FINAL DRAFT SEMI-ARID RIPARIAN FUNCTIONS AND ASSOCIATED REGULATORY PROTECTIONS TO SUPPORT SHORELINE MASTER PROGRAM UPDATES

Prepared for

Grant County

Prepared by

Anchor QEA, LLC
8033 W. Grandridge Blvd., Suite A
Kennewick, Washington 99336

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Participants

Grant County

Damien Hooper, Planning Manager

Peer Review Panel

Jock Conyngham

Duncan Patten

Robert Wissmar

Washington State Department of Ecology

Jaime Short

Jeremy Sikes

Anchor QEA Staff

Betsy Bermingham

Calvin Douglas

Ben Floyd

Derek Koellmann

Pradeep Mugunthan

John Small

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LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	Definition
BLM	Bureau of Land Management
B.P.	Before Present
Cfs	cubic feet per second
CMZ	Channel Mitigation Zone
CRB	Columbia River Basalt
CWA	Clean Water Act
Ecology	Washington State Department of Ecology
ESA	Endangered Species Act
GMA	Growth Management Act
Ha	Hectare
LDW	Large woody debris
M	Meter
NEPA	National Environmental Protection Act
NFIA	National Flood Insurance Act of 1968
NPDES	National Pollutant Discharge Elimination System
OHWM	Ordinary High Water Mark
PUD	Public Utility District
Mm	Millimeter
RCW	Revised Code of Washington
SMA	Shoreline Management Act
SMP	Shoreline Master Program
SPTH	specific tree height
SPTSH	specific tree or shrub height
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
YBF	years before present

1 EXECUTIVE SUMMARY

This document evaluates findings from current scientific literature that describe the functions provided by riparian habitat in semi-arid environments. Information sources include natural resource management agency reports, scientific journals, and other sources of peer-reviewed literature. The findings are applied systematically to support recommendations for riparian buffer protection standards applicable to the rivers and streams in Grant County, Washington and other areas in Washington that are part of the Columbia Basin Plateau region. Findings are also applicable to lake conditions, although that has not been a focus of this effort.

It is anticipated that the SMP literature review findings and methodology provided in this report will be an aid in establishing riparian buffer protection provisions in upcoming SMP updates for counties, cities, and towns in the Columbia Basin Plateau region. These local governments, in coordination with Ecology, can use the information as a guide in developing and applying riparian buffers and vegetation conservation measures tailored to site-specific conditions and environment designations included in their SMPs.

Various riparian functions within the semi-arid context are described in the document. Functions described include habitat corridors- connectivity, shade and cover, erosion control, water quality including water temperature, nutrient cycling, and organic inputs, and accumulations. Land use impacts to these functions are characterized. The regulatory framework in Washington State provides for a variety of specific protections of the various elements comprising a typical riparian corridor.

Key findings and recommendations are provided for the riparian functions addressed, along with a synthesis of these findings applied in establishing riparian buffers for water bodies and riparian conditions typical of the Columbia Basin Plateau region. A methodology for developing representative functional local conditions is also presented. Appendices contain references for literature sources reviewed in developing this report.

2 INTRODUCTION TO SHORELINE MANAGEMENT IN WASHINGTON STATE

2.1 History of the Shoreline Management Act

The Shoreline Management Act (SMA) was approved by voters in 1972. The SMA addresses concerns about the effects of unregulated or incidental influences of development on shorelines (Revised Code of Washington [RCW] 90.58). The SMA applies to all counties and hundreds of towns and cities in Washington, which have "shorelines of the state" and/or "shorelines of statewide significance" within their boundaries.

Shorelines of the state, which are applicable to areas east of the Cascades include:

- Streams or rivers with a mean annual flow greater than 20 cubic feet per second
- Lakes, either natural, artificial, or a combination thereof, which have a surface area of 20 acres or larger
- Upland shoreland areas that extend horizontally 200 feet landward from the edge of these waters
- Associated wetlands and some or all of the 100-year floodplain

Shorelines of statewide significance, which are applicable to areas east of the Cascades include:

- Lakes or reservoirs with a surface area of 1,000 acres or more
- Large rivers that either have a mean annual flow of 200 cubic feet per second or are downstream from the first 300 square miles of drainage area.
- Wetlands that are associated with the above features

2.2 SMP Update Purpose and Requirements

Under the SMA, cities and counties containing shorelines of the state must prepare a Shoreline Master Program (SMP). Local governments are required to prepare SMPs based on state laws and rules while tailoring the document to local geographic and environmental conditions, and existing and future planned development patterns within the shoreline. They are also required to update provisions of their SMPs.

The SMP update process balances and integrates the objectives and interests of local citizens. Key principles of the SMP include striking a balance among environmental protection, public access, and water-oriented uses. The new environmental protection standard for updated shoreline master programs is "no-net-loss of shoreline ecological functions." While restoration of degraded areas is encouraged, this does not mean all shoreline areas are required to be made "pristine" or returned to pre-settlement conditions.

The SMP update process involves developing an Inventory, Analysis, and Characterization report. This document provides an inventory of current shoreline conditions that includes identification of existing ecological processes and functions that influence physical and biological conditions. An associated Shoreline Restoration and Protection Plan and Cumulative Impacts Analysis by Grant County will follow development of the draft code. The cumulative impacts analysis will demonstrate that future development under the proposed SMP will result in no net loss of shoreline ecological function. Restoration measures described in the Shoreline Restoration Plan identify how to improve shoreline ecological functions beyond existing conditions. Figure 1 from the SMP Handbook illustrates how the no net loss standard is demonstrated through the SMP Update.

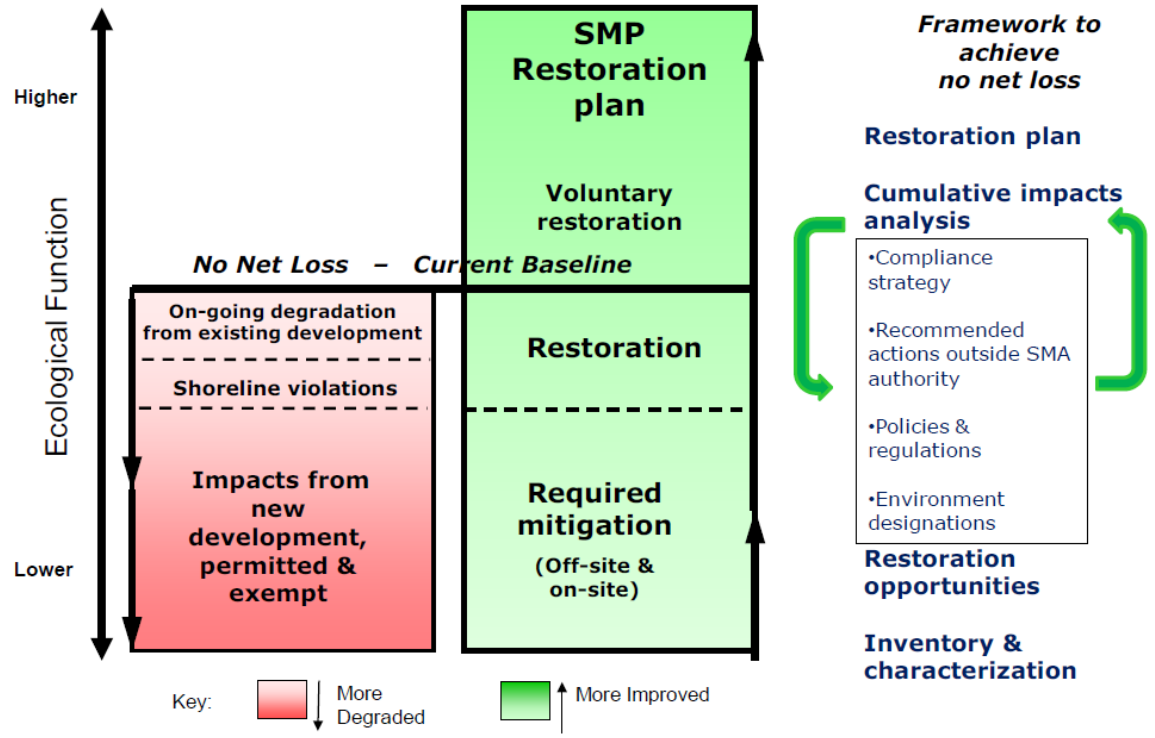


Figure 1

No Net Loss of Ecological Function and SMP Updates

(Ecology 2012)

Grant County's update of the shoreline master program is a partnership that balances the authorities of local and state government (Washington State Department of Ecology [Ecology]). Local governments develop SMPs in close coordination with Ecology, informed by local opportunities and constraints, and consistent with state law and guidelines. The SMP approval includes both local adoption and Ecology review and adoption. Grant funding and technical assistance for the SMP is provided to local governments by Ecology.

3 OBJECTIVES OF THE DOCUMENT

3.1 Purpose

This document evaluates findings from current scientific literature that describe the functions provided by riparian habitat in semi-arid environments. Information sources include natural resource management agency reports, scientific journals, and other sources of peer-reviewed literature. The findings are applied systematically to develop recommendations for riparian buffer protection standards applicable to the rivers and streams in Grant County, Washington and other areas in Washington that are part of the Columbia Basin Plateau region. Findings are also applicable to lake conditions, although that has not been a focus of this effort. Counties, cities, and towns in this region are updating their SMPs, including the goals, policies, and regulations for uses within shoreline jurisdiction areas, as discussed in more detail in Section 3. The SMA was enacted by public referendum in 1972; it has three broad policy goals that must be balanced:

1. Protect shoreline natural resources, including "...the land and its vegetation and wildlife, and the waters of the state and their aquatic life..."
2. Promote public access: "the public's opportunity to enjoy the physical and aesthetic qualities of natural shorelines of the state shall be preserved to the greatest extent feasible consistent with the overall best interest of the state and the people generally."
3. Encourage water-dependent uses: "uses shall be preferred which are consistent with control of pollution and prevention of damage to the natural environment, or are unique to or dependent upon use of the states' shorelines..."

Local jurisdictions are required by statute to develop SMPs that meet these policy goals, and that meet a specific requirement of “no net loss of ecological functions.” (Washington Administrative Code [WAC] 173-26-221(2)(C)(iv)(B)(II). The protection of riparian areas provides a critical regulatory tool to mitigate the impacts of new development on the ecological functions specifically described in the WAC. Regulation and management of development that provides protection for these functions in lakes, streams, stream channel migration zones, floodplains, associated wetlands and hyporheic zones are part of the overall integrated approach to protect and restore ecological functions and eco-system processes (Ecology 2011a).

WAC 173-26-221(5)(b) identifies the primary ecological functions and ecosystem processes provided by riparian vegetation along shorelines, including but not limited to:

- Providing shade necessary to maintain the cool temperatures required by salmonids, spawning forage fish, and other aquatic biota.
- Providing organic inputs critical for aquatic life.
- Providing food in the form of various insects and other benthic macroinvertebrates.
- Stabilizing banks, minimizing erosion, and reducing the occurrence of landslides. The roots of trees and other riparian vegetation provide the bulk of this function.
- Reducing fine sediment input into the aquatic environment through storm water retention and vegetative filtering.
- Filtering and vegetative uptake of nutrients and pollutants from groundwater and surface runoff.
- Providing a source of large woody debris into the aquatic system. Large woody debris is the primary structural element that functions as a hydraulic roughness element to moderate flows. Large woody debris also serves a pool-forming function, providing critical salmonid rearing and refuge habitat. Abundant large woody debris increases aquatic diversity and stabilization.
- Regulation of microclimate in the stream-riparian and intertidal corridors.
- Providing critical wildlife habitat, including migration corridors and feeding, watering, rearing, and refugia areas (WAC 173-26-221(5)(b)

Ecology acknowledges in the WAC codes and SMP guidance that conditions vary across the state. Accordingly, different widths of vegetation areas can be expected both across regions and within local government boundaries. To sustain specific ecological functions of different riparian systems requires consideration of the characteristics of different communities of riparian vegetation (e.g., species diversity and density). The importance of the different functions, in turn, varies with the landscape position and morphology of the shoreline.

The composition and structure (i.e., height, width, and density) of riparian vegetation in a functioning riparian area is highly variable across the multitude of climactic and geomorphic conditions found in Washington state. For example, the extremely large trees and dense multilayer canopies of vegetation communities which dominate many riparian ecosystems west of the Cascade crest are not a naturally found component of riparian plant community

composition in some other shoreline ecosystems, such as on coastal dunes and in the semi-arid Columbia Basin Plateau. In semi-arid riparian systems, the height, width, and density of the vegetation community of a functioning riparian corridor that provides a full suite of vegetation-related shoreline functions may be significantly different than in other areas of the state.

The vegetation conservation provision of the SMP update process encourages local governments to identify which ecological processes and functions are important aspects of the local aquatic and terrestrial ecology and to conserve sufficient vegetation to maintain them. However, vegetation conservation areas are not necessarily intended to be closed to public use. Development should provide for management and recreational uses in a manner adequate to assure no net loss of shoreline ecological functions (WAC 173-26-221(5)(b)).

3.2 Scientific Basis and Information Sources

Per WAC codes and Ecology guidance, SMPs must "make use of and, where applicable, incorporate all available scientific information," including management reports, inventory data, aerial photography, technical manuals-services, scientific publications and other applicable information (Ecology 2011b).

Scientific information used in the SMP updates is expected to be based upon:

- Replicable and clearly stated methods
- Reasonable assumptions supported by other studies with logical conclusions and reasonable inferences
- Analytical techniques, data, and conclusions appropriately framed in proper context and pertinent scientific knowledge
- Analyses using appropriate statistical or quantitative methods
- Findings supported citations to relevant, credible literature, scientific journals and other existing pertinent information
- Peer-review by appropriate areas of expertise to evaluate the quality of the research and provide written comments (Ecology 2011b)

SMP planners should also consider Washington Department of Fish and Wildlife (WDFW) management recommendations for Washington's 20 different "priority habitats" (WAC 173-26-221(5)(b). Priority habitats applicable to the Columbia Basin plateau include:

- Aspen stands – Pure or mixed stands of aspen greater than 0.4 hectare (ha; 1 acre).
- Biodiversity areas and corridors – Areas of habitat that are relatively important to various species of native fish and wildlife.
- Eastside Steppe – Nonforested vegetation type dominated by broadleaf herbaceous flora (i.e., forbs), perennial bunchgrasses, or a combination of both.
- Inland Dunes – Arid lands where sandy sediments were deposited during the Missoula floods.
- Juniper Woodlands - All juniper woodlands.
- Riparian – The area adjacent to flowing or standing freshwater aquatic systems.
- Shrub-steppe – A nonforested vegetation type consisting of one or more layers of perennial bunchgrasses and a conspicuous but discontinuous layer of shrubs.
- Fresh-water wetlands – Lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water.
- Fresh deepwater – Deepwater habitats are permanently flooded lands lying below the deepwater boundary of wetlands.
- Instream – The combination of physical, biological, and chemical processes and conditions that interact to provide functional life history requirements for instream fish and wildlife resources.
- Caves – A naturally occurring cavity, recess, void, or system of interconnected passages (including associated dendritic tubes, cracks, and fissures) which occurs under the earth in soils, rock, ice, or other geological formations, and is large enough to contain a human.
- Cliffs – Greater than 7.6 meters (25 feet) high and occurring below 1524 meters (5000 feet).
- Snags and logs - Snags and logs occur within a variety of habitat types that support trees.
- Talus – Homogenous areas of rock rubble ranging in average size 0.15 to 2.0 meters (m; 0.5 to 6.5 feet), composed of basalt, andesite, and/or sedimentary rock, including riprap slides and mine tailings. May be associated with cliffs.

Literature commonly used in developing and applying riparian buffers in SMP updates includes a guidance document prepared by Washington State Department of Fish and Wildlife titled Management Recommendations for Washington's Priority Habitats, Riparian Areas (Knutson and Naef 1997). This document identifies the functions of riparian habitat and species composition in the state, and impacts from land uses. Other useful information includes riparian habitat area management recommendations by stream type based upon a synthesis of riparian buffers literature. Such recommendations commonly apply to riparian conditions found in higher rainfall areas with forested, salmon-bearing rivers and streams. This does not necessarily apply to riparian conditions found throughout the Columbia Basin Plateau. This literature review is an attempt to provide scientific information more directly applicable to semi-arid riparian ecosystem conditions in the Columbia Basin Plateau and similar landscapes.

3.3 Literature Review

The goal of the literature review was to identify documents that augment the discussion of riparian characteristics (e.g., plant, fish and wildlife species compositions, water quality and quantity) and functions (e.g., hydrologic connectivity, nutrient cycling, shade, temperature moderation and essential life-history habitats such as reproductive rearing, refugia and migration areas) that are applicable to the Columbia Basin Plateau region of Washington. The project team, comprised of Ecology, Anchor QEA staff, and a peer review panel (further discussed below), initially identified 133 technical documents in the literature review. A complete list of these 133 documents is provided in Appendix A. Information provided in Appendix A includes a synopsis of each technical document, riparian conditions discussed, geographic areas covered and habitat types addressed, and publication dates. The synopsis also details whether or not each document was professionally peer reviewed.

All 133 technical documents were reviewed and a subset of 31 documents was identified that provide information more specific to the geographic area and/or habitats and functions addressed in the analysis. The refined list of 31 technical documents is provided in Appendix B. Information provided in Appendix B includes a synopsis of each technical document, and the general applicability of the technical document to the riparian analysis.

Many of the 31 technical documents (Appendix B) referenced in the analysis provide similar technical information and data on the science of riparian functions. To avoid repetitiveness and long lists of citations within the text, only a small number of representative citations that address the whole relevant scientific literature reviewed are identified because many of the documents in Appendix B contain similar, applicable information.

3.4 Peer Review Panel

Three peer review panel members were selected to review and comment on the literature review information sources and findings summarized in this report.

Jock Conyngham works as a Research Ecologist with more than 25 years of experience and is currently employed in the U.S .Army Corps of Engineers Environmental Laboratory of the Engineer Research and Development Center (ERDC). Mr. Conyngham's projects include multi-scaled assessment, restoration, and monitoring of watersheds, streams and rivers, riparian zones, and aquatic communities. He has also provided technical leadership for restoration and research initiatives focused on fish passage, dam removal, large woody debris roles and utilization, and environmental benefits analysis. Prior to joining ERDC, Jock was Director of Watershed Assessment and Geomorphic Restoration for Trout Unlimited.

Duncan Patten is the Director of the Montana University System Water Center and Research Professor in Montana State University's Land Resources & Environmental Sciences department. With more than 51 years of experience, Dr. Patten's research group focuses on the dynamics of plant communities and ecosystems ranging attitudinally from desert to subalpine zones. To aid resource management decision making, the studies often focus on the response of systems to perturbations. The types of perturbations examined include recreation, fire, water diversion and withdrawals, and facility construction.

Robert Wissmar, with more than 39 years of experience, is a Professor in the School of Aquatic & Fishery Sciences at the University of Washington. Dr. Wissmar's research is focused on freshwater ecosystems, fish ecology, and trophic dynamics. His freshwater ecosystem studies examine land-water dynamics and functions, management and restoration

techniques, and responses of systems to regulatory policy and land use practice. His fish ecology studies examine forager behavior towards answering competition and community-level questions. His trophic dynamic research examines the processes influencing carbon and nutrient cycling in aquatic system food webs.

3.5 Use of Document

It is anticipated that the SMP literature review findings and methodology provided in this report will be an aid in establishing riparian buffer protection provisions in upcoming SMP updates for counties, cities and towns in the Columbia Basin Plateau. These local governments, in coordination with Ecology, can use the information as a guide in developing and applying riparian buffers and vegetation conservation measures tailored to site-specific conditions and environment designations included in their SMPs. The technical information in this document is organized in a framework generally consistent with the ecosystem processes and ecological functions described in Section 2.1.

4 GRANT COUNTY AND COLUMBIA BASIN PLATEAU REGION CONDITIONS

4.1 Geology

The geological history, topography and soils of the Columbia River Basin owe much of their existence to processes of plate tectonics and past volcanic and glacial events. In recent geological times (Plieitocene period [20,000 to about 2 million years before present (B.P.)]) unstable climate conditions, volcanic activity and glaciation caused significant changes in geological formations and surface geomorphic conditions (e.g., ice age). Volcanic periods in eastern Washington included eruptions of the Columbia Plateau about 13 to 16 million years B.P. that were followed by Cascade volcanoes (about 2 million years B.P.)(Mckee 1972).

Volcanic activity in the region relates to changes in the earth's lithosphere, the outer shell (about 60 miles deep) which covers the inner-hotter mantle. The lithosphere consists of a mosaic of plates that constantly move and collide with some sinking beneath each other. The primary plate boundary in Washington state occurs along the Pacific coast where the oceanic crust collides with the continental crust. The oceanic crust sinks causing basalt magma to form volcanoes and lava flows. Magma crystallizes to form granite and related igneous rocks (Alt and Hyndman 1984).

During the earlier Miocene period (13 - 16 million years B.P.) lava flows formed Columbia River Basalt (CRB). CRB bedrock in some places (e.g., plateaus) can be capped with varying thicknesses of wind-blown fine sands and silt known (loess deposits). CRB bedrock, formed by molten volcanic rock, can exhibit stratified layers with distinct contacts between each volcanic event. The cooling process of lava flows results in relatively dense but highly jointed rock that is subject to fracturing and erosion. Metamorphism of the CRB also contributed to its weakness and to the development of fold axes that later became preferential pathways for floodwaters. In some locations, such as plateaus, the CRB bed rock is covered by wind-blown deposits of fine sand and silt (e.g., loess). Loess deposits, formed before and during the ice age, contribute to the formation of rich Palouse soils.

Another important type of bedrock was formed during the Miocene/Pliocene/Eocene periods. Lacustrine sedimentary rock known as the Ringold Formation, was formed during

the earlier Eocene period (40 to 50 million years B.P.). Eocene-aged intrusive crystalline rocks are also present in the northern portion of Grant County (Grolier and Bingham 1978).

In recent geologic time, topographic and soil characteristics of eastern Washington relate to landscape changes during the ice age (10,000 to 40,000 years B.P.). Glacial activity induced flood events that occurred near the end of the last glacial period, approximately 18,000 to 20,000 years B.P. The major flood events are referred to as the "Missoula Floods." Much of the surface topography changed because of erosion of geological formations and deposition of sediments carried by the floodwaters. Glaciation and flood events created unique geomorphic features that influence the natural characteristics of present-day aquatic and riparian ecosystems.

The "Missoula Floods" were caused by the failure of ice-debris dams in mountain valleys of the Idaho Panhandle and western Montana. Glacial Lake Missoula (volume about 500 cubic miles) experienced repeated dam failures. These failures and the subsequent flooding were caused by increases in lake water volumes as well as floating ice. The most massive floods, erosion and out-wash deposits occurred approximately 16,000 years B.P. (Waitt 1983; Alt 2001).

During the "Missoula Floods," outburst floods from the rapid drainage of glacial Lake Missoula sent floodwaters through northern Idaho and eastern Washington. High-erosive flows were primarily focused on folds and joints in the bedrock. Today these eroded areas are characterized by steep-walled canyons and coulees. In Grant County, the Grand Coulee and the Crab Creek Valley were two of the major flow paths for the floodwaters and remain as major hydrologic features. The wide and flat, Quincy Basin, which is currently heavily developed for agriculture, is located at the outlet of these two constricted flow path. In this area the floodwaters spread out significantly and temporarily ponded, depositing large quantities of flood-carried sands and gravels; the surficial geology of the Wahluke Slope is similarly dominated by these outburst deposits (Easterbrook and Rahm 1970). Wind-driven fine material from these outburst flood deposits have more recently formed active sand dunes that are in some locations used for off-road vehicle recreation but are not well suited to agriculture or other uses. Several smaller-scale erosional features are present throughout the study area, such as complexes of lakes that were once scour pools of flooding channels; many

of these have eroded to bedrock at the surface. This unique topography lends itself well to the development of modern reservoirs and irrigation systems.

Additional prominent geologic features present include loess deposits atop high-relief areas that were not eroded in the Floods and talus and landslide deposits-associated uplift features such as the Beezley Hills and Saddle Mountains. Loess-dominated areas are typically the source of excellent soils and are dominated by agriculture, particularly wheat farming. Recent fluvial deposits (alluvium) deposited by post-glacial and modern-day streams are present in most of the major stream valleys. These deposits are typically comprised of sands and gravels.

4.2 Climate

The Columbia Basin Plateau area of Washington has the lowest precipitation rates within Washington State. The semi-arid climate of this region has average annual temperatures between 40 and 49 degrees Fahrenheit (4.5 to 9.5 degrees Celsius)(USACE 2008). Summers are dry with high temperatures usually in the lower 90s (32 degrees Celsius) and low temperatures in the upper 50s (10 degrees Celsius) (Western Regional Climactic Center 2012). High temperatures in January can range from 30 to 40 degrees Fahrenheit (1-4.5 degrees Celsius) with low temperatures between 15 to 25 degrees (-9.5-4 degrees Celsius). Average annual precipitation ranges between 6 and 20 inches and is commonly associated with winter rains and snowfall and periodic summer thunderstorms. Snowfall depths rarely exceed 8 to 15 inches and occur from December through February.

Riparian areas that occur within desert lowlands of eastern Washington can experience mean annual precipitation rates of less than 8 inches (Kovalchik 2001; National Water and Climate Center 2004). Low precipitation rates relate to rain-shadow effects of the Cascade Mountains that reduce influences of Pacific maritime weather patterns. Nevertheless, precipitation patterns are subject to influences of continental air masses that vary across interior regions.

Assessments of potential climate changes suggest that extremes in altered temperature, rainfall and snowfall patterns could alter riparian and aquatic ecosystem functions (NCADAC 2013; Edmonds et al. 2003; Wissmar et al. 2003. Consequences for inland PNW regions can

include shifts in the timing of runoff from snow pack that would reduce water availability and change plant species distributions. Climate changes in eastern Washington could reduce water available for agriculture and energy production and cause major economic problems.

Shifts in climate conditions have occurred through geologic time. For example, in eastern Washington after the recent ice-age, elevated temperatures and dry conditions occurred between 6.000 to 9,000 B.P. Model results, based on fossil mussel and pollen studies, suggest that in comparison to today's conditions, temperatures averaged 2 to 5 degrees Fahrenheit higher, average annual stream runoff was 30 percent lower and timberlines in the Cascade Mountains were 450 to 900 feet higher (Chatters et al. 1991).

4.3 Hydrology

In Grant County, the riparian corridors are associated with surface and subsurface water sources, including the Columbia River, its tributaries and springs. The characteristics of the riparian systems in the County vary with changes in the elevation of the surrounding landscape. Minimal increases in elevation of a few feet can influence the extent of the development of vegetated corridors. Riparian systems also develop near water sources in canals and seepages that are controlled by the Columbia Basin Project (e.g., springs feeding Rocky Ford Creek). The extents of riparian corridors are also influenced by hydrologic changes induced by Columbia Basin Project operations on the mainstem of the Columbia River. Changes in water levels are primarily controlled by operations of the Grand Coulee dam, and by the Grant County Public Utility District (PUD) on Wanapum and Priest Rapids dams. Water elevations that commonly fluctuate by several feet are also influenced by the steepness of adjacent terrain; this typically results in relatively narrow riparian corridors. In general, operations of hydro-facilities limit the development of floodplain and associated riparian habitats in comparison to "more-natural ecological systems" that commonly occur near unmanaged hydrological systems in semi-arid and arid areas of the United States.

4.4 Vegetation

Species compositions and distributions of plant communities of riparian areas in Grant County and the Columbia Basin vary widely because of influences of geomorphic, hydrologic and climatic factors. Steep walled canyons and coulees occur within the Columbia River and

Crab Creek valleys. The Quincy Basin, which is wide and flat contains past glacial outwash deposits, fluvial deposits of sands and gravels from major streams and rivers, and sand dunes in wind-blown areas. The semi-arid climate naturally limits the development of riparian vegetation within Grant County, but this condition has been affected by impacts from irrigation and hydroelectric projects on surface and groundwater availability.

The Columbia Basin Plateau and Grant County contain natural vegetation dominated by sagebrush, saltbrush, short grasses, and greasewood. Prairie species including perennial bunchgrasses were once common in southeastern Washington, however much of this area has been converted to agricultural uses (USACE 2008). Sedge and rush species can be common along streams and in wetlands. Cottonwoods and willows are present in areas where seed recruitment and plant vitality is supported, particularly in low gradient, wide alluvial valley systems such as the lower Yakima River. These woody species are vulnerable to altered hydrographs from damming and irrigation diversions. Hydraulic changes affect seedling recruitment through the lack of available cleared and wetted floodplain soils during spring seed dispersal periods (Bradley and Smith 1986, Scott et al. 1996, Mahoney and Rood 1998 as cited in Braatne et al., 2007). As well, dramatic river or lake level drops lead to young seedling mortality through the lack of available water to roots (Mahoney and Rood 1992, 1998 as cited in Braatne et al. 2007).

4.5 Fish and Wildlife

The fish community within Grant County supports more than 40 species, including individuals from 14 families of freshwater fishes. Among these species are both anadromous and resident fishes, including non-native species. Six anadromous fish species are known to occur in Grant County: spring, summer, and fall Chinook (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss*), sockeye salmon (O*. nerka*), Coho salmon (*O. kisutch*), and pacific lamprey (*Lampetra tridentata*). Lakes include trout, mountain whitefish, kokanee, burbot, and introduced fish species like bass and walleye.

There are approximately 304 mammal, bird, amphibian, and reptile species that can occur in Grant County. Of these species, 111 (36 percent) are closely associated with riparian and wetland habitat. About 74 species are predators that consume salmonids during some

portion of their lifecycle. Thirty-three species of wildlife are listed as federal or as state candidate, threatened, or endangered wildlife species and 43 species are managed as game in Washington state. Common terrestrial species include mule deer, jack rabbits, and, in select areas, Rocky mountain elk. Bald eagles, peregrine falcons, golden eagles, and prairie falcons are present along some shorelines and cliffs. Waterfowl and shorebird use of the riparian areas makes Grant County an important resource for bird watchers. Important avian species include dabbling ducks, diving ducks, Canadian geese, as well as rare birds including white pelican, sandhill crane, ring-necked pheasant, great blue heron, tundra swans, grebes, and long-billed curlew (Grant PUD 2010).

4.6 Example Conditions

To better describe the diverse riparian habitat conditions within the Columbia Basin Plateau, a number of river and stream condition typologies are described below. These typologies occur along elevational gradients and include:

- Rivers and stream habitats in upper elevations with higher precipitation rates and cooler water temperatures. Characteristics include diverse habitats of riparian and co-occurring stream channel, floodplain and wetland systems that can support reproductive and rearing habitats of listed (Endangered Species Act [ESA]) fish and wildlife species and numerous populations of large and small mammals and avian species. Where wide, un-constrained valleys and channel of the upland areas exist, the development of robust riparian plant and animal communities can occur. Examples of this type include higher elevations of river drainages in the Columbia Basin Plateau (e.g., upper Yakima, Walla Walla, and Tucannon Rivers). The WDFW Riparian Management recommendations (Knudson and Naef 1997) are more applicable for this typology.
- Rivers and streams in lower elevations with lower precipitation and warmer water temperatures. This type can support salmonid migration and rearing habitats though greater competition with warm-water species occurs than in the preceding type. There are variations in riparian vegetation complexity in terms of the amount and mix of herbaceous versus woody-dominated species. Variations also exist in terms of stream channel complexity, floodplain connectivity with surface/groundwater interaction, and the presence of associated wetlands. These variations may be due to

anthropogenic changes in land use, water management and development impacts and/or due to changes in hydrologic, sediment, and organic input regimes. Examples include the middle Columbia, lower Yakima, lower Snake and Walla Walla rivers, and Rocky Ford Creek. The WDFW Riparian Management recommendations may be less applicable for this typology; recommendations from this document can help address this deficiency.

Representative examples of the lower elevation, Columbia Basin Plateau riparian typology are described below. These include the Rocky Ford Creek, the lower Yakima River, and the Columbia River. These examples include water bodies with "natural habitats' that are dominated by: 1) herbaceous plant species with sparse pockets of woody vegetation; 2) wide floodplain segments that support cottonwood stands; 3) altered stream systems with wide channels and a mixture of grassland and woodland dominated areas; and 4) steep slope reservoir/river systems with sparse riparian vegetation.

Rocky Ford Creek – A stream 8 miles in length located in Grant County, Washington. The contributing drainage area is relatively small, approximately 12 square miles. Upstream inputs are sourced from a spring and regulated by the hatchery dam at the top of the creek. Rocky Ford Creek has an annual average flow of 73.7 cubic feet per second (cfs; USGS 2012)

Vegetation	**Geologic Conditions**	**Photos**
Vegetation within the Rocky Ford Creek is dominated by herbaceous species though some willow species (*Salix sp.)* are present. (Ecology 1998).	Low banks, few local bedrock controls; channel backwater pools from dams; wide, flat valley with valley slopes generally 10-20% up to 30%. Rocky Ford Creek occupies an alluvial valley. Flood deposits and Columbia River Basalts can also be found along the valley margins throughout its extent.	
Fish and Wildlife		
The creek has populations of largemouth and small mouth bass, walleye and rainbow trout. The creek supports high quality waterfowl habitat that support migratory and breeding populations of multiple species.		
Wetlands	**Floodplain and Channel Migration Zone (CMZ)**	
Contains approximately 70 acres of hydrologic-associated wetlands. These wetlands are dominantly palustrine emergent systems with some open water areas.	The upper portion of the creek is a highly confined series of ponded areas regulated by the hatchery operations. The lower is a meandering channel throughout with boulder-lined banks. Evidence of former channel positions or overbank flood pathways in the lower reach, some multi-threaded areas. Recruitment and transport of bedload sediment occurs more gradually in this reach due to flow regime (limited contributing drainage area and water management for hatchery operations).	

Yakima River		
Vegetation	**Geologic Conditions**	**Photos**
Black cottonwood (*Populus trichocarpa*) is the dominant plant species in lowland riparian areas. Other species include a variety of willow species (*Salix spp*.), red-osier dogwood (*Cornus servicea*), aspen (*Populus sp*.), water birch (*Betula occidentalis)*, and other species, including invasive species such as Russian-olive (*Elaeagnus angustifolia*).	The Yakima River is located in a wide alluvial valley where banks are comprised of alluvium with the occasional basalt bedrock outcroppings. The floodplain mostly consists of Holocene alluvium and alluvial derived soils which are generally highly erodible during high stream power events.	
Fish and Wildlife	**Floodplain and Channel Migration Zone (CMZ)**	
Several fish species populate the lower Yakima River. Salmonid fish include steelhead and spring and fall Chinook salmon. Bull trout may occur in low numbers. Lamprey are present but have experienced population decline in recent years. Resident fish include small- and largemouth bass, northern pikeminnow, sculpin, mountain whitefish, white sturgeon, catfish, sucker, walleye, rainbow trout, chiselmouth, dace, common carp, and various minnow species.	The river is characterized as a low-gradient, mostly single-thread channel which widens and becomes braided as it approaches the Columbia River. The CMZ is wide in places where the channel is not confined by infrastructure and where the floodplain is wide and made of erodible materials (alluvium and soils comprised of sand). The CMZ narrows where infrastructure (highways) limits the migration potential.	
Wetlands		
This area primarily provides productive floodplain and wetland habitat for small resident species of reptiles, amphibians, and small mammals, particularly those with lifecycle stages dependent on water.		

Lower Crab Creek – A 30 mile stream located between the mouth of the Columbia River to the eastern border of Grant County. Water quantity is largely dependent on Columbia Basin Project return flows and flows from the Drumheller Channels. The creek has a drainage area of 4,840 square miles and an annual average flow of 201 cfs (USGS 2012).

Vegetation	**Geology**	**Photos**
The riparian zone width ranges from tens of feet to several hundred feet on either side. Trees and shrubs flank the streambed and palustrine wetlands dominate. The adjacent upland is predominantly shrub/scrub, with agriculture. Rare plants are present in some areas (e.g., Hoover's desert parsley).	Valley soils have moderate to high liquefaction susceptibility with local areas of moderate to severe erosion risk. The Saddle Mountain fault and associated active folds and faults border the Lower Crab Creek valley to the south.	
Fish and Wildlife	**Floodplain and Channel Migration Zone (CMZ)**	
Lower Crab Creek provides habitat for anadromous fall Chinook and summer steelhead as well as bass, walleye, and brown and rainbow trout.	Channel migration potential is high due to the low gradient and the less-developed nature of the surrounding area. The basin has a history of channel migration visible north of the existing channel.	
Wetlands		
There are approximately 3,000 acres of wetlands present (NWI), primarily palustrine emergent with some riparian forested present in small patches.		

Columbia River - The Columbia River from Crescent Bar on the Wanapum Reservoir, downstream past the Priest Rapids Hydroelectric Project to White Bluffs along the Hanford Reach National Monument, forms the western and southern boundaries of Grant County. The entirety of the Columbia River within this segment is impounded (Priest Rapids Dam at RM 397.5 and the Wanapum Dam at RM 415.5) with the exception of that portion downstream of Priest Rapids Dam, called the Hanford Reach.

Vegetation	**Geology / Slopes**	**Photos**
The riparian zone is naturally sparse here due to the climate and steep cliff walls and, where it exists, it consists of scattered trees of black cottonwood and yellow and sandbar willow. Riparian habitat forming processes are dominated by pool-level management at upstream dams effectively limits the extent and diversity of riparian vegetation.	Large outburst flood gravel deposits and some river alluvium form shorelines and create islands within portions of the river, steep exposed basalt cliffs are also prevalent throughout. Sediment input and transport are impacted by dams.	
Fish and Wildlife	**Floodplain**	
Dolly varden/bull trout, rainbow trout, and summer steelhead rear or spawn in the river. Anadromous fish include fall, spring, and summer Chinook, coho, sockeye, and summer steelhead, fall Chinook and summer steelhead. Mule deer, elk, bighorn sheep, peregrine and prairie falcons, golden and bald eagle, Caspian terns, sagebrush lizard and vole, and several snake species are present.	Floodplain functions are highly impacted by the regulated pool elevation; the area available for floodplain storage is limited to the narrow wetland areas along the island margins. Within the Hanford Reach, which is the last undammed portion of the Columbia, several islands and more complete channel form exists.	
Wetlands		
Wetlands are primarily palustrine emergent, but also including scrub-shrub and forested areas (NWI).		

5 RIPARIAN ECOLOGICAL FUNCTIONS IN THE SEMI-ARID ENVIRONMENT

5.1 Overview

Riparian ecosystems in semi-arid regions appear as dense vegetative patches and corridors in a landscape otherwise dominated by shrub-steppe communities (a "ribbon of green"). In climates that provide no more than 7 to 14 inches of annual precipitation, mesic plant communities only develop near water sources and wet soils. "Riparian systems are therefore uncommon ecosystems in semi-arid regions, making up less than 1 to 3 percent of the landscape, but are linked hydrologically to the rest of the landscape" (Naiman and Decamps 1997 as cited in Patten 1998).

Different types of riparian conditions that exist in the typical semi-arid setting, including aquatic habitat, riparian vegetation and moist soils/wetlands, and upland areas of influence (Figure 2). The width of the riparian vegetation community can vary from a few feet to a few hundred feet (when associated wetlands also exist). In areas without wetlands, where subsurface water or wet soils are limited, the riparian vegetation typically does not extend more than 20 feet from the ordinary high water mark of the associated waterbody. Exceptions occur where an upland irrigation source provides surface runoff or shallow ground water return to supplement the stream hydrology and when topography is extremely flat and hyporheic (e.g. subsurface) flows extend laterally from the stream maintaining the alluvial aquifer which the riparian vegetation depend on.

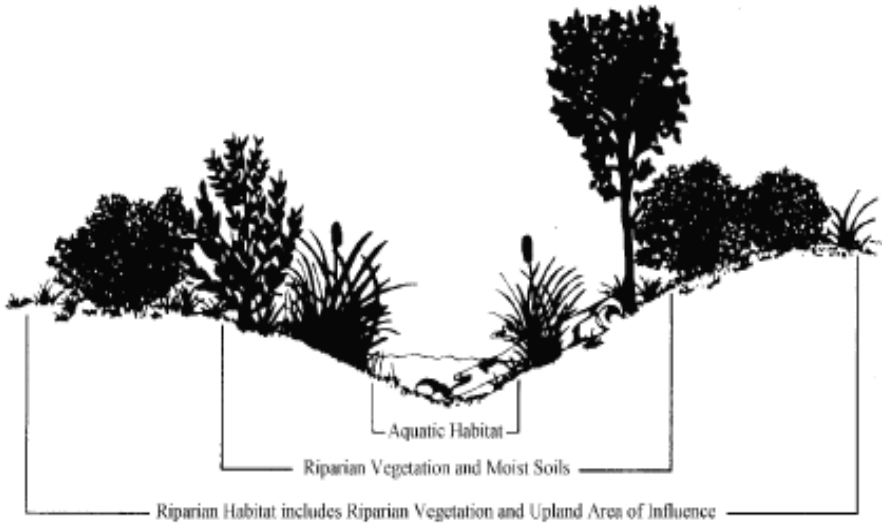


Figure 2
Typical Semi-arid Stream and Riparian Vegatation Zones
(Knudson and Naef 1997)

Large drainages such as the Colorado, Missouri, and Columbia River systems cover most of the arid west. These river drainages include a wide variety of topographic environments such as high-to-low elevations, north-south and east-west gradients, and steep–to-shallow terrain. Riparian ecosystems of the arid west can be associated with alluvial sediment deposits and where surface and subsurface water sources are available (Gregory et al. 1991 as cited in Patten 1998). These conditions apply in general to most semi-arid geographic areas.

5.2 Functions that Riparian Areas Provide

Riparian areas provide a number of functions that benefit ecosystems; these benefits also extend to people that are an inextricable part of ecosystems within the Columbia Basin Plateau. This section will focus on the ecological functions of riparian areas; however a brief discussion of the social values of this habitat type is first presented.

5.3 Social Functions

The social value of riparian areas is tied to many ecological functions as these ecological functions benefit resources that are valued by people. For example, the benefits to salmon and other economically and recreationally important species can also have a social benefit;

and in the case of anadromous fish this direct social benefit can extend far outside of the Columbia Basin region. Water quality ecological functions also provide a health benefit for people who use water resources, or consume species from these aquatic environments.

Past these tied social-ecological functions, described in more detail in the following section, there are functions of riparian areas that more directly benefit shoreline residents. The control of excessive shoreline erosion and thus property loss is one important function of riparian areas. Riparian root systems bind soil within their overlapping network. Portions of vegetation exposed to water slow the water flow and reduce the erosive energy within the localized area. Slowing the water also allows transported sediment to be deposited in these areas further protecting the bank. Riparian areas can also provide a buffer against bank disturbance by water-transported material such as floating debris, or recreation vessels (Klingeman and Bradley 1976 as cited in Hoag and Fripp 2005). The localized slowing of water differs in soft (vegetative) versus hard (rock riprap, concrete) in that hard bank protection can increase wave reflectance, which in turn can increase shoreline erosion at the toe of hard bulkhead structures sometimes leading to the failure of these structures. This phenomenon combined with the cut-off of fine sediments behind bulkheads can lead to increased maintenance needs including nourishment of water access beaches in particular. Also related to property protection, riparian areas can serve as fire barriers. In both eastern Idaho and northern California the time interval in between fire events was shown to be longer in riparian forests than in upland forest stands (Barrett 1988; Skinner 2001 as cited in Dwire and Kauffman, 2003). Some aspects of riparian areas that can contribute to fire suppression include the riparian microclimate of generally cooler air and higher humidity (Brosofske et al. 1997 and Danehy and Kirpes 2000 as cited in Dwire and Kauffman 2003); the higher moisture content of fuel, fuel types (including ratio of live to dead material), and deeper and higher moisture content soils, (Dwire and Kauffman 2003).

Finally riparian areas can also benefit the value of a property based on their aesthetic properties. Taller and/or more mature riparian trees, where found can frame water views attractively and provide privacy in areas where water recreation is common. Auditory aesthetic benefits include noise dampening of boat engines by dense vegetation, and bird songs through the habitat provisions provided by these buffers.

5.4 Ecological Functions

This section provides a summary of ecological functions provided by riparian habitat in the semi-arid areas of western North America. Functions described include habitat corridors-connectivity, shade and cover, erosion control, water quality including water temperature, nutrient cycling and organic inputs and accumulations. Specific elements of each of these functions are also described. While each riparian function is described independently, each function can co-occur within a habitat. This information is consistent with functions considered during SMP development or update processes. The WAC specifies consideration of the following functions in preparing or amending SMPs for rivers and streams, and associated flood plains:

- *Hydrologic: Transport of water and sediment across the natural range of flow variability; attenuating flow energy; developing pools, riffles, gravel bars, nutrient flux, recruitment and transport of large woody debris and other organic material.*
- *Shoreline vegetation: Maintaining temperature; removing excessive nutrients and toxic compounds, sediment removal and stabilization; attenuation of high stream flow energy; and provision of woody debris and other organic matter*
- *Hyporheic functions: Removing excessive nutrients and toxic compounds, water storage, support of vegetation, and sediment storage and maintenance of base flows.*
- *Habitat for native aquatic and shoreline-dependent birds, invertebrates, mammals; amphibians; and anadromous and resident native fish: Habitat functions may include, but are not limited to, space or conditions for reproduction; resting, hiding and migration; and food production and delivery. (WAC 173-26-201 (3)(d)(i)(C)*

With the focus of this document being on the functions provided by riparian areas, instream-related hydrologic and hyporheic functions are addressed in a more general manner.

5.4.1 Fish and Wildlife Habitat

Natural aquatic habitats and corridors of associated riparian vegetation commonly develop along elevation contours and gradients adjacent to hydrologic sources and aquatic ecosystems. Stream channels and associated riparian vegetation of watersheds usually develop dendritic drainage patterns that join downstream to form larger channels and riparian corridors (Forman and Gordon 1986). In the Columbia Basin Plateau region,

drainage patterns can be determined by geomorphic erosional and depositional formations caused by the "Missoula Floods" of the last ice age period (15,000 and 13,000 years B.P.)

Habitat corridors within riparian areas include both terrestrial and aquatic environments. They support the migration, feeding, reproduction and other key functions for a range of aquatic, terrestrial and amphibious species. The unique characteristics of riparian vegetation communities commonly support a much greater density and diversity of plant and animal species than the surrounding uplands.

5.4.1.1 Terrestrial

Riparian vegetation communities along streams commonly provide connectivity between habitats of downstream and upstream channels floodplains and upland areas (Biohabitats Inc. 2007). In semi-arid regions, riparian vegetation communities serve as refugia and migration corridors for many western wildlife species (Patten 1998). These habitats in arid regions make up less than 1 percent of the land area but account for 70 percent of the wildlife species (Fry 1994, Belsky 1999, CRA 2002 as cited in Buffler et al. 2005). Riparian habitats are important to many animal species, which use these areas for some or all of their life stages and provide function in terms of feeding, migration, and reproduction (Brinson et al. 1984; Kondolf et al. 1996, Patten 1998, Pollock and Kennard 1998 as cited in Wall 2011). Different groups of animals occupy or use the different habitat types and patches of vegetation within riparian corridors of arid landscapes (Anderson et al. 1983 and Hunter et al. 1987 as cited in Patten 1998). In particular, riparian systems are often the only available moist-habitat in the landscape for many amphibians and invertebrates (Patten 1998). Deciduous shrub lands and forests found within semi-arid riparian landscapes are particularly vital for many bird species (Biohabitats, Inc. 2007).

Vegetation in arid and semi-arid regions tends to be unique in comparison to other regions of the U.S. These areas have stronger changes in character between riparian and upland zones (Malanson 1993 as cited in Buffler 2005). Non-riparian plant density in these regions is lower due to the lack of rainfall. Shallow and coarse soils are common and the lack of soil moisture content can only support sparse vegetation and drought tolerant species (Mee et al. 2003 as cited in Buffler 2005). Biomass production in riparian areas tends to be lower in arid

regions than is present in mesic regions (Malanson 1993, Stromberg 2001 as cited in Buffler 2005). Plant species diversity tends to be lower in the riparian vegetation communities associated with intermittent and ephemeral stream systems than in those associated with perennial stream channels in arid regions. This leads to low plant resilience with reduced groundwater (Buffler 2005) or when summer rains from thundershowers are too scarce to support typical levels of biomass production and cover (Malanson 1993, Stromberg 2001 as cited in Buffler 2005). In areas where regional irrigation system development exists, riparian vegetation and habitat can be more plentiful because greater water is available near water courses and from upland sources. This greater water availability also affects vegetation community characteristics including invasive species spread. Management of stream and river hydrology for irrigation and other activities includes the diversion of water from stream systems with canals, ditches, pipes, groundwater withdrawals, etc. Manipulating hydrology can significantly influence riparian habitats and the terrestrial plant and wildlife species that occupy them. Overall, the availability of water in the semi-arid west environment is typically a major limiting factor for the diversity and abundance of terrestrial plant and wildlife species within riparian habitats.

5.4.1.2 Aquatic

Riparian vegetation communities are the primary source of organic material and woody debris for food webs, habitat structures, and the maintenance of stream-bank morphology in many fluvial ecosystems (Suberkropp 1998; Bilby and Bisson 1998 as cited in Wall 2011).

Plant canopies shade the aquatic environment which regulates stream water temperatures. The roots of riparian vegetation stabilize shoreline soils and can hold overhanging banks creating habitat for fish and other aquatic organisms (Patten 1998) as well as denning opportunities of burrowing mammals. The protection of both aquatic and terrestrial areas are important for fish habitat, studies note that floodplain pools are critical habitat providing refuge from natural disturbances and rearing areas for juvenile fish (McIntosh et al. 1994).

Variations in nutrient and energy inputs caused by variations in the density and area of riparian vegetation may affect benthic invertebrate and stream fish abundance and distribution (Tschaplinski and Hartman 1983 as cited in Tait et al. 1994). Tait et al. (1994)

demonstrated that the loss of shaded aquatic sites on the John Day River in eastern Oregon affected local algal characteristics leading to a greater abundance of dicosomoecus larvae over other insect species; these insects are a lower quality forage resource for cold water fish species. Leaves and twigs from woody species also, provide energy for aquatic food webs. Leaves and associated detritus in streams are usually colonized by algae and microscopic organisms, and invertebrates such as caddis fly larvae. These invertebrates are the primary food source for many native fish species in the Columbia Basin Plateau region. Aquatic insect species that forage on riparian vegetation detritus have reduced growth when riparian vegetation is lost (Johnson et al. 2003 as cited in Biohabitats, Inc. 2007).

Tree and shrub vegetation adjacent to the shoreline and overhanging stream banks is necessary for optimally functioning aquatic habitat. Functional quality provided by herbaceous riparian habitat with no tree or shrub canopy generally provides less function in terms of food web support, thermal regulation, and soil stabilization. Riparian habitat in the semi-arid west can have limited or no tree or shrub vegetation due to both land use activities, natural environmental conditions, or both (see Photo 1).

Photo 1

Lower Sand Hollow Creek in Grant County, Washington

5.4.2 Shade and Cover

Shade and cover are provided by riparian vegetation communities. These functions help regulate temperature of waters that are subject to solar warming and nitrification due to agricultural runoff. Riparian vegetation communities provide shaded areas and overhanging bank habitats that create habitat refugia and migratory corridors for a variety of aquatic and wildlife species. The height and density of the riparian vegetation as well as its proximity to the water can determine the effectiveness of the vegetation to both regulate water temperature and provide cover.

5.4.2.1 Temperature

Riparian vegetation has an important role in the food web system of streams (Cummins et al. 1989 as cited in Tait et al. 1994). Where it exists, overhanging vegetation can filter and

absorb incident radiation, this affects periphyton primary productivity and, improves water temperatures (Lyford and Gregory 1975, Towns 1981, Bott 1983 as cited in Tait et al. 1998).

Riparian areas with tree cover are most efficient in reducing solar heating of stream water by shading, especially in low order streams (Brown and Krygier 1970 as cited in Tabacchi et al. 1994). Riparian vegetation also provides cooling through evapotranspiration (Beschta 1984, Theuer et al. 1984, Sinokrot and Stefan 1993 as cited in Tabacchi et al. 1998). Stream temperature can also be moderated by cool groundwater upwellings from deep phreatic sources and from hyporheic zones near stream margins (Stanford et al. 1994 as cited in Tabacchi et al. 1998).

Similar to habitat corridor functions, tree and shrub vegetation canopies adjacent to the shoreline and overhanging the stream banks are required for optimal temperature function. As tree and shrub density decreases near the shoreline the function also decreases. In semi-arid west environments, tree and shrub vegetation is often limited not only through land use activity but also because of natural conditions such as streams in steep sloped ravines and valley systems which typically have limited tree cover. Riparian habitats can also include shrub vegetation with little or no tree cover. Shrub communities in semi-arid riparian habitats typically do not provide the height, density, and overhanging vegetation characteristics that shrub species in wetter environments provide and therefore provide a lesser temperature regulation function than in wetter environments (see Photo 2). Herbaceous riparian vegetation provides little or no temperature functional value (see Photo 1), except in low-order, low-energy systems that support reed beds and/or forb dominated vegetation.

Photo 2

Riparian Area along the Columbia River in Grant County, Washington

Stream water temperatures are also influenced by direct runoff from nearby impervious surfaces such as roads. These thermal impacts can be mitigated by directing the surface runoff to vegetated riparian areas and allowing warm water to infiltrate and be retained in nearby shallow groundwater areas (Biohabitats, Inc. 2007).

5.4.2.2 Erosion Control

Riparian vegetation communities act to control erosion in semi-arid environments. The three primary mechanisms of erosion include: scour associated with high stream flows, high winds acting on very dry, friable soils, and soil loss associated with runoff or sheetflow during infrequent intense rain events. The ability of the riparian root zone to perform erosion control functions is also typically linked to the presence and density of trees and shrubs within the riparian zone, though herbaceous species with deep roots also provide this function. In addition to erosion control, riparian areas can become important sediment deposition areas (Sharpe and Sheridan 1986).

5.4.2.3 High Flow Scour

Vegetated riparian areas stabilize soils of stream banks and floodplain and reduce erosion (Patten 1998). Vegetated stream banks help protect infrastructure and reduce siltation. Strong, thick roots of trees and/or shrubs growing along the edge of a stream channel greatly increases the stability of the stream banks and exposed vegetation stalks, roots, and branches can effectively dampen energy in stream water, slow water velocities, and promote infiltration. Plant roots increase the effective size and cohesiveness of soil particles, thereby protecting soil in stream banks from the erosive forces of water and reducing the amounts of stream bank erosion (Biohabitats, Inc. 2007).

Where shoreline erosion occurs, wildlife habitat can be destroyed. In addition, as the energy of the water in a stream diminishes following a storm, eroded materials are deposited in the stream channel. These depositional areas can cause channel widening, reduce flood storage capacity, block fish movement, and smother aquatic habitats (Biohabitats, Inc. 2007). With that said, shoreline erosion that occurs naturally can benefit habitats through the introduction of beneficial sediment. The maintenance of shallow water habitat along lakes, rivers, and streams is driven by the recruitment and transport of appropriately-sized small, clean natural substrates (e.g., sand and pebbles). These shallow areas are important for benthic production and as refuge for juvenile fish (Anchor QEA 2012).

5.4.2.4 Wind

Loess soils of the region are of aeolian (wind-blown) origin and are subject to wind transport. Wind erosion is a common feature of semi-arid west environments due to existing land use activities such as agriculture and grazing. These activities can promote wind erosion due to the manipulation and disturbances of topsoil and vegetation. Vegetated land cover is Important in reducing wind erosion and thus dust storms that contribute to air quality problems in semi-arid portions of Washington state. Dust storms often occur in the spring and fall and are believed to be partially caused by catastrophic wind erosion of fallow farmlands present during these seasons. Factors that affect wind erosion include wind velocity, soil moisture and type, and vegetative cover. Within Benton and Franklin counties of Washington, intact shrub–steppe areas have an annual erosion rate between one half and

one ton of sediment per acre, while agricultural areas have an erosion rate of 10 to 15 tons per acre (Holmes 1994 as cited in Scott et al. 1998).

5.4.2.5 Runoff

Riparian vegetated areas trap and remove sediment associated with runoff from adjacent or nearby development and land use activities (Horowitz 2009). Riparian areas can play a critical role in reducing non-point source pollution by intercepting surface runoff. Riparian buffers improve water quality by processing, removing, transforming, and storing potential pollutants such as sediment, nitrogen, phosphorus, and various dissolved heavy metals (Ecology 1996 as cited in USEPA 2005). Riparian areas also help control the release of herbicides into surface waters and reduce the effect of pollutants within receiving waters. The degradation of riparian areas can decrease their ability to reduce non-point source pollution. Degraded riparian areas can also become sources of non-point source pollution, as denuded vegetation along a river bank increase sediment inputs to water bodies (USEPA 2005).

Hydrologic connectivity is the primary factor controlling the effectiveness of riparian buffer-functions (Gilliam et al. 1997 as cited in Buffler 2005). The occurrence of steep slopes and other topographic features within riparian areas can increase surface runoff and reduce infiltration to soils (Buffler 2005).

5.4.3 Water Quality

Riparian vegetation communities and soils can improve water quality through the uptake and retention of nutrients and the sequestration of certain toxins (Patten 1998). Accumulation of organic matter produced by riparian plants also releases nutrients that allow primary production in streams and other aquatic ecosystems (Tabacchi et al. 1998).

5.4.3.1 Nutrient and Toxin Uptake

Riparian vegetation buffers trap and remove sediment and dissolved phosphorus, nitrogen, and other nutrients. Both particulate and dissolved matter can be retained by growing riparian vegetation and decomposing organic detritus. These biological processes reduce the potential for eutrophication (Horowitz 2009).

Riparian vegetation allows for suspended sediment removal, along with dissolved nutrients from surface runoff of stormwater (Peterjohn and Correll 1986, Chescheir et al. 1991, Klarer and Millie 1989, Lowrance et al. 1986, Mitsch et al. 1979, Parsons et al. 1994; as cited in Tabacchi et al. 1998) and flood waters entering (Brunet et al. 1994, Hart et al. 1987, Hupp and Morris 1990, Hupp et al. 1993, Johnston 1993, Kleiss et al. 1989; as cited in Tabacchi et al. 1998). Riparian vegetation facilitates the removal or storage of particulates. Increased friction with the soil surfaces can reduce water flow velocity and increase sedimentation of particulates. Riparian vegetation and organic detrital layers on the soil surfaces and bottom sediments are also very effective in slowing the velocity of the surface waters. The roots of the plants, which are on or near the surface, and the microbial communities on surfaces of soil, organic litter, and above ground vegetation can also assimilate dissolved nutrients from surface waters (Peterjohn and Correll 1986 as cited in Tabacchi et al. 1998).

In agricultural areas, dissolved phosphorus can be attached and exported in suspended sediments. Several studies have demonstrated the effectiveness of the riparian zones in controlling phosphorus inputs from agricultural lands to the aquatic systems (Omernik et al. 1981, Peterjohn and Correll 1984, Cooper and Gilliam 1987, as cited in Tabacchi et al. 1998) and produced equivocal results. Therefore, depending on the soil texture and the form of phosphorus, riparian forest soils can be considered "either as a source or a sink of phosphorus" (Fabre et al. 1996 as cited in Tabacchi et al. 1998).

Within the hyporheic zone riparian vegetation roots reduce subsurface pollution, particularly nitrogen (Peterjohn and Correll 1986 as cited in Tabacchi et al. 1998). Nitrogen buffering in the riparian zone occurs through plant uptake and microbial denitrification. This buffering is most effective where the surface contact between riparian wetland and the adjacent agricultural land is maximized along low order streams (Haycock et al. 1993, Brinson 1990 as cited in Tabacchi et al. 1998). However, this function of regulating subsurface nitrogen is often limited by a riparian zone's geomorphic character, which determine the groundwater flow path and thus influences transported nitrate availability. Thus the efficiency of the attenuation of nitrogen or other pollutants is dependent not only on the area of riparian vegetation but also on the area of length of hydrologic contact with vegetation in riparian areas. (Tabacchi et al. 1998).

In addition to their nutrient uptake properties, riparian areas also serve to reduce toxin inputs into aquatic environments. Since the character of vegetation corridors (width, density, type of vegetation) directly influence the amount of soil and sediment lost to the river this also influences the rate of immobilization of fertilizers, pesticides, and spilled contaminants found on the surface and subsurface of soils (Patten 1998).

5.4.4 Organic Input

Riparian vegetation communities are the primary source of organic inputs in most streams and lakes in semi-arid regions. The mesic nature and higher biomass of the riparian community combined with the proximity to the water bodies makes it a crucial source of organic matter. These organic inputs provide the basis of the aquatic food web as well as structural components of the aquatic ecosystem.

5.4.4.1 Nutrients

Riparian trees and other vegetation provide inputs of detrital particulate matter (e.g., leaves, pollen grains and terrestrial insects) to aquatic ecosystems. These organic materials comprise major sources of nutrients and energy source for food webs that sustain production of various consumers like fish and beaver (Tait et al. 1994).

Litterfall including fallen woody debris can form debris dams that retain organic matter and sediment beneficial for habitat and/or as nutrients for aquatic species (Benke et al. 1985, Gregory et al. 1991, Prochazka et al. 1991 Speaker et al. 1984, Bisson et al. 1987 as cited in Tait et al. 1994). The limited water sources in semi-arid environments for tree and shrub vegetation in riparian habitats reduces the biomass of nutrients through organic input compared to riparian habitats in wetter climates.

5.4.4.2 LWD and Organic Inputs

Large woody debris (LWD) that falls across a stream channel can create small dams that help prevent channel down cutting , retain nutrients, charge groundwater, dissipate energy, alter any ice regime, induce plant colonization, and provide and form habitats like large pools (Wohl 2001, Naiman et al. 2005 as cited in Biohabitats, Inc. 2007).

In semi-arid west environments, large woody vegetation can be rare and its presence decreases rapidly with increasing distance of the stream channel from flow patterns of the water table (Malanson 1993 as cited in Buffler 2005). The potential size of large wood recruited into streams east of the Cascade Divide is generally less than the size of these features on the west side of the region. The larger average size and density on the west side is due to higher moisture availability , greater plant productivity and ample sources for LWD recruitment (Kershner and Roper 2010). Typical large wood sources in larger river systems on the east side of the Cascades include cottonwood, alder and willow species (see Photo 3), with conifers present in higher elevation systems .

Photo 3

Cottonwood and Willows Riparian Area in the Lower Yakima River

6 DEVELOPMENT AND MANAGEMENT IMPACTS TO RIPARIAN ECOLOGICAL FUNCTIONS

A variety of human activities affect the ability of riparian habitats to provide the functions discussed above. The lateral extent in which these riparian functions occur is naturally controlled by groundwater elevation, topography, soils, climate, microclimate, and other environmental controls. The lateral and longitudinal extent is further influenced by water management practices, particularly storage, diversion and irrigation of agricultural areas. Flood control and hydropower projects, water withdrawals, recreation, and other navigation impacts, can modify natural flows and flooding regimes thus producing substantial alterations to the riparian zone (Fischer and Martin 1998).

Riparian habitats in the semi-arid west are also influenced by surrounding land uses, including agriculture, livestock grazing, timber harvest, industry, transportation infrastructure, and urbanization. These land use changes can have detrimental effects on riparian and aquatic habitats (Fischer and Martin 1998) (see Photo 4).

Piece-meal, unregulated development within riparian areas can lead to long-term degradation of water quality, wildlife and fish habitat, and recreation resources; this in turn can eliminate many economic benefits associated with these resources (Fischer and Martin 1998). Riparian buffers in arid and semi-arid regions are more fragile than those found in more moderate climate regions. This is due to the more limited area they take up, the hydrologic limits and features such as more erodible soils (Levick et al. 2008). The following sections describe specific development features that impact riparian habitat in semi-arid west environments.

Photo 4

Tilled Field with Associated Drainage Ditch

6.1 Irrigated Agriculture

Traditionally, irrigation for agriculture consumes the greatest amount of water in the West (Patten 1998). In arid and semi-arid environments, most agriculture crops must be irrigated due to the low annual rainfall. Irrigation activities can lead to reduced stream flows from groundwater pumping or stream diversions (Levick et al. 2008).

In some areas of the Columbia Basin Plateau where irrigation development projects exist, irrigation has altered flows, in most rivers and streams increasing flows in late spring and early summer. Irrigation projects have also increased the number of lakes for water storage, and increased groundwater returns; all of these alterations alter the width of riparian areas and the number and size of associated wetlands (Anchor QEA 2012).

In semi-arid and arid areas without irrigation system-altered hydrology, the lack of surface water flows can place increased reliance on groundwater pumping for agricultural irrigation. Pumping can lower groundwater levels, impacting riparian vegetation that can no longer reach the aquifer with their roots (Stromberg et al. 1996 as cited in Levick et al. 2008). The loss of riparian vegetation from this impact affects bank stability as plant roots desiccate and can no longer reinforce the soils (Groeneveld and Griepentrog 1985 as cited in Levick et al. 2008).

Alterations, including increased water availability where irrigation development projects exist, or reduced groundwater levels from ground water pumping, can result in changes in riparian vegetation, including an increase in the invasion of exotic species. These alterations to riparian areas can negatively affect human and wildlife use of these areas (Levick et al. 2008).

6.2 Residential Development

Residential development can impact riparian and associated upland areas through the replacement of existing riparian vegetation communities with ornamental non-native vegetation, and water demand for landscape irrigation. Additional impacts occur through the replacement of vegetation with nonvegetated land covers such as pavement or hardscapes, the introduction of exotic species including invasive plants, predatory animals (e.g., domestic dogs and cats) and pests such as exotic, herbivorous insects.

6.3 Pavement

Stream systems are impaired by the introduction of impervious surfaces within the watershed. Irreparable impairment begins when the impervious land cover of a watershed exceeds 10 percent with dramatic changes to aquatic systems occuring when this ratio exceeds 20 percent (Coleman et al. 2005, Miltner et al. 2003, Schueler 1994 as cited in Levick et al. 2008). Impervious surface reduces the percolation of precipitation into the ground, and concentrates pollutants into stormwater discharge areas. Reduced water infiltration increases the amount and rate of surface water runoff causing high stream discharge or high direct delivery of water to the stream and lake shorelines (Dunne and Leopold 1978; Arnold

and Gibbons 1996; Poff et al. 1997). Shoreline and bank erosion can result from stormwater discharges where higher flow velocities may periodically collect from impervious surfaces.

6.4 Structures and Roads

Erosion and sedimentation can occur through development, including road-building. These changes to the uplands can alter base flow and precipitation-runoff relationships, resulting in erosion and sedimentation into the streams, leading to increased downstream sediment loads. (USDA 2002 as cited in Levick et al. 2008).

Water-quality impacts from development, including nonpoint source pollution are considered to be the single largest water quality threat in the United States (University of Connecticut 1999 as cited in Levick et al. 2008). Human-induced changes to water quality (e.g., industrial effluents, sewer overflows, and runoff from upland areas) can alter river and lake water temperatures, turbidity, and oxygen content, as well as nutrient, toxin, sediment, and pathogen concentrations (Karr 1995; Welch and Lindell 2000). In general, these changes can affect the presence, abundance, and vitality of all aquatic organisms.

Development of houses and roads can fragment habitat and impact drainage systems; this development also creates extensive impervious areas which reduce infiltration. Changing stream systems through fragmentation and channelization disrupts riparian areas and hydrologic functions important for sensitive aquatic and terrestrial species. (University of Connecticut 1999 as cited in Levick et al. 2008).

Land use related habitat changes have been tied to changes in the physical, chemical, biological and process-related features of stream systems, which impact the habitats, thermal regimes, organic inputs, and abundance and diversity of periphyton, macrophytes, macroinvertebrates, fish and bird communities, including declines in Pacific salmon and steelhead populations (Allan 2004, Beschta 1997 as cited in Fullerton et al. 2006).

6.5 Bank Stabilization and Steep Slopes

Development along shorelines is often accompanied by bank armor or other measures to stabilize slopes along the bank. These measures typically involve the removal of any existing

vegetation and also preclude the establishment of new vegetation. While bank stabilization techniques that utilize native vegetation (including willows) do exist, they are not typically the lowest cost alternative and are not compatible with all shoreline uses. In certain cases rock armor or rip-rap is used to provide a non-vegetated, stable bank. This eliminates most of the functions of a riparian vegetation community other than bank stabilization.

6.6 Lawns

Lawns are a common component of the residential landscape in most developed landscapes in the region. Due to the semi-arid climate, lawns require a significant amount of irrigation and fertilization, as well as pest and weed control. The result is that lawns near water bodies are often a source of nutrient loads, pesticides and herbicides.

6.7 Clearing for Views

Development along the shoreline is often intended to provide views from buildings with landscaping to the water edge. Riparian vegetation communities are often pruned or removed entirely in order to maximize these views. When removed they are often replaced by non-native species or hardscapes that do not support many or all the functions provided by a riparian buffer composed of native vegetation.

6.8 Recreation

Studies of bird habitat within wash systems have shown heavy recreational use and in turn degradation of habitat and impacts to wildlife (England and Laudenslayer 1995 as cited in Levick et al. 2008). Motorized recreation in particular can have major impacts on riparian areas. Off-road vehicles utilize areas during low flow periods, trampling vegetation, and compacting soils. Periodic recreation in these areas can have limited impacts with systems rebounding in between disturbances, but repeated recreation use can have long-term, irreparable impacts (Patten 1998).

Some streams in the Columbia Basin Plateau region such as Rocky Ford Creek are highly used recreational fisheries. Disturbances to riparian habitats occur as a result of recreational fishing. Pedestrian or vehicle access to streams creates heavily used trails and unpaved roads to streams, often on both stream banks, cause soil compaction, vegetation disturbance, and

introduction and spread of non-native plants. Trails through the riparian vegetation and trampling of the shoreline areas can inhibit the health of a riparian vegetation community.

6.9 Mowing/ Clearing

Increased salinity can be caused by clearing of native vegetation which increases soil leaching and raises the groundwater reservoir (Levick et al. 2008). Tree and shrub removal in riparian areas can lead to increased soil erosion and more rapid water runoff (Sidle et al. 1985, Swanson et. al 1987 as cited in Patten 1998). Clearing within the watershed leads to larger flood flows, which are flashier and more sediment-laden. Percolation of precipitation into the ground is reduced which in turn lowers base flows that sustain riparian vegetation during the dry season. Loss of vegetation also diminishes health of habitat areas, affecting the ability of the riparian areas to sustain wildlife (Patten 1998).

6.10 Grazing

Livestock grazing is one of the more common uses of rural land in the west. Grazing can occur within private, state and federal lands, and often watering is only provided through natural sources (streams, rivers, ponds). Due to the scarcity of watering areas, livestock can overuse streamside and riparian areas, leading to the trampling and eating of vegetation, compaction of soils, and contamination through waste and sedimentation. Non-native and sometimes invasive species can be introduced through livestock management that involves the importation of hay or feed brought in from outside areas. These species may out-compete native species, leading to the degradation of natural ecosystem functions (Pima County 2000 as cited in Levick et al. 2008, Kershner and Roper 2010).

Studies on grazing impacts on ephemeral streams in Wyoming found that seasonal grazing had an impact on channel morphology. The greatest affects including increases in the width of the channel cross section occurred during summer and fall grazing. (Levick et al. 2008). Grazing during the spring has the greatest impact on riparian willows, which are highly palatable to livestock (Baker et al. 2001). Many studies have stressed that the cumulative impacts of unmanaged livestock in southwestern riparian ecosystems can be a key factor in the degradation of riparian ecosystems (e.g., Krueper 1995, Wagner 1978, Ohmart, 1995 as cited in Levick et al. 2008).

6.11 Agricultural Application of Herbicides and Pesticides

The majority of water quality impacts from non-point sources of pollution occur in agricultural land use areas (EPA 2000 as cited in Buffler 2005). The contaminants of concern from these areas include fertilizers, herbicides, pesticides and sediment (Buffler 2005).

Agricultural activities that use fertilizers near streams can lead to increased nutrients and turbidity levels and cause excessive algae growth. These toxins that run off into streams of infiltrate ground water tables can lead to fish, aquatic invertebrate, and bird kills (Levick et al. 2008).

7 PROTECTING RIPARIAN ECOLOGICAL FUNCTIONS

The literature reviewed for this report, as discussed in previous sections and included in the appendices, provides a wealth of data and information on the science of riparian functions. However, in reviewing the reference documents, much of the available technical information is geographically broadly based and does not provide site-specific details for identifying specific widths of riparian protections to maintain the various types of semi-arid riparian ecological functions found in the Columbia Basin Plateau region.

The literature reviewed provides a wide range of findings on the identified width of area needed to maintain riparian functions. In some cases the width of this area corresponds to individual functions (e.g., width of vegetation needed for sediment removal) but more typically findings address the width of area needed to maintain collective ecological functions of floodplain connectivity, wetlands, riparian vegetation and water quality protection. While the value of these various riparian functions is well-established in the scientific literature, the specific width of area needed to maintain the individual and collective ecological riparian functions varies based upon local and regional conditions and on the specific function(s) being addressed in the literature. Caution must be used in applying or relating these prescriptions for wetland, riparian, and floodplain protection from other geographic areas to these features in the Columbia Basin Plateau region. This caution is tied to the variability in riparian functions and the area in which these functions occur in a semi-arid environment. In many cases, the intent of the prescriptions found in the literature is to protect vegetation types that are relatively rare or absent within the Columbia Basin Plateau region.

Given these general qualifications on the direct applicability of the literature review findings, the review did result in some findings that can be applied, along with the development of a suggested methodology. The findings provided in this section of the report are consistent with the report purpose, which is to apply the best available scientific information in establishing riparian buffer recommendations that protect and maintain the ecological functions of riparian areas outside of jurisdictional water and wetlands typically found in the Columbia Basin Plateau region. Information in this section is organized according to the following:

- Regulatory protections applicable to riparian ecological functions—describes how federal, state and local laws and regulations protect these functions, and set the stage for the focus of the literature review findings on non-wetland riparian vegetated areas and adjacent uplands.
- Literature review findings and recommendations organized by selected ecological functions, including:
  - Fish and wildlife habitat
  - Shade and cover
  - Erosion control
  - Water quality
  - Organic inputs

  These functions were selected as representative at the landscape scale to include the typical area necessary to protect and maintain riparian ecological functions from the edge of the water body upland to where the riparian vegetation transitions into shrub-steppe as the dominant vegetation cover type.
- Synthesized findings applied to SMP riparian buffer protections - describes how the five identified ecological functions are individually and collectively addressed, along with other riparian conditions such as wetlands or steep slopes, which are protected through other regulatory approaches in addition to or as an overlay to riparian buffer protections. Several example conditions are examined.
- Suggested methodology for developing representative functional local conditions

7.1 Regulatory Protections Applicable to Riparian Ecological Functions

The regulatory framework in the United States and Washington state provides for a variety of specific protections of the various elements comprising a typical riparian corridor. Examples of these regulations include the federal Clean Water Act (CWA), the Endangered Species Act (ESA), SMA, Growth Management Act (GMA), state Clean Water Act, and other titles of the WAC.

Federal policies and regulations such as the National Environmental Policy Act (NEPA), the CWA, the National Flood Insurance Act of 1968 (NFIA), and ESA do not generally include specific prescriptive buffer protections for streams and lakes. Under specific circumstances

however, riparian buffers can be protected under federal law. For example, designated critical habitat for an ESA-listed species can be protected from impacts of a project that is federally permitted, federally funded or can be shown to have a direct impact on a federally listed species.

Critical areas regulations are adopted by local governments in the state for the shoreline jurisdiction area (and in other areas within the geographic boundary of a jurisdiction) to comply with SMP and GMA requirements. These regulations protect:

- Wetlands
- Geologic hazards
- Critical aquifer recharge areas
- Frequently flooded areas
- Fish and wildlife habitat conservation areas, including streams and lakes

Each type of critical area is protected through specific regulations applied to protect health and safety, property and ecological functions. For example, wetlands are regulated through wetland-specific standards that are applicable to their ecological functions. Wetland buffers are also protected by the state Clean Water Act against the degradation of wetlands.

The basis for the regulatory protections applied to the critical area categories was determined in the scoping of this report to be relatively well-established except for the semi-arid riparian areas without wetlands that are typically protected under vegetation conservation and riparian buffer provisions within the SMP context. Accordingly, recommendations in this document are focused on strengthening the scientific basis for developing and applying riparian buffer protections in the Shoreline Jurisdiction. The other federal, state and local laws and regulations often serve as overlapping protections, as discussed below.

For SMPs, "local governments must identify SMA jurisdiction for the shorelands along their stream corridors, within minimum and maximum areas defined in statute" [RCW 90.58.030(20(d)]. The minimum shoreline jurisdiction for shorelands is the greater of the following:

- Lands extending landward 200 feet in all directions from the Ordinary High Water Mark (OHWM), including 200 feet in all directions from the OHWM at the 20 cfs point. (Shoreline jurisdiction would extend above the 20 cfs point.)
- The floodway plus the contiguous floodplain 200 feet landward of the floodway.
- Associated wetlands and river deltas" (Ecology 2011a)

Examples of the relationship between shoreline jurisdiction and riparian buffer vegetation are illustrated in Figure 3: Extent of Shoreline Jurisdiction. This figure simply shows the shoreline jurisdiction extending 200 feet from the OHWM; a steep slope area is also shown as it relates to local jurisdictions' critical area buffers for steep slopes and/or geologic hazard areas. In many cases the shoreline jurisdiction boundary extends far outside the existing riparian areas.

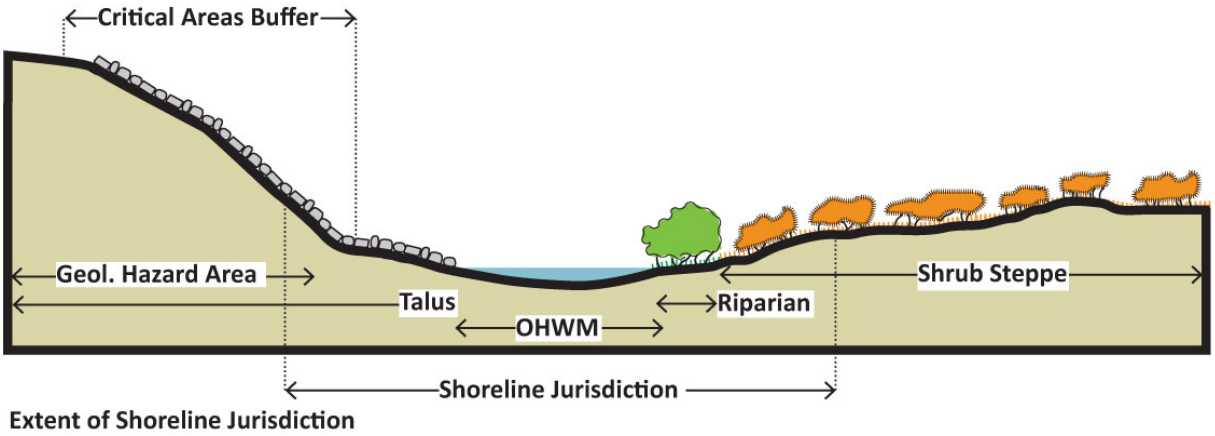
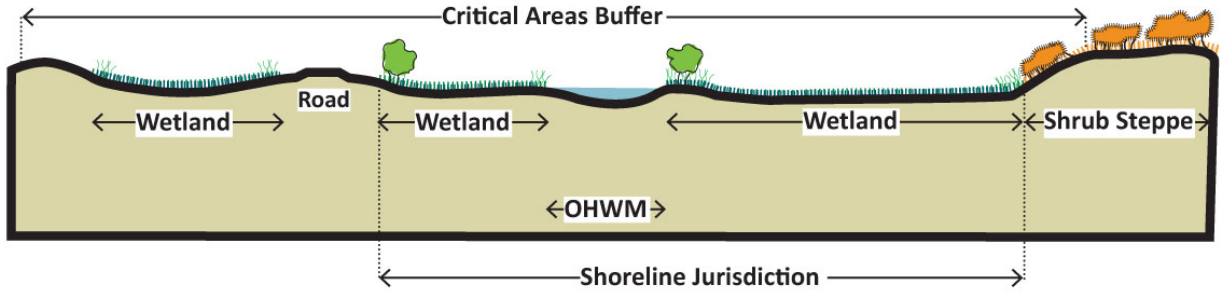


Figure 3
Extent of Shoreline Jurisdiction

Grant County has many examples where associated wetlands greatly expand the shoreline jurisdiction. These wetlands fall partially within 200 feet of a shoreline of the state, but can extend well beyond that distance. The shoreline jurisdiction includes these wetlands, but does not include the jurisdictional wetland buffer unless the local city or county elects to do so. In cases where the local jurisdiction does not elect to include the wetland buffer in shoreline jurisdiction, then buffer protections are provided through a critical areas code that applies to the rest of the area in the city or county outside of the shoreline area Figure 4: shows how the extent of Shoreline Jurisdiction is influenced by associated wetlands. This

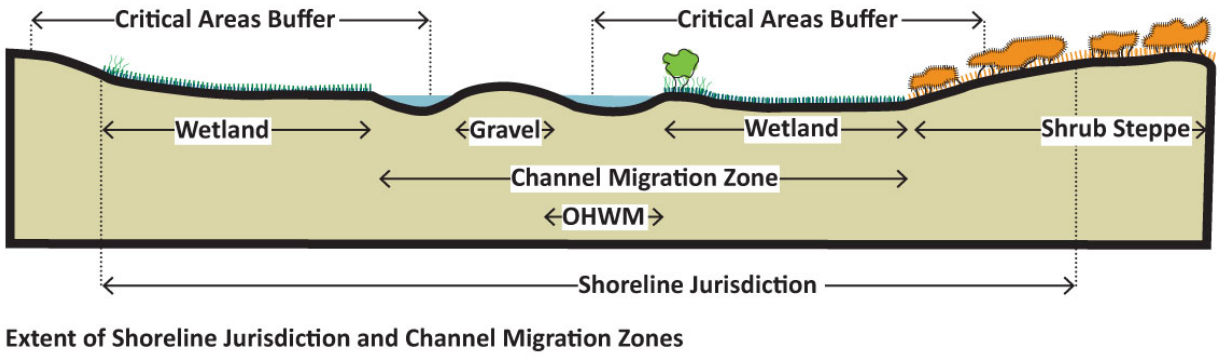
figure also illustrates that embankments may cut-off wetlands that would otherwise be associated with the shoreline jurisdiction, in these cases the critical areas code alone applies to this wetland feature.



Extent of Shoreline Jurisdiction and Wetland Buffers

Figure 4
Extent of Shoreline Jurisdiction and Wetland Buffers

Development restrictions are also in place in areas that are prone to flooding and channel migration. Channel migration zones can extend outside the shoreline jurisdiction or be included, again, at the discretion of the local government. Figure 5 depicts the channel migration zone in relationship to shoreline jurisdiction and other features. Channel migration can be a fairly regular occurrence in some systems with low confinement, high gradient, and/or with high sediment load. Other systems may not experience much if any lateral channel movement in a time span of years or decades. Channel migration is part of the natural ecological function of most rivers, and occurs at varying rates. In systems where channel migration is likely to occur, the channel migration zone is mapped and appropriate protections are included in shoreline regulations. Wetlands may appear within or outside of the CMZ; these features are protected by the critical areas code.

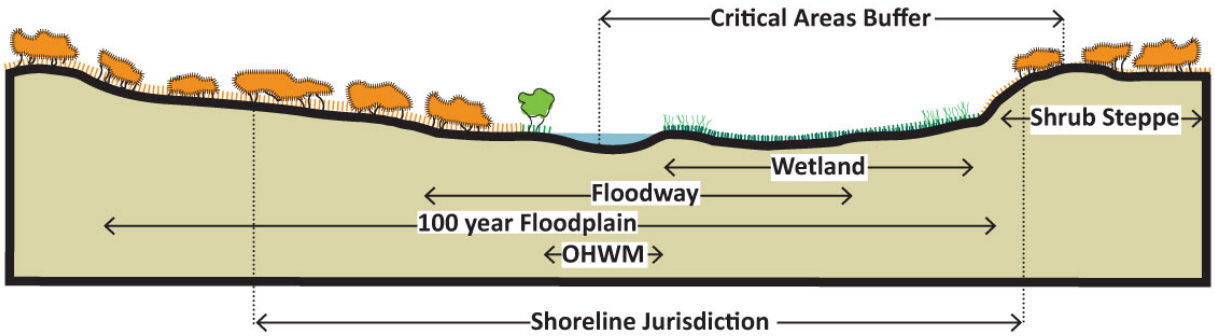


Extent of Shoreline Jurisdiction and Channel Migration Zones

Figure 5

Extent of Shoreline Jurisdiction and Channel Migration Zones

The NFIA 1968 had among its goals to identify areas of high and low flood hazard and establish flood insurance rates for structures inside each flood hazard area. Most water bodies subject to SMA jurisdiction have mapped flood hazard areas. The areas that are most likely to be flooded are mapped as floodways. These areas are flooded frequently enough that any development is discouraged. Beyond the floodway the 100-year and 500-year floodplains are mapped. These areas have a 1 percent and 0.2 percent chance of being flooded in a given year, respectively. Local jurisdictions have the option of including these mapped floodplain areas in the Shoreline Jurisdiction. Figure 6 shows the extent of Shoreline Jurisdiction in mapped floodplains in a Columbia Basin Plateau example condition. The figure illustrates that the shoreline jurisdiction extends from the edge of the floodway rather than OHWM boundary in development of the shoreline jurisdiction boundary.



Extent of Shoreline Jurisdiction in Mapped Floodplains

Figure 6

Extent of Shoreline Jurisdiction and Mapped Floodplains

7.2 Literature Review Findings and Recommendations by Selected Ecological Functions

In determining buffer widths, both the baseline conditions of a site and the ecological functions at risk of impact should be assessed. As discussed previously, in many areas of the Columbia Basin, riparian areas are often naturally limited by climate and available groundwater resources necessary to support vegetation. These areas are further affected by impacts of water resource management caused by water storage, water diversion and large scale irrigation projects. These management efforts impact natural flood regimes, natural delivery, transport and loss of sediment and water across the landscape. The hydrologic context is an important factor for each jurisdiction to consider in updating their local SMP. In the semi-arid environment it largely sets the stage for the associated riparian ecological functions, and what is required to maintain no net loss of these functions that exists at the time the SMP is developed or updated. In some areas, such as Grant, Adams and Franklin counties, the level and amount of area where these functions exist has increased overall compared to what existed prior to the Columbia Basin Project.

While the literature providing specific functional riparian buffer widths pertinent to regional semi-arid and arid environments is limited in direct applicability, a review of potentially applicable studies provides some buffers-related information that can be applied to support ecological functions in the semi-arid Columbia Basin plateau.

The following sections describe specific riparian functions of vegetated areas. These are broadly characterized in WAC 173-26-201(3)(d)(i) as:

- "Hydrologic: Transport of water and sediment across the natural range of flow variability; attenuating flow energy; developing pools, riffles, gravel bars, nutrient flux, recruitment and transport of large woody debris and other organic material.
- Shoreline vegetation: Maintaining temperature; removing excessive nutrients and toxic compounds, sediment removal and stabilization; attenuation of high stream flow energy; and provision of woody debris and other organic matter.

- Hyporheic functions: Removing excessive nutrients and toxic compounds, water storage and recharge that supports vegetation, and sediment storage and maintenance of base flows.
- Habitat for [native in the case of rivers and streams] aquatic and shoreline-dependent birds, invertebrates, mammals; amphibians; and anadromous and resident native fish. Habitat functions may include, but are not limited to, space or conditions for reproduction; resting, hiding and migration; and food production and delivery."

These broad categories were further focused for the purposes of this study to reflect the scientific literature most pertinent to the region. The functions described below were selected as representative at the landscape scale of the physical area needed from the edge of the water body upland to where the riparian vegetation transitions into shrub-steppe as the dominant vegetation cover type. It is acknowledged that focusing on these five functions does not address all shoreline functions described in WAC 173-26-201. Table 1 below lists these functions, and has in bold the WAC function that is primarily targeted under the five ecological functions addressed in this report. There is much overlap among the functions listed in the WAC. Other riparian functions, such as serving as a firebreak and other social and economic benefits were not directly addressed in this report, but these are briefly discussed in Section 5.3.

The selected ecological functions focused on for the purposes of this study, and adapted to the semi-arid setting, include:

- **Fish and wildlife habitat** - Provide resources and structure to meet life history requirements such as feeding, roosting, refuge, migration corridors, and clean water; contributes to high species diversity and high productivity in aquatic and upland areas.
- **Shade and cover** - Vegetation intercepts a portion of solar inputs and has some effects on microclimate conditions such as soil, ambient air temperatures, soil moisture, wind speeds, and humidity. Vegetation assists in avoidance of soil moisture buildup through evapotranspiration and roots stabilize slope.
- **Erosion control** - Undisturbed soils and vegetation in riparian areas and upland areas reduce erosion and slow transport of fine sediment across land. Vegetative controls on the rate of bank erosion are related to roots providing stabilization of soils when

stream stage is above OHWM. This varies with bank height, bank slope and vegetation type.

- **Water quality** – Includes water infiltration; reduction of surface runoff rates and volumes; intercepting precipitation and nutrients; intercepting fine sediments and associated pollutants from surface water; binding dissolved pollutants with clay and humus particles in soil; converting excess nutrients/pollutants/and bacteria into less harmful forms; and can provide some help in regulating water temperatures until overwhelmed by ambient air temperatures.
- **Organic inputs** - Provides litter which serves as habitat and food for fish and aquatic invertebrates; influences amount and type of terrestrial invertebrates that fall into aquatic systems; and provides nutrient exchange between terrestrial and aquatic systems. Provides limited moderation of water temperatures and increases soil moisture; accumulation of detritus for invertebrate food source and habitat; and provides some structural complexity for fish and bank erosion control.

In defining and recommending riparian buffers, ecological functions are defined in relation to buffer widths. For the purposes of the recommendations below, a targeted effectiveness of provisions to protect and enhance riparian habitat functions/values is somewhere in the 75 percent to 100 percent effectiveness range.

The following sections describe the rationale for proposed buffer widths based on the targeted functions.

7.2.1 Fish and Wildlife Habitat

Riparian vegetated areas provide important habitat for a variety fish and wildlife species. Access to fresh water for most species is critical in a semi-arid environment and many species are limited in their ability to forage beyond a certain distance from an accessible water source. The relatively high species density and diversity in riparian areas is indicative of their importance in species movement, migration, feeding and reproduction. The areas used vary by species but include not only the water, wetland fringe and associated riparian vegetation, but also include the nearby shrub-steppe areas that provide better forage, cover, and migratory corridors for some species.

7.2.1.1 Key Finding

A variety of literature describes the effect of riparian vegetation and upland shrub-steppe communities on fish and wildlife habitat. However species specific requirements are extremely varied and are often interrelated with non-riparian habitat requirements. For these reasons the establishment of a "one size fits all" habitat buffer distance is highly problematic. The recommendations made here are general. In the case of habitats of specific importance to state or federally listed threatened or endangered species a species-specific recommendation to protect habitat should be established. This can be done under existing endangered species protections and need not be done under SMA.

7.2.1.1 Recommendation

The entire riparian vegetation community should be protected. In Grant County and many other areas of the Columbia Basin Plateau this is 20 feet or less (Anchor QEA 2012). In addition, another 30 to 50 feet of uplands should be protected in areas with higher habitat value. It is the opinion of the Anchor QEA authors that this measure would allow the majority of wildlife species to move along the outer edge of the riparian vegetation community without significant loss of the migration and movement functions of riparian habitat in areas threatened by development incursions. This buffer could be reduced where habitat value is low and wildlife use is unlikely. This recommendation can be superseded by unique habitat requirements of one or more threatened species, as described above. Those recommendations should be supported by scientific evidence that links the recommendation to specific habitat requirements, based upon available information.

7.2.2 Shade and Cover

Shade and cover usually provides crucial thermal regulation functions for water bodies. Temperature requirements should support the suitability of the aquatic habitat for cold water fishes such as trout or warm water fishes such as bass. Functioning riparian areas in a semi-arid environment do not always sustain vegetation that effectively provides thermal regulation. In many cases, intermittent flows or other conditions limit the establishment of woody vegetation. However, herbaceous vegetation or sparse woody vegetation still provides important cover from predators for both aquatic and terrestrial species. This

important aspect of the riparian structure can require the presence of specific types of riparian vegetation (e.g., cottonwood trees) that do not typically extend upland into shrub-steppe habitats.

7.2.2.1 Key Findings

A variety of literature describes the effect of riparian vegetation communities on the regulation of water temperature through both direct shading and micro-climate effects associated primarily with higher rates of evapotranspiration (Castelle et al. 1994, May 2003, Osborne and Kovacic 1993, Brosofske et al. 1997, Johnson and Ryba 1992, Hansen et al. 2010, Knutson and Naef 1997, Anderson et al 2007). However none of these sources indicate a link to similar functions linked to adjacent shrub-steppe vegetation communities.

7.2.2.2 Recommendation

Protection of existing functional riparian vegetation communities should be a priority and protective buffers should be developed based on the width of functional (undisturbed) riparian communities in the reach. In Grant County, the width of this area is typically less than 20 feet.

7.2.3 Erosion Control

Sediment erosion control from upland flows is dependent upon local precipitation patterns, slope and vegetation. A significant body of literature exists on this topic. A list of related sediment studies and reviews was compiled by Buffler (2005) on the effectiveness of buffer widths and types in controlling and filtering sediment. These information sources represented a variety of different riparian conditions, including forest lands, woody and deciduous riparian areas, grasslands, and rangeland, with most sources from areas with higher precipitation than the Columbia Basin Plateau. One additional article by Yuan et al (2009), also synthesized previous study information on vegetation performance in erosion control. The key findings from these literature reviews are provided below.

7.2.3.1 Key Findings

No significant difference between various vegetation types was found related to the water quality functions of reducing sediments/erosion control (Barden et al. 2003 as cited in Buffler 2005), and as described below:

- Riparian buffers of 40 feet from the receiving waterbody achieved 85 percent reduction in grass and small grains at 4 percent slope (more typical of range conditions) (Fasching and Bauder 2001, as cited in Buffler 2005)
- The first 10 to 20 feet often reduced sediment by 70 percent or more even at slopes up to 12 percent (Robinson et al 1996; Hook 2003; Mendez et al 1999, as cited in Buffler 2005)
- High flows overwhelmed vegetation filter (Daniels and Gilliam 1996 as cited in Buffler 2005; Yuan et al. 2009), with effectiveness plateauing at around 15 percent slope

Yuan et al (2009) also included regression analysis of the varying information sources to demonstrate that 16 feet of vegetated buffer can trap approximately 80 percent of incoming sediment in slopes with a 5 percent or less gradient. A buffer width of 33 feet achieves approximately 80 percent in slopes greater than a 5 percent gradient (Figures 7 and 8). Sediment trapping efficiency usually declines as slope increases, although one study found that efficiency actually increased up to 11 percent slope and then started dropping at a 16 % slope (Dillaha et al. 1989, Yuan 2009).

This information indicates that to protect stream water quality from erosion a vegetative buffer of 40 to 50 feet should provide adequate protection. This achieves, for example, approximately 90 percent reduction in sediment for slopes up to 5 percent, and 80 percent reduction for slopes between 5 and 15 percent. This should be viewed as a conservative protection value, based upon the higher rainfall, intensity of rainfall and runoff potential in the geographic areas where most of the referenced studies were conducted. Semi-arid and arid areas experience significantly less precipitation (3 to 15 inches per year) than most of the study areas referenced (e.g., 20 inches [Nebraska] to 45 inches [Georgia]) per year. It is possible that at these lower precipitation levels and less frequent storm that less sediment

overall can be transported. Verification of this assumption with additional information, particularly as it relates to storm intensities, is recommended.

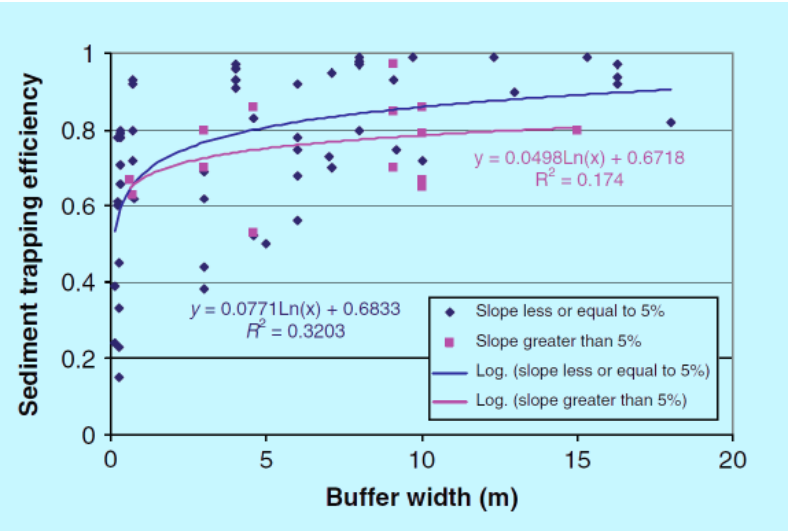


Figure 7

Slope and sediment trapping efficiency.

(Yuan et al. 2009)

Yuan et al. (2009) also found that different types of vegetation were roughly equal at sediment trapping efficiency, as illustrated in Figure 8.

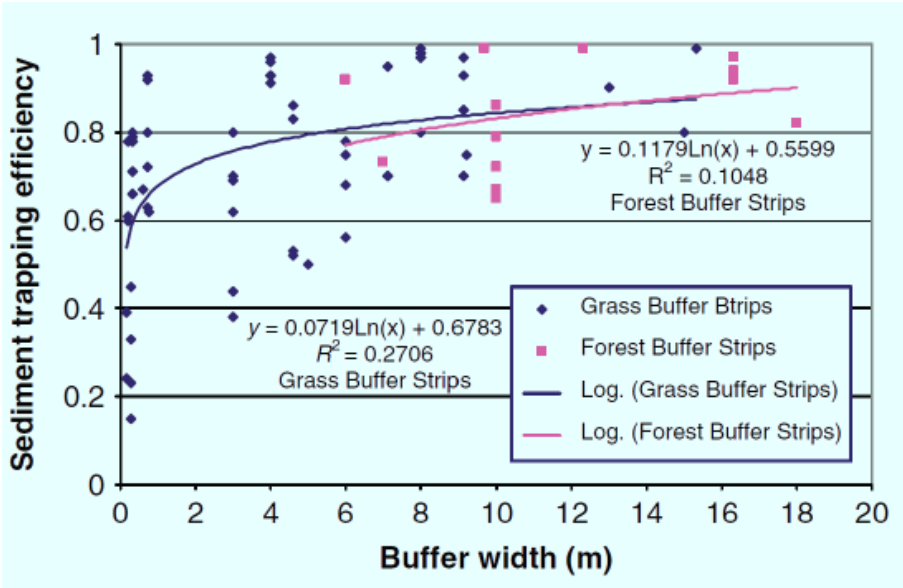


Figure 8

Vegetation Type and Sediment Trapping Efficiency

(Yuan et al. 2009)

7.2.4 Water Quality

Other water quality parameters affected by functional buffers in addition to erosional control described above, include pathogens, pesticides, and nutrients (phosphorous and nitrogen).

7.2.4.1 Key Findings

- Pathogens - Narrowest buffer width was 10 feet at 3 percent slope (Chaubey et al, 1994 as cited by Buffler 2005) with 20 feet of tall fescue pasture achieving 100 percent percent removal at 3 percent slope (Barfield et al. 1998, as cited by Buffler 2005).
- Pesticide - Filtering achieves high efficiency (95 percent) at 25 feet grass in loamy sand (no slope information available) (Lowrance et al. 1998 as cited in Buffler 2005) and at 30-foot buffers (97 percent reduction) (Barfield et al. 1998 as cited in Buffler 2005).
- Phosphorous - For particulate and dissolved phosphorus, 50 to 65 feet achieved 90 percent or greater reduction of both phosphorous types in 3 to 15 percent slope conditions (Chaubey et al. 1995; and Patty et al. 1997 as cited in Buffler 2005).

- Nitrogen - Attenuation requires a buffer of as little as 30 feet (Cooper 1990 as cited in Buffler 2005) to 60 feet in slopes up to 15 percent (Schnabel 1995; and Patty et al. 1997 as cited in Buffler 2005), and up to 100 percent removal of nitrogen with a buffer of 65 feet (Fennessy and Cronk 1997). The degree of filtration, land use and sensitive feature context, shoreline slope, and type of contaminants to filter all contribute to the variability of suggested functional buffer widths.

7.2.4.2 Recommendation

Based on the review of the information summarized in 7.2.4.1, protecting stream water quality from contaminated runoff, with buffer widths of 50 to 65 feet will achieve a 90 percent or greater reduction in dissolved phosphorus levels. A vegetative buffer of 65 feet should provide adequate protection of stream water quality for slopes up to 15 percent. This should be viewed as a conservative protection value, based upon the higher rainfall and runoff potential in the geographic areas most of the referenced studies were conducted (Buffler 2005, Yuan et al. 2009). Semi-arid and arid areas experience significantly less precipitation (3 to 15 inches per year) than most of the study areas referenced (e.g., 20 inches [Nebraska] to 45 inches [Georgia] per year). In semi-arid and arid area ,it is expected that at these lower precipitation levels and assumed less frequent storm events that lower amounts of nutrients, pathogens and pesticides are transported. The intensity of storm events in arid regions might also create short-term heavy runoff that may test the absorption rate of buffer areas. Verification of these assumptions with additional information, as available, is recommended.

7.2.5 Organic Inputs

Organic inputs within the aquatic environment can include small woody and herbaceous debris and invertebrates. This material is recruited through incremental erosion over time and plant life histories. Invertebrate inputs are largely generated by vegetation very near, or overhanging the water. Inputs of large woody debris (LWD) usually require mature tree stands, which is not typically present in many areas of the study area. For LWD, a number of studies suggest a buffer equal to at least one specific tree height (SPTH), or as adapted by this study, one specific tree or shrub height (SPTSH).

7.2.5.1 Key findings

Based on the vegetation in the Columbia Basin Plateau region (including the lower Yakima River) three categories of potential tree heights usually occur.

- Up to 125 feet for reaches that support mature cottonwood (*Populus tricocarpa tricocarpa*).
- 30 feet for reaches that do not support trees but that do support mature willow (*Salix lasiandra, S. sp.)*
- 10 feet for reaches that only support herbaceous vegetation.

7.2.5.2 Recommendation

To protect shade and cover by riparian buffers should be equal to or greater than the site potential tree height, but also as constrained by the overall width of the riparian area. The full width of the functional riparian vegetation community should be protected from developmental encroachments while providing for continued organic recruitment (FEMAT 1993). These protections may be reduced and mitigated where access to the water is required for water-dependent uses.

7.2.6 Findings Summary

Table 1 lists the five targeted ecological functions (column headings across the top) and how they relate to associated buffer widths necessary to protect this function or, if variable, guidance on how to obtain the buffer width based on local conditions. Findings (or lack of findings) from the literature review are summarized under the heading Literature Review Findings and/or Representative Local Conditions for Protecting Ecological Functions in Riparian Areas Outside of Jurisdictional Waters and Wetlands. Some functions vary significantly based on local conditions, such as shade and cover, or organic input, and the literature review findings were not as directly applicable to these functions. Other functions such as erosion control and water quality are more applicable under a variety of settings. These widths directly address the specific riparian buffer protections for streams (and lakes, as applicable) that are needed to protect ecological functions. The specific recommendations include only those buffer protections not already addressed by the other existing regulations as summarized above and as included in the lower half of the table. Regulations within SMPs should protect these areas from activities that could impair the associated ecological

functions. This includes the protection of riparian vegetation communities, along with the other habitat types identified below.

The lower half of the table, under the heading Existing Regulatory Protections, explains how the various regulations discussed earlier protect shoreline areas, shoreline related habitats and/or functions through other approaches that either complement or overlap the riparian buffer protections. Protection under the SMP should incorporate or be consistent with these other regulations. For example, encroachment by development activities into a jurisdictional wetland or wetland buffer should be precluded regardless of whether the area is under shoreline management jurisdiction.

Table 1

Riparian Functions and Associated Regulatory Protections

General Functions	Fish and Wildlife Habitat	Shade and Cover	Erosion Control	Water Quality	Organic Input
Functions described in WAC (for reference) Primary in Bold *Ancillary in Italics*	**Habitat** *Shoreline Vegetation* *Water Quality*	**Shoreline Vegetation** *Hyporheic functions* *Habitat* *Hydrologic*	**Hydrologic** *Shoreline Vegetation* *Habitat*	Hyporheic Functions ***Water Quality***	*Hydrologic* *Habitat* ***Shoreline Vegetation***
Literature Review Findings and/or Representative Local Conditions for Protecting Ecological Functions Provided by Riparian Areas outside of Jurisdictional Waters and Wetlands					
Basis for Width of Riparian Buffer[1]	• Based on representative functional local conditions – For example, in Grant County the width of naturally occurring riparian vegetation areas along rivers and streams ranges from 0 to 20 feet in width from OHWM.)		• From 40 to 50 feet in width: – Achieves approximately 90 percent reduction in sediment for slopes up to 5 percent – Achieves 80 percent reduction for slopes between 5 and 15 percent • High overland flow conditions and slopes greater than 16 percent overwhelm filtering functions (Yuan et. al., 2009)	• From 50 to 65 feet, achieves 90 percent reduction in particulate and total phosphorous • From 26 to 30 feet achieves 99 percent reduction (or below detection limits) for nutrients in grassy vegetation • High overland flow conditions and slopes greater than 16 percent overwhelm filtering functions (Yuan et. al. 2009)	• Based on representative functional local conditions, use 1STSH • For herbaceous only, up to 10 feet • For herbaceous with willows, up to 30 feet • For willows and cottonwood, up to 125 feet
Existing Regulatory Protections					
Federally-identified Critical Habitats	Protect consistent with ESA requirements in all critical habitat areas designated by USFWS and NMFS	NA	NA	NA	NA
State-identified Priority Habitats	Protect consistent with Fish and Wildlife Habitat Conservation Areas and as described below, including mitigation and achieving no net loss of ecological functions	NA	NA	NA	Protect consistent with Fish and Wildlife Habitat Conservation Areas and as described below, including mitigation and achieving no net loss of ecological functions
Wetlands	Protect consistent with Ecology's 2004 and 2006 Eastern Washington Wetlands Manuals, as well as 2007 amendments; with USACE Mitigation Ratios; and with achieving no net loss of ecological functions				
Floodplain and Channel Migration Zone	Protect consistent with frequently flooded areas regulations, flood protection zones, and flood hazard reduction plans, and/or geologic hazards regulations, as applicable			NA	NA
Geologic Hazards	NA	NA	Protect consistent with geologic hazards regulations	NA	NA

Notes:
1 Measured in linear feet upland from the OHWM or top of bank, as applicable.
1STSH one specific tree or shrub height
ESA Endangered Species Act
NMFS National Marine Fisheries Service
USFWS U.S. Fish and Wildlife Service
WAC Washington Administrative Code

7.3 Synthesized Findings Applied to SMP Riparian Buffer Protections

SMPs under the SMA have specific requirements for the protection of riparian habitat and other ecological functions. Many of these ecological functions are also protected – at least in part – by other related federal, state and local regulations, as discussed in Section 7.1. The overall environmental protections provided under the SMP include the associated local regulations such as the Critical Areas protections and water quality protections through stormwater management requirements, and should complement and be consistent with other state and federal regulations. SMPs should also provide specific measures and standards for protecting riparian functions based on the best available science (as applied in the semi-arid context for this report).

The identified buffer protections complement and typically overlap with endangered species, wetlands, geologic hazards and other protections, as applicable. In many cases where these additional protections exist the protections will be spatially wider and more restrictive than the identified riparian buffers. The most protective buffer should always be given precedent.

The buffer recommendations presented in this document are specific to those shorelines that do not have an associated riparian wetland. As described in earlier sections of this report, this exists commonly in the Columbia Plateau Region due to semi-arid hydrology and other associated conditions.

The findings described in Section 7.2 are applied in several example conditions in Table 2 below. Examples include large and small rivers, and a lake, with varying assumed ecological functions, habitat conditions, and types of land use and development.
The identified buffers would be applied to protect and maintain riparian ecological functions regardless of a specified SMP environment designation. Additionally, buffers could be reduced if additional water quality protections are employed, restoration and/or enhancement measures are applied, or if supplemental scientific documentation demonstrates that reduced buffer widths will meet the “no net loss” (WAC 173-26-186) of ecological functions requirement.

In these examples, the identified buffers protect the riparian vegetation along with upland habitat to provide for up and downstream migration and riparian habitat access, and additional area important for protecting water quality. Shade, cover, and erosion control functions should be fully protected.

It should be noted for context, that SMPs approved by Ecology after September 1, 2011 may consider existing residential structures and their appurtenances as conforming uses in regards to riparian buffers and associated setbacks, as applicable (Ecology 2011a. Expansion of existing structures within a riparian buffer is considered new development and associated mitigation of impacts to achieve no net loss of ecological functions would be required, and possibly also a variance depending upon the specifics of the development proposal. Residential development and appurtenances are required to be set back from steep slopes and shorelines vulnerable to erosion, so that structural improvements are not needed to protect new development. (Ecology 2011a).

Table 2

Example Scenarios

Example Conditions	Fish and Wildlife Habitat	Shade and Cover	Erosion Control	Water Quality	Organic Input	Synthesis
Smaller stream and narrow riparian corridor, partially incised channel and limited habitat	Representative functional local condition – Riparian vegetation ranges from 0 to 20 feet Upland vegetation consists of disturbed agriculture and rangeland Limited habitat and species presence documented	Representative functional local condition – Riparian vegetation ranges from 0 to 20 feet Vegetation dominated by herbaceous species	Slopes less than 5 percent, so minimum width of 40 feet required	Minimum of 50 feet to protect water quality without additional water quality treatments	Representative functional local condition – 0 to 20 feet in width, and vegetation dominated by herbaceous species 10 feet and less in height.	Recommend 50-foot buffer. Riparian buffer width should be based on water quality protection, which provides the greatest width of protection. Opportunity to reduce width if additional surface water quality BMPs and treatment measures employed and/or with habitat enhancements and demonstration of no net loss of ecological function
River delta with wider riparian corridor, active floodplain and complex habitat	Representative functional local condition – Riparian vegetation width ranges from 40 to 100 feet. Upland vegetation consists of shrub-steppe habitat, and rangeland, with pockets of low density development Complex habitat, including multiple riparian wetlands and multiple species presence documented	Representative functional local condition – Riparian vegetation ranges from 30 to 100 feet Vegetation dominated by woody and herbaceous species	Slopes vary but on average are less than 5 percent, so minimum width of 40 feet required	Minimum of 50 feet to protect water quality without additional water quality treatments	Representative functional local condition – Riparian vegetation ranges from 30 to 100 feet Vegetation dominated by woody and herbaceous species, including large cottonwood stands with heights up to 85 feet.	Recommend 100 foot buffer. Riparian buffer width should be based on fish and wildlife habitat, and organic input, which provides the greatest width of protection. Limited opportunity to reduce buffer width except perhaps with habitat enhancements and demonstration of no net loss of ecological function. Wetland buffers will also apply in many areas and provide additional protection

Table 2

Example Scenarios

Large river with narrow riparian corridor and steep slopes/ cliffs dominate	Representative functional local condition – Riparian vegetation ranges from 0 to 20 feet Upland vegetation consists of shrub steppe, irrigated agriculture and rangeland Typical species associated with cliffs/talus and shrub steppe habitat documented	Representative functional local condition – Riparian vegetation ranges from 0 to 20 feet Vegetation dominated by shrub-steppe species, with some invasive species	Slopes often greater than 10 percent, so minimum width of 50 feet required	Minimum of 65 feet to protect water quality without additional water quality treatments	Representative functional local condition – 0 to 20 feet in width, and vegetation dominated by shrub-steppe species, with some invasive species 10 feet and less in height. E	Recommend 65 foot buffer. Riparian buffer width should be based on water quality protection, which provides the greatest width of protection. In this example, regulations of geologic hazards likely to further require setback beyond the recommended riparian buffer.
Smaller river or larger stream with narrow riparian corridor, limited floodplain and less complex habitat	Representative functional local condition – Riparian vegetation width ranges from 20 to 45 feet. Upland vegetation consists of shrub-steppe and habitat, and rangeland, with pockets of low density development Functional habitat with species presence documented	Representative functional local condition – Riparian vegetation ranges from 20 to 45 feet. Elevation increases relatively quickly from edge of water body Vegetation dominated by herbaceous and woody species	Slopes vary but on average are less than 10 percent, so minimum width of 50 feet required	Minimum of 65 feet to protect water quality without additional water quality treatments	Representative functional local condition – Riparian vegetation ranges from 20 to 45 feet Vegetation dominated by herbaceous species with some woody species, including willows with heights up to 30 feet.	Recommend 65 foot buffer. Riparian buffer width should be based on fish and wildlife habitat, and organic input, which provides the greatest width of protection. Opportunity to reduce width if additional surface water quality BMPs and treatment measures employed and/or with habitat enhancements and demonstration of no net loss of ecological function

Table 2

Example Scenarios

Lake with narrow riparian corridor and mix of developed shoreline with open space	Representative functional local condition – Riparian vegetation ranges from 0 to 20 feet Upland vegetation consists of lawns, pasture and disturbed, non-native vegetation Limited habitat and species presence documented	Representative functional local condition – Riparian vegetation ranges from 0 to 20 feet Vegetation dominated by herbaceous species	Slopes less than 5 percent, so minimum width of 40 feet required	Minimum of 50 feet to protect water quality without additional water quality treatments	Representative functional local condition – 0 to 20 feet in width. Vegetation dominated by herbaceous species with some woody species, including willows and non-native trees with heights up to 45 feet.	Recommend 50 foot buffer. Riparian buffer width should be based on water quality protection, which provides the greatest width of protection. Opportunity to reduce width if additional surface water quality BMPs and treatment measures employed and/or with habitat enhancements and demonstration of no net loss of ecological function

7.4 Suggested Methodology for Developing Representative Functional Local Conditions

This section provides methodology considerations for developing representative functional local conditions as part of the inventory, characterization and analysis phase of the SMP development process. This local information can be developed to provide inputs to the fish and wildlife habitat, shade and cover and organic input ecological functions for specific reaches and water bodies.

7.4.1 Define reach

Define specific reaches as part of preparing the inventory, characterization and analysis. Reach delineation can be performed by evaluating aerial photography, topographic data, geologic maps, and land cover data in a GIS database. Specific factors that influence the delineation of stream reaches include channel and floodplain geomorphology, geologic controls (e.g., bedrock), channel confinement and modification, hydrology and adjacent land use. These physical conditions often translate into differences in shoreline ecological and physical process functions, presence or absence of associated wetlands, and types of riparian vegetation and widths of riparian areas.

7.4.2 Characterize Riparian and Wetland Vegetation, Structure, Width and Function

Characterize the type of riparian and wetland vegetation that exists within reaches, including both native and non-native species. Describe the common species as woody and/or herbaceous, and associated dimensions – height, width, and structure of the vegetation. Categorize reaches in terms of ecological function. Ecological function is defined here as the degree of similarity between existing physical and biological conditions, and the potential ecological function of a site; the higher the ecological function, the closer the site is to potential. Potential, for this assessment, encompasses all the resources defined by the interaction of hydrology, vegetation, water quality, and erosion/deposition (soils), and aquatic and riparian habitat. For example, the potential of the hydrologic component includes the concept of a stream channel's physical characteristics (dimension, pattern, and profile) being within a "normal or usual" range (e.g., entrenchment, sinuosity, width, depth,

and slope of the bankfull channel) as defined by landform and geomorphic stream type given current hydrology.

Make judgment on the functionality of the riparian area within the context of watershed and localized conditions, and categorize areas within the reach as functioning, partially functioning and/or impaired; or other suitable categories and framework. The framework and definitions for these suggested categories were adapted from a system originally developed for Riparian Area Management guidelines proposed by the U.S. Bureau of Land Management (BLM) (Prichard et al. 1998).

- Functioning is a state of resiliency that will allow a shoreline to hold together during high-flow events with a high degree of reliability. This resiliency allows an area to then produce desired values, such as fish habitat, bird habitat, or forage, over time. Riparian areas that are not functioning properly cannot sustain these values over time and are susceptible to stochastic disturbances such as fire.
- Partially functioning is a state in which the ecological function of the shoreline is somewhat compromised by development or management trends, or is particularly susceptible to future degradation due to development, management or ecological conditions. A partially functioning shoreline has some ability to recover through changes in management or the removal of identified stressors on ecological function.
- Impaired is a state in which the ecological functions of the shoreline are heavily compromised by development or management of the reach. An impaired reach has a low probability of recovery without major restoration, due to the degree of structural change to the shoreline, waterbody, and surrounding shorelands. Impaired shorelines can be functionally improved, but are unlikely to be self-sustaining, without major restoration.

Applying these categories is a relative assessment with some degree of calibration to reflect the overall hydrologic conditions found in a particular watershed within the Columbia Basin Plateau region of Eastern Washington, or larger context, where applicable. Characterize the effects (enhancements and limitations) of management, storage, diversion, use, and reclamation of water for agriculture, hydropower, and other uses, on the amount of shoreline jurisdiction area as well as the overall function of those shorelines.

Characterizing existing conditions is important for establishing the baseline used in demonstrating how a jurisdiction will achieve the no net loss of ecological functions, for demonstrating how proposed buffers "fit" existing conditions and functions (including natural and modified), and also for identifying restoration opportunities. Establishing a representative reach can help to identify what "functioning conditions" look like, as a template for establishing the buffer width for a given stream reach or water body.

7.4.3 Characterize Typical Species Presence and Habitat Needs

Using Washington State Priority Habitat and Species (PHS) and Natural Heritage Program (NHP) databases, and other applicable information sources, characterize species and associated shoreline habitat needs for threatened and endangered species, along with more common species usage and habitat requirements for species such as deer, coyote and smaller mammals. Address aquatic, riparian and adjacent upland habitat needs, including latitudinal and longitudinal connectivity.

7.4.4 Applying Representative Functional Local Conditions Information in Develop Riparian Buffers

With this information characterized for specific local conditions for a given SMP jurisdiction water body, it can be added to the sediment and water quality findings provided in Section 7.2 and applied to develop riparian buffer recommendations that protect the targeted ecological functions.

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APPENDIX A
LITERATURE REVIEW INFORMATION SOURCES

Appendix A
Riparian Buffer Literature Review Master List

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
1	Proceedings of workshop on reservoir shoreline erosion, held in 1992. Relevant topics include mechanisms of shoreline erosion along lakes and reservoirs, shoreline erosion control - engineering considerations, planting techniques for vegetating shorelines and riparian areas, and Blue River and Dorena Reservoir erosion control vegetation survival tests. This document also includes working groups' summary reports on cause, effects, and fixes of shoreline erosion.	Allen, H., and J. L. Tingle, 1993. Proceedings, workshop on reservoir shoreline erosion: A national problem. Prepared for U.S. Army Corps of Engineers. Miscellaneous Paper W-93-1. August 1993.	Erosion / Hydrology	USA	General Range	1992	No
2	The article discusses cattle grazing effects on the vegetation surrounding cold-water springs and their downslope creeks in three watersheds at the University of California's Sierra Foothill Research and Extension Center (SFREC), Marysville, Calif. As an outcome of randomly assigned treatments (ungrazed, lightly grazed and moderately grazed), researchers found total herbaceous cover was more sensitive to interannual rainfall fluctuations, than grazing effects alone.	Allen-Diaz, B., and R. D. Jackson, 2000. Grazing effects on spring ecosystem vegetation of California's hardwood rangelands. Journal of Range Management 53(2): 215-220.	Grazing	California	Grazing	2000	Yes
3	Surface water contamination can often be reduced by passing runoff water through perennial grass filters. Research was conducted to evaluate the size of cool season grass filters relative to drainage area size in reducing runoff sediment and phosphorus (P). Filter effect on runoff volume and contaminant load was determined using total runoff and composites of samples collected from 12 runoff events. Grass filters reduced sediment and P load largely by reducing runoff volume rather than reducing concentration. Well designed and well-placed grass filters that occupy 1.0 to 1.5% of the drainage area and intercept a uniform flow of runoff from a drainage area can reduce sediment and nutrient loss in runoff by greater than 50%.	Al-wadaey, A., Wortmann, C. S., Franti, T. G., Shapiro, C. A., & Eisenhauer, D. E. (2012). Effectiveness of Grass Filters in Reducing Phosphorus and Sediment Runoff. Water, Air, & Soil Pollution, 1-11.	Vegetation / Water Quality	Nebraska	General Range	2012	Yes
4	A full report on the state of water resources in Western United States. The second half of report is consisted of the role of science, discussed in three phases: 1) development and construction; 2) consequences and environmental awareness; and 3) sustainability. It also presents three case studies regarding groundwater, water recharge, ecosystems, and endangered species.	Anderson, M. T. and L. H. Woosley Jr., 2005. Water Availability for the Western United States—Key Scientific Challenges. Reston: U.S. Geological Survey.	Hydrology / Impacts / Wildlife	Western USA	General Range	2005	Yes
5	Investigation of buffer width and density management effects on riparian microclimates of headwater streams in western Oregon. Spatial variations in stand density, canopy cover, and microclimate were measured along transects extending from stream center upslope into thinned stands, patch openings, or unthinned stands, with riparian buffers ranging from <5 meters (m) up to 150 m width. Buffers of widths defined by the transition from riparian to upland vegetation or topographic slope breaks appear sufficient to mitigate the impacts of upslope thinning on the microclimate above headwater streams	Anderson, P. D., Larson, D. J., & Chan, S. S. (2007). Riparian buffer and density management influences on microclimate of young headwater forests of western Oregon. Forest Science, 53(2), 254-269.	Vegetation Density	Western Oregon	General Range	2007	Yes
6	The survey of creeks and tributaries within Okanogan River Basin, which spanning over 8,000 square miles across the United States and Canada. Survey includes observational surveys by biologists and data-driven survey based on both measured and web-based data. Surveys were conducted in Antoine Creek, Nine mile Creek, Loup Loup Creek, Tonasket Creek, Bonaparte Creek, Wanacut Creek, Whistler Canyon Creek, and Wildhorse Spring Creek in the United States (Figure 2) and along major tributaries in Canada.	Arterburn J., K. Kistler, and C. Fisher, 2007. Anadromous Fish Passage Barriers In The Okanogan Basin. Prepared for Colville Tribes Department Of Fish And Wildlife Anadromous Fish Division-Omak Office. January 2007.	Fish Passage	Western USA & Canada	General Range	2007	Yes
7	The article discusses how loss of quality brood rearing habitat is associated with decline of greater Sage Grouse (*Centrocercus urophasianus*) populations. More specifically, the study used Southwest Regional Gap land cover types to identify early and late greater sage-grouse brood rearing in east-central Nevada. The researchers examined land cover types and other ecogeographical variables, then generated land-scape scale suitability maps. The research found a strong selection of particular land cover types (e.g., higher elevation, moist sites with riparian shrubs or montane sagebrush) during late brood rearing, suggesting the potential that such habitat could limit sage grouse populations in east-central Nevada.	Atamian M. T., J. S. Sedinger, J. S. Heaton, and E. J. Blomberg, 2010. Landscape-level assessment of brood rearing habitat for greater sage-grouse in Nevada. Journal of Wildlife Management 74(7): 1533-1543.	Wildlife Sage Grouse	Nevada	Arid	2010	Yes

Appendix A
Riparian Buffer Literature Review Master List

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
8	The episodic nature of water availability in arid and semiarid ecosystems has significant consequences on belowground carbon and nutrient cycling. The asynchrony of resource availability, particularly nitrogen versus water due to pulsed water events, may be central to understanding the consequences for ecosystem nutrient retention and long-term effects on carbon and nutrient pools.	Austin, A. T., L. Yahdjian, J. M. Stark, J. Belnap, A. Porporato, U. Norton, D. A. Ravetta, S. M. Schaeffer, 2004. Water pulses and biogeochemical cycles in arid and semiarid ecosystems. Oecologia 141: 221-235.	Hydrology / Nutrient Functions	USA	Arid / Semi-Arid	2004	Yes
9	This guidance document summarizes the characteristics and importance of Washington State shrub steppe habitat, provides the history and impacts of the loss of this habitat, and provides management recommendations including long-range planning and site-specific management techniques. The document also provides techniques towards restoration of shrub-steppe habitat.	Azerrad, J. M., K. A. Divens, M. F. Livingston, M. S. Teske, H. L. Ferguson, and J. L. Davis., 2011. Management recommendations for Washington's priority habitats: managing shrub-steppe in developing landscapes. Washington Department of Fish and Wildlife, Olympia,	Shrub-Steppe Restoration / Management	Washington	Shrub-Steppe	2011	Yes
10	This study delineated 10 patch types within the floodplain of the San Pedro River (Arizona) on the basis of physiognomy, dominant overstory species, and tree size class; also assessed differences in hydrogeomorphology, vegetation structure, plant species richness, and soil chemistry and texture. Patch types include tamarisk (*Tamarix*), cottonwood-willow (*Populus-Salix*), mesquite (*Prosopis*), wet shrublands (*Baccharis salicifolia–Salix exigua*) and dry shrublands (*Hymenoclea-Ericameria*).	Bagstad, K. J., Lite, S. J., & Stromberg, J. C. (2006). Vegetation, soils, and hydrogeomorphology of riparian patch types of a dryland river. Western North American Naturalist, 66(1), 23-44.	Vegetation	Arizona	Dry Shrubland	2006	Yes
11	This article describes an approach that improves traditional groundwater models, such as MODFLOW, through several innovations. First, evapotranspiration from riparian/wetland systems is modeled in a manner that more realistically reflects plant ecophysiology and vegetation complexity. Second, accuracy is further improved by more effective spatial handling of vegetation distribution, which allows modeling of surface elevation and depth to water for multiple vegetation types within each large model cell.	Baird, K. J., Stromberg, J. C., & Maddock, T. (2005). Linking riparian dynamics and groundwater: an ecohydrologic approach to modeling groundwater and riparian vegetation. Environmental Management, 36(4), 551-564.	Groundwater / Vegetation	Arizona	General Range	2005	Yes
12	The manual was prepared to help shrub-steppe and grassland restoration practitioners capitalize on the experiences of their predecessors and colleagues within the Columbia River Basin. The manual includes technical information that veteran shrub-steppe and grassland restoration practitioners in the Columbia Basin indicated were necessary for new restoration project managers to properly plan and successfully execute habitat restoration projects.	Benson, J. E., R.T. Tveten, M. G. Asher, and P.W. Dunwiddie. 2011. Shrub-Steppe and Grassland Restoration Manual for the Columbia River Basin. Bonneville Power Administration. Prepared for Washington Department of Fish and Wildlife. October 2011.	Shrub-Steppe & Grassland Restoration	Columbia River Basin	Shrub-Steppe / Grassland	2011	Yes
13	Report for habitat mitigation associated with the original construction of the Grand Coulee Dam and inundation of habitat by Lake Roosevelt. This report is designed to provide guidance for the management of project lands in relation to the habitat cover types discussed and the indicator species used to evaluate these cover types. In addition, the plan discusses management actions, habitat enhancements, and tools that will be used to enhance, protect and restore habitats to desired conditions.	Berger, M., 1993. Hellsgate winter range mitigation project long-term management plan. Prepared for Colville Confederated Tribes and U.S. Department of Energy. Bonneville Power Administration project number 92-048 . 1993	Dam Hydrology / Management	Lake Roosevelt	General Range	1993	No
14	A report generated to provide the Planning Board, City Council and the Boulder community with information on the value of wetland and stream buffers and a review of regulatory approaches to buffer protection across the U.S. Section I provides background on the role of local governments in regulating wetland and stream buffers. Section II reviews the purpose and functions of buffers and the science-supported buffer widths needed to protect the ecological functions of streams and wetlands. Section III is a discussion and analysis of various approaches to buffer protection among several local jurisdictions across the country. Section IV presents a conclusion to the report and recommendations for change to Boulder's ordinance.	Biohabitats, Inc., 2007. Wetland and stream buffers: A review of the science and regulatory approaches to protection. City of Boulder Planning and Development Series. Prepared for City of Boulder. April 2007.	Buffers	Colorado	General Range	2007	No

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
15	Proper functioning condition (PFC) is a qualitative method for assessing the condition of riparian-wetland areas. PFC is a qualitative assessment based on quantitative science. The manual describes the PFC assessment procedures, including both quantitative and qualitative techniques that covers three quantification areas, hydrology, vegetation and erosion/deposition.	BLM (Bureau of Land Management), 1998. A user guide to assessing proper functioning condition and the supporting science for lotic areas. Technical Report 1737-15. 1998.	Functions	Western USA	General Range	1998	Yes
16	Does flood pulsing drive metacommunity dynamics and provide insurance against catastrophic flooding in desert southwestern riparian ecosystems? Do upland and wetland species in the floodplain differ in their dynamics? → This study found Flood pulsing is one mechanism that drives spatiotemporal metacommunity dynamics in dynamic desert riparian ecosystems. The homogenized regional propagule bank created by flood pulsing provides wetland species with a mechanism to escape local extinction by allowing for recolonization after flooding creates suitable establishment conditions. Upland species are able to germinate from in-situ sources after small-scale flooding or rainfall moistens soil. In fluctuating environments, these dynamics sustain biodiversity in the face of ongoing environmental change.	Boudell, J. A., & Stromberg, J. C. (2009). Flood pulsing and metacommunity dynamics in a desert riparian ecosystem. Journal of Vegetation Science, 19(3), 373-380.	Hydrology / Vegetation	Southwest USA	Desert	2009	Yes
17	Documents effects of altered flow regimes on riparian cottonwood forests along the Yakima River. Negative impacts to species composition, structure, seedling recruitment, sex ratios, and age structure were shown. Invasion by exotic species was also documented. Spring flow release of impounded water was suggested as a solution to cottonwood declines.	Braatne, J. H., R. Jamieson, K. M. Gill, and S. B. Rood, 2007. Instream flows and the decline of riparian cottonwoods along the Yakima River, Washington, USA. River Research and Applications (23)3: 247-267.	Hydrology / Impacts/ Vegetation	Yakima River	General Range	2007	No
18	The study of two sub-basins that documents historic impacts of human activity on alluvial floodplain areas, provide analysis of the impacts of flow regulation on riparian vegetation with two very different flow regulation systems, demonstrate that altered spring flows will result in recruitment to cottonwood stands, and assess the applicability of remote sensing tools for documenting the distribution and health of cottonwood stands and riparian vegetation.	Braatne, J., B. Braatne, and J. Braatne, 2001. Riparian Cottonwood Ecosystems and Regulated Flows in Kootenai and Yakima Subbasins; Impacts of Flow Regulation on Riparian Cottonwood Forests of the Yakima River, 2000-2001. Technical Report, Project No. 200006800, 53 electronic pages, (BPA Report DOE/BP-00000005-3) Prepared for Bonneville Power Administration. October 2001.	Hydrology / Impacts/ Vegetation	Yakima River	General Range	2001	No
19	This study evaluates the effects of season (i.e. dry/cool and wet/warm) and riparian land use (i.e. urban, grazed pasture, ungrazed pasture, wetland, cultivated agriculture and grassland) on surface water quality in a first-order stream within a diverse agricultural watershed in the Ozark Highlands. Results clearly demonstrate the significant effect of adjacent land use on in-stream water quality of a first-order stream in a diverse agricultural watershed and highlight the importance of managing upstream land use in order to regulate downstream water quality	Brion, G. K. R. Brye, B. E. Haggard, C. West, and J. V. Brahana, 2011. Land-use effects on water quality of a first-order stream in the Ozark Highlands, mid-southern United States. River Research and Applications 27: 772-790.	Land Use / Water Quality	Ozark Mountain Range	General Range	2011	Yes
20	This review paper assesses how the functions of the riparian buffer are affected by the design and management of the riparian forest zone, with a focus on the width of the buffer, the structure of the vegetation and species choices.	Broadmeadow, S., and T. R. Nisbet, 2004. The effects of riparian forest management on the freshwater environment: a literature review of best management practice. Hydrology and Earth System Sciences 8(3): 286-305.	Buffers / Riparian Functions	United Kingdom	General Range	2004	Yes
21	A thesis document attempting to synthesize appropriate buffer width using a matrix format. Differences between arid and non-arid landscape characteristics, soil, topography, vegetation, climate and hydrology and their effect on buffers for water quality were also researched in the document. Used as an appendix to develop Buffer Design Guidelines for Water Quality and Wildlife Habitat Functions on Agricultural Landscapes in the Intermountain West.	Buffler, S., 2005. Synthesis of design guidelines and experimental data for water quality function in agricultural landscapes in the intermountain west. Forestry, National Agroforesty Center, Utah State University, Logan, Utah.	Buffers / Water Quality	Intermountain West	Arid / Non-Arid	2005	No

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
22	Study of plant species composition relationship with depth to water-table, soil moisture holding capacity, and soil moisture content in a central Nevada riparian meadow complex. Vegetation types included wet meadow, mesic meadow, dry meadow and sagebrush.	Castelli, R. M., J. C. Chambers, and R. J. Tausch, 2000. Soil-Plant Relations Along a Soil-water Gradient in Great Basin Riparian Meadows. Wetlands 20(2): 251-266.	Hydrology / Vegetation	Nevada	General Range	2000	Yes
23	Discusses how good management of uplands and effective buffer zones along the streams can protect water quality. Suggest various methods such as planted grass and woody strips, contouring the buffer surface, amending soils in degraded riparian areas, and providing short-term erosion protection.	Correll, D. L. (2005). Principles of planning and establishment of buffer zones. Ecological Engineering, 24(5), 433-439.	Vegetation / Water Quality	USA	General Range	2005	Yes
24	The study assesses how fish assemblages within the Isleta Reach respond to irrigation season and off-season variations in water and fish contributions from upstream river channels (Albuquerque Reach) and from the Peralta irrigation system. The results shows irrigation management could be modified to favor native fish ecology by controlling movement of nonnative predators in canal systems and in providing refuge habitats for native fish during periods when water demand exceeds the supply	Cowley, D.E., R. C. Wissmar and R. Sallenave. 2007.Fish assemblages and seasonal movements of fish in irrigation canals and river reaches of the middle Rio Grande, New Mexico (U.S.A.). Ecology of Freshwater Fish. 1 –11.	Fish / Hydrology	New Mexico	General Range	2007	Yes
25	The few available studies suggest that in arid/semi-arid areas groundwater/surface water interactions in wetlands are highly dynamic, are both temporally and spatially complex, and often extend beyond the surface water boundaries of the wetland. In areas where groundwater is low in salinity, it has beneficial impacts on wetland ecology which can be diminished in dry times when groundwater levels and hence inflows to wetlands are reduced or even cease. Conversely, if groundwater is saline, and inflows increase due to raised groundwater levels caused by factors such as land use change and river regulation, then this may have detrimental impacts on the ecology of a wetland and its surrounding areas.	CSIRO Land and Water, 2006. Groundwater - surface water interactions in arid/semi-arid wetlands and the consequences of salinity for wetland ecology. Project 054121: Surface Water -Groundwater Interactions in River Murray Wetlands and Implications for Water Quality and Ecology. Prepared for South Australian Centre for Natural Resources Management. December 2006.	Groundwater / Hydrology	Australia	Arid / Semi-Arid	2006	No
26	The U.S. Geological Survey's National Water-Quality Assessment Program showed that all but two sites in the Columbia Basin ecoregion were impaired, some severely primarily due to the agricultural practices. Multimetric condition indices were developed and used to rank sites on the basis of physical, chemical, and biological characteristics. All indices of biological condition (fish, invertebrates, and algae) declined as agricultural intensity increased.	Cuffney, T. F., M. R. Meador, S. D. Porter, and M. E. Gurtz, 2000. Responses of physical, chemical, and biological indicators of water quality to a gradient of agricultural land use in the Yakima River Basin, Washington. Environmental Monitoring and Assessment 64: 259-270.	Agriculture / Water Quality	Columbia River Basin	Agriculture	2000	Yes
27	General and broad investigation of the role of riparian processes on biogeochemical cycles and biodiversity under different climatic conditions. Their role is investigated by focusing on: i) lateral eco tone between land and water systems, ii) their longitudinal corridor structure and, iii) the dry-wet cycles.	Décamps, H., G. Pinay, R. J. Naiman, G. E. Petts, M. E. Mcclain, A. Hillbricht-Ilkowska, T. A. Hanley, R. M. Holmes, J. Quinn, J. Gibert, A. Planty Tabacchi, F. Schiemer, E. Tabacchi, and M. Zalewski, 2004. Riparian zones: Where biogeochemistry meets biodiversity in management practice. Polish Journal of Ecology 52(1): 3-18.	Climate / Chemical Functions	Poland	General Range	2004	Yes
28	The study proposes that effectiveness can be improved by placing more filter strip where the runoff load is greater and less where the load is smaller. A modeling analysis was conducted of the relationship between pollutant trapping efficiency and the ratio of filter strip area to upslope contributing area, i.e., buffer area ratio. The results were used to produce an aid for designing filter strips having consistent effectiveness along field margins where runoff load is nonuniform.	Dosskey, M. G., Helmers, M. J., & Eisenhauer, D. E. (2011). A design aid for sizing filter strips using buffer area ratio. journal of soil and water conservation, 66(1), 29-39.	Buffers / Water Quality	Nebraska	General Range	2011	Yes
29	Many ecosystems of western North America have been dramatically changed by non-native species. This study reviews ecological impacts of 56 plant, animal, fungus, and protist species that were brought to this region by humans. Then, it discusses characteristics of invasive species that can lead to major ecosystem impacts, and explore how invasive species alter many different attributes of ecosystems.	Dukes, J., and H. Mooney, 2004. Disruption of ecosystem processes in western North America by invasive species. Revista Chilena de Historia Natural 77: 411-437.	Nonnative Species	Western USA	General Range	2004	Yes

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
30	Heterogeneity in stream water temperatures created by local influx of cooler subsurface waters into geomorphically complex stream channels was associated with increased abundance of rainbow trout (*Oncorhynchus mykiss*) and Chinook salmon (*Oncorhynchus tshawytscha*) in northeastern Oregon. The physiognomy, distribution, and connectivity of cold water patches, important attributes determining the effectiveness of these habitats as thermal refuges for stream fishes, were associated with channel bedform and riparian features. Monitoring of thermal heterogeneity and salmonid populations in response to ongoing habitat restoration efforts will provide additional insights into causal relationships among these factors.	Ebersole, J. L., W. J. Liss, and C. A. Frissell, 2003. Thermal heterogrneity, stream channel morphology, and salmonid abundance in northeastern Oregon streams. Canadian Journal of Fisheries and Aquatic Science 60: 1266-1280.	Fish / Water Temperature	Northeast Oregon	General Range	2003	Yes
31	We used a combination of field studies and laboratory experiments to characterize key ecological aspects of the seed biology and soil seed bank dynamics of annual plant communities in chenopod shrublands of South Australia. A sequential study of the soil seed bank demonstrated seasonal and between-year variability in numbers and composition of the soil seed bank.	Facelli, J., P. Chesson, and N. Barnes, 2005. Differences in Seed Biology of Annual Plants in Arid Lands: A Key Ingredient of the Storage Effect. Ecology 86(11): 2998-3006.	Vegetation Seeds	Australia	Shrub	2005	Yes
32	Defines buffer strips and wildlife corridors, then presents comprehensive overview of literatures suggesting various buffer widths and corridors for water quality. Also talks about buffer composition (zones) and vegetation types.	Fischer, R. A., & Fischenich, J. C. (2000). Design recommendations for riparian corridors and vegetated buffer strips (No. ERDC-TN-EMRRP-SR-24). ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS ENGINEER RESEARCH AND DEVELOPMENT CENTER.	Buffers / Water Quality	USA	General Range	2000	No
33	An overview of the Ecosystem Management and Restoration Research Program (EMRRP) and description of its research projects in 4 different phases: 1) site evaluation and selection, 2) plant species selection, 3) available planting techniques, spacing, and architecture, and 4) techniques for developing long-term monitoring protocols.	Fischer, R., 2008. Riparian restoration and management needs in the semi-arid western United States. Technology News from the Ecosystem Management and Restoration Research Program. January 2003.	Management / Vegetation	Western USA	Semi-Arid	2008	No
34	This article describes work to develop technical guidelines for restoring and managing riparian buffer zones and corridors. The potential benefits-with regard to water quality and many important ecological functions-are significant.	Fischer, R., C. Martin, and U.S. Army Engineer Waterways Experiment Station, 1998. Corridors and vegetated buffer zones—guidelines for Corps of Engineers projects. Technology News from the Ecosystem Management and Restoration Research Program. April 1998.	Management	Southeast USA	General Range	1998	No
35	Blue elderberry is the sole host plant for the federally threatened Valley elderberry longhorn beetle, yet controls on the shrub's distribution have largely been untested. We used nested hierarchical analyses to test hypotheses about the role of broad- and fine-scale variables structuring the distribution of elderberry in one undammed and three dammed rivers in California's Central Valley (USA). It was found that Elderberry presence across the floodplains was primarily driven by broad-scale hydrologic regime, as represented by the relative elevation, floodplain width, and lateral distance of shrubs from the stream, and secondarily by sediment texture and topography.	Fremier, A. K., and T. S. Talley, 2009. Scaling riparian conservation with river hydrology: Lessons from blue elderberry along four California rivers. Wetlands 29(1): 150-162.	ESA / Hydrology / Vegetation	California	General Range	2009	Yes
36	Spatial analysis of riparian modifications on anadromous fish bearing streams in the interior Columbia basin to provide a starting point for restoration priorities. Interesting citations on the required width of buffers and connectivity or riparian patches for full function (Broadmeadow/Nisbet) and length of riparian needed to restore control levels of nutrients, dissolved oxygen and temperature (pg 1356 2nd para.)	Fullerton, A. H., T. J. Beechie, S. E. Baker, J. E. Hall, and K. A. Barnas, 2006. Regional patterns of riparian characteristics in the interior Columbia River basin, northwestern USA: Application for restoration planning. Landscape Ecology 21: 1347-1360.	Buffers / Fish / Management	Columbia River Basin	General Range	2006	Yes

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
37	Three river conceptual models make differing predictions about the major source of primary production in lowland rivers, acknowledging the importance of primary productivity in the ecology and management of lowland rivers. Patterns of primary production in lowland rivers are still an area of considerable uncertainty. The objective of this study was to examine the major sources and transformations of organic matter in an Australian lowland river and compare them to the predictions of existing models.	Gawn, B., C. Merrick, D. G. Williams, G. Rees, R. Oliver, P. M. Bowen, S. Treadwell, G. Beattie, I. Ellis, J. Frankenberg, and Z. Lorenz, 2007. Patterns of Primary and Heterotrophic Productivity in an Arid Lowland River. River Research and Applications 23: 1070-1087.	Hydrology / Organic Productivity	Australia	General Range	2007	Yes
38	A background information on riparian buffers, designed to accompany the RappFLOW Riparian Buffer Evaluation Data Sheet. The manual also contains additional information for volunteers, such as safety tips, a checklist for equipments and an in-depth explanation of each evaluation items.	Gloyd, M., 2006. Riparian buffer evaluation program. Volunteer handbook. Prepared for Virginia Technical Institute. Summer 2006.	Other (Handbook)	Virginia	General Range	2006	No
39	Within a semi-arid region, study of the factors affecting riparian litterfall biomass. Results indicated that river distance and nutrient cycling (particularly P over N) and forest structure (basal area) were the limiting factors.	Gonzalez, E., E. Mueller, B. Gallardo, F. Comin, and M. Gonzalez-Sanchis, 2010. Factors controlling litter production in a large Mediterranean river floodplain forest. Canadian Journal of Forest Restoration 40: 1698-1709.	Nutrient Functions / Vegetation	Spain	Semi-Arid	2010	Yes
40	In this study, the mortality rates and abundances of *Populus alba, P. nigra, Salix alba* and local *Tamarix spp.* were examined in 43 plots with different hydrologic conditions distributed across the floodplain of a large semi-arid and Mediterranean river, the Ebro River (Spain). The results suggested that eventual natural or regulation-induced droughts and groundwater declines would accelerate the loss of all phreatophytic species, especially S. alba.	Gonzalez, E., M. Gonzalez-Sanchis, F. A. Comin, and E. Muller, 2012. Hydrologic thresholds for riparian forest conservation in a regulated large mediterranean river. River Research and Applications 28: 71-80.	Hydrology / Vegetation	Spain	Semi-Arid	2012	Yes
41	The study examined differences in sockeye salmon spawning times in the river and riparian ponds and pond habitat preferences. Researchers found several factors that differentiates ponds habitats from rivers, such as usages at high flow at the river, habitat preferences in upwelling areas, as well as timing of spawning.	Hall, J. L., R. K. Timm and R. C. Wissmar. 2000. Physical And Biotic Factors Affecting Use of Riparian Ponds Sockeye Salmon. Pages 89 – 94, in P. J. Wigington and R. L. Beschta, editors. Proceedings of the International Conference on Riparian Ecology and Management in Multi-Land Use Watersheds. American Water Resources Association.	Fish	Cedar River Basin	General Range	2000	Yes
42	Another report aims to establish a scientific guidance "to make decision about what widths are necessary to restore riparian zones to the point where they can perform these functions". The report also reviews existing literatures organized in functions, physical factors, species and land uses. Then, it makes recommendations for minimum protected and restored riparian widths for Victorian riverine environments, and also set up a guidelines operable for land managers and field assessors to determine suitable fenced-off riparian zone widths.	Hansen, B., Reich, P., Lake, P. S., & Cavagnaro, T. (2010). Minimum width requirements for riparian zones to protect flowing waters and to conserve biodiversity: a review and recommendations. Report to the Office of Water, Victorian Department of Sustainability and Environment.	Buffers / Management	Canada	General Range	2010	No
43	This hardcopy report is an excerpt from the CAO: BAS review. It discusses riparian buffer widths in relation to limiting factors, provides a summary of BAS recommended buffer widths for ecological function, reviews existing riparian conditions in the County, and makes recommended provisions for the County CAO Code.	HDR, Inc., 2008. Critical areas ordinance: Best available science review. Prepared for Walla Walla County. August 2008.	Buffers / CAO	Walla Walla County	General Range	2008	No

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
44	This is a fact-finding report prepared for Washington State's Senate Bill 5248 Preserving the viability of agricultural lands. The paper includes a summary of facts and highlights that would appear to be of interest and relevance to the SSB 5248. Contents of the report includes the definition of Riparian Buffers, functions of riparian zones, anadromous habitat reliance on riparian zones, and other riparian habitat protection practices, such as stewardship, large woody debris and stream bank stabilization.	Horowitz, J., 2009. Buffers and agricultural practices related to riparian habitat protection. UW Department of Civil and Environmental Engineering, University of Washington, Seattle, Washington.	Agriculture / Buffers / Functions	Washington	General Range	2009	No
45	Same as above, but this document contains case studies and appendix.	Johnson, C. W., and B. Susan, 2008. Riparian Buffer Design Guidelines for Water Quality and Wildlife Habitat Functions on Agricultural Landscapes in the Intermountain West. Case Study. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Mountain Research Station. 53 p.	Agriculture / Management	Intermountain West	Agriculture	2008	Yes
46	Document contains a hypothetical case study to illustrate how the riparian buffer protocol can be used to plan a buffer for both water quality and wildlife conservation. Majority of document consists of appendices to work through the protocol (data sheets, worksheets, specifications).	Johnson, C. W., and B. Susan, 2008. Riparian Buffer Design Guidelines for Water Quality and Wildlife Habitat Functions on Agricultural Landscapes in the Intermountain West. General Technical Report RMRS-GTR-203. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Mountain Research Station. 53 p.	Agriculture / Management	Intermountain West	Agriculture	2008	Yes
47	A technical memo on stream setback regulations for Napa County. It describes that setbacks are designed to address sediment delivery issues are commonly developed to increase in width as slope increases. On the other hand, setbacks designed to protect and enhance habitat generally increase as natural floodplain width increases or as slope decreases	Jones & Stokes, 2002. Stream Setback Technical Memo. Prepared for the Napa County Conservation, Development, and Planning Department. October 2002.	Buffers / Management	California	General Range	2002	No
48	The study examines a restoration project aimed at recovery of groundwater levels and base flows on an undammed desert river by sampling streamside plants communities and hydrology annually from 2003 to 2008. The result indicates that while hydrology is a key factor shaping desert streamside plant communities, sites may respond differently due to differences in hydrogeomorphic context, exacerbated by drought.	Katz, G. L., Stromberg, J. C., & Denslow, M. W. (2009). Streamside herbaceous vegetation response to hydrologic restoration on the San Pedro River, Arizona. Ecohydrology, 2(2), 213-225.	Groundwater / Vegetation	Arizona	Desert	2009	Yes
49	Expanding upon studies of above-ground effects of grazing on riparian communities, this study quantifies the belowground effects of grazing (infiltration rates, biomass, soil properties) in herbaceous-dominated riparian meadows.	Kauffman, J. B., A. S. Thorpe, and E. N. J. Brookshire, 2004. Livestock Exclusion and Belowground Ecosystem Responses in Riparian Meadows of Eastern Oregon. Ecological Applications 14(6): 1671-1679.	Grazing	Eastern Oregon	Grazing	2004	Yes
50	They evaluated eight habitat objectives used by land management agencies within the Interior Columbia Basin to determine if the current riparian management objectives (RMOs) were representative of conditions found at reference sites, had values which differed significantly between reference and managed watersheds, and whether these RMOs could be consistently applied across the study area.	Kershner, J. L., and B. B. Roper, 2010: An Evaluation of Management Objectives Used to Assess Stream Habitat Conditions on Federal Lands within the Interior Columbia Basin. Fisheries 35(6): 269-278.	Management	Columbia River Basin	General Range	2010	Yes
51	Review of USGS streamflow gains and losses in the Columbia Basin (Snake, Lemhi, Willamette, Deschutes, Methow, Spokane Rivers) to identify patterns in the location and timing of river-aquifer exchanges. Largest exchanges were associated with unconsolidated sedimentary deposits with uneven thicknesses in the downstream direction, lithologic contacts providing vertical permeability contrasts, and channel form that increases the hydraulic gradient of the cross-sectional area of flow paths between groundwater and surface water.	Konrad, C. P., 2006. Location and timing of river-aquifer exchanges in six tributaries to the Columbia River in the Pacific Northwest of the United States. Journal of Hydrology 329: 444-470.	Hydrology	Columbia River Basin	General Range	2006	Yes

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
52	Review of provincial, territorial and state guidelines for riparian buffer preservation, does not have a semi-arid focus. Discussion includes a review of studies that recommend buffer widths based on riparian function, structure, and /or biota (pgs 172-174).	Lee, P., C. Smyth, and S. Boutin, 2004. Quantitative review of riparian buffer width guidelines from Canada and the United States. Journal of Environmental Management 70(2): 165-80.	Buffers / Functions	USA & Canada	General Range	2004	Yes
53	The report was prepared to synthesize current knowledge of the ecology and hydrology of ephemeral and intermittent streams in the American Southwest, which make up approximately 81% of all streams in the region. The report is aimed at placing these streams in a watershed context, thereby highlighting their importance in maintaining water quality, overall watershed function or health, and provisioning of the essential human and biological requirements of clean water. It concludes that consideration of the cumulative impacts from anthropogenic uses on these streams is critical in watershed-based assessments and land management decisions to maintain overall watershed health and water quality.	Levick, L., J. Fonseca, D. Goodrich, M. Hernandez, D. Semmens, J. Stromberg, R. Leidy, M. Scianni, D. P. Guertin, M. Tluczek, and W. Kepner, 2008. The Ecological and Hydrological Significance of Ephemeral and Intermittent Streams in the Arid and Semi-arid American Southwest. Washington D.C.: U.S. Environmental Protection Agency and USDA/ARS Southwest Watershed Research Center, EPA/600/R-08/134, ARS/233046, 1-116.	Hydrology / Water Quality	Southwest USA	Arid / Semi-Arid	2008	Yes
54	The study examined the effect of plastic mulch type (permeable and non permeable) and distance fro the center of the mulch to the edge (half the width) on soil water potential and plant survivorship. The result showed Mulch type had no effect on soil moisture retention. Wide strips held water longer than narrow strips. - N/A?	Link, S. O., A. Bower, 2004. Effect of mulch type and width on soil water potential and plant survivorship in a semi-arid riparian ecosystem. Northwest Science 78(3): 334-338.	Mulch / Vegetation	Walla Walla County	Semi-Arid	2004	Yes
55	Relates to species richness of riparian buffers based on environmental gradients rather than riparian buffer functions - probably NA	Lite, S. J., K.J. Bagstad, and J.C. Stromberg, 2005. Riparian plant species richness along lateral and longitudinal gradients of water stress and flood disturbance, San Pedro River, Arizona, USA. Journal of Arid Environments 63(4).	Vegetation Diversity	Arizona	Arid	2005	Yes
56	Discusses a type of riparian habitat feature 'litter hovel', (i.e. flood-deposited clumps of intertwined plant material and inorganic debris attached to trees and elevated above the ground by past high water events), as spider habitats as a unique, persistent, and unstudied habitat type for spiders. Spider abundance and diversity at the family level were positively correlated with litter hovel size.	Loeser, M., B. H. McRae, M. M. Howe, and T. G. Whitham, 2006. Litter hovels as havens for riparian spiders in an unregulated river. Wetlands 26(1): 13-19.	Debris / Insects	Arizona	General Range	2006	Yes
57	A review of policy tools used for the protection of riparian landscapes in arid and semi-arid Israel, focusing on legislation, institutional structure and physical planning as they emerge from relevant laws, reports and literature. The article concludes with a few suggestions, including: integration of existing laws based on a whole watershed approach; reorganization of institutional structure to facilitate a national vision of riparian landscapes rather than the existing particularistic approach; formulation of structured planning procedures to ensure the realization of designated national plans; and promotion of awareness to riparian values at various levels.	Maruani, T., and I. Amit-Cohen, 2009. The effectiveness of the protection of riparian landscapes in Israel. Land Use Policy 26: 911-918.	Management	Israel	Arid / Semi-Arid	2009	Yes
58	Collection (survey) of researches on the topic of the effects of water temperature on freshwater fish. Current researches are organized in varying scales and approaches, such as molecular, organism, population/species, community and ecosystem, and policy issues in water quality. The last two categories can be related to the issue of riparian buffer management.	Mccullough, D. A., J. M. Bartholow, H. I. Jager, R L. Beschta, E. F. Cheslak, M. L. Deas, J. L. Ebersole, J. S. Foott, S. L. Johnson, K. R. Marine, M. G. Mesa, J. H. Petersen, Y. Souchon, K. F. Tiffan, and W. A. Wurtsbaugh. Research in thermal biology: Burning questions for coldwater stream fishes. Reviews in Fisheries Science 17(1): 90-115.	Fish / Water Temperature	Western USA	General Range	2009	Yes

Appendix A
Riparian Buffer Literature Review Master List

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
59	Collection (survey) of researches on the topic of the effects of water temperature on freshwater fish. Current researches are organized in varying scales and approaches, such as molecular, organism, population/species, community and ecosystem, and policy	McIntosh, B.A., J.R. Sedell, J.E. Smith, R.C. Wissmar, S.E. Clarke and G.R. Reeves,and L.A. Brown. 1994. Historical changes in fish habitat for select river basins of eastern Oregon and Washington. Special Issue: Northwest Science.69: 36-53.	Fish / Water Temperature	Columbia River Basin	General Range	1994	Yes
60	Study of the environmental factors that influence *Oncorhynchus mykiss gairdneri* occurrence and abundance in the Snake River of Idaho. In desert sections the main variables for occurrence included shading (+), percent of fine substrate (-), percent of cobble/boulders (+), and abundance of northern pike minnow and smallmouth bass (-). Density was affected by stream order (-), stream shading (+), and percent of cobble/boulder substrate (+).	Meyer, K. A., J. A. Lamansky, and D.J. Schill, 2010. Biotic and Abiotic Factors Related to Redband Trout Occurrence and Abundance in Desert and Montane Streams. Western North American Naturalist 70(1): 77-91.	Fish	Idaho	General Range	2010	Yes
61	Overview of impacts from river regulation. Upstream effects include habitat inundation and new riparian zones. Downstream effects include hydrology and geomorphology (sediment) changes, alterations of riparian communities, salinization, and exotic species invasions.	Nilsson, C., and K. Berggren, 2000. Alterations of Riparian Ecosystems Caused by River Regulation. Bioscience 50(9).	Dam Hydrology / Management	Europe & North America	General Range	2000	Yes
62	NOAA guideline & case studies of visual impact assessment techniques, existing programs, mitigation, and summary.	NOAA (National Oceanic and Atmospheric Administration), 2005. Visual impact assessment of small docks and piers: Theory and practice. Decision Analysis Series No. 25.	Dock & Pier Impacts	Eastern USA	General Range	2005	No
63	The article describes a method to rapidly categorize buffer width and landuse attributes using 2007 leaf-on aerial photography in a 65 km section of the Toccoa River in north Georgia, then repeated with 1999 images to assess its potential usages for monitoring. The result showed almost half (45%) of the length of the Toccoa River was bordered by buffers less than 50 ft wide in 2007. However, field verification indicated that our method overestimated buffer widths and forested land use and underestimated built-up land use and the number of buildings within 100 ft of the river.	Owers, K. A., Albanese, B., & Litts, T. (2012). Using Aerial Photography to Estimate Riparian Zone Impacts in a Rapidly Developing River Corridor. Environmental management, 1-10.	Buffers / Management	Georgia	General Range	2007	Yes
64	General overview of the riparian ecosystems of the semi-arid west. It talks about landscape, elevation, hydrologic and geomorphic factors that affect characteristics of each riparian systems. This paper can be a good reference for broadly defining different ecosystem types in the semi-arid west. Also discusses general trends in human impact and urbanization.	Patten, D. T. (1998). Riparian ecosytems of semi-arid North America: Diversity and human impacts. Wetlands, 18(4), 498-512.	Functions	Western USA	Semi-Arid	1998	Yes
65	Discussion of the functions and controlling factors of riparian ecosystems as well as human impacts within semi-arid regions of North America. Includes a comparison of driving variables of this habitat over elevational (longitudinal), latitudinal and temporal gradients as well as geographic similarities of structure and function.	Patten, D. T., 1998. Riparian ecosytems of semi-arid North America: Diversity and human impacts. Wetlands 18(4): 498-512.	Functions / Management	Western USA	Semi-Arid	1998	Yes
66	Study concluded that LWD piles formed after large floods act as resource nodes by accumulating fine sediments and by retaining soil nutrients and soil moisture.	Pettit, N., and R. J. Naiman, 2005. Flood-deposited wood debris and its contribution to heterogeneity and regeneration in a semi-arid riparian landscape. Ecosystem Ecology 145: 434-444.	Wood Functions	South Africa	Semi-Arid	2005	Yes
67	Recognizing the fact that interfering with natural flow of water comes at great cost, the study looks at the history of altering the flow of streams and rivers, then how this alteration in hydrological processes affected ecological functions of streams and rivers. Finally, recent restoration and management projects toward natural flow regime are introduced and discussed.	Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., ... & Stromberg, J. C. (1997). The natural flow regime. BioScience, 769-784.	Hydrology / Management	Western USA	General Range	1997	Yes

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
68	Talks about climate change mitigation and adaptation plans and limited resources (such as federal funding or ACESA) availability to fund planning activities. Sectional discussions includes water quality and quantity, disproportionate burdens on tribes imposed by some regulations, land use and population growth, protection of traditional knowledge and adaptation technologies and projected treaty changes for the future climate change. It concludes by demanding direct funding structure and language changes in ACESA bill.	Quinault Nation, Swinomish Nation, Tulalip Tribes, 2009. A tribal white paper on climate change adaptation and mitigation from the intertribal climate change working group. Prepared for U.S. Environmental Protection Agency. August 2009.	Climate Change	Alaska & Washington	General Range	2009	No
69	pdf missing	Riggs, A. C., and J. E. Deacon, 2004. Connectivity in desert aquatic ecosystems - The Devils Hole Story. Spring-fed Wetlands, Important Scientific and Cultural Resources of the Intermountain Region, Las Vegas, Nevada, May 7-9, 2002, Proceedings. Las Vegas: Department of Human Services Publication No. 41210, p. 1-38.	Hydrology	Nevada	pdf missing	2004	No
70	Looking at the relationship between the input of terrestrial invertebrates and emergence of adult aquatic insects in a coastal Mediterranean basin in California to assess seasonal patterns, annual fluxes, and local variation. It relates to organism-scale habitat functions of the riparian areas.	Rundio, D. E., and S. T. Lindley, 2012. Reciprocal fluxes of stream and riparian invertebrates in coastal California basin with Mediterranean climate. Ecological Research 27: 539-550.	Invertebrates / Insects	California	Coastal	2012	Yes
71	This is a modeling study to compare alternative layout and strip sizes while dealing with challenges in flow routing scheme. In this study, the Soil and Water Assessment Tool (SWAT) was applied to the Walnut Creek watershed and the hillslope option was used to examine the effectiveness of contour and riparian buffer strips in reducing NO3-N outflows from crop fields to the river.	Sahu, M., & Gu, R. R. (2009). Modeling the effects of riparian buffer zone and contour strips on stream water quality. Ecological Engineering, 35(8), 1167-1177.	Buffers / Water Quality	Iowa	General Range	2009	Yes
72	Relates to species richness of riparian buffers based on environmental gradients rather than riparian buffer function.	Salinas, M. J., and J.J. Casas, 2007. Riparian vegetation of two semi-arid Mediterranean rivers: Basin-scale responses of woody and herbaceous plants to environmental gradients. Wetlands 27(4): 831-845.	Species Diversity	Mediterranean	Semi-Arid	2007	Yes
73	Riparian zones can strongly influence the exchange of nutrients between streams and their watersheds, but not much works have been done in arid climates. This article tries to determine the strength and direction of hydrologic linkages between stream and riparian zone, and to estimate the extent of uptake of streamwater N by riparian trees in Sycamore Creek, a Sonoran Desert stream.	Schade, J. D., J. R. Welter, E. Martí, and N. B. Grimm, 2005. Hydrologic exchange and n uptake by riparian vegetation in an arid-land stream. Journal of North American Bethnological Society 24(1): 19028.	Hydrology / Nutrient Functions	California	Arid	2005	Yes
74	Describes riparian areas in the Great Basin region through their limiting factors and ecological values (including their composition of flora and fauna). Discusses the threats to this habitat type including various land uses, infrastructure projects, plant invasions, and disturbances (fire) and discusses conservation policy and local techniques for landowners.	Schenk, M., and L. Goldblatt. Riparian areas of the Great Basin: A management guide for the landowners. Prepared for Wildlife Habitat Council. 2005.	Impacts / Management	Western USA	General Range	2005	No
75	Present designs tend to use one model with a zone of unmanaged trees nearest the stream followed by a zone of managed trees with a zone of grasses adjacent to the crop field. Numerous variations of that design using trees, shrubs, native grasses and forbs or nonnative cool-season grasses may provide better function for riparian forest buffers in specific settings.	Schultz, R. C., Isenhart, T. M., Simpkins, W. W., & Colletti, J. P. (2004). Riparian forest buffers in agroecosystems–lessons learned from the Bear Creek Watershed, central Iowa, USA. Agroforestry Systems, 61(1), 35-50.	Management / Vegetation	Iowa	General Range	2004	Yes

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
76	Riparian setbacks are a zoning tool local governments can use to maintain riparian functions as communities grow and land is developed. In the Chagrin River watershed and nationwide, communities recognize the need for riparian setbacks as a preventive tool to minimize encroachment on stream channels while providing a cost-effective alternative that minimizes the need for storm water infrastructure and engineered solutions to flooding, erosion, and water quality problems. This report provides the technical information necessary for these decision makers, and also discusses the economics of riparian setbacks and the implementation of riparian setbacks through zoning regulations.	Schwartz, S., & Houser, D. (2006). Riparian Setbacks: Technical Information for Decision Makers. Chagrin River Watershed Partners. Inc. Willoughby, Ohio.	Buffers	Ohio	General Range	2006	No
77	In an effort to determine a value of ecological and natural resources that provide necessary functions within ecosystems, this paper presents a framework that estimates and compiles the components of value for a natural ecosystem. When the framework was applied to ecological resources in a shrub–steppe dryland habitat being displaced by development, the highest values of natural shrub–steppe habitat appear to be derived from soil stabilization.	Scott, M. J., P. F. Ricci, H. E. Seely, G. R. Bilyard, S. O. Link, C. A. Ulibarri, H. E. and Westerdahl, 1998. Valuation of Ecological Resources and Functions. Environmental Management 22(1): 49-68.	Functions / Management	Intermountain West	Shrub-Steppe	1998	Yes
78	This paper compares ecosystem water and carbon dioxide (CO2) fluxes over a grassland, a grassland–shrubland mosaic, and a fully developed woodland to evaluate potential consequences of woody-plant encroachment on important ecosystem processes.	Scott, R., T. E. Huxmanw, D. G . Williams, and D. C. Goodrich, 2006. Ecohydrological impacts of woody-plant encroachment: seasonal patterns of water and carbon dioxide exchange within a semiarid riparian environment. Global Change Biology 12: 311-324.	Chemical Functions	Southwest USA	Semi-Arid	2006	Yes
79	Areas surrounding wetlands and streams are more than just zones to protect aquatic resources. Two conservation biologists describe these areas as core habitat for semi-aquatic species and call for new criteria to evaluate, protect, and mange these critical areas.	Semlitsch, R., and J. Jensen, 2001. Core habitat, not buffer zone. National Wetlands Newsletter 23(4): 5-6, 11. September 2005.	Wildlife / Management	USA	General Range	2005	No
80	This paper retrospectively examines establishment of four woody riparian species along the Bill Williams River, Arizona, USA, in the context of annual patterns of streamflow for the years 1993-1995. The results of this study suggest that the basic components of models that relate establishment of *Populus spp* . to annual patterns of streamflow may also be applicable to other woody riparian species.	Shafroth, P. B., G. T. Auble, J. C. Stromberg, and D. T. Patten, 1998. Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams River, Arizona. Wetlands 18(4): 577-590.	Hydrology / Vegetation	Arizona	General Range	1998	Yes
81	River damming and flow regulation can alter disturbance and stress regimes that structure riparian ecosystems. The paper studies the Bill Williams River in western Arizona, USA, to understand dam-induced changes in channel width and in the areal extent, structure, species composition, and dynamics of woody riparian vegetation.	Shafroth, P. B., G. T. Auble, J. C. Stromberg, and D. T. Patten, 2002. Riparian vegetation response to altered disturbance and stress regimes. Ecological Society of America 12(1): 107-123.	Dam Hydrology / Vegetation	Arizona	General Range	2002	Yes
82	The study observes groundwater dynamics and the response of Populus fremontii, *Salix gooddingii* , and *Tamarix ramosissima* saplings at 3 sites between 1995 and 1997 along the Bill Williams River, Arizona. The result founds a decline in water table relative to the condition under which roots developed may strand plant roots where they cannot obtain sufficient moisture. At the same time, plant response is likely mediated by other factors such as soil texture and stratigraphy, availability of precipitation-derived soil moisture, physiological and morphological adaptations to water stress, and tree age.	Shafroth, P. B., Stromberg, J. C., & Patten, D. T. (2000). Woody riparian vegetation response to different alluvial water table regimes. Western North American Naturalist, 60(1), 66-76.	Groundwater / Vegetation	Arizona	General Range	2000	Yes

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
83	Among low-elevation riverine environments within the Colorado River watershed, restoration is typically conducted to improve degraded habitats for birds of conservation concern by replacing the exotic tamarisk (*Tamarix ramosissima*) with native cottonwoods (*Populus spp.*) and willows (*Salix spp.*). The paper argues that based on data collected at exotic and restored (i.e., native) sites along the Las Vegas Wash, Nevada, not all birds benefit from restoration.	Shanahan, S.A., S. M. Nelson, D. M. Van Dooremolen, J. R. Eckberg, 2011. Restoring habitat for riparian birds in the lower Colorado River watershed: An example from the Las Vegas Wash, Nevada. Journal of Arid Environments 75: 1182-1190.	Birds / Vegetation	Nevada	Arid	2011	Yes
84	Understanding riparian habitat distributions is important for assessing nutrient buffering potential in watersheds. The study used field based vegetation data and digitally-derived terrain variables to assess and predict the extent of riparian vegetations and their compositions. The result also founds that the optimum grid size of 20 - 30m can be used in this watershed.	Shoutis, L., Patten, D. T., & McGlynn, B. (2010). Terrain-based predictive modeling of riparian vegetation in a Northern Rocky Mountain watershed. Wetlands, 30(3), 621-633.	Nutrients / Vegetation	Northern Rocky Mountains	General Range	2010	Yes
85	Streamflow dynamics and channel interactions help determine natural or background habitat quality within and along river longitudinal and environmental gradients from mountains through basins in the western United States. In addition stream size, position in the watershed, and flow are related to sediment sorting, channel bank strength, and channel configuration.	Skinner, Q., 2003. Rangeland Monitoring: Water Quality and Riparian Systems. Arid Land Research and Management 17(4): 407-429.	Erosion / Hydrology	Western USA	General Range	2003	Yes
86	Understanding patterns of plants species composition and distribution within riparian corridors is helpful in planning for the management and protection of buffer strips. The paper compare and analyze 192 quadrants located on transects radiating away from mixed perennial and intermittent stream system in semi-arid regions in Arizona by sampling woody and herbaceous plants.	Snyder, K. A., D. P. Guertin, R. L. Jemison, and P. F. Ffolliott, 2002. Riparian plant community patterns: A case study from southeastern Arizona. Journal of the Arizona-Nevada Academy of Science 34(2): 106-111.	Buffers / Vegetation	Arizona	Semi-Arid	2002	Yes
87	The purpose of this study was to develop a methodology to evaluate the potential for riparian vegetation restoration and groundwater recharge in arid southwestern United States. recharge. A numerical groundwater flow model was coupled with a conceptual riparian vegetation model to predict hydrologic conditions favorable to maintaining riparian vegetation downstream of a reservoir. Simulations indicated that seasonally variable releases would produce surface flow 5.4-8.5km below the dam in a previously dry reach, and a 5-6.5 fold increase in area capable of sustaining riparian vegetation.	Springer, A. E., Wright, J. M., Shafroth, P. B., Stromberg, J. C., & Patten, D. T. (1999). Coupling groundwater and riparian vegetation models to assess effects of reservoir releases. Water Resources Research, 35(12), 3621-3630.	Groundwater / Vegetation	Southwest USA	Arid	1999	Yes
88	pdf missing	Stonestrom, D. A., D. E. Prudic, R. J. Laczniak, and K. C. Akstin, 2004. Tectonic, climatic, and land-use controls on ground-water recharge in an arid alluvial basin: Amargosa Desert, U.S.A. Groundwater recharge in a desert environment---The southwestern United States: American Geophysical Union Water Science and Applications Series, v. 9. Washington D.C.: American Geophysical Union, 29-47.	Groundwater / Hydrology	Southwest USA	Arid	2004	Yes
89	Many riparian ecosystem restoration projects are achieving success because they recognize the importance of restoring the hydrologic regime. This paper describes that successful projects are restoring flows of water and sediment in sufficient quantities and with appropriate temporal and spatial patterns.	Stromberg, J. C. (2001). Restoration of riparian vegetation in the south-western United States: importance of flow regimes and fluvial dynamism. Journal of Arid Environments, 49(1), 17-34.	Hydrology / Management	Southwest USA	General Range	2001	Yes

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
90	The research discovers that plant diversity and patterning along a topogradient from the floodplain to the arid upland can be shifted as microscale factors changes. Disturbance and resource availability thus interacted to influence plant species diversity in a fashion consistent with the dynamic-equilibrium model of species diversity. In contrast to the microscale patterns, mesoscale diversity of species and functional types remained high in the floodplain because of the combination of moderate resource levels (groundwater, seasonal flood water) and persistent effects of flood disturbance (high spatial heterogeneity, absence of competitive exclusion), in concert with the same climatic factors that produce seasonally high diversity in the region (temporally variable pulses of rainfall).	Stromberg, J. C. (2007). Seasonal reversals of upland-riparian diversity gradients in the Sonoran Desert. Diversity and distributions, 13(1), 70-83.	Hydrology / Vegetation	Arizona	General Range	2007	Yes
91	southwestern United States. This chapter of the book discusses examples of flood-assisted restoration efforts, organized by restoration goals. Restoration goals include restoring dominant species, exotic species management, restoring plants productivity, minimizing fire disturbance, and restoring	restoration of riparian vegetation in the American Southwest. Flood pulsing in wetlands: restoring the natural hydrological balance. John Wiley and Sons, New York, New	Hydrology / Management / Vegetation	Southwest USA	General Range	2002	Yes
92	The effects of stream flow diversion on riparian vegetation can vary from subtle to extreme. Extreme effects include extensive loss of riparian vegetation. This study reveals that the presence of subtle diversion effects within Bishop Creek, as indicated by younger age and size, higher mortality, and lower canopy foliage density of black cottonwood stands.	Stromberg, J. C., & Patten, D. T. (1992). Mortality and age of black cottonwood stands along diverted and undiverted streams in the eastern Sierra Nevada, California. Madrono, 39(3), 205-223.	Hydrology / Vegetation	California	General Range	1992	Yes
93	The upper Owens River channel has tripled the volume of flow and altered channel and floodplain morphology. These changes have influenced density, distribution, and growth response of dominant riparian tree, *Salix lasiolepis* (white willow). As opposed to the natural flow reach, he study founds that growth of willow in the augmented reach decreases with annual flow volume and limited by very high flows.	Stromberg, J. C., & Patten, D. T. (1992). Response of Salix lasiolepis to augmented stream flows in the upper Owens River. Madrono; a West American journal of botany, 39(3), 224.	Hydrology / Vegetation	Arizona	General Range	1992	Yes
94	Dendro-ecological studies indicated that radial growth of Populus trichocarpa was significantly related to annual streamflow at 20 riparian sites in the eastern Sierra Nevada of California. The strength of the relationship varied among sites, depending on geomorphology and tree cover. More specifically, the data suggests that *P. trichocarpa* trees in confined canyons, in comparison with those in wide alluvial valleys, may rely to a greater extent on water sources that are not in direct hydraulic connection with surface water.	Stromberg, J. C., & Patten, D. T. (1998). Instream flow and cottonwood growth in the eastern Sierra Nevada of California, USA. Regulated Rivers: Research & Management, 12(1), 1-12.	Hydrology / Vegetation	California	General Range	1998	Yes
95	Much of the San Pedro river flows intermittently, and there are concerns over the future status of the riverine ecosystem. This study describes the response of the streamside herbaceous vegetation to changes in stream flow permanence.	Stromberg, J. C., Bagstad, K. J., Leenhouts, J. M., Lite, S. J., & Makings, E. (2005). Effects of stream flow intermittency on riparian vegetation of a semiarid region river (San Pedro River, Arizona). River Research and Applications, 21(8), 925-938.	Hydrology / Vegetation	Arizona	General Range	2005	Yes
96	Marshes are rare in the desert Southwest, but a riverine marsh along the Hassayampa River increased 5-fold after a large winter flood in 1993. The article documents how the transition from mature woodlands into a marsh habitat occurs, highlighting the transitory nature of riverine marsh and other vegetation patch types in the dynamic floodplains of alluvial, arid-land rivers.	Stromberg, J. C., Fry, J., & Patten, D. T. (1997). Marsh development after large floods in an alluvial, arid-land river. Wetlands, 17(2), 292-300.	Hydrology / Vegetation	Arizona	Arid	1997	Yes
97	In March 1991, a 10 year return flood occurred in the Hassyampa River. This paper documents native and exotic trees and herbaceous species responses on high flood plains, on lower-elevation flood plains, and along overflow channels and main channel sediment bars.	Stromberg, J. C., Richter, B. D., Patten, D. T., & Wolden, L. G. (1993). Response of a Sonoran riparian forest to a 10-year return flood. Western North American Naturalist, 53(2), 118-130.	Hydrology / Vegetation	Arizona	General Range	1993	Yes

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
98	river. Discussed how this variability affected riparian vegetation (population & community levels, including composition and structure). These results informed projections about how the riparian vegetation could change based on climate change effects to hydrology. Generally suggested greater Tamarix (mesic) composition over hydric pioneer species, reduced canopy cover and shorter canopies at drier sites. Annuals would dominate over perennials for herbaceous cover and overall a younger	Stromberg, J. C., S.J. Lite, and M.D. Dixon, 2010. Effects of stream flow patterns on riparian vegetation of a semiarid river: Implications for a changing climate. River Research and Applications 26(6): 712-729.	Climate Change / Vegetation	Arizona	Semi-Arid	2010	Yes
99	This paper demonstrates the important role of shallow ground- water in structuring the San Pedro River plant community. The relationship between groundwater decline and the wetland indicator score, cover plants, and frequency of indicator species are examined. One sequential "desertification" of the riparian flora (i.e., loss or reduction in cover of species based on their probability of occurrence in wetlands) is one predicted response to groundwater decline. Other predicted impacts of groundwater decline include reduced establishment of Populus fremontii-Salix gooddingii forests, and reduced cover of herbaceous species associated with the fine-textured soils and shady conditions of floodplain terraces stabilized by these early seral tree species.	Stromberg, J. C., Tiller, R., & Richter, B. (1996). Effects of groundwater decline on riparian vegetation of semiarid regions: the San Pedro, Arizona. Ecological Applications, 6(1), 113-131.	Groundwater / Vegetation	Arizona	General Range	1996	Yes
100	Introduction of papers produced through riparian workshop in the UK. Themes include evidence of catchment to regional/national-scale effectiveness, functions of linking terrestrial and aquatic habitat, modeling tools for assessing effectiveness and cost, pollutant retention in buffers and management to enhance this function.	Stutter, M. I., W. J. Chardon, and B. Kronvang, 2012. Riparian buffer strips as a multifunctional management tool in agricultural landscapes: Introduction. Journal of Environmental Quality 41(2): 297-303.	Functions / Management	United Kingdom	General Range	2012	Yes
101	A landscape-scale study of riparian structures and functions. The study characterized functional zones (with respect to vegetation development in association with various biogeochemical processes) within geomorphological settings using a delineation based upon erosional, transitional and depositional properties. Findings include vegetation dynamics within the riparian corridor, surface and groundwater linkage as landscape connectors, and the importance of riparian zones as sources and sinks.	Tabacchi, E, R. D. L. Correll, R. Hauer, G. Pinay, A. P. Tabacchi and R. C. Wissmar. 1998. Landscape connectivity of riparian ecosystems. Freshwater Biol. 40 (3): 497-516.	Functions / Management	Europe & North America	General Range	1998	Yes
102	Study of the effects of riparian canopy cover on benthic invertebrate production and aquatic species composition. Open areas produced greater periphyton (algae with epilithic diatoms), then shaded sites. This led to greater abundance of Dicosmoecus larvae over bactids and chironomid midges. This species is not preyed upon as much, leading to sequestering of herbivory energy water temperatures often exceeded lethal levels for coldwater fish, warmwater species including bridgelip suckers, northern squawfish, redside shiners, and chiselmouths were most abundant.	Tait, C. K., J.L. Li, G.A. Lamberti, T.N. Pearsons, and H.W. Li, 1994. Relationships between Riparian Cover and the Community Structure of High Desert Streams. Journal of the North American Benthological Society 13(1): 45-56.	Invertebrates / Wildlife	Oregon	Arid / Semi-Arid	1994	Yes
103	In an effort to develop a method for screening opportunities for prioritizing management of riparian areas, the study adopts a spatially explicit linear, additive model for quantifying site characteristics of riparian areas of the lower Cedar River, Washington, USA. The spatial complexity and distribution of combined habitat and anthropogenic landscape features were used to define habitat “indices” that indicate the relative quality of riparian habitats. Patches of contiguous grid cells were measured in terms of their locations, sizes, and relative degree of fragmentation. Additionally, intrapatch heterogeneity was measured to identify unique combinations of habitat and anthropogenic factors for individual grid cells within patches.	Timm, R. K., Wissmar, R. C., Small, J. W., Leschine, T. M., & Lucchetti, G. (2004). A screening procedure for prioritizing riparian management. *Environmental management* , *33* (1), 151-161.	Functions / Management	Cedar River Basin	General Range	2004	Yes

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
104	A study that follows up a magnitude 6.8 earthquake which triggered a channel-damming landslide causing the lower Cedar River, Washington, then occupied an existing floodplain side channel. One year of pre-disturbance data was compared with three years of post-disturbance data in a spatially explicit analysis of the complexity of channel form and bed surface elevations.	Timm, R.K. & Wissmar, R.C. (in review) Response to disturbance in a highly managed alluvial river: Does it conform to Le Chatelier's general law. Geomorphology.	Functions / Impacts	Cedar River Basin	General Range	2012	No
105	Landcover change analysis of the Wenatchee River and tributaries between 1949 and 2006. Results indicated that urban landcover has increased and agricultural landcover decreased, high quality island braided or meandering reaches declined, and channel migration zone areas declined.	Tomlinson, M. J., S. E. Gergel, T. J. Beechie, and M. M. McClure, 2011. Long-term changes in river-floodplain dynamics: Implications for salmonid habitat in the Interior Columbia Basin, USA. Ecological Applications 21(5): 1643-1658.	Fish / Impacts / Land Use	Wenatchee River	General Range	2011	Yes
106	Study of bird response to urbanization within riparian areas of Reno, Nevada along the Truckee River. Native bird richness was highest near the river and at distances 1600-3400 meters (potentially due to suburban landscaping that effectively extends riparian habitat into the city). Road density and the presence of people did not negatively impact overall richness. Concludes that planners should focus on designating more open space to protect riparian habitat from development.	Trammell, E. J., P. J. Weisberg, and S. Bassett, 2011. Avian response to urbanization in the arid riparian context of Reno, USA. Landscape and Urban Planning 102(2):93-101.	Birds / Impacts	Nevada	General Range	2011	Yes
107	In the Arid West region of the U.S., the most problematic Ordinary High Water (OHW) delineations are associated with the ephemeral/intermittent channel forms that dominate the Arid West landscape. This report presents a method for delineating the lateral extent of the non-wetland waters in the Arid West using stream geomorphology and vegetation response to the dominant stream discharge.	USACE (U.S. Army Corps of Engineers), 2008. A field guide to the identification of the ordinary high water mark (OHWM) in the arid west region of the western United States: A delineation manual. August 2008.	OHWM Delineation	Western USA	Arid	2006	Yes
108	Regarding cultural resources protection. The objective of study is stated that to provide archaeologists and lake managers with the tools for more effective management of historic properties within the fluctuating drawdown zones of Corps reservoirs. Contents include evaluating, assessing mitigating as well as management of historic properties. There are three case studies to demonstrate this procedures.	USACE, 1996. Managing historic properties in drawdown zones at Corps of Engineers reservoirs: Three case studies. Technical Report EL-96-14. September 1996.	Cultural / Hydrology	USA	General Range	1996	Yes
109	This technical note is a product of the Ecosystem Management and Restoration Research Program (EMRRP) work unit titled "Reservoir Operations - Impacts on Target Species." Current knowledge regarding the occurrence of sensitive species that have been identified as a management concern in the operation o(Corps projects is reviewed. The status and management of these species are examined, and species of management concern are arranged into groups based on similarities in life history characteristics and habitat requirements. These groups are further examined to identify opportunities for habitat and ecosystem-level management of sensitive species on Corps lands.	USACE, Ecosystem Management and Restoration Research Program, 2000. Characterization of sensitive species and habitats affected by the operation of USACE water resource development projects. April 2000.	Hydrology / Management / Restoration / Wildlife	USA	General Range	2000	No
110	A chapter of the guidance report for soil bioengineering treatments for flood control projects. This chapter is about handling plant materials for soil bioengineering projects.	USACE, Ecosystem Management and Restoration Research Program, 2001. Plant material acquisition, layout, and handling for flood control projects. Technical Report ERDC TR-01-14. September 2001.	Management / Restoration / Vegetation	USA	General Range	2001	Yes
111	USACE specific procedure for 'Level One inventories'. May be Not Applicable.	USACE, Ecosystem Management and Restoration Research Program, 2006. Natural Resources level one inventories: What are the needs and process for Corps projects? Technical Report ERDC TN-EMRRP-EM-04. September 2006.	Management / Restoration	USA	General Range	2006	Yes

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
112	Guideline of actions necessary to develop a plan for assessing restoration and rehabilitation efforts in arid and semi-arid environments. There are five steps in this process: (1) establishing monitoring goals and objectives, (2) developing a monitoring protocol, (3) implementation of the monitoring design, (4) analysis and interpretation of monitoring data, and (5) final assessment of restoration efforts.	USACE, Ecosystem Management and Restoration Research Program, 2008. Guidelines for establishing monitoring programs to assess the success of riparian restoration efforts in arid and semi-arid landscapes. Technical Report ERDC TN-EMRRP-SR-50. August 2008.	Management / Restoration	Western USA	Arid / Semi-Arid	2008	Yes
113	pdf missing	USDA (U.S. Department of Agriculture) Forest Service, 2004. Riparian and floodplain screen analysis, draft. January 2004.	Management	pdf missing	pdf missing	2004	No
114	This chapter of the EPA report is aimed to understand the role of wetlands, riparian areas, and vegetated treatment systems in abating NPS pollution requires an understanding of several terms. Because federal, state, and local laws, ordinances, and policy documents define these terms in a number of different ways, this chapter provides an overview of how the terms might be interpreted and defines the terms as they are used in this document.	USEPA (U.S. Environmental Protection Agency), 2005. National management measures to protect and restore wetlands and riparian areas for the abatement of nonpoint source pollution,Chapter 2: Overview of wetlands, riparian areas, and vegetated treatment systems. Technical Report EPA-841-B-05-003. July 2005.	Water Quality / Functions Terminology	USA	General Range	2005	Yes
115	A one-page graphic illustration of the stream ecosystems with urban development. Two detailed sectional graphics depict a healthy stream ecosystem and degraded urban stream ecosystem side-by-side. Also included is information comparing the hydrology, habitat and chemistry of natural and urban stream ecosystem.	USGS (U.S. Geological Society), and U.S. Department of the Interior, 2002. Stream ecosystems change with urban development. National Water-Quality Assessment Program. General Product 143. October 2002.	Functions / Land Use	USA	Urban	2003	No
116	Research is investigating two prominent landscape-scale habitat frameworks, gradients and patch hierarchy, in a semi-arid South Africa system in order to show their complimentary relationships. The gradient data set consisted of vertical, lateral and longitudinal dimensions of the macro-channel, while the patch hierarchy data set consisted of substratum type, morphological unit and channel type. The study concludes that in systems characterized by strong environmental gradients as well as a patch mosaic at different spatial and temporal scales, the combined use of both perspectives to develop a fuller understanding of vegetation pattern is imperative and is encouraged.	van Coller, A. L., K. H. Rogers, and G. L. Heritage, 2000. Riparian vegetation-environment relationships: complimentarity of gradients versus patch hierarchy approaches. Journal of Vegetation Science 11: 337-350.	Functions	South Africa	Semi-Arid	2000	Yes
117	The article discusses changes in shrub-steppe habitat in the intermountain west, and examines how certain habitat types associated with deep loamy soil communities are affecting bird habitats the most.	Vander Haegen, W. M., F. C. Dobler, and D. J. Pierce, 2000. Shrub-steppe bird response to habitat and landscape variables in eastern Washington, U.S.A. Conservation Biology 14(4): 1145-1160.	Birds / Soil	Eastern Washington	Shrub-Steppe	2000	Yes
118	The thesis study argues that revegetation is a common riparian restoration practice, but there is little information available on whether revegetation projects are effective. Determining efficacy of revegetation projects is difficult due to the lack of monitoring results. Of the 36 projects that did have a monitoring report, two operational factors influencing the outcome of revegetation efforts. These factors are: 1)the need to select plant material and planting techniques that are well suited to the site, and 2) the need for ongoing maintenance to reduce impacts due to environmental factors such as herbivory, plant competition, moisture, erosion/flooding/scour, and coarse substrate.	Wall, S. M., 2011. Efficacy of riparian revegetation projects in the inland Pacific Northwest. Master of Science, Resource Conservation, University of Montana, Missoula, Montana.	Management / Vegetation	Eastern Oregon & Washington & Idaho	General Range	2011	No

Appendix A
Riparian Buffer Literature Review Master List

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
119	pdf missing	Walvoord, M. A., and B. R. Scanlon, 2004. Hydrologic processes in deep vadose zones in interdrainage arid environments. Groundwater recharge in a desert environment—The southwestern United States: American Geophysical Union Water Science and Applications Series, v. 9. Washington D.C.: American Geophysical Union, p. 15-28.	Groundwater / Hydrology	Southwest USA	Arid	2004	Yes
120	pdf missing	Webb, R. H., and R. M. Turner, 2004. Climate and vegetation change in the Sonoran Desert. Sonorensis 24: 16-19.	Climate Change / Vegetation	Southwest USA	Arid	2004	pdf missing
121	This document has been written as a scientifically-based guideline to help local governments in Georgia set effective and comprehensive riparian buffer regulations. The document reviews over 140 articles and books, categorized by topics such as sediment, nutrients and other contaminants, aquatic habitat, terrestrial wildlife habitat, and development of riparian guidelines. In the end, three options for buffer guidelines were proposed.	Wenger, S. (1999). A review of the scientific literature on riparian buffer width, extent and vegetation. Athens, Georgia, USA: Institute of Ecology, University of Georgia.	Management	Georgia	General Range	1999	Yes
122	Looking at chemical and biological relationships between the riparian vegetations and hydrological processes in monsoonal climates.	Williams, D. G., R. L. Scott, T. E. Huxman, D. C. Goodrich, and G. Lin, 2006. Sensitivity of riparian environments in arid and semiarid environments to moisture pulses. Hydrological Processes 20: 3191-3205.	Functions / Hydrology	Mexico	Arid / Semi-Arid	2006	Yes
123	A guideline document designed to assist applicants and inspectors in developing plans for bank facilities for stabilizing and restoring damaged stream banks. The contents includes the guideline for describing damaged banks, designing bank stabilizing facilities, and determining the expected risks and performance of the facility.	Wissmar, R. C. 1996. Recommeded Guidelines for Developing Bank Stabilization Facilities of Rivers in Western Washington. Fisheries Research Institute Technical Report FRI-UW-9619, School of Fisheries Box 357980, University of Washington, Seattle, WA. 98195. 22 p.	Erosion	Western Washington	General Range	1996	Yes
124	This study proposes that strategies for the management of riparian ecosystems should incorporate concepts of landscape ecology and contemporary principles of restoration and conservation. A detailed understanding of the temporal and spatial dynamics of the catchment landscape (e.g. changes in the connectivity and functions of channel, riparian and terrestrial components) is critical.	Wissmar, R. C. and R. Beschta. 1998. Restoration and the management of riparian ecosystems. Freshwater Biol. 40 (3): 571-585.	Management / Restoration	Cedar River Basin	General Range	1998	Yes
125	A book about uncertainties in river restorations and how we can work to understand ecological variability and policy uncertainties, and we can put that knowledge to use in designing robust river restoration programs.	Wissmar, R. C., & Bisson, P. A. (2003). Strategies for restoring river systems: Sources of variability and uncertainty.	Management	USA	General Range	2003	Yes
126	Overview of the factors influencing sustainability of riparian corridors within eastern Washington and Oregon. Factors discussed include plant associations and distributions, ecological and physio-chemical functions of different riparian systems (by varying elevation), cumulative impacts of human alterations, and management provisions for restoration and preservation.	Wissmar, R. C., 2004. Riparian corridors of Eastern Oregon and Washington: Functions and sustainability along lowland-arid to mountain gradients. Aquatic Sciences 66(4):373.	Functions / Impacts	Eastern Oregon & Washington	Arid	2004	Yes

Appendix A
Riparian Buffer Literature Review Master List

	Description	Citation	Category	Geographic Area	Habitat Type	Date of Publication	Peer Reviewed
127	Examines sources and influences of natural and human-induced variability in riparian ecosystems and discuss their implications for restoration actions and recovery. The study emphasizes the importance of the connectivity of riparian systems to associated terrestrial and aquatic ecosystem. It also argues that the development of strategies should be based on understanding how past natural disturbances and human alterations and uses alter the connectivity and processes of riverine habitats throughout a drainage. Three general restoration strategies are presented: conservation, passive restoration (riparian reserves and buffer zones), and active restoration (flow and floodplain manipulations, restoring cottonwood/willow communities, and reducing invasive and exotic plants).	Wissmar, R. C., Braatne, J. H., Beschta, R. L., & Rood, S. B. (2003). Variability of riparian ecosystems: Implications for restoration. Strategies for Restoring River Ecosystems: Sources of Variability and Uncertainty in Natural and Managed Systems., 107-127.	Management	USA	General Range	2003	Yes
128	Land cover within the lower Cedar river basin was evaluated for change between 1991 and 1998. Significant increases in developed land cover in the more urbanized areas included the widening of a major highway on the river floodplains and conversion of isolated forest patches through infill development. More rural areas demonstrated increases in developed land cover which correspond with patterns of scattered low-density residential, clustered dense commercial and residential development near newly incorporated areas.	Wissmar, R. C., Douglas C. Pflugh and Ray K. Timm. 2000. Changes in Developed Land Cover (1991-1998): Cedar River, Washington. Pages 287 - 292, in P. J. Wigington and R. L. Beschta, editors. Proceedings of the International Conference on Riparian Ecology and Management in Multi-Land Use Watersheds. American Water Resources Association.	Land Cover	Cedar River Basin	General Range	2000	No
129	Another spatially explicit hydrology model study to assess effects of land covers on watershed hydrology during presettlement conditions ("full forest cover"), 1991 and 1998. It concludes that variations in different types and spatial distributions of land covers can affect flood regimes and flows of different watersheds.	Wissmar, R. C., R. K. Timm and M. G. Logsdon 2004. Effect of land cover change on discharge regimes of urbanizing watersheds. Environmental Management 34:91- 98.	Hydrology / Vegetation Cover	Cedar River Basin	General Range	2004	Yes
130	Variable riparian buffer width calculated from erosion-risk indices derived from a spatially explicit procedure. The indices are based on land cover types that can contribute to erosion either alone or collectively. Land cover information (e.g., unstable soils, immature forest stands, roads, critical slope for land failure and rain-on-snow areas) was used to estimate erosion-risk indices.	Wissmar, R. C., W. N. Beer, R. K. Timm 2004. Spatially explicit estimates of erosion-risk indices and variable riparian buffer widths in watersheds. Aquatic Sciences 66: 446-455.	Erosion / Land Cover	Cedar River Basin	General Range	2004	Yes
131	A historical review of human activities influencing stream and riparian ecosystems in eastern Washington and Oregon shows that cumulative effects of resource uses and management over the past two centuries are altering the health of many river basins. The study examines past practices dating from early 1800s to 1990, then suggests new basin-wide strategies of federal and environmental organizations.	Wissmar, R.C., J.E. Smith, B.A. McIntosh, H. W. Li, G.H. Reeves and J.R. Sedell. 1994. A history of resource use and disturbance in riverine basins of eastern Washington and Oregon. Special Issue: Northwest Science.69: 1 -35.	Impacts / Management	Eastern Oregon & Washington	General Range	1994	Yes
132	Extensive review of case studies discussing the effectiveness of riparian buffers for trapping sediment and thus protecting water quality. Efficiency was based on width of buffers, this is further affected (though not a consistent relationship) with slope. The efficiency did not vary by vegetation type. Summary states that grass buffers as thin as 3 meters can remove much sediment from field runoff, maximum benefit is achieved with buffers of 6 meters or greater.	Yuan, Y., R. L. Bingner, and M. A. Locke, 2009. A review of effectiveness of vegetative buffers on sediment trappings in agricultural areas. Ecohydrology 2:321-336.	Agriculture / Buffers /Water Quality	North America	Agriculture	2009	Yes
133	Document describes Arizona's riparian areas and their characteristics. A review of hydrologic, stream, biological, and climate processes is provided as well as a summary of human alterations to the habitat type.	Zaimes, G., M. A. Crimmins, D. Green, and M. Nichols, 2007. Understanding Arizona's riparian areas. AZ 1432. Tuscon: University of Arizona, College of Agriculture and Life Sciences, 1-116.	Functions / Impacts	Arizona	General Range	2007	Yes

APPENDIX B
MOST RELEVANT INFORMATION SOURCES

Appendix B
Riparian Buffer Literature Review Subset List

Description	Citation	Applicability to Report Objective
A report generated to provide the Planning Board, City Council, and the Boulder community with information on the value of wetland and stream buffers and a review of regulatory approaches to buffer protection across the United States. Section I provides background on the role of local governments in regulating wetland and stream buffers. Section II reviews the purpose and functions of buffers and the science-supported buffer widths needed to protect the ecological functions of streams and wetlands. Section III is a discussion and analysis of various approaches to buffer protection among several local jurisdictions across the United States. Section IV presents a conclusion to the report and recommendations for change to Boulder's ordinance.	Biohabitats, Inc., 2007. Wetland and stream buffers: A review of the science and regulatory approaches to protection. City of Boulder Planning and Development Series. Prepared for City of Boulder. April 2007.	Science and regulatory approach for wetland and stream riparian habitats in Colorado.
Proper functioning condition (PFC) is a qualitative method for assessing the condition of riparian-wetland areas. PFC is a qualitative assessment based on quantitative science. The manual describes the PFC assessment procedures, including both quantitative and qualitative techniques that covers three quantification areas, hydrology, vegetation, and erosion/deposition.	BLM (Bureau of Land Management), 1998. A user guide to assessing proper functioning condition and the supporting science for lotic areas. Technical Report 1737-15. 1998.	Science and management approach for stream and wetland riparian habitats in 11 western states.
A thesis document attempting to synthesize appropriate buffer width using a matrix format. Differences between arid and non-arid landscape characteristics, soil, topography, vegetation, climate, and hydrology and their effect on buffers for water quality were also researched in the document. Used as an appendix to develop Buffer Design Guidelines for Water Quality and Wildlife Habitat Functions on Agricultural Landscapes in the Intermountain West.	Buffler, S., 2005. Synthesis of design guidelines and experimental data for water quality function in agricultural landscapes in the intermountain west. Forestry, National Agroforesty Center, Utah State University, Logan, Utah.	Stream water quality functions for agricultural habitats in intermountain west states.
An overview of the Ecosystem Management and Restoration Research Program (EMRRP) and description of its research projects in 4 different phases: 1) site evaluation and selection; 2) plant species selection; 3) available planting techniques, spacing, and architecture; and 4) techniques for developing long-term monitoring protocols.	Fischer, R., 2008. Riparian restoration and management needs in the semi-arid western United States. Technology News from the Ecosystem Management and Restoration Research Program. January 2003.	Management and restoration of riparian habitats in arid and semi-arid western states.
This article describes work to develop technical guidelines for restoring and managing riparian buffer zones and corridors. The potential benefits-with regard to water quality and many important ecological functions-are significant.	Fischer, R., C. Martin, and U.S. Army Engineer Waterways Experiment Station, 1998. Corridors and vegetated buffer zones—guidelines for Corps of Engineers projects. Technology News from the Ecosystem Management and Restoration Research Program. April 1998.	Corps management guidelines for riparian habitats in southeast states.
Spatial analysis of riparian modifications on anadromous fish bearing streams in the interior Columbia basin to provide a starting point for restoration priorities. Interesting citations on the required width of buffers and connectivity or riparian patches for full function (Broadmeadow/Nisbet) and length of riparian needed to restore control levels of nutrients, dissolved oxygen and temperature (pg 1356 2nd para.)	Fullerton, A. H., T. J. Beechie, S. E. Baker, J. E. Hall, and K. A. Barnas, 2006. Regional patterns of riparian characteristics in the interior Columbia River basin, northwestern USA: Application for restoration planning. Landscape Ecology 21: 1347-1360.	Riparian habitat restoration specific to salmon species in interior Columbia Basin.
A background information on riparian buffers, designed to accompany the RappFLOW Riparian Buffer Evaluation Data Sheet. The manual also contains additional information for volunteers, such as safety tips, a checklist for equipments and an in-depth explanation of each evaluation items.	Gloyd, M., 2006. Riparian buffer evaluation program. Volunteer handbook. Prepared for Virginia Technical Institute. Summer 2006.	Forested riparian habitat science and evaluation approach in Virginia.
Within a semi-arid region, study of the factors affecting riparian litterfall biomass. Results indicated that river distance and nutrient cycling (particularly P over N) and forest structure (basal area) were the limiting factors.	Gonzalez, E., E. Mueller, B. Gallardo, F. Comin, and M. Gonzalez-Sanchis, 2010. Factors controlling litter production in a large Mediterranean river floodplain forest. Canadian Journal of Forest Restoration 40: 1698-1709.	Floodplain habitat litter production science in semi-arid climates in the Mediterranean.
This hardcopy report is an excerpt from the Critical Areas Ordinance (CAO): Best Available Science (BAS) review. It discusses riparian buffer widths in relation to limiting factors, provides a summary of BAS recommended buffer widths for ecological function, reviews existing riparian conditions in the County, and makes recommended provisions for the County CAO Code.	HDR, Inc., 2008. Critical areas ordinance: Best available science review. Prepared for Walla Walla County. August 2008.	Science of stream riparian habitats and buffer guidelines in Walla Walla County.
This is a fact-finding report prepared for Washington State's Senate Bill (SSB) 5248 Preserving the viability of agricultural lands. The paper includes a summary of facts and highlights that would appear to be of interest and relevance to the SSB 5248. Contents of the report includes the definition of Riparian Buffers, functions of riparian zones, anadromous habitat reliance on riparian zones, and other riparian habitat protection practices, such as stewardship, large woody debris, and stream bank stabilization.	Horowitz, J., 2009. Buffers and agricultural practices related to riparian habitat protection. UW Department of Civil and Environmental Engineering, University of Washington, Seattle, Washington.	Science of stream riparian buffer habitats in agricultural habitats in Washington State.
Same as above, but this document contains case studies and appendix.	Johnson, C. W., and B. Susan, 2008. Riparian Buffer Design Guidelines for Water Quality and Wildlife Habitat Functions on Agricultural Landscapes in the Intermountain West. Case Study. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Mountain Research Station. 53 p.	Stream riparian buffer guidelines for agricultural habitats in intermountain west states.
Document contains a hypothetical case study to illustrate how the riparian buffer protocol can be used to plan a buffer for both water quality and wildlife conservation. Majority of document consists of appendices to work through the protocol (data sheets, worksheets, specifications).	Johnson, C. W., and B. Susan, 2008. Riparian Buffer Design Guidelines for Water Quality and Wildlife Habitat Functions on Agricultural Landscapes in the Intermountain West. General Technical Report RMRS-GTR-203. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Mountain Research Station. 53 p.	Stream riparian buffer guidelines for agricultural habitats in intermountain west states.
Evaluation of eight habitat objectives used by land management agencies within the Interior Columbia Basin to determine if the current riparian management objectives (RMOs) were representative of conditions found at reference sites, had values which differed significantly between reference and managed watersheds, and whether these RMOs could be consistently applied across the study area.	Kershner, J. L., and B. B. Roper, 2010: An Evaluation of Management Objectives Used to Assess Stream Habitat Conditions on Federal Lands within the Interior Columbia Basin. Fisheries 35(6): 269-278.	Management objectives to assess stream habitat on federal lands in the Columbia River Basin.

Appendix B
Riparian Buffer Literature Review Subset List

Description	Citation	Applicability to Report Objective
Review of provincial, territorial and state guidelines for riparian buffer preservation, does not have a semi-arid focus. Discussion includes a review of studies that recommend buffer widths based on riparian function, structure, and/or biota (pgs 172-174).	Lee, P., C. Smyth, and S. Boutin, 2004. Quantitative review of riparian buffer width guidelines from Canada and the United States. Journal of Environmental Management 70(2): 165-80.	Review of riparian buffer width guidelines in the USA and Canada.
The report was prepared to synthesize current knowledge of the ecology and hydrology of ephemeral and intermittent streams in the American Southwest, which make up approximately 81% of all streams in the region. The report is aimed at placing these streams in a watershed context, thereby highlighting their importance in maintaining water quality, overall watershed function or health, and provisioning of the essential human and biological requirements of clean water. It concludes that consideration of the cumulative impacts from anthropogenic uses on these streams is critical in watershed-based assessments and land management decisions to maintain overall watershed health and water quality.	Levick, L., J. Fonseca, D. Goodrich, M. Hernandez, D. Semmens, J. Stromberg, R. Leidy, M. Scianni, D. P. Guertin, M. Tluczek, and W. Kepner, 2008. The Ecological and Hydrological Significance of Ephemeral and Intermittent Streams in the Arid and Semi-arid American Southwest. Washington D.C.: U.S. Environmental Protection Agency and USDA/ARS Southwest Watershed Research Center, EPA/600/R-08/134, ARS/233046, 1-116.	Science of ephemeral and intermittent stream habitats in the arid and semi-arid southeast states.
Discussion of the functions and controlling factors of riparian ecosystems as well as human impacts within semi-arid regions of North America. Includes a comparison of driving variables of this habitat over elevational (longitudinal), latitudinal and temporal gradients as well as geographic similarities of structure and function.	Patten, D. T., 1998. Riparian ecosytems of semi-arid North America: Diversity and human impacts. Wetlands 18(4): 498-512.	Science of stream riparian habitats and human impacts in semi-arid western states.
Riparian zones can strongly influence the exchange of nutrients between streams and their watersheds, but not much works have been done in arid climates. This article tries to determine the strength and direction of hydrologic linkages between stream and riparian zone, and to estimate the extent of uptake of streamwater N by riparian trees in Sycamore Creek, a Sonoran Desert stream.	Schade, J. D., J. R. Welter, E. Martí, and N. B. Grimm, 2005. Hydrologic exchange and n uptake by riparian vegetation in an arid-land stream. Journal of North American Bethnological Society 24(1): 19028.	Stream riparian hydrology and nutrient functions for arid habitats in California.
Describes riparian areas in the Great Basin region through their limiting factors and ecological values (including their composition of flora and fauna). Discusses the threats to this habitat type including various land uses, infrastructure projects, plant invasions, and disturbances (fire) and discusses conservation policy and local techniques for landowners.	Schenk, M., and L. Goldblatt. Riparian areas of the Great Basin: A management guide for the landowners. Prepared for Wildlife Habitat Council. 2005.	Stream riparian habitat science and management approach for land owners in arid environments in western states.
In an effort to determine a value of ecological and natural resources that provide necessary functions within ecosystems, this paper presents a framework that estimates and compiles the components of value for a natural ecosystem. When the framework was applied to ecological resources in a shrub–steppe dryland habitat being displaced by development, the highest values of natural shrub–steppe habitat appear to be derived from soil stabilization.	Scott, M. J., P. F. Ricci, H. E. Seely, G. R. Bilyard, S. O. Link, C. A. Ulibarri, H. E. and Westerdahl, 1998. Valuation of Ecological Resources and Functions. Environmental Management 22(1): 49-68.	Science of ecological functions in shrub-steppe habitats in intermountain west states.
Areas surrounding wetlands and streams are more than just zones to protect aquatic resources. Two conservation biologists describe these areas as core habitat for semi-aquatic species and call for new criteria to evaluate, protect, and mange these critical areas.	Semlitsch, R., and J. Jensen, 2001. Core habitat, not buffer zone. National Wetlands Newsletter 23(4): 5-6, 11. September 2005.	Science and management approach for wildlife species in wetland and stream riparian habitats in the USA.
Understanding patterns of plants species composition and distribution within riparian corridors is helpful in planning for the management and protection of buffer strips. The paper compare and analyze 192 quadrants located on transects radiating away from mixed perennial and intermittent stream system in semi-arid regions in Arizona by sampling woody and herbaceous plants.	Snyder, K. A., D. P. Guertin, R. L. Jemison, and P. F. Ffolliott, 2002. Riparian plant community patterns: A case study from southeastern Arizona. Journal of the Arizona-Nevada Academy of Science 34(2): 106-111.	Science of stream riparian plant communities in southeastern Arizona.
Introduction of papers produced through riparian workshop in the UK. Themes include evidence of catchment to regional/national-scale effectiveness, functions of linking terrestrial and aquatic habitat, modeling tools for assessing effectiveness and cost, pollutant retention in buffers and management to enhance this function.	Stutter, M. I., W. J. Chardon, and B. Kronvang, 2012. Riparian buffer strips as a multifunctional management tool in agricultural landscapes: Introduction. Journal of Environmental Quality 41(2): 297-303.	Stream riparian habitat management in agricultural habitats in the United Kingdom.
A landscape-scale study of riparian structures and functions. The study characterized functional zones (with respect to vegetation development in association with various biogeochemical processes) within geomorphological settings using a delineation based upon erosional, transitional and depositional properties. Findings include vegetation dynamics within the riparian corridor, surface and groundwater linkage as landscape connectors, and the importance of riparian zones as sources and sinks.	Tabacchi, E, R. D. L. Correll, R. Hauer, G. Pinay, A. P. Tabacchi and R. C. Wissmar. 1998. Landscape connectivity of riparian ecosystems. Freshwater Biol. 40 (3): 497-516.	Science of stream riparian ecosystem functions in Europe and North America.
Study of the effects of riparian canopy cover on benthic invertebrate production and aquatic species composition. Open areas produced greater periphyton (algae with epilithic diatoms), then shaded sites. This led to greater abundance of Dicosmoecus larvae over bactids and chironomid midges. This species is not preyed upon as much, leading to sequestering of herbivore energy water temperatures often exceeded lethal levels for coldwater fish, warmwater species including bridgelip suckers, northern squawfish, redside shiners, and chiselmouths were most abundant.	Tait, C. K., J.L. Li, G.A. Lamberti, T.N. Pearsons, and H.W. Li, 1994. Relationships between Riparian Cover and the Community Structure of High Desert Streams. Journal of the North American Benthological Society 13(1): 45-56.	Science of the relationship of stream riparian vegetation cover and wildlife species in high elevation desert streams in Oregon.
In the Arid West region of the U.S., the most problematic Ordinary High Water (OHW) delineations are associated with the ephemeral/intermittent channel forms that dominate the Arid West landscape. This report presents a method for delineating the lateral extent of the non-wetland waters in the Arid West using stream geomorphology and vegetation response to the dominant stream discharge.	USACE (U.S. Army Corps of Engineers), 2008. A field guide to the identification of the ordinary high water mark (OHWM) in the arid west region of the western United States: A delineation manual. August 2008.	Corps ordinary high water delineation guidelines for arid west region in western states.
Guideline of actions necessary to develop a plan for assessing restoration and rehabilitation efforts in arid and semi-arid environments. There are five steps in this process: (1) establishing monitoring goals and objectives, (2) developing a monitoring protocol, (3) implementation of the monitoring design, (4) analysis and interpretation of monitoring data, and (5) final assessment of restoration efforts.	USACE, Ecosystem Management and Restoration Research Program, 2008. Guidelines for establishing monitoring programs to assess the success of riparian restoration efforts in arid and semi-arid landscapes. Technical Report ERDC TN-EMRRP-SR-50. August 2008.	Corps management guidelines for stream riparian restoration in arid and semi-arid habitats in western states.

Appendix B
Riparian Buffer Literature Review Subset List

Description	Citation	Applicability to Report Objective
This chapter of the EPA report is aimed to understand the role of wetlands, riparian areas, and vegetated treatment systems in abating NPS pollution requires an understanding of several terms. Because federal, state, and local laws, ordinances, and policy documents define these terms in a number of different ways, this chapter provides an overview of how the terms might be interpreted and defines the terms as they are used in this document.	USEPA (U.S. Environmental Protection Agency), 2005. National management measures to protect and restore wetlands and riparian areas for the abatement of nonpoint source pollution, Chapter 2: Overview of wetlands, riparian areas, and vegetated treatment systems. Technical Report EPA-841-B-05-003. July 2005.	EPA management measures for stream riparian and wetland habitats for nonpoint source pollution in the USA.
The article discusses changes in shrub-steppe habitat in the intermountain west, and examines how certain habitat types associated with deep loamy soil communities are affecting bird habitats the most.	Vander Haegen, W. M., F. C. Dobler, and D. J. Pierce, 2000. Shrub-steppe bird response to habitat and landscape variables in eastern Washington, U.S.A. Conservation Biology 14(4): 1145-1160.	Science of human impacts on bird species and soils in shrub-steppe communities in eastern Washington.
The thesis study argues that revegetation is a common riparian restoration practice, but there is little information available on whether revegetation projects are effective. Determining efficacy of revegetation projects is difficult due to the lack of monitoring results. Of the 36 projects that did have a monitoring report, two operational factors influencing the outcome of revegetation efforts. These factors are: 1)the need to select plant material and planting techniques that are well suited to the site, and 2) the need for ongoing maintenance to reduce impacts due to environmental factors such as herbivore, plant competition, moisture, erosion/flooding/scour, and coarse substrate.	Wall, S. M., 2011. Efficacy of riparian revegetation projects in the inland Pacific Northwest. Master of Science, Resource Conservation, University of Montana, Missoula, Montana.	Science of revegetation of stream riparian habitats in eastern Oregon, Washington, and Idaho.
Overview of the factors influencing sustainability of riparian corridors within eastern Washington and Oregon. Factors discussed include plant associations and distributions, ecological and physio-chemical functions of different riparian systems (by varying elevation), cumulative impacts of human alterations, and management provisions for restoration and preservation.	Wissmar, R. C., 2004. Riparian corridors of Eastern Oregon and Washington: Functions and sustainability along lowland-arid to mountain gradients. Aquatic Sciences 66(4):373.	Science of stream riparian functions and human impacts in lowland arid to mountain habitats in eastern Oregon and Washington.
Extensive review of case studies discussing the effectiveness of riparian buffers for trapping sediment and thus protecting water quality. Efficiency was based on width of buffers, this is further affected (though not a consistent relationship) with slope. The efficiency did not vary by vegetation type. Summary states that grass buffers as thin as 3 meters can remove much sediment from field runoff, maximum benefit is achieved with buffers of 6 meters or greater.	Yuan, Y., R. L. Bingner, and M. A. Locke, 2009. A review of effectiveness of vegetative buffers on sediment trappings in agricultural areas. Ecohydrology 2:321-336.	Science of stream riparian sediment trapping effectiveness in agricultural habitats in North America.