the bibliography on page 93. See additional review above.*

BAS submissions provided by Steve George, Hop Growers of Washington and the Yakima Valley Dairy Association

Pizzimenti, John, J. PhD. 2002. Efficacy and Economics of Riparian Buffers on Agricultural Lands. GEI Consultants, Inc. 6950 S. Potomac St. Suite 200, Englewood, CO, 80112. In association with Pacific Northwest Project and Mason Bruce & Girard, Inc. Submitted to the Washington Hop Growers Association, Ag Caucus, and Multi Agricultural Caucus.

Staff Review: *The Report cited above was reviewed in the first draft of the BAS Report, and can be reviewed in Chapter 2, section 7.4.3, page 73 and listed in the bibliography on page 93. See additional review above.*

BAS submissions provided by Washington Farm Bureau

Pizzimenti, John, J. PhD. 2002. Efficacy and Economics of Riparian Buffers on Agricultural Lands. GEI Consultants, Inc. 6950 S. Potomac St. Suite 200, Englewood, CO, 80112. In association with Pacific Northwest Project and Mason Bruce & Girard, Inc. Submitted to the Washington Hop Growers Association, Ag Caucus, and Multi Agricultural Caucus.

Staff Review: *The Report cited above was reviewed in the first draft of the BAS Report, and can be reviewed in Chapter 2, section 7.4.3, page 73 and listed in the bibliography on page 93. See additional review above.*

Henri, C.J., Waller, A. 2004. Economics of Riparian Restoration on selected Stillaguamish Farms. Prepared by Resource Consulting. Prepared for the Stillaguamish Implementation Review Committee, WA Department of Agriculture Contract #03-02-01, US Fish and Wildlife Service Contract # 134102J010.;

Staff Review: *See review above*

"Wider Buffers Not Necessarily Better" by Wendell Gilliam and Deanna Osmond, North Carolina State University, in *Buffer Notes*, October 2003

Staff Review: *This is an opinion article arguing against the need for "wide" buffer to protect water quality. The authors recommend, based on their experience, that buffers of 50-100 feet are sufficient to protect water quality. This does not meet the statutory requirements for BAS, but does match the buffer width proposed in the CAO revisions.*

Monohan. C., 2004. Riparian buffer function along lowland agricultural streams. Watershed Review, Washington State University, Center for Water and Watershed Studies.

Abstract: *The majority of buffer science is based on forestry science, and may not be applicable to agricultural areas. In summary, the soil properties of agricultural areas of the Pacific Northwest in the historic floodplains of lowland rivers, differ significantly from the sandy substrates of the Southeast agricultural regions where most existing buffer research has been conducted to date. This has direct implications for the flow of subsurface water and delivery of excess fertilizer nutrients to the stream ecosystem.*

Staff Review: *A discussion of agricultural best management practices to mitigate for water quality impacts. Buffers are one tool that can be utilized*

to address water quality concerns. This meets the statutory requirements for BAS.

BAS citations submitted by 1000 Friends of Washington

The 1000 Friends of Washington submission was on CD, with the citations organized by category.

Biodiversity

Gorsline, g. 2003. Biodiversity Conservation and Washington's Growth Management Act. Washington Environmental Council.

Staff Review: *A two page newsletter for regional workshops held in 2003 to train citizens for effective participation in the updates to Critical Areas ordinances required by the Growth Management Act. This does not meet the statutory requirements for BAS.*

Ohland. G., Dittmar, H. 2002. Biodiversity and Smart Growth. Translation paper #10, Funders Network for Smart Growth and Livable Communities.

Staff Review: *An opinion paper that translates the impact of suburban sprawl and disinvestment on issues of importance to America's communities and suggests opportunities for progress that would be created by smarter growth policies and practices. This does not meet the statutory requirements for BAS.*

Craig R. Groves, Deborah B. Jensen, Laura L. Valutis, Kent H. Redford, Mark L. Shaffer, J. Michael Scott, Jeffrey V. Baumgartner, Jonathan V. Higgins, Michael W. Beck, And Mark G. Anderson. 2002. Planning for Biodiversity Conservation: Putting Conservation Science into Practice. BioScience, Vol. 52 No. 6.

Abstract: *An outline of a framework for identifying the most important remaining areas for conservation and restoration. The seven-step framework is based upon scientific principles and theories. The seven-step approach to conservation planning, which has been applied to terrestrial, freshwater, and marine environments, offers numerous benefits. First, it allows conservation planners to set goals that are based on assessments of the biological needs of species, communities, and ecosystems. Second, this framework complements single species conservation approaches by incorporating a broad set of conservation targets at a variety of levels of biological organization and spatial scales. Third, at a median cost of $234,000 per plan and an average completion time of just less than 2 years, application of the framework strikes a reasonable balance between planning and action. Fourth, the framework provides an explicit means for conservation planners to measure whether the set of conservation areas that they have identified will sufficiently represent the biodiversity of the region and achieve the target-based goals of the plan. Fifth, the proposed framework pays due diligence to a long-overlooked aspect of conserving biodiversity: the underlying ecological processes and functions that support the long-term persistence of biodiversity. Finally, by using an approach that represents biodiversity in a set of conservation areas across environmental*

regimes in which targeted features are known to occur, the framework may help conserve biodiversity in the face of global climate change
Staff Review: *This document is a planning tool based on science, but does not constitute science its self. While this methodology may be a useful tool, it is well above the requirements for updating the CAO. Some of the underpinnings of the seven steps rest on assumptions that remain inadequately tested (e.g., surrogate measures for biodiversity) and methods that are not yet fully developed (e.g., assessing persistence of conservation targets). This does not meet the statutory requirements for BAS.*

Cohn, J.P., Lerner, J.A. 2003. Integrating Land Use Planning & Biodiversity. Defenders of Wildlife.
Abstract: *Defenders of Wildlife brought together land use planners and conservationists at a workshop held in the spring of 2002. The workshop's goal was to begin a national dialogue about the integration of biodiversity and land use planning. This report attempts to summarize that discussion and draw attention to the numerous fledgling efforts at conservation planning currently underway in communities throughout the country.*
Staff Review: *This document is a planning tool, but does not constitute science itself. While the methodologies presented are a useful tool, Yakima County conducted a habitat mapping exercise described in Chapter 4. This does not meet the statutory requirements for BAS.*

Fish and Wildlife Habitat

What is a Riparian Zone? Washington State Department of Ecology.
Staff Review: *An informational brochure that briefly describes the importance of Riparian Areas. This does not meet the statutory requirements for BAS.*

State of the Birds. 2004. Audubon Washington
Staff Review: *A review of threatened and endangered birds in Washington State. This report is an executive summary of a much longer, more detailed article, which was not submitted for review. This does not meet the statutory requirements for BAS.*

Fish & Aquatic Areas

Leavitt, J. 1998. The functions of riparian buffers in urban watersheds. Masters of Science thesis, University of Washington, Seattle.
Staff Review: *the citation above was reviewed in the Draft BAS Report.*

Washington State Salmonid Stock Inventory: Bull Trout/Dolly Varden. Washington Department of Fish and Wildlife (Olympia, Washington: July 1998). Downloaded on August 2, 2004 at:
Abstract: *The objective of this report was to develop a simple and consistent system of collating and reporting statewide salmonid resource*

assessment information, recognizing the inventory will change over time. This inventory incorporated information already available in existing documents and information compiled for submission to the USFWS as part of ESA proceedings. Future updates and associated reports will evolve as necessary to accommodate new information and be integrated with developing regional resource information systems. The planned growth and refinement is an important point. This report, and related data collation, was developed in a short time period. Given the large number of stocks in the inventory, the amount of detailed data and depth of analysis has been limited. This report is meant to provide a first glimpse of current stock status and build a foundation for future restoration and inventory efforts.
Staff Review: *Yakima County is constantly updating its GIS data, and all relevant data has been reviewed through the CAO revision. This meets the statutory requirements for BAS.*

Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP) Executive Summary.
Abstract: *The SSHIAP is an interactive mapping application designed to display and report a wide range of data related to salmon distribution, status, and habitats within Washington State.*
Staff Review: *Yakima County is constantly updating its GIS data, and all relevant data has reviewed through the CAO revision. This meets the statutory requirements for BAS.*

Dale E. Miller, Peter B. Skidmore, & Dale J. White. 2001. Channel Design. Submitted to Washington Department of Fish and Wildlife, Washington Department of Ecology And Washington Department of Transportation
Abstract: *This document is one of a series of white papers developed to provide a scientific and technical basis for developing Aquatic Habitat Guidelines. The white papers address the current understanding of impacts of development and land management activities on aquatic habitat, and potential mitigation for these impacts. The report contains a detailed discussion of stream geomorphology, channel classification, processes of channel de-stabilization as a basis for applied stream channel design.*
Staff Review: *This document is a "how to" manual an applicant could use for a project proposal to meet the BAS requirements. This meets the statutory requirements for BAS.*

Bolton, S., Monohan, C., 2001. A Review of the Literature and Assessment of Research Needs in Agricultural Streams in the Pacific Northwest as it Pertains to Freshwater Habitat for Salmonids. Center for Streamside Studies, University of Washington
Staff Review: *Reviewed in Draft BAS Report*

Carrasquero, J. 2001. Over-Water Structures: Freshwater Issues. Submitted to Washington Department of Fish and Wildlife, Washington Department of Ecology And Washington Department of Transportation

Abstract: *This document is one of a series of white papers developed to provide a scientific and technical basis for developing Aquatic Habitat Guidelines. The white papers address the current understanding of impacts of development and land management activities on aquatic habitat, and potential mitigation for these impacts. This white paper evaluates the state of knowledge of the effects of over-water structures on the functioning of freshwater ecosystems and their relation to salmonids. Scientific and technical literature on the subject was compiled and examined, and input from experts on freshwater habitats and organism life histories was solicited and evaluated. Effects on an array of organisms and communities are considered.*
Staff Review: *This document is a "how to" manual an applicant could use for a project proposal to meet the BAS requirements. This meets the statutory requirements for BAS.*

Bolton, S. and Shellberg, J. 2001. *Ecological issues in floodplains and riparian corridors.* University of Washington, Center for Streamside Studies, Seattle, WA.
Staff Review: *Reviewed in Draft BAS Report*

Norman, D.K., Cederholm, J., and Lingley, W.S. Jr. 1998. Flood plains, salmon habitat, and sand and gravel mining. *Washington Geology, 26*(2, 3).
Staff Review: *Reviewed in Draft BAS Report*

Norman, D.K. 1998. Reclamation of Flood-Plain Sand and Gravel Pits as Off-Channel Salmon Habitat, Washington Geology, vol. 26, no. 2/3, p. 21
Staff Review: *Reviewed in Draft BAS Report*

Kondolf, G.M., Smeltzer, M., Kimball, L. 2001. Freshwater Gravel Mining and Dredging Issues. Submitted to Washington Department of Fish and Wildlife, Washington Department of Ecology and Washington Department of Transportation
Abstract: *This white paper, reviews the scientific information regarding the mechanical removal of sediment from river channels, which is conducted for a variety of reasons: to improve navigation, agricultural drainage, flood control, channel stability, and production of construction aggregate. As the environmental impacts of aggregate extraction from river channels become increasingly well understood, the practice has received increased scrutiny, especially in salmon-bearing rivers and streams. The purpose of this report is to build upon existing literature for Washington and elsewhere to summarize current scientific information regarding the environmental effects of mining gravel and sand for construction aggregation from rivers and streams, along with the effects of other freshwater dredging. The emphasis is on effects on salmonids in their various freshwater-based life stages, to provide a scientific basis for future development of guidelines that will be protective of the resource.*
Staff Review: *This document is a "how to" manual an applicant could use for a project proposal to meet the BAS requirements. This meets the statutory requirements for BAS.*

Poston, T. 2001. Treated Wood Issues Associated with Overwater Structures in Marine and Freshwater Environments. Submitted to Washington Department of Fish and Wildlife, Washington Department of Ecology And Washington Department of Transportation.

Abstract: *This white paper is an assessment of chemical contaminants in treated wood and the potential for adverse impact to salmon listed under the Endangered Species Act (ESA) and other aquatic resources when used in "over water" and "in water".*

Staff Review: *This document is a "how to" manual an applicant could use for a project proposal to meet the BAS requirements. This meets the statutory requirements for BAS.*

The Cumulative Impacts of Watershed Urbanization on Stream-Riparian Ecosystems. Christopher W. May and Richard R. Horner AWRA Riparian Ecology and Management in Multiland Use Watersheds Conference Portland Or August 28-31, 2000

Abstract: *Historically, watersheds of the Puget Sound lowland ecoregion contained an abundance of complex, diverse, and productive salmonid habitat in the form of small stream ecosystems and associated riparian ecotones. However, development of these lowland watersheds has significantly impacted the ecological integrity of their aquatic ecosystems. The cumulative effects of watershed urbanization have resulted in a loss of natural forest and wetland cover, as well as a significant increase in impervious surface area. Riparian forests, floodplains, and off-channel wetlands have also been severely degraded by the incremental encroachment of residential and commercial development. The decline in ecological integrity of the stream-riparian ecosystem begins at very low levels of watershed development and continues with increasing watershed urbanization. A conservation-based strategy for managing stream-riparian ecosystems in our urbanizing watersheds should be adopted if the remaining salmonid resources are to be protected and to facilitate recovery of those already in decline. Initial research indicates that maintaining natural riparian corridors around streams and wetlands can have a positive influence on ecological integrity even at moderate levels of watershed development. These results suggest that resource managers should place a high priority on preservation of remaining high quality stream-riparian ecosystems. In addition, our long-term objective should be to actively manage for natural riparian buffers throughout our watersheds.*

Staff Review: *While this document was developed for the Puget Sound region, it is till applicable to Yakima County concerning habitat quality and anadromous fish. Similar documents developed with the Yakima River Basin were utilized in the BAS report. The current and proposed CAO currently utilize the premise behind this document. This meets the statutory requirements for BAS.*

Cederholm, C.J., Johnson, D.H., Bilby, R.E., Dominguez, L.G., Garrett, A.M., Graeber, W.H., Greda, E.L., Kunze, M.D., Marcot, B.G., Palmisano, J.F., Plotnikoff, R.W., Pearcy, W.G., Simenstad, C.A., and Trotter, P.C. 2000. *Pacific salmon and*

wildlife: Ecological contexts, relationships, and implications for management. Special edition Technical Report. In Johnson, D.H. and O'Neil, T.A. *Wildlife-Habitat Relationships in Oregon and Washington*. Washington Department of Fish and Wildlife.

Staff Review: *Reviewed in Draft BAS Report*

1992 Washington State Salmon and Steelhead Stock Inventory (SASSI).1993. Washington Department of Fisheries, Washington Department of Wildlife and Western Washington Treaty Indian Tribes

Abstract: *This report documents the results of an initial stock status inventory that is the first step in a statewide effort to maintain and restore wild salmon and steelhead stocks and fisheries. The inventory's intent is to help identify currently available information and to guide future restoration planning and implementation. While overall objectives and future steps of the restoration initiative are briefly described, the report primarily focuses on current condition of Washington's naturally reproducing anadromous salmonid populations and not on the adequacy of current resource management objectives. Assessment of management objectives and strategies will be one of many subsequent steps aimed at improving the status of wild salmon and steelhead resources in Washington.*

Staff Review: *Yakima County is constantly updating its GIS data, and all relevant data has reviewed through the CAO revision. This meets the statutory requirements for BAS.*

An Ecosystem Approach to Salmonid Conservation [ManTech Report]. Brian C. Spence, Gregg A. Lomnicky, Robert M. Hughes, Richard P. Novitzki. ManTech Environmental Research Services Corporation. 21TR-4501-96-6057 (December 1996

Staff Review: *Reviewed in Draft BAS Report*

Integrated Streambank Protection Guidelines. Washington Department of Fish and Wildlife, Washington Department of Transportation, & Washington Department of Ecology (April 2003). Downloaded on August 4, 2003 at: http://www.wa.gov/wdfw/hab/ahg/ispgdoc.htm

Abstract: *The Aquatic Habitat Guidelines collection was created by a consortium of public agencies to assist property owners, planners, designers and regulators protect and restore marine, freshwater and riparian fish and wildlife habitat.*

Staff Review: *This document is a "how to" manual an applicant could use for a project proposal to meet the BAS requirements. This meets the statutory requirements for BAS.*

Plants

List of Plants Tracked by the Washington Natural Heritage Program. Washington Natural Heritage Information System (April 2004). Downloaded on June 24, 2004 at http://www.dnr.wa.gov/nhp/refdesk/lists/plantrnk.html

Abstract: *This table lists threatened, endangered, and sensitive plants and other plants needing management and protection.*

Staff Review: *This list does not meet the statutory requirements for BAS. While maintaining and protecting threatened, endangered, and sensitive plants is important, their protection is not required by the GMA.*

Impervious Surface & Forest Loss

Forest Cover, Impervious-Surface Area, and the Mitigation of Urbanization Impacts in King County, Washington. Derek B. Booth, Ph.D., P.E. (September 2004) Downloaded on June 24, 2004 at: http://depts.washington.edu/cuwrm/research/forest.pdf

Abstract: *This paper focuses on changes in hydrology, because hydrologic processes dominate the formation and functioning of aquatic habitat, and because these changes are ubiquitous in urban settings. The purpose here is to remind readers of the scientific framework for evaluating the consequences of urban development on aquatic systems; to review the history of surface-water management in King County as it relates to the analysis and mitigation of those consequences; and to evaluate the basis for a specific proposal, first explored almost a decade ago, to limit effective impervious areas in high-quality watersheds at or below 10 percent and to maintain forest cover above 65 percent.*

Staff Review: *While this is an important piece of science, its applicability to Yakima County is questionable due to dramatic climatic differences between eastern and western Washington. Recent Growth Management Hearings Board decisions have found that requiring developments to maintain imperviousness below 10 percent is not required. This meets the statutory requirements for BAS.*

Urban Stream Rehabilitation in the Pacific Northwest: Physical, Biological and Social Considerations. Booth, D. B, J. R. Karr, S. Schauman, C. P. Konrad, S. A. Morley, M. G. Larson, P. C. Henshaw, E. J. Nelson and S. J. Burges. 2001. Final Report, EPA Grant Number R82-5284-010. University of Washington. Seattle, Washington. Downloaded on June 24, 2004 at: http://depts.washington.edu/cuwrm/research/final%20rehab%20report.pdf

Abstract: *The goal in this project was to develop a robust approach to urban stream rehabilitation, using examples from the Puget Lowland region of western Washington, that blended knowledge from the physical, biological, and social sciences by:*

• documenting the consequences of urban development on urban streams;
• understanding the causes of the resulting ecological degradation; and
• using that understanding to evaluate rehabilitation strategies and techniques.

Staff Review: *Stream rehabilitation is a non-regulatory tool utilized by many entities within the Yakima River Basin. While stream rehabilitation may be an important component of a new project, it can only be required as mitigation to compensate for increased impacts from new development. This meets the statutory requirements for BAS.*

The Cumulative Effects of Urbanization on Small Streams in the Puget Sound Lowland. Christopher W. May, Richard R. Horner, James R. Karr, Brian W. Mar,

Eugene B. Welch, University of Washington, Seattle, Washington. Downloaded on January 23, 2003 at: http://pluto.apl.washington.edu/etg/chrisrdp.html

Abstract: *A key objective of the Puget Sound lowland (PSL) stream study was to identify the linkages between landscape-level conditions and instream environmental factors, including defining the functional relationships between watershed modifications and aquatic biota. The goal was to provide a set of stream quality indices for local resource managers to use in managing urban streams and minimizing resource degradation due to development pressures. In this scenario, there would be a reasonable expectation that a goal of maintaining given populations or communities of organisms (native salmonids) at a specified level could be met by sustaining a certain set of habitat characteristics, which in turn depend on an established group of watershed conditions. A part of this overall objective was to identify any thresholds of watershed urbanization as related to instream salmonid habitat and aquatic biota. The study was designed to establish the linkages between landscape-level conditions, instream habitat characteristics, and biotic integrity.*

Staff Review: *Results of the study indicate that physical, chemical, and biological characteristics of streams change with increasing urbanization in a continuous rather than threshold fashion. Although the patterns of change differed among the attributes studied and were more strongly evident for some than for others, physical and biological measures generally changed most rapidly during the initial phase of the urbanization process as %TIA (Total Impervious Area) above the 5-10% range. As urbanization progressed, the rate of degradation of habitat and biologic integrity usually became more constant. There was also direct evidence that altered watershed hydrologic regime was the leading cause for the overall changes observed in instream physical habitat conditions. While this is an important piece of science, its applicability to Yakima County is questionable due to dramatic climatic differences between eastern and western Washington. This meets the statutory requirements for BAS.*

Mammals

Management Recommendations for Washington's Priority Species, Volume V: Mammals Appendix A: Contacts Useful When Evaluating Pesticides and Their Alternatives. J. M. Azerrad, editor. [Online]. Downloaded on August 3, 2004 at: http://wdfw.wa.gov/hab/phs/vol5/appendixa.pdf

Abstract: *The Washington State Department of Fish and Wildlife has developed management recommendations for Washington's priority habitats and species to provide planners, elected officials, landowners, and citizens with comprehensive information on important fish, wildlife, and habitat resources. These management recommendations are designed to assist in making land use decisions that incorporate the needs of fish and wildlife. Agency biologists develop management recommendations for Washington's priority habitats and species through a comprehensive review and synthesis of the best scientific information available. Management recommendations for Washington's priority habitats and species are*

guidelines based on the best available scientific information and are designed to meet the following goals:

- *Maintain or enhance the structural attributes and ecological functions of habitat needed to support healthy populations of fish and wildlife;*
- *Maintain or enhance populations of priority species within their present and/or historical range in order to prevent future declines;*
- *Restore species that have experienced significant declines.*

Staff Review: *Staff has utilized the PHS Management Recommendations and associated data. The PHS data is recommended as a source of information in WAC 365-190-080(5), but is not required to be used in the designation of fish and wildlife habitat. This meets the statutory requirements for BAS.*

PHS (Priority Habitats and Species) Management Recommendations

Addendum to the PHS List. Washington State Department of Fish and Wildlife. This list updates the Priority Species and Habitats List for some species. Please use the Addendum in together with the Priority Species and Habitats List. Downloaded on June 24, 2004 at: http://wdfw.wa.gov/hab/phsinsert.pdf

Staff Review: *Staff has utilized the PHS Management Recommendations and associated data. The PHS data is recommended as a source of information in WAC 365-190-080(5), but is not required to be used in the designation of fish and wildlife habitat. This does not meet the statutory requirements for BAS.*

Priority Species and Habitats List. Washington State Department of Fish and Wildlife. The Addendum to the PHS List above updates the Priority Species and Habitats List for some species. Please use the Addendum in together with the Priority Species and Habitats List. Downloaded on June 24, 2004 at: http://wdfw.wa.gov/hab/phslist.pdf

Staff Review: *Staff has utilized the PHS Management Recommendations and associated data. The PHS data is recommended as a source of information in WAC 365-190-080(5), but is not required to be used in the designation of fish and wildlife habitat. This does not meet the statutory requirements for BAS.*

Species of Concern in Washington State. Washington State Department of Fish and Wildlife. Downloaded on June 24, 2004 at: http://wdfw.wa.gov/wlm/diversty/soc/soc.htm

Staff Review: *Staff has reviewed the Species of Concern list. Species of Concern are not required to be protected under WAC 365-190-080(5), or to be used in the designation of fish and wildlife habitat. This does not meet the statutory requirements for BAS.*

Management Recommendations for Washington's Priority Species, Volume I: Invertebrates. Larsen, E.M., E. Roderick, and R. Milner, eds. 1995. Washington Department of Fish and Wildlife, Olympia. Downloaded on August 5, 2004 at: http://wdfw.wa.gov/hab/vol1.pdf

Staff Review: *See Abstract and Staff Review above for Volume V: Mammals.*

Management Recommendations for Washington's Priority Species, Volume III: Amphibians and Reptiles. Larsen, E. M., editor. 1997. Washington Department of Fish and Wildlife, Olympia. Downloaded on June 24, 2004 at: http://wdfw.wa.gov/hab/vol3.pdf

Staff Review: *See Abstract and Staff Review above for Volume V: Mammals.*

Management recommendations for Washington's priority species, Volume IV: Birds. E. Larsen, J. M. Azerrad, N. Nordstrom, editors. 2004. Washington Department of Fish and Wildlife, Olympia, Washington, USA. Downloaded on June 24, 2004 from: http://wdfw.wa.gov/hab/phs/vol4/phs_vol4_birds.pdf

Staff Review: *See Abstract and Staff Review above for Volume V: Mammals.*

Management Recommendations for Washington's Priority Habitats: Riparian. Knutson, K. L. and V. L. Naef. 1997. Washington Department of Fish and Wildlife, Olympia. 181 pp. Downloaded on August 5, 2004 at: http://wdfw.wa.gov/hab/ripfinal.pdf

Staff Review: *See Abstract and Staff Review above for Volume V: Mammals. The referenced document was utilized in the BAS synthesis.*

Management Recommendations for Washington's Priority Habitats: Oregon White Oak Woodlands. Larsen, E. M., and J. T. Morgan. 1998. Washington Department of Fish and Wildlife, Olympia. Downloaded on August 5, 2004 at: http://wdfw.wa.gov/hab/oakfinal.pdf

Staff Review: *See Abstract and Staff Review above for Volume V: Mammals.*

Management recommendations for Washington's priority habitats and species. Elizabeth Rodrick and Ruth Miller, editors. May 1991. Washington Department of Wildlife, Wildlife Management, Fish Management, and Habitat Management Division. Olympia, Washington, USA. Downloaded on June 24, 2004 at: http://wdfw.wa.gov/hab/phs/phs1991.pdf

Staff Review: *See Abstract and Staff Review above for Volume V: Mammals. Staff has utilized the PHS Management Recommendations and associated data. The PHS data is recommended as a source of information in WAC 365-190-080(5), but is not required to be used in the designation of fish and wildlife habitat.*

Salmon Limiting Factors Summary Reports

The limiting factors analysis prepared as part of the state's Watershed Planning can help identify salmon habitats that need to be protected by city and county critical areas ordinances or regulations. The report summaries available in April 2003 are

in this directory. They were downloaded from http://salmon.scc.wa.gov/reports/index.html

Staff Review: *the Limiting Factors Analysis for the Yakima River Basin was utilized in the BAS report.*

Shrub-Steppe

Teetering on the Edge or Too Late? Conservation and Research Issues for Avifauna of Sagebrush Habitats. Report of the Cooper Ornithological Society Committee for Conservation of Sagebrush Ecosystems. Steven T. Knick, David S. Dobkin, John T. Rotenberry, Michael A. Schroeder, W. Matthew Vander Haegen, & Charles Van Riper III. The Condor 105:611–634 (2003). Downloaded on August 2, 2004 at: http://wdfw.wa.gov/wlm/research/papers/shrub/conservation_avifauna.pdf

Abstract: *Degradation, fragmentation, and loss of native sagebrush (Artemisia spp.) landscapes have imperiled these habitats and their associated avifauna. Historically, this vast piece of the Western landscape has been undervalued: even though more than 70% of all remaining sagebrush habitat in the United States is publicly owned, 3% of it is protected as federal reserves or national parks. We review the threats facing birds in sagebrush habitats to emphasize the urgency for conservation and research actions, and synthesize existing information that forms the foundation for recommended research directions. Management and conservation of birds in sagebrush habitats will require more research into four major topics: (1) identification of primary land-use practices and their influence on sagebrush habitats and birds, (2) better understanding of bird responses to habitat components and disturbance processes of sagebrush ecosystems, (3) improved hierarchical designs for surveying and monitoring programs, and (4) linking bird movements and population changes during migration and wintering periods to dynamics on the sagebrush breeding grounds. This research is essential because we already have seen that sagebrush habitats can be altered by land use, spread of invasive plants, and disrupted disturbance regimes beyond a threshold at which natural recovery is unlikely. Research on these issues should be instituted on lands managed by state or federal agencies because most lands still dominated by sagebrush are owned publicly. In addition to the challenge of understanding shrubsteppe bird habitat dynamics, conservation of sagebrush landscapes depends on our ability to recognize and communicate their intrinsic value and on our resolve to conserve them.*

Staff Review: *The extent and wildlife populations of sagebrush habitats were utilized in the BAS methodology in Chapter 4. This meets the statutory requirements for BAS.*

Predation on Real and Artificial Nests in Shrubsteppe Landscapes Fragmented by Agriculture. W. Matthew Vander Haegen, Michael A. Schroeder & Richard M. Degraaf. The Condor 104:496–506. Downloaded on August 2, 2004 at: http://wdfw.wa.gov/wlm/research/papers/shrub/nest_predation.pdf

Abstract: *Clearing of shrubsteppe communities for agriculture has created a highly fragmented landscape in eastern Washington, a condition that has*

been shown to adversely affect nesting success of birds in some forest and grassland communities. We used artificial nests monitored by cameras to examine relative effects of fragmentation, distance to edge, and vegetation cover on nest predation rates and to identify predators of shrubsteppe nesting passerines and grouse. Predation rate for artificial nests was 26% (n 5 118). Fragmentation had a strong influence on predation rates for artificial nests, with nests in fragmented landscapes about 9 times more likely to be predated as those in continuous landscapes. Daily survival rate for 207 real nests of 4 passerine species also was greater in continuous than in fragmented landscapes, although pattern of predation between real and artificial nests was not consistent among sites.

Staff Review: *The extent and wildlife populations of sagebrush habitats were utilized in the BAS methodology in Chapter 4. This meets the statutory requirements for BAS.*

Status of Washington's Shrub-Steppe Ecosystem: Extent, ownership, and wildlife/vegetation relationships. Frederick C. Dobler, Jim Eby, Chuck Perry, Scott Richardson, and Matthew Vander Haegen. (Washington Department of Fish and Wildlife, Olympia, Washington: August 1996). Downloaded on August 2, 2004 at: http://wdfw.wa.gov/wlm/research/songbird/shrub.pdf

Abstract: *Changes in land use over the past century have resulted in the loss of over half of Washington's shrub-steppe habitat. The few remaining large areas of shrub-steppe are primarily on federal holdings (Yakima Training Center, Hanford Nuclear Site, and the Yakama Indian Nation) and may represent the only sites suitable for species requiring extensive areas of continuous shrub-steppe. Washington's shrub-steppe communities support a wide diversity of wildlife. The suitability of Washington's shrub-steppe habitat for wildlife differs from that which occurred a century ago. Conversion of sites with deep, loamy soil to agriculture; invasion by non-native grasses and forbs; and fragmentation of the remaining shrub-steppe habitats have likely lowered the suitability of Washington's shrub-steppe habitat for many native species.*

Staff Review: *The extent and wildlife populations of sagebrush habitats were utilized in the BAS methodology in Chapter 4. This meets the statutory requirements for BAS.*

Shrubsteppe Bird Response to Habitat and Landscape Variables in Eastern Washington, USA. W. Matthew Vander Haegen, Frederick C. Dobler and D. John Pierce Conservation Biology 14: 1145-1160 (August 2000). Downloaded on August 2, 2004 at: http://wdfw.wa.gov/wlm/research/papers/shrub/shrubsteppe.pdf

Abstract: *The landscape of the intermountain west has changed dramatically in the last 150 years, particularly in the State of Washington, where over half of the native shrubsteppe ecosystem has been converted to agricultural lands, resulting in a fragmented landscape with few extensive tracts of shrubsteppe. We examined the historical and current distribution of shrubsteppe on different soil types in eastern Washington, and we censused bird communities at 78 sites in shrubsteppe from 1991 to 1993. We compared abundance of species among soil types and range conditions*

and developed models of species occurrence using site-specific vegetation and landscape variables. The pattern of shrubsteppe conversions resulted in a disproportionate loss of deep soil communities. Eight bird species showed strong relationships with soil types and three with range condition. These associations likely resulted from the influence of soil type and range history on the vegetation of these communities. Brewer's Sparrows and Sage Sparrows reached their highest abundances in deep loamy soils, whereas Loggerhead Shrikes were most abundant in deep, sandy soils. Sage Sparrows occurred more frequently in landscapes dominated by shrubsteppe, indicating a negative relationship with fragmentation. Our results suggest that fragmentation of shrubsteppe and the pattern of agricultural conversion among soil types have had a detrimental effect on numerous shrubsteppe species. The landscape for species with an affinity for deep, loamy soil communities has changed considerably more than the overall loss of shrubsteppe would indicate. Conservation practices that emphasize retention of shrubsteppe communities on deep soils and that reduce further fragmentation will be critical to the maintenance of avian biological diversity.

Staff Review: *The extent and wildlife populations of sagebrush habitats were utilized in the BAS methodology in Chapter 4. This meets the statutory requirements for BAS.*

Shrubsteppe Mapping Of Eastern Washington Using Landsat Satellite Thematic Mapper Data. John E. Jacobson & Michelle C. Snyder. (Washington State Department of Fish and Wildlife: August 2000) Downloaded on August 2, 2004 at: http://wdfw.wa.gov/wlm/research/papers/shrubsteppe_map/shrubsteppe_map.pdf

Abstract: *Shrubsteppe provides important habitat for many wildlife species in Washington State, such as the sage grouse (Centrocerus urophasianus), sharp-tailed grouse (Tympanuchus phasiannellus), and pygmy rabbit (Brachylagus idahoensis) which are currently listed as threatened or endangered with extinction. Shrubsteppe once extended over nearly all of the non-forested land in Washington east of the Cascade Mountain Range, but now only occupies about 50% of its historical range. The continuous loss of this important habitat makes it imperative the spatial distribution and characteristics of shrubsteppe be mapped for the effective conservation and management of obligate wildlife species. The wide distribution of shrubsteppe land cover throughout eastern Washington made the data obtained from the Thematic Mapper (TM) sensor onboard the Landsat 5 satellite platform a logical and cost-effective choice for this mapping project. An exhaustive literature review and research effort was conducted to determine an image processing methodology which would optimally discriminate between numerous shrubsteppe habitat conditions, and other land cover in eastern Washington. CRP areas were mapped for Okanogan, Douglas, Lincoln, Grant, Adams, Franklin, Benton, Klickitat, Walla Walla, and Yakima counties by compiling and digitizing CRP field boundaries from aerial photographs. Shrubsteppe land cover as of 1993 covered only 30% of the eastern Washington landscape compared to approximately 60% historically. The diminishing extent and fragmentation of shrubsteppe*

makes it imperative this habitat and other interspersed land cover be monitored at least every 5-10 years. Such a mapping effort will assist in the effective management of shrubsteppe and the many wildlife species dependant upon this vital habitat.
Staff Review: *The extent and wildlife populations of sagebrush habitats were utilized in the BAS methodology in Chapter 4. This meets the statutory requirements for BAS.*

Wildlife of Eastside Shrubland and Grassland Habitats. W. Matthew Vander Haegen, Scott M. McCorquodale, Charles R. Peterson, Gregory A. Green, & Eric Yensen. (2001). Downloaded on August 2, 2004 at: http://wdfw.wa.gov/wlm/research/papers/shrub/wildlife_of_shrubsteppe.pdf

Abstract: *Much of the historical vegetation in shrubsteppe habitats, particularly in eastern Washington, has been converted to agricultural crops. In some areas, the only remaining native communities are on rocky soils or steep slopes unfit for agriculture. The dominant land use in these shrubland and grassland habitats is livestock grazing, and a few examples of undisturbed stands exist, limited primarily to sites where topography or remoteness from water has made access for livestock grazing impractical. Although pristine communities do exist for eastside grassland and shrub habitats, the majority of sites have been shaped by a legacy of past land uses that includes continuous grazing by livestock forage and that in turn has facilitated invasion be exotic vegetation. This legacy has modified the vegetation community in many areas, with some changes occurring so long ago that they are not apparent today. Changes in the herb community brought about by excessive grazing and exotic invaders are particularly damaging in these arid habitats where the herb layer often contains the most vegetative biomass. Moreover, the successional trajectory of vegetation communities in arid habitats can be modified by influences such as grazing and fire, resulting in present day "zootic" climax communities that differ greatly from those that occurred historically. Sites in south-central Washington that were dominated by exotic annuals in the 1950's still have not been colonized by native plants. The low vertical structural diversity inherent in these habitats provides fewer habitat layers for wildlife, resulting in lower diversity. Habitats with a shrub component tend to have more diverse wildlife communities than grass dominated habitats, a function of increased nesting and foraging strata. Available water is a defining factor in these arid and semi-arid habitats, and this strongly shapes the composition of plant communities and influences the ecology and behavior of associated wildlife*
Staff Review: *The extent and wildlife populations of sagebrush habitats were utilized in the BAS methodology in Chapter 4. This meets the statutory requirements for BAS.*

Flooded Areas

Floodplain Management in the State of Washington: A Status Report as of February 2004. Washington Department of Ecology Northwest Regional Office. (Publication

#04-06-016 March, 2004). Downloaded on July 27, 2004 from: http://www.ecy.wa.gov/pubs/0406016.pdf

***Abstract**: A review of existing floodplain management laws applicable in Washington State and the various agencies that have authority. To cope with significant flooding issues, there have been numerous innovations by local governments in the field of floodplain management, efforts that exceed the minimum requirements established by the NFIP regulations, including: freeboard, cumulative substantial improvement rule, channel migration zones, deep and fast flowing waters, prohibition of fill, prohibition of residences in the floodplain, zero-rise criteria in the flood fringe, setbacks, compensatory storage, higher floodway surcharge, septic system prohibition, enclosures below BFE, determining BFEs where they do not exist, subdivisions and floodplains, hazardous materials, critical facilities, water wells, floodway prohibition, FEMA fish-flood ordinance.*

***Staff Review:** This document does not meet the statutory requirements for BAS, although some new applications have been incorporated where appropriate.*

Floodplain Management: Higher Regulatory Standards. Federal Emergency Management Agency (FEMA).

***Abstract:** The purpose of this document is to provide local communities with some regulatory land-use ideas that seek to better balance the needs between floodplain development and maintaining the natural and beneficial functions of the floodplain.*

***Staff Review:** This document does not meet the statutory requirements for BAS, although some new applications have been incorporated where appropriate.*

Geo Hazards

A Framework for Delineating Channel Migration Zones. Cygnia F. Rapp, R.G. & Timothy B. Abbe, Ph.D., R.G. (Olympia, Washington, Ecology Publication #03-06-027 [Final Draft] November 2003). Downloaded on August 3, 2004 from: http://www.ecy.wa.gov/pubs/0306027.pdf

***Staff Review:** reviewed in the BAS Synthesis Report.*

Optional Comprehensive Plan Element for Natural Hazard Reduction. Jane Preuss, Doug Pflugh, Richard Mayo, Lori Emadi (Urban Regional Research), Roger Wagoner & Nancy Eklund (Berryman & Henigar) & Jon Koloski & Mary Ann Reinhart (GeoEngineers). (Olympia, Washington: Department of Community, Trade, and Economic Development June 1999). Downloaded on April 6, 2004 at: http://www.cted.wa.gov/DesktopModules/Documents/ViewDocument.aspx?DocumentID=1254 it is listed under "Natural Hazard Reduction."

***Abstract:** This Guidebook provides local government planners with tools that can be used to address hazard avoidance and mitigation in their community comprehensive plans. While the Guidebook is primarily intended for use by cities and counties planning under the Growth Management Act (GMA), the principles and methods can generally be applied to jurisdictions not planning under GMA. The preparation of the Guidebook is supported by*

federal and state agencies involved in hazard-reduction planning to provide better communications between these agencies and local planners.
Staff Review: *This document does not meet the statutory requirements for BAS, although some new applications have been incorporated where appropriate.*

Liquefaction Susceptibility and NEHRP Soil-Type Maps
The Washington State Department of Natural Resources, Division of Geology and Earth Resources has received grant funding through the Hazard Mitigation Grant Program (HMGP) following the Nisqually Earthquake of March 2001.

Abstract: *A statewide liquefaction susceptibility and National Earthquake Hazards Reduction Program (NEHRP) soil-type maps. Regional earthquake hazard maps such as these support hazard mitigation, critical areas regulations updates, emergency planning and response, planning of local zoning ordinances, and building code enforcement. The primary reason for producing this preliminary series of earthquake hazard maps is to support revisions to the State Hazard Mitigation Plan required to implement 44CFR201.4 and 44CFR201.6, which include the requirement that revised mitigation plans describe the location and extent of the earthquake hazards within the jurisdictional boundary. Additionally, these maps will serve a great variety of other partners involved in earthquake hazard mitigation planning and implementation.*
Staff Review: *This meets the statutory requirements for BAS.*
The reconnaissance level inventory conducted for Yakima County is too general, and does not adequately address the actual liquefaction hazard present. Staff has concluded that the current IBC standards adequately address liquefaction hazards in Yakima County. Yakima County is currently utilizing a geologically hazardous areas inventory that was developed for Yakima County.

Landslide Hazards
Digital Compilation of "Landslide Overview Map Of The Conterminous United States" by Dorothy H. Radbruch-Hall, Roger B. Colton, William E. Davies, Ivo Lucchitta, Betty A. Skipp, and David J. Varnes, 1982. Jonathan W. Godt. U.S. Department of the Interior, U.S. Geological Survey Open-File Report 97-289.

Staff Review: *This meets the statutory requirements for BAS.*
The reconnaissance level inventory conducted for Yakima County is too general, and does not adequately address the actual landslide hazard present. Yakima County is currently utilizing a geologically hazardous areas inventory that was developed for Yakima County.

BAS Synthesis Reports
Stream-Riparian Ecosystems In the Puget Sound Lowland Eco-Region: A Review of Best Available Science Christopher W. May (Watershed Ecology LLC: 2003) prepared for Kitsap County.

Abstract: *The purpose of this report is to present a summary of the current level of scientific knowledge on the management of riparian ecosystems and the use of riparian buffers to protect aquatic resources in*

the Puget Sound Lowland Eco-region, including sensitive biota and critical instream habitat. This report will also make recommendations as to how riparian zone management guidelines should be modified to make them more ecologically sound and scientifically defensible. The objective of this report is to provide sufficient information, such that natural resource managers can properly identify the boundaries of the stream-riparian ecosystem and make sound decisions on the appropriate configuration of the riparian management zone and associated buffers. Buffer criteria, sensitive area ordinances, and land-use regulations designed to protect aquatic resources should be based on best-available science. The underlying goal of this report is the conservation of our valuable aquatic resources, including native biota (e.g.salmonids). In addition, the information presented here should provide a foundation for enhancement, rehabilitation, and restoration efforts within the stream-riparian ecosystem.
Staff Review: *Yakima County performed an independent review of the BAS with more science relevant to local conditions. This meets the statutory requirements for BAS.*

Best Available Science: Volume I: A Review of Science Literature, Stephanie Brown, Terry Butler, Robert Fuerstenberg, Ph.D, Priscilla Kaufmann, Gino Lucchetti, Klaus Richter, Ph.D., Jeanne Stypula, P.E. Jennifer Vanderhoof, & James Hatch (Seattle, Washington: King County Executive Report, February 2004).

Abstract: *The purpose of this report is to provide a compilation and review of the best available scientific information that is applicable to King County. This scientific information was selected to meet the Washington Administrative Code requirements given in WAC 365-195-900 to 925. The companion report, Assessment of Proposed Ordinances, discusses the State requirements to include best available science in the development of policies and regulations to protect critical areas. This report describes the overarching scientific framework and organizing principles for King County's approach to environmental management. Discussion covers principles of conservation, context, complexity, and connectivity. The effects of development and landscape change are also illustrated in a brief discussion. A review of BAS for each critical area contains the following sections: (1) introduction (2) a review of the scientific literature, which includes a discussion of functions and values of the critical areas, (3) conclusions, and (4) literature references. The literature Review summarizes a considerable amount of the most applicable scientific and technical literature.*
Staff Review: *Yakima County performed an independent review of the BAS with more science relevant to local conditions. Staff did utilize the BAS bibliography of this report to acquire relevant science. This meets the statutory requirements for BAS.*

Wetlands

Washington State Wetland Mitigation Evaluation Study, Phase I: Compliance. 0206009.pdf is a companion study. Downloaded on January 22, 2003 at: http://www.ecy.wa.gov/biblio/0006016.html

Staff Review: *reviewed in the BAS Synthesis Report.*

Washington State Wetland Mitigation Evaluation Study - Phase 2, Evaluating Success. 0006016.pdf is a companion study. Downloaded on January 22, 2003 at: http://www.ecy.wa.gov/biblio/0206009.html

Staff Review: *reviewed in the BAS Synthesis Report.*

Draft Freshwater Wetlands in Washington State - Vol. 1: A Synthesis of the Science. Sheldon, D., T. Hruby, P. Johnson, K. Harper, A. McMillan, S. Stanley, E. Stockdale. (Washington State Department of Ecology Publication # 03-06-016 August 2003). The following are companion documents: draft_appendix8-c-westernwaguidance.pdf, draft_appendix8-d-easternwaguidance.pdf, draft_appendix8-e-bufferrationale.pdf, & draft_appendix8-f-ratiosrationale.pdf. Downloaded on September 11, 2003 at: http://www.ecy.wa.gov/biblio/0306016.html

Staff Review: *reviewed in the BAS Synthesis Report.*

Washington State Wetland Rating System for Eastern Washington Revised. Hruby, T. (2004) Ecology Publication # 04-06-015. Downloaded on July 27, 2004 at: http://www.ecy.wa.gov/pubs/0406015.pdf

Staff Review: *reviewed in the BAS Synthesis Report.*

Wetland Buffers: Use and Effectiveness. Downloaded on January 22, 2003 at: http://www.ecy.wa.gov/biblio/92010.html

Abstract: This report was developed to assist efforts by Washington State agencies and local governments developing policies and standards for wetlands protection. The report summarizes and evaluates scientific literature, an agency survey, and a recent field study on wetland buffer use and effectiveness. Published literature was obtained from several sources and contains information from throughout the country on the concept of wetland buffers, their important functions, effective buffer widths, and buffer determination models. The agency survey reviewed buffer requirements of several states throughout the U.S. and for counties and cities in Washington. The field study reviewed the current state of buffers at several sites in King and Snohomish counties.

Staff Review: *the science in this document has been supplanted by the WDOE science synthesis distributed in 2003. This meets the statutory requirements for BAS.*

Washington State Wetlands Delineation Manual. Downloaded on January 22, 2003 at: http://www.ecy.wa.gov/biblio/9694.html

Staff Comment:

Abstract: *This document is the wetland delineation manual that is to be used in determining wetland areas when applying state and local government regulations under the Shoreline Management Act and the Growth Management Act in Washington State. This delineation manual is a revised version of the Corps of Engineers 1987 manual (see Preface for a description of the revisions). The relevant mandatory elements of this manual have been adopted into state regulations (WAC 173-22-080). In addition to the mandatory elements, this manual contains additional*

background material, recommended data gathering methods, illustrations and appendices.
Staff Review: *This document is required for all wetland delineations by the revised CAO. This meets the statutory requirements for BAS.*

Wetlands and Urbanization: Implications for the Future. Azous, Amanda L. and Richard R. Horner, 1997. Final Report of the Puget Sound Wetlands and Stormwater Management Research Program. Downloaded on June 2, 2003 at: http://splash.metrokc.gov/wlr/basins/weturban.htm

Abstract: *The wetlands chosen for the study were representative of those found in the Puget Sound lowlands and most likely to be impacted by urban development. The program's goal was to employ the research results to improve the management of both urban wetland resources and stormwater. This overview paper begins by defining the issues facing the program at its inception. It then summarizes the state of knowledge on these issues existing at the beginning and in the early stages of the program. The paper concludes by outlining the general experimental design of the study. Subsequent papers present the specific methods used in the various monitoring activities.*
Staff Review: *the science in this document has been supplanted by the WDOE science synthesis distributed in 2003. This meets the statutory requirements for BAS.*

Yakima County Public Services – Environmental Division – Surface Water Management Section

Leopold, Wolman, Miller 1964. Fluvial Processes in Geomorphology. General Publishing Company, Ltd. 30 Lesmull Road, Don Mills, Toronto, Canada. ISBN 0-486-68588-8

Staff Review: *This citation was utilized to edit standard 16A.04.14 (5) to add the 1/3 bankfull depth requirement. This meets the statutory requirements for BAS.*

Washington Department of Fish and Wildlife

The WDFW submitted five documents at the Planning Commission Hearing on 01/20/05 to counter a statement made at the 01/19/05 Planning Commission Study Session that Cottonwood trees were not native to Yakima County. Copies of the submittals are available at the Planning Division. All submittals substantiated that the Cottonwood in native to Yakima County. All of the documents meet the statutory requirements for BAS.

Pacific Northwest Forest and Range Experiment Station. 1973. Vascular Plants of the Pacific Northwest. US Department of Agriculture, Forest Service. General Technical Report PNW-8. Portland, OR.

Natural Vegetation of Oregon and Washington

Natural Resource Conservation Service. Online Plants database. http://plants.usda.gov/checklist.html

Hitchcock, L, C. Cronquist, A. Ownbey, M. Thompson, J.W. No Date. Vascular Plants of the Pacific Northwest. University of Washington Press, Seattle, WA.

NatureServe Explorer. Online database. http://www.natureserve.org/explorer/servlet/NatureServe?init=Species

Unknown web printout. http://www.na.fs.fed.us/spfo/pubs/silvics_manual/volume_2/populus/tricocarpa

Yakima Valley Audubon Society

Stepniewski, Andy. 1999. Birds of Yakima County, Washington. Yakima Valley Audubon Society. ISBN 0-9674378-0-6

Abstract:

Staff Review: *This book is a synthesis of ornithology for Yakima County. The book begins with an introduction and discussion of the methods used, a brief description of the geography and climate, a description of the vegetation zones, a brief history of Yakima County ornithology, birdlife through the seasons, good locations for finding birds, an annotated list of species, a summary of the distribution of birds, and data concerning bird surveys. The report indicates that there are approximately 302 bird species that inhabit Yakima County for at least part of the year. In the authors opinion, Yakima County's "claim to fame" is the diversity of migrant, breeding birds, especially noticeable along the and near the Columbia River at Priest Rapids, and the nearby ridges and riparian areas on the Yakima Traing Center. Riparian areas are noted as being critically important for avian diversity, especially in the shrub-steppe zone. A wide array of species are present in the riparian zone, the most diverse of any zone within the County. Many species in the riparian zone are migratory. The Shrub-steppe zone covers large areas of the County, but most has been extensively modified, more so than any other zone. The shrub-steppe zone is most active for birds from March through June. The Columbia River at Priest Rapids and nearby cliffs and shrub-steppe habitars attract great numbers of birds and a variety of speices, especially water birds. Bird habitat in the Yakima Valleylowlands mainly consists of converted habitats of agriculture. The Ponderosa Pine Zone exhibits a mosaic of habitats between soutern and northern slopes along the ridges. Most of the Ponderosa Pine Zone has been logged, altering the natural mosaic. Resident diversity of the Ponderosa Pine Zone is limited due to climate, but spring brings many migrants to breed. The Mixed-Conifer Zone has been greatly affect by logging, with numerous clear cuts in various stages of regeneration. These clear cut openings offer an array of several habitats, each hostong a bird fauna different from the original, mostly unbroken forest. The Mixed-Conifer Zone harbors a modest list of resident birds due to climate, spring however brings many migrants to breed. The Sub-Alpine*

Zone has been less affected by humans than the zones at lower elevations. The Sub-Alpine Zone harbors few resident birds due to climate, seasonally it attracts many migrants to breed with a delayed season due to elevation. Birdlife in the Alpine Zone is extremly limited due to climate, with late summer and fall migrations. This meets the statutory requirements for BAS.

Cassidy, K.M., Smith, M.R., Grue, C.E., Dvornich, K.M., Cassady, J.E., McAllister, K.R., Johnson, R.E. 1997. Gap Analysis of Washington State: An Evaluation of the Protection of Biodiversity. Volume 5 in Washington Ste Gap Analysis – Final Report. Washington Cooperative Fish and Wildlife Reasearch Unit, University of Washington, Seattle, 192 pp.

Abstract: *The objectives of the Washington State Gap Analysis Project (WAGAP) were to map land cover; model the distributions of terrestrial vertebrates; identify land cover types, vertebrate species, and areas of high vertebrate species richness inadequately represented on protected areas; and make these data available to users in a readily accessable format. To achieve the latter, data and results are reported in both a hard copy and digital format. The hard copy format is a five volume report. Volume 1 is a description of current land cover and its conservation status. Volumes 2, 3, and 4 are atlasas for herptofaunna, mammuals, and birds, respectively. This volume, Violume 5, is a summary and analysis of the informationpresented in the first four volumes, with our conclusions concerning conservation prioirities.*

Staff Review: *Staff utilized a mapping methodology that utilized Gap data as one of the tools, but was not the only consideration in anilitically mapping species richness and representation in Yakima County. For more detail on the mapping methodology, see Chapter 4.*

Roza/Sunnyside Board of Joint Control

Smith, D. L., Johnson, G., Williams, T. 2006. Natural Streamflow Estimates for Watersheds in the Lower Yakima River. S.P. Cramer and Associates. Unpublished report submitted to the *Roza/Sunnyside Board of Joint Control.*

"Executive Summary: *Irrigation in the Yakima Valley has altered the regional hydrology through changes in streamflow and the spatial extent of groundwater. Natural topographic features such as draws, coulees and ravines are used as drains to discharge irrigation water (surface and groundwater) back to the Yakima River. Salmonids are documented in some of the drains raising the question of irrigation impacts on habitat as there is speculation that the drains were historic habitat. We assessed the volume and temporal variability of streamflow that would occur in six drains without the influence of irrigation. We used gage data from other streams that are not influenced by irrigation to estimate streamflow volume and timing, and we compared the results to two reference streams in the Yakima River Valley that have a small amount of perennial streamflow. We estimate that natural streamflow in the six study drains ranged from 33 to 390 acre ft/year depending on the contributing area. Runoff occurred*

infrequently often spanning years between flow events, and was unpredictable. The geology of the study drains was highly permeable indicating that infiltration of what runoff occurs would be rapid. For fish to use intermittent streams there must be local groundwater to maintain perennial pools and a reliable connection to other perennial water bodies. The study drains did not have a local groundwater, perennial pools or a reliable surface flow connection to the Yakima River prior to irrigation. We therefore conclude that there was no salmonid habitat within the study drains prior to irrigation."

*"**Conclusions:***

1) Mean annual runoff for the study drainages was less than 400 acre ft/year (range 33-391 acre ft/year)

2) Natural streamflow contributed approximately 1% of the current streamflow in the study drainages.

3) Watershed area is important in determining mean annual runoff. Precipitation or runoff per unit area was not correlated with mean annual runoff. Larger watersheds have greater natural streamflow.

4) The temporal distribution of natural streamflow was unpredictable and several years can pass between flow events.

5) The role of geology on streamflow was important. Watersheds with greater than 80% low permeability substrates may support perennial surface flow. None of the study drains have a high percentage of low permeability substrates.

6) Study drains would be ephemeral with negligible benefit as fish habitat without the influence of irrigation."

***Staff Review:** This report, while unpublished or peer reviewed, meets the statutory requirements for BAS. This report estimates how the study drains may, or may not have provided fish (i.e. aquatic) habitat before the introduction of irrigation. The assumption that perennial water presence is required for a streams use as fish habitat could be questionable. Fish habitat would generally not exist in ephemeral streams, but some fish biologists may dispute that habitat is limited intermittent streams with perennial pools. Whether that would change the results of the study is unknown.*

The problem is that there are a number of drains/streams within the county that currently, and have for quite some time, provided aquatic and riparian habitat; and state laws and administrative rules do not provide any guidance on their application to artificially enhanced/altered habitat areas. This report concludes that the study drains/streams did not provide aquatic habitat, or habitat for salmonids, but does not assess the potential for other functional properties provided by intermittent and ephemeral streams, which includes upland wildlife habitat/migratory corridors, food web functions, and sediment sources for downstream perennial tributaries. This report oversimplifies the geologic/groundwater relationship. While the permeability of the geologic matrix can cause surface waters to become groundwater, that water does not simply disappear, but often will resurface somewhere downslope as a spring. A review of the General Land Office

(GLO) surveys along the leftbank of the Yakima River parallel to Rattlesnake Ridge indicated numerous intermittent/ephemeral tributaries with a surface connection to the Yakima River. One entry reads as follows: Jesse Richardson, Surveyor

> *"Field Notes of the of the boundaries of Township 9 N. of Range 23 E. of the Willamette Meridian, in the Territory of Washington, by Jesse Richardson deputy surveyor, under his contract. No. 88 date the 24th day of Sept., 1866."*
> *"Commenced October 30th 1866"*
> *"Completed October 31st 1866"*
>
> *"Between Townships 9 & 10 North, Range 23 E. W.M., General Land Description"*
> *"This Township is well watered and embraces fine farming and grazing lands." "Flowing through this Township have formed and rendered productive a large proportion of its area. Although all of the brooks become dry in the summer. Springs of water North and the Yakama River South of this Township render the lands available at all seasons. Its grassy prairies are choice and superior, and are now grazed upon by large droves of American cattle and horses."*

Yakima County and the Joint Board have agreed to work out the issues regarding drains/streams, including mapping, regulatory control, and the use of best management practices, in 2007.

GEI Consultants Inc.

Pizzimenti, John, J. PhD. 2005. Efficacy and Economics of Riparian Buffers on Agricultural Lands – State of Washington – Phase II. GEI Consultants, Inc. 311 B Avenue, Suite F, Lake Oswego, OR 97034. In association with the Pacific Northwest Project. 3030 West Clearwater #205-A Kennewick, WA 99336. Submitted to the Washington Ag Caucus.

> *"**Executive Summary**. This Phase II Report is an extension of the work done in Phase I. In Phase I, we examined the scientific literature of riparian buffers on agricultural lands. Best available science validates the importance of riparian habitat for fish and wildlife, but it does not validate the State Caucus proposal that wide fixed-width riparian buffers should be mandatory on all agricultural streams in the State of Washington to protect listed salmon… Since Phase I was complete we received comments on the report and found new scientific literature relevant to protecting Washington's critical areas. Buffers are one means of protecting the states watersheds and fish from agricultural impact. But many other scientifically tested methods recommended by the USDA Natural Resource Conservation Service are also important and may be more effective and cost-effective than mandatory fixed width buffers. These are commonly known as "Best Management Practices" on the farm. Phase II addresses "Best Management Practices" (BMPs) including the use of riparian buffers, which is one BMP. In summary, Phase II has three components: (1) a review of agriculture BMPs (2) a review of additional scientific literature on effectiveness of buffers and*

other BMPs and (3) suggested approaches for applying BMPs including riparian buffers in Washington agriculture. Two additional appendices support these as follows: Appendix II includes detailed reviews of additional Scientific Literature supplied by NOAA Fisheries and other scientists and agencies; Appendix III is a suggested model county ordinance that can be adopted for meeting Washington Growth Management Act to protect Critical Areas. That ordinance, based on the Phase I and II reports, suggests a specific range of riparian buffers between 25 and 60- feet contingent upon employment of other BMPs, slope (gradient) and local precipitation. The ordinance is intended to be broadly "protective" of all ecological and water quality functions of buffers. Because significant economic aspects of buffer prescriptions must also be considered as well as special natural resource conditions, the ordinance provides an exemption process for the local county government for exceptional circumstances."

Staff Review: *Section 4 of the report is a synthesis of BAS, and therefore meets the statutory requirements for BAS, although does not add any additional information on what was addressed in Phase I or this report. Section 3 discusses BMP's and references the NRCS FOTG (Field Office Technical Guide). While the FOTG may be considered science, the general discussion of BMP's in Section 3 is not. The remainder of the document does not meet the statutory requirements for BAS.*

Appendix III, which includes the draft model ordinance, describes the purpose of a CAO system that the model ordinance is to fit within. "The Critical Area protection ordinance directs existing and future agricultural operations to review their…" Consequently, the Model ordinance would apply to existing farm operations. The existing and updated CAO/SMP is a development based ordinance that regulates new developments and uses with a number of development standards, including buffers, to mitigate for increased impacts on critical areas. The CAO/SMP does not regulate legally established, on-going operations, including agriculture, so the proposed model ordinance has limited applicability in Yakima County. The development of NRCS BMPs, or other scientifically based BMPs, constitutes the application of BAS, but since the CAO/SMP does not regulate on-going agriculture, their application would have to be on a voluntary basis. If a new agricultural operation were proposed within a critical area, the BMPs could be implemented to mitigate for increased impacts.