Landscape Analysis for Critical Areas Ordinance Update

Prepared for

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ACRONYMS

BAS	Best Available Science
CAO	critical areas ordinance
City	City of Duvall
CMZ	channel migration zone
CPSWSF	Central Puget Sound Water Suppliers Forum
DO	dissolved oxygen
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
GIS	geographic information system
GMA	Growth Management Act
KCDNRP	King County Department of Natural Resources and Parks
msl	mean sea level
NMFS	National Marine Fisheries Service
RM	river mile
ROS	rain-on-snow
SCS	Soil Conservation Service
SBSRF	Snohomish Basin Salmon Recovery Forum
WDFW	Washington Department of Fish and Wildlife
WRCC	Western Regional Climatic Center

1. INTRODUCTION

The City of Duvall is in the process of updating its critical areas ordinance (CAO) (Chapter 14.42 of the Duvall Municipal Code) to incorporate new information and comply with Growth Management Act (GMA) mandates for critical area protection. The City hired Parametrix to develop scientific recommendations for the update based on a landscape-scale assessment of ecosystem process and their relationship to critical area functions, and Best Available Science. This analysis is primarily focused on streams and wetlands, however other GMA-designated[1] critical areas (frequently flooded areas, critical aquifer recharge areas, and geologically hazardous areas) are also considered as these areas are interconnected and interdependent.

1.1 REPORT PURPOSE

The purposes of this report are to characterize ecosystem-wide processes; assess the condition and function of these processes within the City of Duvall (City); and develop recommendations for protecting and restoring critical areas through the CAO update process. The characterization includes a coarse analysis of the broad area that influences the City's critical areas and a more detailed assessment of the critical area conditions within the City limits. This report expands on the Best Available Science review work previously prepared for the Snoqualmie Watershed Near-Term Action Agenda Implementation Project (Adolfson Associates 2004) and the Model Code for Critical Areas prepared for the cities of Duvall, Carnation, Snoqualmie, and North Bend (Snoqualmie Watershed Forum 2004) by identifying areas of importance for maintaining hydrologic and biologic processes that shape and influence Duvall's critical areas. This work is intended to facilitate development of science-based approaches for meeting the GMA goal of no net loss of ecological function by focusing protection and restoration efforts on key areas within the City (Figure 1-1).

1.2 REGULATORY OVERVIEW

The GMA requires all cities and counties in Washington State to adopt development regulations to protect the functions and values critical areas. Local governments can tailor their policies and regulations to fit local circumstances but must demonstrate that they have:

- included the best available scientific information, and
- given special consideration to measures that preserve and enhance anadromous fisheries.

The GMA requirement to include Best Available Science was adopted by the state legislature in 1995 (RCW § 36.70A.172.1). In 2000, the state's Office of Community Trade and Economic Development (CTED) adopted procedural criteria to implement these changes and provided guidance for identifying Best Available Science. The rule makers concluded that identifying and describing critical areas functions and values and estimating the types and likely magnitudes of adverse impacts were scientific activities. Thus, RCW 36.70A.172(1) and the implementing regulations require the substantive inclusion of Best Available Science in developing critical area policies and regulations.

[1] RCW 36.70A.050

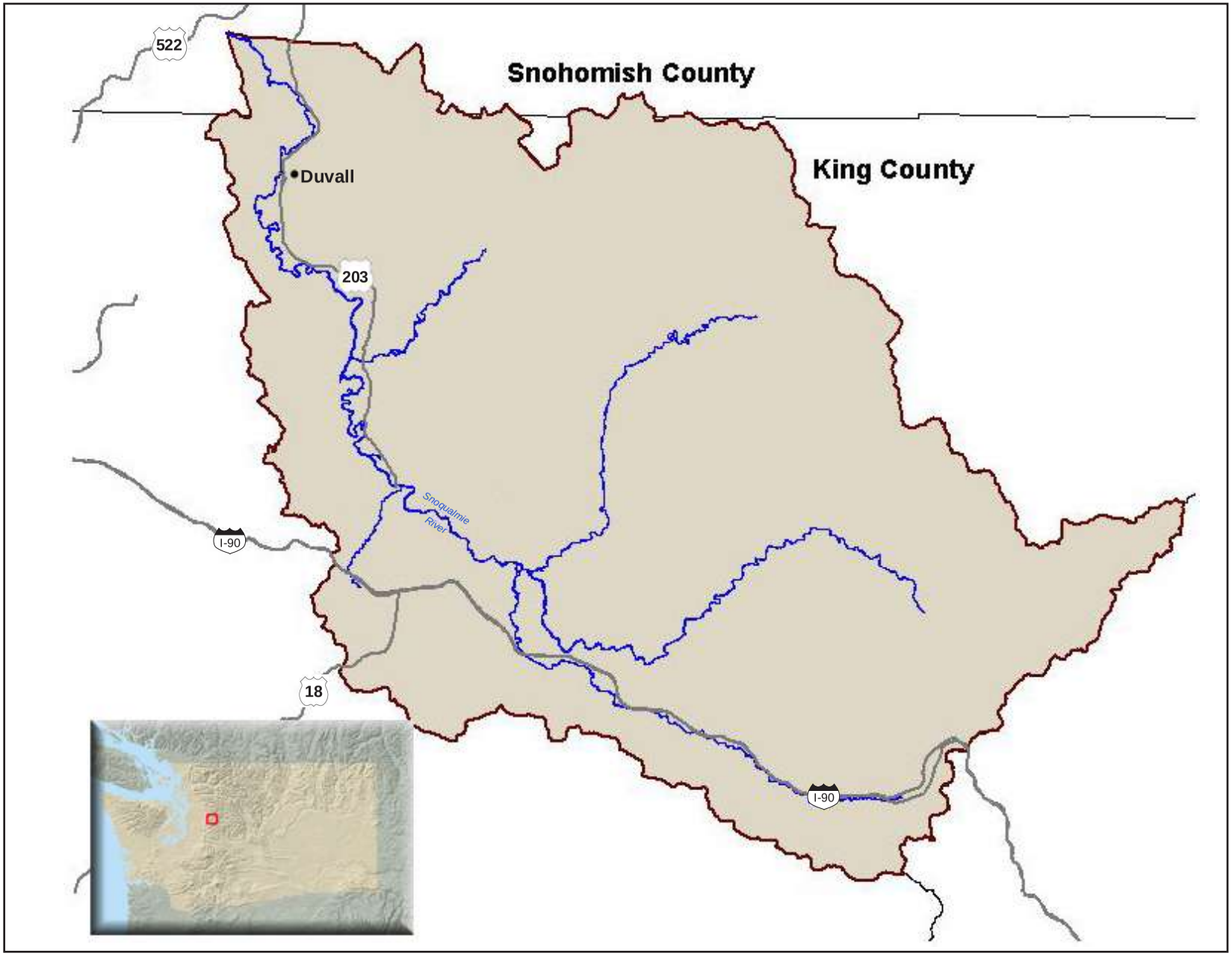

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Figure 1-1
Vicinity Map

The State legislature and the Growth Management Hearings Boards have defined critical area "protection" to mean preservation of critical area "structure, function, and value." Local governments are not required to protect all functions and values of all critical areas, but are required to achieve "no net loss" of critical area functions and values within their jurisdiction. Local governments are also required to develop regulations that reduce hazards associated with some types of critical areas including geologically hazardous areas and frequently flooded areas. The standard of protection is to prevent adverse impacts to critical areas, to mitigate adverse impacts, and/or reduce risks associated with hazard areas.

The information contained within this report was prepared by qualified scientists acting as consultants for City staff. It is intended to be a scientific basis for recommended changes and additions to the Duvall critical areas ordinance.[2] The information presented is pertinent to Duvall, applicable to the types of critical areas present, and is consistent with the Best Available Science criteria contained in WAC 365-195-900 through 925.

[2] In some instances, the BAS review supports existing provisions of the City code and no changes are recommended.

2. METHODS

Major components of the analysis are: (1) review existing scientific information, (2) assess landscape-scale processes using available literature and geographic information system (GIS) data, 3) map resources and areas of interest, and (4) recommend measures for critical areas protection and restoration.

2.1 REVIEW OF EXISTING INFORMATION

Parametrix reviewed existing reports describing the current and historic conditions of natural resources within the Snoqualmie Watershed and the City limits. Existing data sources that were reviewed for this study included, but were not limited to:

- Draft Snohomish River Basin Salmon Conservation Plan (Snohomish Basin Salmon Recovery Forum 2004)
- Snoqualmie Watershed Aquatic Habitat Conditions Report: Summary of 1999-2001 Data (Solomon and Boles 2002)
- Snoqualmie Watershed Stream Habitat Reconnaissance Report (Solomon and Boles 2004).
- Snoqualmie Near-Term Action Agenda Implementation Project: Best Available Science Issue Paper (Adolfson Associates, Inc. 2004)
- Mapping Historical Conditions in the Snoqualmie River Valley (RM 0 - RM 40) (Collins and Sheikh 2002)
- Stream Habitat Assessment for the City of Duvall, Washington: Existing Conditions Report (Herrera Environmental Consultants, Inc 2002)
- A Comparison of the City of Duvall and the Western Washington State Wetland Rating Programs, an Assessment of Best Available Science–Draft (Cooke Scientific, Inc. 2004).

GIS data were used to characterize current conditions within the Snoqualmie Watershed and Duvall. The City provided most of the GIS data layers used for the analysis, but King County provided data for areas outside the city limits.

2.2 LANDSCAPE–SCALE ANALYSIS

The landscape-scale analysis provided in this report is based generally on the approach developed by the Washington State Department of Ecology (Ecology) Shorelands and Environmental Assistance Program (Stanley et al. unpublished) and reported in Ecology's Wetlands in Washington State, Volume 2 (Hruby et al. 2004). The approach addresses two main questions:

- Which geographic areas are important for key landscape processes?
- Have human activities in the important areas altered the key processes?

Ecology has identified the following steps for addressing these questions:

(1) Identify and map existing aquatic resources using available data;

(2) Define and describe the contributing area using available data;

(3) Identify key processes necessary for maintaining ecosystem integrity;

(4) Assess important areas and areas where processes have been altered; and

(5) Develop restoration and protection recommendations.

This coarse-grained analysis allows local governments to integrate ecosystem processes into critical areas assessment and planning (Hruby et al. 2004). The need to consider processes and functions at multiple scales when developing plans for protecting or restoring critical areas is well-established (Gove et al. 2001; Poiani et al. 2000; Dale et al. 2000). Researchers including NMFS (1996) and Hruby et al. (2000) have developed different methods for evaluating site-specific functions or indicators of function but few methods provide rapid and effective approaches for characterizing processes at the watershed or landscape scale.

2.2.1 Identifying Aquatic Resources

Available digital information from the City and the King County GIS Center (2005) was used in identifying and mapping aquatic resources in Duvall. We did not field verify critical areas for this review.

2.2.2 Contributing Area

The contributing area is that portion of the landscape contributing water (surface and groundwater) and water-borne materials to the aquatic resources within the analysis area, and where key processes influence aquatic functions (Stanley et al. 2004). For this study, we defined the contributing area for the Snoqualmie Watershed as the topographic basin boundary. Although the contributing areas for surface water and groundwater sometimes differ they appear to be consistent for this study area. Groundwater movement in the Snoqualmie Watershed downstream of approximately North Bend (river mile [RM] 44), corresponds to topography, flowing downslope along the Snoqualmie River (Turney et al. 1995).

For this analysis of aquatic resources in Duvall, the contributing area for surface water and groundwater is assumed to be equivalent and is defined by the sub-basin boundaries. Because the streams above the Snoqualmie River floodplain in Duvall are all first-order (headwater) streams, the contributing area differs for each. Sub-basins are described in more detail in Section 3.2 below.

2.2.3 Key Processes

Ecosystem processes and functions are complex, interrelated, and work on multiple temporal and spatial scales. Key process important for maintaining aquatic resources such as streams, lakes, and wetlands are (Beechie et al. 2003):

- Hydrology (surface and ground water)
- Sediment supply
- Water quality (e.g., nutrients, pathogens, and toxins/metals)
- Organic matter
- Heat/Light.

These processes are all related to the transport of materials and energy across the landscape. All of these processes affect aquatic resources, but some processes have a greater effect on a particular resource type than others (Table 2-1) (Hruby et al. 2004).

Table 2-1. Landscape Processes that Maintain Aquatic Resources in the Puget Sound Lowlands

Aquatic Resource	Key Landscape Processes[1]
Rivers/ Riverine Wetlands	**Surface water runoff (peak flow)** **Groundwater movement** **Sediment supply** **Water quality (nutrients, pathogens, toxins/metals)**, contaminant cycling **Large Woody Debris (LWD) delivery**
Lakes/ Lacustrine Wetlands	Surface water runoff **Surface water storage** Groundwater movement Sediment supply **Water quality (nitrogen and phosphorous cycling)**, contaminant cycling
Depressional Wetlands	Surface water runoff **Groundwater movement** **Sediment supply** **Water quality (nitrogen and phosphorous cycling)**, contaminant cycling LWD delivery
Slope Wetlands	**Groundwater movement**

1 Processes in bold are most important for maintaining the integrity of the aquatic resource.

2.2.3.1 Process Controls

The key processes noted above operate in a framework established by process controls, including geology, climate, vegetation, and land use. Geology and climate are ultimate controls that are generally not manageable by humans and are relatively free from human influence.[3] Vegetation and land use are proximate controls that are more manageable and susceptible to human activity.

Geology

Geology imposes a suite of conditions on landscape processes. To that affect, (1) It influences topography, landform stability, and substrate permeability and reactivity. (2) Geology determines the route and type of water transport pathways (overland flow, streams, and subsurface flow) over and through the landscape. (3) It also influences water quality through residence time (infiltration rate), substrate chemistry and pH, sediment availability, and to some extent toxin availability (heavy metals) (Turney et al. 1995).

Climate

Climate interacts with geology to determine watershed conditions. Glaciation resulting from climate change was the predominant process that shaped much of the surficial geology in the

[3] Human activities can affect climate (global warming) however climate change is not manageable at the local scale.

Puget Sound region. While geology can determine where and how materials move through a system, climate is directly responsible for the amount, form, and timing of water inputs.

Vegetation

The plant cover over a landscape, or on a site, influences the interaction of water and surficial geology. Plants perform a number of important functions that control the distribution of water including: intercepting precipitation, which decreases water's available energy for sediment transport; recirculating water through transpiration, which may, in turn, influence local climatic conditions; providing shade, which moderates temperatures and humidity near the ground's surface; stabilizing soil structure with their roots; and providing organic input, nutrient enrichment, and habitat structure. Thus, vegetation is extremely important for protecting and restoring aquatic resources. The ability of vegetation to perform these functions varies with vegetation type (forest, meadow, shrub wetland).

Unlike geology and climate, human activities can easily alter vegetation. The type and extent of vegetation on a site, or within a region, can vary dramatically over a short time-interval as a result of human actions (i.e., burning, clearing, irrigation). Thus, it is a proximate control that can be managed.

Land Use

Land use activities related to agriculture, forestry, and residential/commercial development, can alter vegetation and, to a lesser extent, surficial geology, which can affect landscape processes. Land use acts as a stressor on natural processes disrupting the interception and uptake of precipitation and nutrients; microclimate; the type and amount of nutrient and pollutant inputs; infiltration and recharge; and the proportion of water distributed via surface and subsurface flows.

2.2.4 Important Areas and Process Alterations

Each landscape process works via a suite of mechanisms through which the process influences ecological functions and by which it may be impaired. For example, erosion and mass wasting mechanisms determine sediment inputs to aquatic systems, while other mechanisms act to store or transport the delivered sediment through the system. These mechanisms are associated with specific areas (referred to as important areas) on the landscape that exhibit certain characteristics (geology, vegetation, and land use). The relationship between processes, mechanisms, and important areas is summarized in Table 2-2.

Table 2-2. Mechanisms and Important Areas for Landscape Processes

Process	Mechanism	Important Areas
Hydrology	Infiltration/recharge	Permeable soils, riparian areas, floodplains
	Surface water storage	Depressional wetlands, lakes, floodplains,
	Peak flows	Impervious surfaces, rain-on-snow (ROS) zone, forest cover
	Groundwater movement (baseflow)	Permeable deposits, fissured bedrock
Sediment Supply	Erosion	Erodible soils, especially on steep slopes, Channel Migration Zones (CMZs)
	Mass wasting	Slopes prone to landslides
Water Quality	Physical properties (temperature, turbidity)	Forest cover, riparian zones
	Chemical properties (pH, nutrient levels)	Depressional wetlands, wetlands with organic soils, riparian zones, hyporheic zones, floodplains
	Contaminants (toxins, pathogens)	Depressional wetlands, riparian zones, hyporheic zones, floodplains
Organic Inputs/LWD	Riparian vegetation	Riparian zones, forested CMZs
	LWD recruitment	Riparian zones, forested CMZs, landslide hazard areas

2.2.4.1 Hydrology

Hydrology is the study of the movement of water through the landscape. For purposes of this report, hydrologic mechanisms include infiltration and recharge, surface water storage, peak flows, and groundwater flow. Interception and evapotranspiration, two other important hydrologic mechanisms, are not considered in this landscape analysis, but their alteration is inferred from changes in land cover.

Well-drained soils, floodplains, rain-on-snow (ROS) zones, depressional wetlands, and lakes are all areas of importance for the distribution of water over the landscape. As water, typically in the form of precipitation, contacts the ground surface, infiltration is the first mechanism that determines the movement of water through the landscape. Infiltration is important as the source of water (recharge) for lateral subsurface movement (interflow) or baseflow (groundwater), which in turn are important for aquifer recharge and stream discharge. Depressional wetlands, floodplains, and lakes/ponds all have the potential to store

water, particularly during peak flow events (Sheldon et al. 2003; Hruby et al. 2000). This surface water storage desynchronizes runoff, attenuating the duration of storm events and reduces peak flows. Runoff is the discharge of surface water through a watershed. Sources of runoff include direct precipitation onto surface waters, overland flow, interflow, and groundwater discharge. The rate, distance, and volume of water movement across the landscape vary for each of these water sources, and this variability desynchronizes flows.

Water's distributive pathway across the landscape affects the volume, location, and timing of water availability. Hydrologic connectivity affects stream base flows and wetland hydrology, particularly during low-flow periods, and is an important issue for fisheries management. Flow volume and water depth to a large degree determine habitat suitability for fish in streams and off-channel waters. Stream channelization (the straightening and armoring of channels) increases flow velocities and simplifies instream habitat. Culverts, while maintaining hydrologic connectivity, may be barriers to fish passage by altering flow velocities or channel morphology (Solomon and Boles 2002, 2004; SBSRF 2004; Stockard and Harris 2005).

Groundwater flow paths occur at regional, intermediate and shallow scales corresponding to shorter flow paths and residence time, respectively. Regional groundwater is maintained along deep flow paths in pre-Quaternary bedrock and is defined by large-scale topographic features such as Puget Sound and the Cascade Mountains. Local groundwater occurs in upper Quaternary deposits and is governed largely by local topography. Recharge occurs mainly in glacial drift plains and is discharged as surface water via springs and seeps. Shallow groundwater boundaries typically follow surface watersheds. The location, flow path depth, and scale of movement of intermediate groundwater falls somewhere between regional and shallow groundwater. Groundwater serves as a source of stream baseflow during summer and can be an important source of drinking water. In Puget Sound, groundwater is the primary source of drinking water for rural areas and is increasingly being used for urban consumption (Ebbert et al. 2000).

2.2.4.2 Sediment Supply

Water is the medium and gravity the energy that move sediment from hillslopes to aquatic systems. Hillslope sediment transport is accomplished primarily through surface erosion, mass wasting, and slope creep; therefore areas of erodible soil and landslide-pone hillslopes are important areas for sediment supply processes. Clearing vegetation, exposing erodible soils, or increasing the amount of impermeable surface may affect the pattern and timing of water distribution, which may, in turn, accelerate erosion and slope failures.

Over time, streams move laterally, or migrate, across their floodplains. Channel migration may be gradual as a stream erodes its banks or may occur as a sudden event when a stream shapes a new channel, avulsing a portion of the floodplain and abandoning the previous channel. The area of active channel migration is called the channel migration zone (CMZ) and it can be an important area for sediment supply (KCDNRP 2004).

Surface erosion occurs as the result of physical soil entrainment by water. Conversely, mass wasting transports soil down hillslopes discontinuously, at high rates over very brief periods of time, and can transport soils at greater depths than creep. This landscape analysis is limited to surface erosion and mass wasting because they are the dominant natural sources of increased sediment inputs due to land use (Nelson 1999; Slaymaker 2000). Erosion above natural background levels may degrade stream habitat by increasing the proportion of fines in the substrate and if elevated sufficiently, aggrade the streambed. Streambed aggradation may lead to channel braiding (the development of multiple shallow channels) and can limit or

block fish passage and further degrade habitat suitability (Dunne and Leopold 1978; Herrera Environmental Consultants, Inc. 2002).

2.2.4.3 Water Quality

Important areas for water quality processes are depressional wetlands, floodplains, and hyporheic zones. These areas affect the rate at which water moves over and through the landscape. Slower transport times allow sediments, chemicals, and nutrients to settle out of water (Minton 2002). Water quality is affected by parameters that include the physical properties (temperature, clarity) and chemical composition of water. Degraded water quality results when these parameters exceed normal baseline levels, often from the input of additional sediment, nutrients (phosphorous or nitrogen), or the introduction of toxins (e.g., pathogens, heavy metals, or pesticides). Water quality can also be impaired by a decrease in specific parameters, such as dissolved oxygen (DO) or pH. Toxins, such as mercury and fecal coliform, may present a health risk to humans (WAC §173-201A).

Alterations in heat and light reaching a water body can alter water quality. Heat inputs may occur within a given water body or stream reach, or in upstream tributary waters. Light inputs are a function of the amount of shade at a given site, but elevated water temperatures may by transported to receiving waters. Changes in the amount of light may affect the density and composition of the water plants within a water body, which may in turn, determine habitat suitability for aquatic animals. In this study, alterations in heat will be discussed under water quality and alterations in light (shading) will be discussed under organic inputs.

When water quality is degraded beyond the normal range the endemic aquatic community is adapted to, species may be lost from the community (Naiman et al. 1992). Impaired water quality may lead to algal blooms or the proliferation of non-native species, further compromising water quality. Salmonids are sensitive to changes in dissolved oxygen, turbidity, temperature, and pH and alterations in these parameters, have been identified as limiting factors for salmonid reproduction and survival (NMFS 1996; WAC §173-201A; SBSRF 2004; Solomon and Boles 2004).

Land use and the proportion of the built environment within a watershed can directly impact water quality in a given basin, including groundwater. Generally, the more developed a basin, the greater the proportion of impervious surface and potential for increased input of sediment, pollutants such as hydrocarbons, and nutrients to a water body.[4] The primary mechanism of contaminant transport from urban and rural lands to the surrounding watershed is runoff. Impervious surfaces (i.e., roads, sidewalks, pavement, and rooftops) are key in the transport of stormwater runoff and associated contaminants (Minton 2002). Irrigation and storm events can enhance the movement of pesticides and metals bound to loose organic matter (Minton 2002), and increased sediment loads created by erosion can accumulate adsorbtive pollutants (EPA 2001). Elevated nutrient, pesticide, and fecal coliform levels in water have been found in agricultural areas (Solomon and Boles 2002; Onwumere and Batts 2004).

[4] Increased impervious surface area is also associated with higher peak flows and lower base flows in small streams (Paul and Meyer 2001; Adolfson Associates, Inc. 2004; Glasoe and Christy 2004).

2.2.4.4 Organic Matter and LWD Inputs

Organic matter, often in the form of leaf litter and other plant detritus, is the basis of the food web and largely determines productivity in aquatic and terrestrial systems. Riparian areas are important areas for organic and heat/light processes. Organic inputs provide nutrients and structure to the substrate and are an important food source for microbes, invertebrates, vertebrates, and plants (Knutson and Naef 1997; Kauffman et al. 2001; Sheldon et al. 2003). If abundant enough, organic matter may be the principal component of organic soils (peat, muck). Originating as plant and animal matter, organics may be imported to an aquatic site by surface waters or may originate *in-situ*.

LWD (greater than 4-inches diameter and 6-feet length) provides nutrients, structure, and essential fish and wildlife habitat to streams and wetlands (Knutson and Naef 1997; Kauffman et al. 2001; Solomon and Boles 2002; Sheldon et al. 2003). By altering stream hydraulics, LWD contributes to the creation of scour pools and eddies and also provides cover (shade and refugia), all of which are important habitat features for salmonids and other aquatic species (Kauffman et al. 2001; Solomon and Boles 2002; SBSRF 2004). Delivery of LWD to streams results from landslides along steep slopes or bank failures via active channel migration in CMZs (Collins and Sheikh 2002; KCDNRP 2004).

2.3 RESOURCE MAPPING

The analysis area for resource mapping includes the municipal boundary and designated urban growth area (UGA) for the City of Duvall. Base layers for resource mapping and analysis were provided by the City. The digital municipal and UGA boundaries were merged to create the analysis area boundary. Digital stream, basin, and two-foot contour layers were used to define Sub-basins within the analysis area. Sub-basin boundaries were delineated based on topography and streams.

Land cover within the City was mapped from true color digital orthophotographs (2002) . The coordinate system for the analysis was Washington State Plane North, North American Datum 1983, feet. Five general land cover categories were defined prior to mapping:

- **Developed –** main arterial roads and highways, paved surfaces, and building or structure footprints and the associated landscaping (less than 1 acre in size);
- **Grass –** meadows, pastures, and landscaped areas (greater than 1 acre in size) dominated by herbaceous vegetation;
- **Tree/shrub –** discontinuous mature tree cover, usually deciduous species, continuous sapling tree cover, or shrub cover;
- **Forest –** continuous mature tree cover, usually conifers; and
- **Water –** open water in Rasmussen Lake and the Snoqualmie River.

Land cover polygons, down to approximately 1-acre in size, were delineated onscreen using ArcVIEW GIS®, Version 3.2 and attributed with the appropriate cover category. Polygon delineation and attribution were based on an ocular estimate of the dominant cover type within the polygon.

To assess the condition of aquatic resources within the City, digital layers provided by the City (wetlands, streams, soils, topography) were overlaid on the land cover layer produced by Parametrix. Distances from aquatic resource areas to other features and the radius of potential resource buffers were calculated by ArcVIEW GIS®.

2.4 ASSUMPTIONS AND DATA GAPS

The landscape analysis approach uses readily available information to assess conditions. This approach assumes that adequate data are available; that available site-specific studies are applicable to the watershed; and that conditions within the analysis area have not changed appreciably since the available studies were done. Where data are not available, or current, surrogates for a given parameter may be appropriate (existing forest conditions as a surrogate for LWD in streams).

3. RESULTS

This section provides a broad overview of the Snoqualmie Watershed and the landscape processes influencing the functions of aquatic resources. Processes are assessed in regard to their historic conditions and the subsequent impairments that have occurred as a result of human activity. Landscape processes and ecological functions are discussed at the watershed and the sub-basin scales to provide the context for management decisions for the protection and restoration of critical areas within the City of Duvall.

3.1 Overview of Snoqualmie Watershed and Duvall

The following sections describe the characteristics of the contributing areas and outline the framework within which landscape processes function in the watershed and in the Duvall analysis area.

3.1.1 Aquatic Resources

Aquatic resources within the watershed include the Snoqualmie River and tributary streams; floodplain, depressional, and slope wetlands; lakes; and groundwater. Historically, these aquatic resources provided important functions such as peak flow storage, groundwater recharge, water quality maintenance, and fish and wildlife habitat. The Snoqualmie Watershed is composed of 16 basins, ranging in size from 4 to 170 square miles in area. The larger basins are generally found in the eastern portion of the watershed, where the topography steepens appreciably above approximately 1,500 feet elevation. Approximately 2,243 miles of streams have been mapped throughout the watershed, ranging in size from small unnamed tributaries to the mainstem Snoqualmie River (King County GIS 2005). Major tributaries to the Snoqualmie River include Cherry Creek (right bank, RM 7), the Tolt River (right bank, RM 24), the Raging River (left bank, RM 35), and Tokul Creek (right bank, RM 38). The gradient of the Snoqualmie River is steepest above Snoqualmie Falls and is gradual below the falls (Solomon and Boles 2002).

Historically, wetlands within the watershed would have been most abundant within the Snoqualmie River floodplain. Lakes are found throughout the watershed. Porous and alluvial soils, conducive to groundwater recharge are found primarily along the mainstem Snoqualmie River.

The Snoqualmie River provided migratory, spawning, and rearing habitat for all salmonids native to Western Washington, except for sockeye salmon (*Oncorhynchus nerka*) (Wydoski and Whitney 2003). Riparian and instream habitat would have supported a number of species that today are listed or classified as special status species, including Chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), bull trout (*Salvelinus confluentus*), and bald eagles (Haliaeetus leucocephalus),. Tributary streams, including Duvall area streams, would have likely provided spawning and rearing habitat for coho salmon, steelhead and rainbow trout (*O. mykiss*), and cutthroat trout (*O. clarki*).

In the Duvall area, important aquatic resources include approximately 2 miles of the mainstem Snoqualmie River, Thayer and Coe-Clemmons Creeks, Cherry Creek tributaries, and a number of palustrine wetlands (Figure 3-1). The area of Duvall west of State Route 203 is within the Snoqualmie River floodplain and the boundary between the Snoqualmie and Cherry Creek basins bisects Duvall, running in a northwesterly to southeasterly direction (King County GIS 2005). For this study, eleven sub-basins were identified within the analysis area (Table 3–1).

Table 3-1. Sub-basins Within Duvall Analysis Area.

Basin	Sub-basin	Area (acres)	Percent Analysis Area
Snoqualmie	Snoqualmie North	213	11
	Coe-Clemmons Creek	374	18
	Snoqualmie River	29	1
	Thayer Creek	269	13
	Snoqualmie South	324	16
Cherry Creek	Cherry Creek A	223	11
	Cherry Creek B	91	4
	Cherry Creek C	174	9
	Cherry Creek D	195	10
	Snoqualmie East	77	4
	Snoqualmie Southeast	54	3

3.1.2 Geology

Encompassing approximately 692 square miles, the Snoqualmie Watershed extends from the crest of the Cascade Mountains in the east to the confluence of the Snoqualmie and Skykomish Rivers in southwestern Snohomish County. Elevation within the watershed varies from approximately 15 feet (mean sea level [msl]) at the confluence of the Snoqualmie and Skykomish Rivers to approximately 6,700 feet msl along the Cascade crest. The Snoqualmie Watershed is located within the 1,856-square-mile Snohomish Basin (Water Resource Inventory Area 7), the second largest basin on Puget Sound (SBSRF 2004).

The topography steepens in the eastern portion of the watershed and bedrock is relatively common in the mountains. A large bedrock outcrop, at approximately RM 40 on the mainstem Snoqualmie River, forms Snoqualmie Falls and separates the upper Snoqualmie Valley from the lower valley. The landforms within the Snoqualmie Watershed have been shaped by glaciation. The foothills of the Cascades and surrounding the Snoqualmie Valley are generally overlain with glacially derived soils such as till and outwash. Alluvium, varying in size from boulders and cobble to silt, is found along the floor of the Snoqualmie Valley and major tributaries. Snoqualmie Falls blocks the downstream transport of coarse sediment; tributary streams below the falls supply coarse sediment to the lower valley (Solomon and Boles 2002).

The City of Duvall is located on the east slope of the lower Snoqualmie Valley, between approximately RMs 9 and 11 (Solomon and Boles 2004). The analysis area for this study (city limits and UGA) encompasses approximately 2,023 acres. Duvall is situated along the western slope of a knoll that is contiguous with hilly topography on the western edge of the Cascade foothills. Topography along the northeastern portion of the analysis area is quite steep and King County has mapped this area as prone to landslides (King County GIS 2005). The Snoqualmie River forms the western city limits of Duvall and approximately 7 percent of the city (138 acres) lies within the Snoqualmie floodplain.

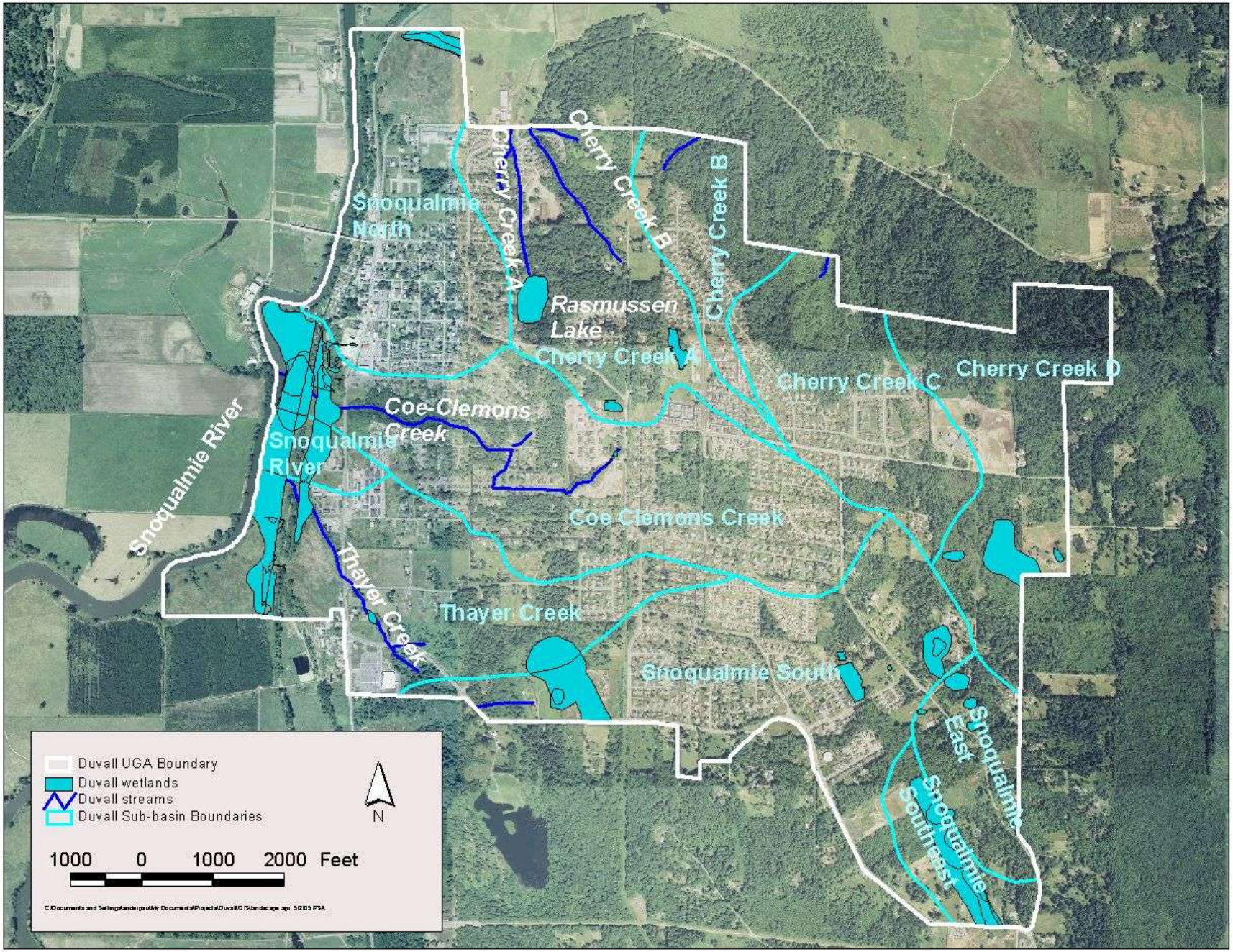

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Figure 3-1
Sub-basins and Important Aquatic Resources, City of Duvall

Relatively impermeable till (Alderwood gravely sandy loam) is the principal soil type (1,837 acres; 91 percent) found in the analysis area; the remainder being outwash (48 acres; 2 percent) and alluvium (138 acres; 7 percent). The outwash is Alderwood and Kitsap soils on very steep slopes (25 to 70 percent slope), which have rapid runoff, a severe to very severe erosion hazard rating, and a severe potential for slippage (SCS 1973). Outwash soil is found primarily along the northeastern city limits, roughly corresponding to the landslide hazard area mapped by King County (King County GIS 2005), and is also found along Coe-Clemmons Creek between State Route 203 and 3rd Avenue Northeast. Alluvial soils in the analysis area (Briscot silt loam, Nooksack silt loam, and Puget silty clay loam) are fine grained, having slow to moderate permeability, slow runoff, and a slight erosion hazard (SCS 1973). Two of these alluvial soils (Briscot silt loam and Puget silty clay loam) are classified as hydric soils (SCS 1991), which typically develop in low-energy (floodplains, wetlands, and off-channel areas), saturated conditions and may be a wetland indicator (Sheldon et al. 2003).

3.1.3 Climate

Climate is directly responsible for the gross patterns of thermal inputs and the magnitude, type, and timing of water inputs to a region. Climate also indirectly influences the movement of other materials. Western Washington has a maritime climate characterized by cool summer and mild winter temperatures. Prevailing southwesterly winds from the Pacific Ocean deliver an annual average of up to 48 inches of precipitation, primarily as rainfall, to the Puget Trough lowlands. Most precipitation falls between October and March and summers are typically dry. At lower elevations, winter temperatures below freezing and snow may occur but are usually of short duration (Franklin and Dyrness 1987).

Weather patterns can be regionally generalized in the Snoqualmie Watershed. Due to orographic effects, the Cascade Mountains receive the bulk of precipitation in the watershed, with Snoqualmie Pass (elevation 3,020 feet msl) receiving up to 105 inches of precipitation annually (period of record 1931 to 1972) (WRCC 2005). Much of this precipitation occurs in the form of snow; the mean average snow depth for the period of record was 34 inches at Snoqualmie Pass (WRCC 2005). Precipitation and the snowfall:rain ratio decrease with elevation and to the west towards the shoreline of Puget Sound. In contrast to Snoqualmie Pass, average annual precipitation at Snoqualmie Falls (elevation 440 feet msl) and Everett (elevation 60 feet msl) is 61 inches and 37 inches, respectively, while average annual snow depth for both is 0 inches (WRCC 2005).

Runoff processes are a function of the timing and type of rainfall. The Snoqualmie River headwater streams receive a large proportion of total annual runoff from snowmelt originating in the Cascade Mountains. At mid to high elevations within the watershed (between 1,500 and 4,500 feet elevation msl), ROS events play an important role in runoff. Below approximately 1,500 feet elevation, rainfall is the principal source of precipitation to the Snoqualmie River and smaller drainages within the watershed (Brunengo et al. 1992; Solomon and Boles 2002; Ketcheson et al. 2003).

3.1.4 Vegetation

Historically, Western Washington and the Snoqualmie Watershed were mostly forested (Franklin and Dyrness 1987; Collins and Sheikh 2002). Upland areas were dominated by coniferous forest. Hardwoods and shrub communities were found along valley bottoms and within floodplains. However, conifers accounted for the majority of biomass in valley bottoms and over the landscape.

The majority of the Snoqualmie Watershed lies within the *Tsuga heterophylla* (western hemlock) forest zone; that portion of the watershed above approximately 2,000 feet elevation lies within the *Abies amabilis* (Pacific sliver fir) zone (Franklin and Dyrness 1987). Historically, forests were the dominant plant communities in the Snoqualmie Watershed. Upland areas were dominated by coniferous forest, composed primarily of western hemlock, Douglas-fir (*Pseudotsuga menziesii*), and western redcedar (*Thuja plicata*), with Pacific sliver fir predominant at higher elevations. Hardwoods, such as red alder (*Alnus rubra*), black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), and willows (*Salix* spp.), were more abundant than conifers in valleys and floodplains, but conifers increased in frequency with distance from active stream channels (Franklin and Dyrness 1987; Collins and Sheikh 2002).

In a reconstruction of Snoqualmie Valley habitat conditions in approximately 1870, prior to settlement by Anglo-Americans, Collins and Sheikh (2002) identified a large shrub-dominated wetland complex between RM 4 and RM 11 (which includes the Duvall vicinity). This wetland complex occupied the full breadth of the valley, contained remnant channels and depressions that appeared to be at lower elevations than the Snoqualmie River banks, and included extensive areas of emergent marsh (Collins and Sheikh 2002).

Conifer forests are still the dominant plant community over much of the watershed, particularly in the foothills of the Cascades. Riparian forests along the mainstem Snoqualmie River have, to a large extent, been cleared and converted to agricultural or developed lands (Collins and Sheikh 2002; Solomon and Boles 2004).

Emergent and shrub communities are found in wetlands and riparian zones throughout the watershed. Shrub communities dominated by Sitka alder (*Alnus sinuata*) and blueberries (*Vaccinium*) are common on high elevation slopes and avalanche chutes. Dominant species in the lowland shrub communities include red alder, willow, red-osier dogwood (*Cornus sericea*), and hardhack (*Spiraea douglasii*), while common emergent wetland species include sedges *(Carex* spp.), rushes (*Juncus* spp.), cattails (*Typha latifolia*), and skunk cabbage (*Lysichiton americanum*).

Prior to settlement, it is likely that nearly all of Duvall was forested. Non-forested areas would have primarily been wetlands, open water, and active landslides (Franklin and Dyrness 1987).

3.1.5 Land Use

Approximately 97 percent (664 square miles) of the watershed are within King County, and the northerly 3 percent (21 square miles) are within Snohomish County (Figure 3-2). Today, over 76 percent of the Snoqualmie Watershed is classified as forest land (525 square miles) (Solomon and Boles 2002; King County GIS 2005; Snohomish County GIS 2005). The Mount Baker-Snoqualmie National Forest, commercial timberlands, and the City of Seattle's South Fork Tolt Watershed are found in the eastern two-thirds of the Snoqualmie Watershed. Timber harvest on the publicly owned forestlands has declined dramatically since the early 1990s due to concern over threatened fish species and water quality (Seattle Public Utilities 2003).

Agricultural lands within the watershed, primarily in dairy production, are concentrated within the Snoqualmie River floodplain downstream from the City of Snoqualmie (RM 34).

Designated agricultural lands cover approximately 4 percent (26 square miles) within the Snoqualmie Watershed (King County GIS 2005; Snohomish County GIS 2005).

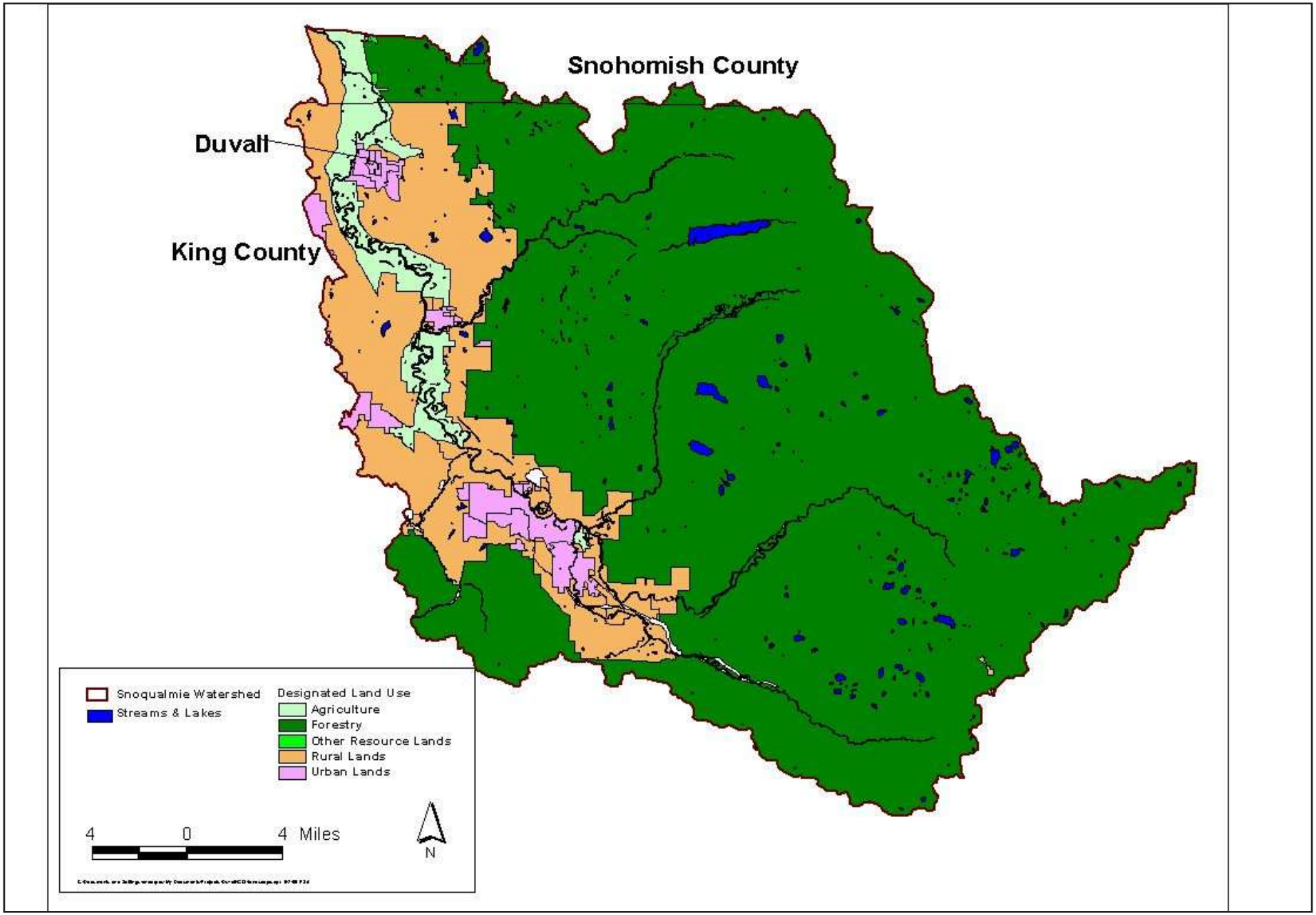

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Figure 3-2
Land Use, Snoqualmie Watershed

Urban lands within the watershed account for approximately 3 percent (19 square miles) of the lands. Four incorporated cities are found within the Snoqualmie Valley (Duvall, Carnation, Snoqualmie, and North Bend) and portions of the urban growth areas for the cities of Redmond and Sammamish are located on the western edge of the watershed (King County GIS 2005; Snohomish County GIS 2005). In 2000, the Snoqualmie Valley human population was of 40,000 and is expected to reach 70,000 by the year 2020 (Solomon and Boles 2002).

The remainder of land use within the watershed (117 square miles; 17 percent) is designated as rural residential (King County GIS 2005; Snohomish County GIS 2005). Table 3–1 summarizes the designated land use categories within the Snoqualmie Watershed and Duvall.

Land use within Duvall is primarily urban, including a number of residential designations, commercial, employment, and public facilities. Designated open space within Duvall includes parks, open space, and vacant lands (see Table 3–2, Figure 3–3).

Table 3-2. Land Use within the Snoqualmie Watershed and Duvall.

Snoqualmie Watershed	Land Use Category	Acres	Percent of Area
	Agriculture	16,673	4
	Forestry	335,906	76
	Other Resource Lands[1]	477	<1
	Rural Lands[2]	74,571	17
	Urban Lands[3]	11,870	3
Total		43,9497	100
Duvall[4]	Land Use Category	Acres	Percent of Area
	Urban[5]	896	70
	Open Space[6]	388	30
Total		**1,284**	**100**

1 Includes Mineral, Open Space, and Rural Conservation lands
2 Includes Rural-5 acre, Rural Neighborhood, Rural Residential, Rural Town, and Rural City Urban Growth Area lands
3 Includes Urban Growth Area, Urban Planned Development, and Urban Residential lands
4 Acreage within city limits from Duvall Comprehensive Plan (2004)
5 Includes Commercial, Employment, Mixed Use, Public Facilities, and Residential land use
6 Includes Parks Open Space and Vacant land use
Source: King County GIS (2005); Snohomish County GIS (2005); City of Duvall (2004)

3.2 Landscape Process Inventory

This section describes important areas for key processes based on historic conditions.

3.2.1 Hydrology

Important areas for hydrologic mechanisms are found throughout the Snoqualmie Watershed. High precipitation and ROS areas are found at the higher elevations in the eastern watershed; well-drained soils, important for infiltration, are found along the valley bottoms and lower side slopes; floodplains and depressional wetlands are found along the mainstem Snoqualmie and major tributaries; and lakes are scattered across the landscape from the lowlands to the higher elevations. Figure 3-4 highlights the important areas for hydrologic mechanisms in the Snoqualmie Watershed.

3.2.1.1 Infiltration and Recharge

Two geologic formations in the Snoqualmie Watershed are important to infiltration and are associated with surficial recharge: porous, coarse-grained soils (outwash) above relatively impermeable subsurface strata; and alluvium along major streams. Deep recharge is found in areas with fissured bedrock (Turney et al. 1995; Adolfson Associates, Inc. 2004). These areas occur within and adjacent to the Snoqualmie River and tributary floodplains (King County Groundwater Protection Program 2004). King County mapped a large, contiguous area of coarse-grained soils along the Snoqualmie River floodplain in King County from approximately RM 50 (east of North Bend) downstream to approximately RM 6 on the Snohomish County line (King County Groundwater Protection Program 2004) (see Figure 3–4). Tributary basins also contain smaller areas of high infiltration capacity contiguous with the Snoqualmie floodplain. Mapped groundwater movement within the East King County Groundwater Management Area areas is downslope towards the Snoqualmie River and downstream within the Snoqualmie Valley. Groundwater elevations (above msl) vary from approximately 800 feet in the Snoqualmie-North Bend area to 40 feet within the Snoqualmie floodplain near Duvall (King County Groundwater Protection Program 2004).

Precipitation rates within the watershed are higher in the Cascade Mountains and foothills than to the west, and areas with high infiltration and recharge capacity typically occur in the upper Snoqualmie Valley. Mapped annual recharge rates along the Snoqualmie River vary from approximately 10 inches at Duvall up to approximately 60 inches at North Bend (Turney et al. 1995).

Two large aquifers are found beneath the Snoqualmie River, the larger of the two is the Snoqualmie Aquifer, in the vicinity of North Bend (East King County Ground Water Advisory Committee 1998). This aquifer is of sufficient size to have been identified as potential source of municipal water and low-flow augmentation for the river (Seattle Public Utilities 2001; Adolfson Associates, Inc. 2004).

The East King County Groundwater Management Plan has identified the Snoqualmie Aquifer as a high priority for protection (East King County Ground Water Advisory Committee 1998) and the county has established a groundwater protection committee for eastern King County (King County Ordinance 14214). The relatively high infiltration rate through the substrate overlying the Snoqualmie Aquifer is correlated with a high risk of aquifer contamination, and Ecology monitors groundwater quality in this region (Onwumere and Batts 2004) (see Water Quality below).

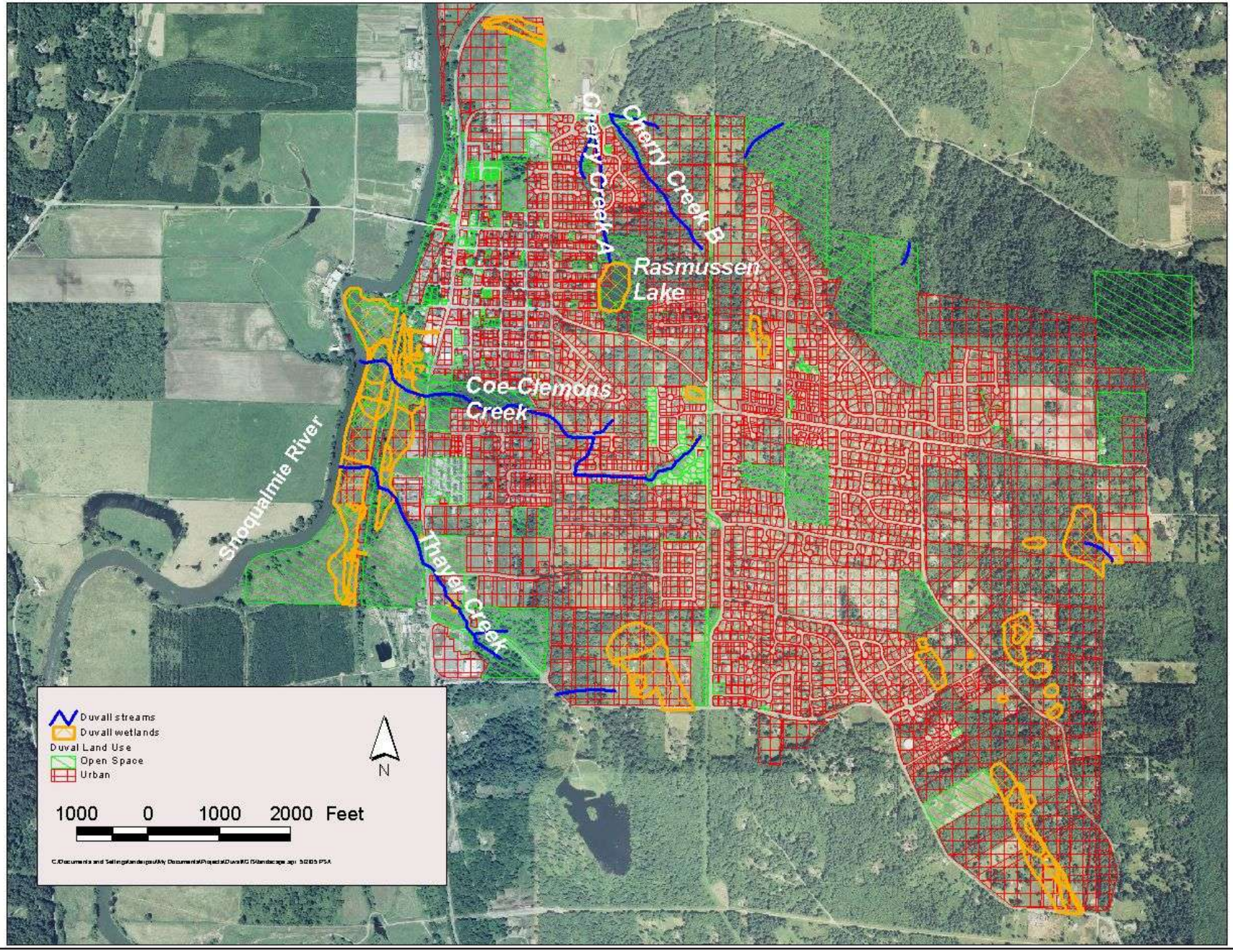

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Figure 3-3
Land Use Designations
City of Duvall

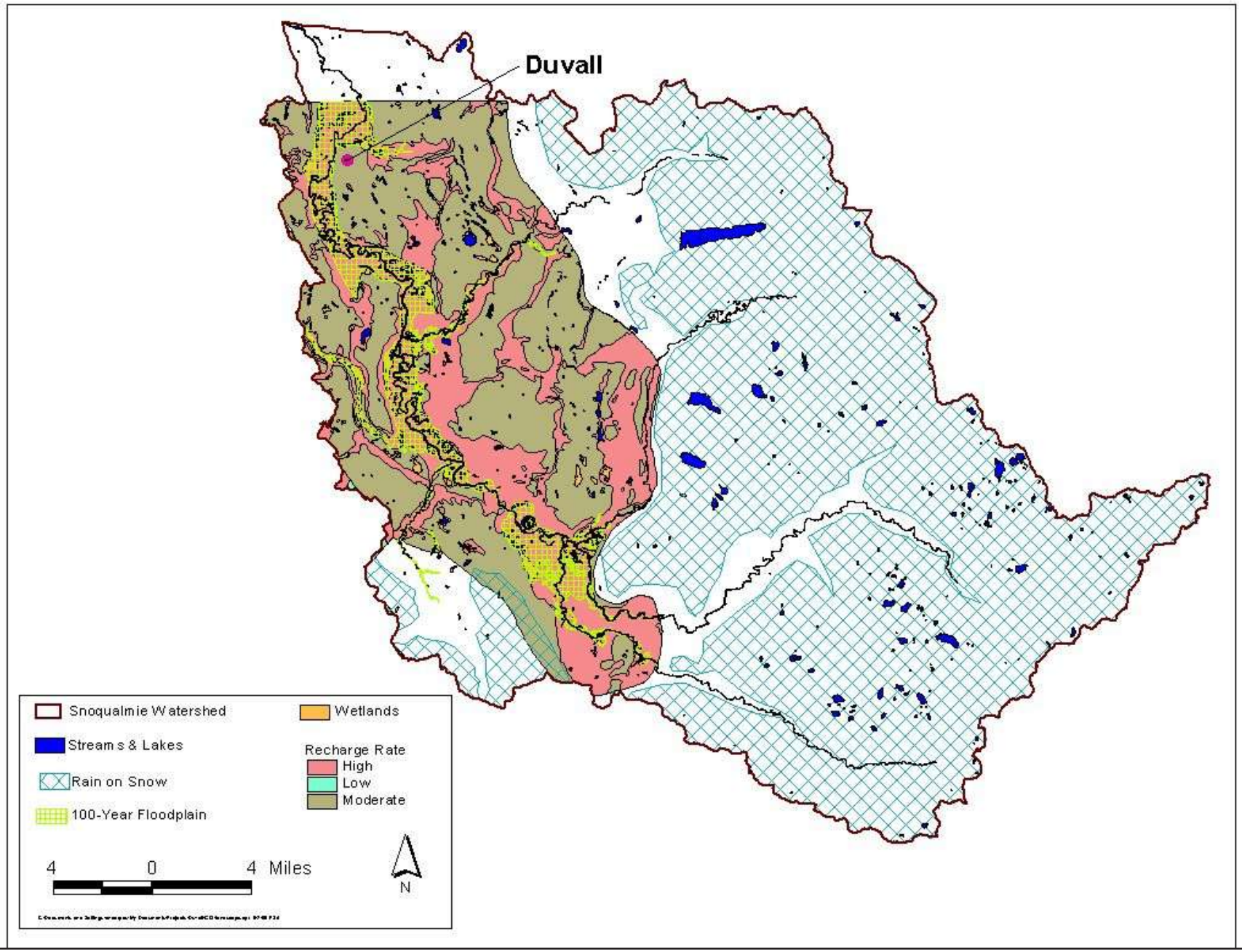

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Figure 3-4
Hydrologic Mechanisms and Important Areas, Snoqualmie Watershed

Due to the steep slopes and relatively impermeable till soils that underlie much of Duvall, infiltration and groundwater recharge within Duvall is limited. The estimated annual recharge of 10 to 20 inches for most of the Duvall area is a relatively low rate of recharge (Turney et al. 1995). Porous soils in northeastern Duvall have been mapped by King County as an important area for recharge (Figure 3-5) (King County GIS 2005).

3.2.2 Surface Water Storage

Within the Snoqualmie Watershed, surface water storage at high elevation is found primarily in tarns and the Tolt Reservoir; and at lower elevations within lakes, alluvial channels and floodplains, and depressional wetlands. The mapped Snoqualmie 100-year floodplain encompasses approximately 34 square miles (King County GIS 2005).

Within the Duvall analysis area, approximately 200 acres are available for surface water storage in the Snoqualmie River floodplain, wetlands outside of the floodplain and Rasmussen Lake. The 100-year floodplain within Duvall (133 acres) accounts for approximately 0.6 percent of the mapped Snoqualmie 100-year floodplain storage capacity.

The principal streams arising in Duvall (Thayer Creek, Coe-Clemmons Creek, and Cherry Creek tributaries) generally have limited surface water storage capacity due to the relatively steep stream gradients, impermeable soils, and limited off-channel wetlands above the Snoqualmie Valley. One exception to the limited storage capacity in Duvall is the westerly tributary to Cherry Creek, identified as Cherry Creek Tributary A by Herrera Environmental Consultants, Inc. (2002), which passes through Rasmussen Lake, the largest water body in the city. Rasmussen Lake, approximately 5.3 acres, is identified on the National Wetlands Inventory map as a palustrine unconsolidated bottom permanently flooded wetland.

3.2.2.1 Peak Flows

Peak flows in the Snoqualmie River and principal tributaries typically occur November through January because of ROS and May and June as a result of snowmelt (Solomon and Boles 2002). Historically, overbank flooding by the Snoqualmie River in the lower valley was likely a regular occurrence. A number of tributary streams (Tolt River, Raging River, Cherry Creek, and Tuck Creek) in the lower valley would have also been subject to overbank flooding during the winter (Solomon and Boles 2002, 2004).

Although overbank flooding is a regular occurrence along the mainstem Snoqualmie River, prolonged inundation of the floodplain periphery was likely an infrequent occurrence historically (Collins and Sheikh 2002). Forest cover within the Snoqualmie floodplain, circa 1870, appeared to be stratified by species tolerance to inundation. Trees relatively tolerant of saturated soils, predominantly hardwoods, were found closest to the river, while the incidence of conifers increased with distance away from the mainstem Snoqualmie (Collins and Sheikh 2002).

Warm, moisture-laden tropical weather systems in winter usually produce the heaviest rains and stream flows, particularly in the ROS zone (Dunne and Leopold 1978; Solomon and Boles 2002). The ROS zone occurs in middle elevations where temperatures alternate from freezing to non-freezing conditions. In Puget Sound, these conditions usually occur in elevations ranging from 1,500 to 4,500 feet (Brunengo et al. 1992). Approximately 370 square miles of the Snoqualmie Watershed (54 percent) are within the ROS zone (see Figure 3-4).

The highest elevation in Duvall is less than 500 feet, well below the ROS zone. However, the Duvall portion of the Snoqualmie floodplain may be inundated as a result of rapid snowmelt in upstream, higher elevation basins. Because all of the streams within Duvall, except for the

Snoqualmie River, are headwater streams with relatively small contributing basins, extensive overbank flooding from these streams was likely not a regular occurrence historically. The reaches of these streams within the Snoqualmie floodplain would have been subject to flooding from the Snoqualmie River.

3.2.2.2 Groundwater Flow

Intermediate and shallow are the appropriate scales for discussing groundwater within the Snoqualmie Watershed and Duvall analysis areas. At these scales, groundwater is largely controlled by topography, confining geologic features, and patterns of recharge and discharge (Vaccaro et al. 1998). Principal groundwater areas within the Snoqualmie Watershed include the Snoqualmie Valley and major tributary valleys (Appendix A).

The primary historic conditions influencing groundwater flow in Duvall are the City's topographic location and the predominant, relatively impermeable soils, which do not allow significant infiltration or augmentation of groundwater flow. Duvall's position on a hilltop limits groundwater flow to Duvall from the surrounding landscape. Groundwater in Duvall was mapped below approximately 200 ft elevation (above sea level) in coarse-grained deposits and between 200 and 300 feet elevation in Vashon outwash till by Turney et al. (1995). The flow path for groundwater in the coarse-grained deposits followed the topography (Turney et al. 1995) (Appendix A).

3.2.3 Sediment Supply

Mass wasting is a common phenomenon in the eastern portion of the watershed, where relief is extreme. Areas important for surface erosion are also located in hilly areas containing outwash and other coarse-grained soils. Puget Sound Lowlands typically have only isolated areas in which erosion naturally occurs at high rates, such as transitions from plateaus to terraces, alluvial fans, and upland canyons formed by streams. Areas susceptible to erosion have been mapped throughout the western portion of the watershed. Mapped landslide hazard areas have been mapped along the sidewalls of the Snoqualmie Valley and major tributary valleys, including Cherry Creek (King County GIS 2005).

Channel migration contributes to sediment supply by eroding stream banks (KCDNRP 2004). In an examination of channel migration in the lower Snoqualmie Valley, Collins and Sheikh (2002) concluded that the Snoqualmie River CMZ below RM 12 has been relatively narrow and stable since glacial retreat. The CMZ between RM 12 and RM 23 is up to 0.6-mile wide, except where narrowed by tributary deltas, and channel migration within this reach has been active. Upstream of RM 23 the Snoqualmie River CMZ is more confined due to steepening gradient and till or bedrock geology (Collins and Sheikh 2002).

In Duvall, the Alderwood and Kitsap soil series found in the northeastern portion of the city and along Coe-Clemmons Creek are prone to mass wasting. The King County soil survey rates the erosion hazard for this soil as severe to very severe and the slippage potential as severe (SCS 1973). The landslide hazard area in the northeastern part of the City corresponds with the Alderwood and Kitsap soil series (SCS 1973; King County GIS 2005). The Alderwood series are rated as moderate for erosion hazard and slippage potential. The Alderwood series also contain gravels that may be of suitable size for salmonid spawning, whereas the grain size in the Alderwood and Kitsap soils is finer and channel substrate derived from this soil series may not be suitable for salmonid spawning (SCS 1973; Herrera Environmental Consultants, Inc. 2002).

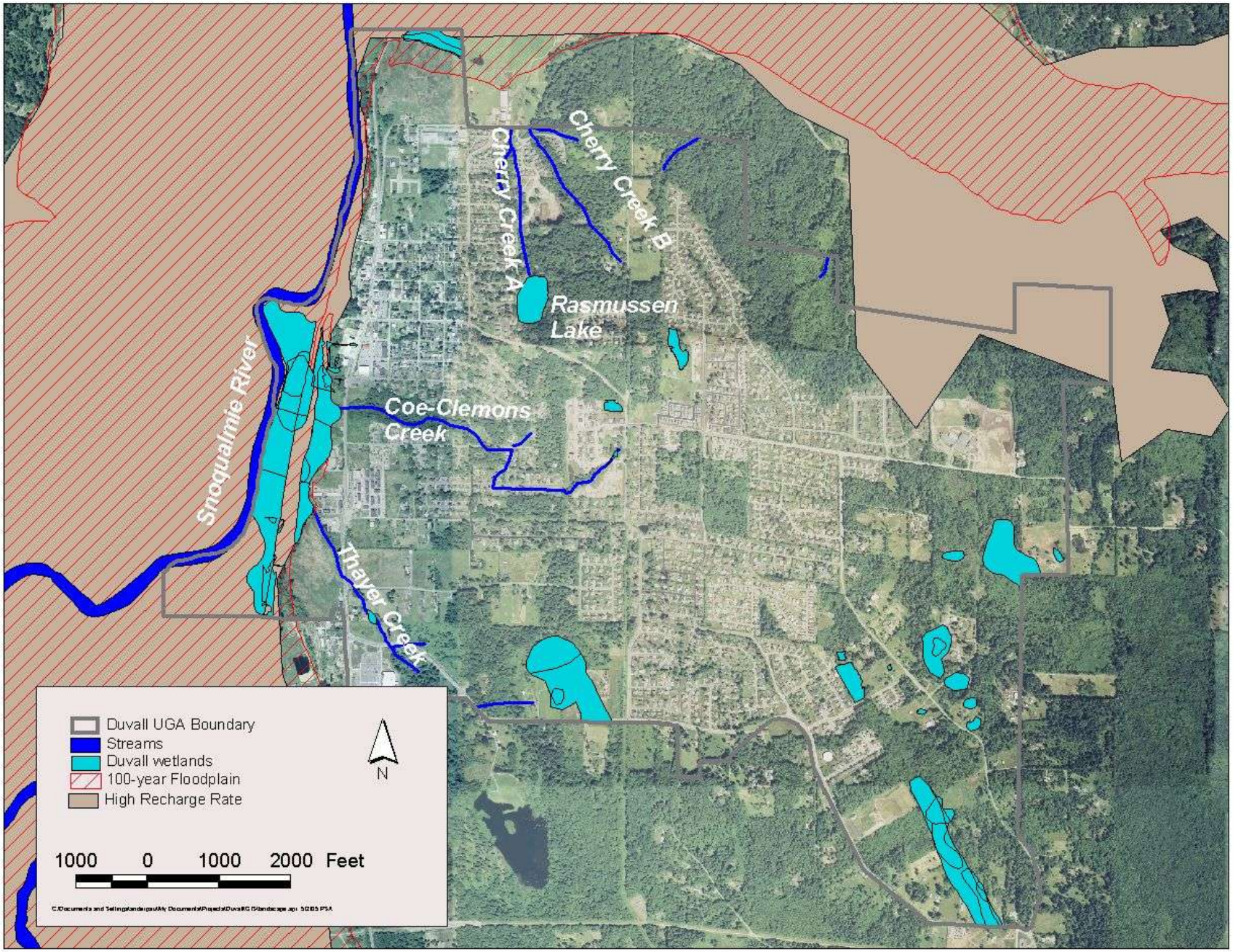

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Figure 3-5
Hydrologic Mechanisms and Important Areas, City of Duvall

3.2.4 Water Quality

Important areas for water quality in the Snoqualmie Watershed historically would have been found in wetlands, hyporheic zones, and vegetated riparian areas and upland forests. Many of these areas would have been found along the mainstem Snoqualmie River, its floodplain, and major tributaries. Riparian communities in the upper watershed would have been forested and in the lower valley were shrub dominated (Collins and Sheikh 2002). These intact riparian communities would have contributed to water quality by limiting erosion and providing shade.

Important areas in Duvall for water quality would have included wetlands, Rasmussen Lake, riparian zones along Thayer, Coe-Clemmons and Cherry Creeks, the porous outwash soils found in northeastern Duvall, and the forested uplands.

3.2.5 Organic Matter and Heat/Light Inputs

Riparian vegetation within and along streams and wetlands is a major source of organic input to aquatic ecosystems. Riparian vegetation historically was well developed along most streams in Western Washington. Conifers were the predominant forest species throughout the Snoqualmie Watershed prior to Anglo-American settlement, and were likely the dominant overstory along streams lacking active floodplains. Hardwoods were the dominant overstory within active floodplains and valley bottoms (Franklin and Dyrness 1987; Collins and Sheikh 2002). Organic matter is delivered to streams via leaf litter, bank failure, landslides, and mass wasting.

The majority of low-order headwater streams occur in the eastern Snoqualmie Watershed, and landslide processes are important for LWD recruitment to these streams. Where headwater streams are present in the lowlands, hillslope processes are less important sources of LWD. Streams along valley floors are more dependent on riparian zones for LWD inputs, although isolated areas of bank failures and landslides are present, particularly where the landform changes from hills and plateaus to the Snoqualmie Valley.

Channel migration is an important source of LWD for alluvial streams as a result of bank erosion. The CMZ has not been determined for most alluvial streams in the Snoqualmie Watershed, but it has been mapped for the mainstem Snoqualmie River (King County GIS 2005).

In the Duvall reach of the Snoqualmie River, Collins and Sheikh (2002) reported a dense scrub-shrub wetland complex near RM 11 and this wetland would not have been an important source of LWD. Records from the 1800s on the amount of LWD in the Snoqualmie River are not available, but Collins and Sheikh (2002) speculate that historically, LWD in the Snoqualmie was comparable to the amounts documented for other area rivers. Pre-settlement riparian zones above the Snoqualmie floodplain in Duvall were likely not extensive due to the small size of streams and wetlands, low-permeability soils, and the steepness of the topography. Occasional isolated bank failures along streams would have delivered LWD to streams.

3.3 Landscape Process Alterations

Landscape processes in the Snoqualmie Watershed have been altered to some degree since the late 1800s (Collins and Sheikh 2002). The primary alterations within the watershed have been vegetation clearing, through timber harvest and/or conversion to agricultural or developed land uses, and stream channelization. Since the early 1900s there has been a continual increase in the proportion of the watershed covered by impervious surfaces.

Streams and wetlands have been altered or eliminated to accommodate agriculture and other development. Groundwater flow has been interrupted and aquifers have been accessed for groundwater withdrawals to supply drinking water and irrigate agricultural lands. These alterations have occurred primarily within the Snoqualmie Valley. Table 3-3 summarizes indicators of alteration applicable to this analysis.

Table 3-3. Indicators of Landscape Process Alteration within the Snoqualmie Watershed

Process	Mechanism	Indicators of Alteration
Hydrology	Infiltration and recharge	Impervious land cover, wetland loss
	Surface water storage	Impervious land cover, decreased floodplain capacity, increased flooding, channelization, wetland loss
	Peak flows	Impervious land cover, decreased floodplain capacity, duration and frequency of peak flows, loss of forest cover in ROS zones, stream channelization[1], wetland loss, incised channels, increased erosion,
	Groundwater movement	Impervious land cover - especially roads and associated utility infrastructure, groundwater contamination, decreased baseflow to streams and wetlands
Sediment Supply	Erosion	Developing areas, roads within 200 ft of waters, till agriculture, increase in braided channels over historic conditions, excessive fines in stream substrate
	Mass wasting	Roads and development in landslide hazard areas, changes in channel morphology (alluvial fans, braided channel), excessive fines in stream substrate
Water Quality	**Physical properties (temperature, turbidity)**	Disturbed riparian zones, channelization, impervious land cover, wetland loss, 303(d) exceedance listing
	Chemical properties (pH, nutrient levels)	Residential development, agricultural lands, disturbed riparian zone, channelization, wetland loss, decreased DO, algal blooms, 303(d) exceedance listing
	Contaminants (toxins, pathogens)	Urban and rural residential land use, road density within 200 ft of waters, livestock, channelization, wetland loss, 303(d) water quality exceedance listing
Organic Inputs/LWD	Riparian vegetation	Urban, rural residential, agricultural land use in riparian zone (loss of forest cover), livestock, wetland loss, dominance of non-native riparian vegetation
	LWD recruitment	Urban, rural residential, agricultural land use in riparian zone (loss of forest cover), livestock, channelization, dominance of non-native riparian vegetation

1 Includes channel straightening and/or bank hardening, resulting in floodplain disconnection.

Source: Turney et al. (1995); Collins and Sheikh (2002); Herrera Environmental Consultants, Inc. (2002); Solomon and Boles (2002, 2004).

Within Duvall, the primary alterations to landscape processes include vegetation clearing (hydrology, water quality, organic input), increased impervious surface (hydrology, sediment supply, water quality), and floodplain disconnection of streams within the Snoqualmie floodplain (hydrology, sediment supply, water quality, organic input).

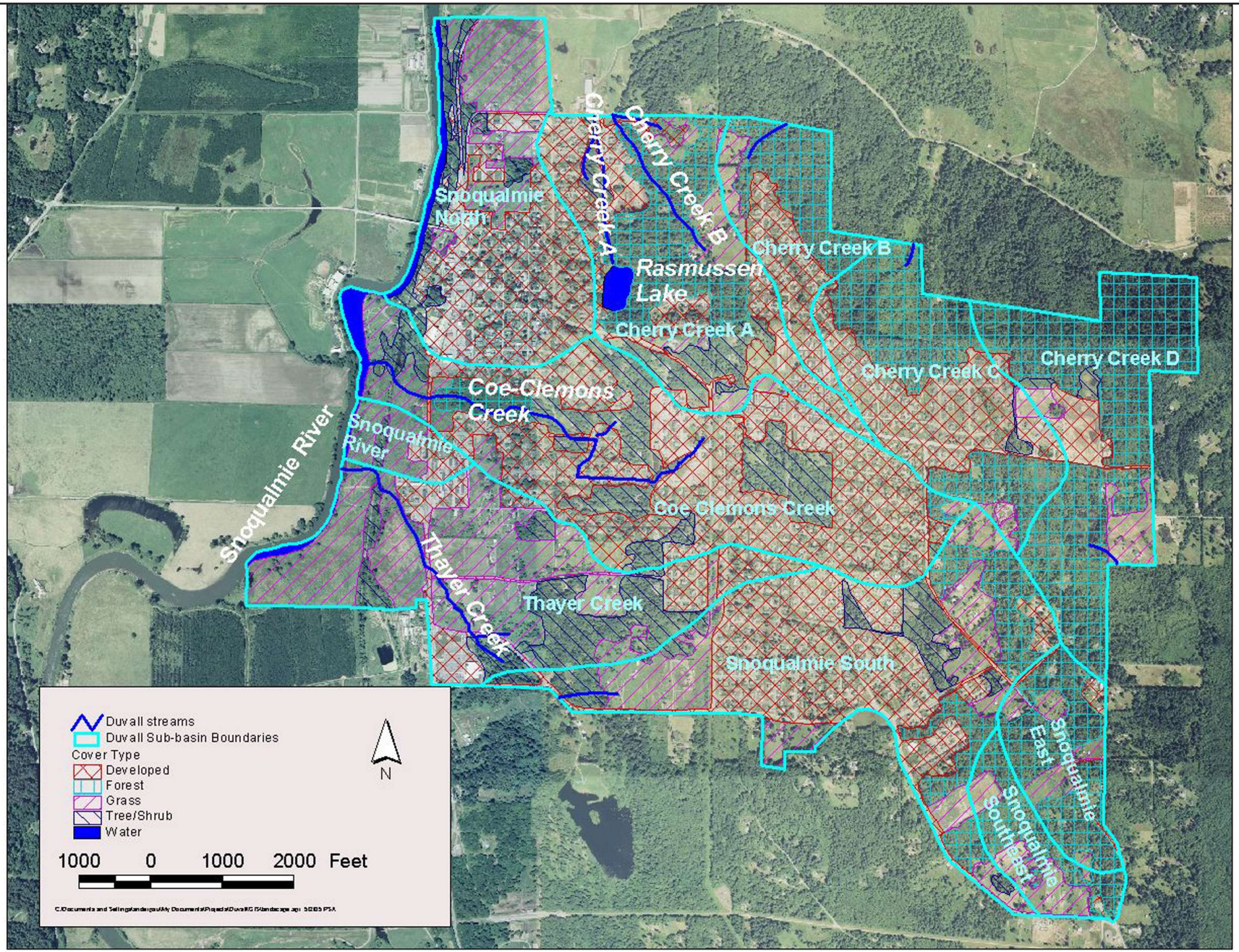
Based on the analysis of the 2002 orthophotographs, the estimated amount of developed land cover in Duvall is 40 percent (Table 3-4, Figure 3-6). The Coe-Clemmons Sub-basin had the highest estimated developed area (62 percent) and the Snoqualmie Southeast Sub-basin had the lowest (3 percent). Urban development within Duvall is concentrated in western (Snoqualmie North, Coe-Clemmons Creek, Snoqualmie River, and Thayer Creek Sub-basins) and central portions of the City (Cherry Creek A, Cherry Creek B, Cherry Creek C, Coe-Clemmons Creek, and Snoqualmie South Sub-basins). Development in western Duvall includes commercial, retail, public facilities, and residential land use, while the development in central Duvall is residential.

Table 3-4. Land Cover by Sub-basin within Duvall Analysis Area

Sub-basin	Cover Type	Area (acres)	Percent Analysis Area
Cherry Creek A	Forest	70	31
	Tree/Shrub	33	15
	Grass	27	12
	Developed	88	39
Cherry Creek B	Forest	46	50
	Tree/Shrub	0	0
	Grass	8	9
	Developed	37	41
Cherry Creek C	Forest	88	51
	Tree/Shrub	2	1
	Grass	6	4
	Developed	78	44
Cherry Creek D	Forest	159	82
	Tree/Shrub	4	2
	Grass	16	8
	Developed	16	8
Coe-Clemons Creek	Forest	16	4
	Tree/Shrub	89	24
	Grass	31	8
	Developed	230	62
Snoqualmie East	Forest	54	70
	Grass	17	22
	Tree/Shrub	0	0
	Developed	7	8

Table 3-4. Land Cover by Sub-basin within Duvall Analysis Area (continued)

Sub-basin	Cover Type	Area (acres)	Percent Analysis Area
Snoqualmie North	Forest	0	0
	Tree/Shrub	25	12
	Grass	56	26
	Developed	124	58
Snoqualmie River	Forest	0	0
	Tree/Shrub	2	8
	Grass	17	57
	Developed	9	32
Snoqualmie SE	Forest	31	58
	Tree/Shrub	<1	<1
	Grass	21	38
	Developed	2	3
Snoqualmie South	Forest	52	16
	Tree/Shrub	36	11
	Grass	80	25
	Developed	156	48
Thayer Creek	Forest	0	0
	Grass	153	57
	Tree/Shrub	59	22
	Developed	54	20
Total	**Forest**	**517**	**26**
	Tree/shrub	**251**	**12**
	Grass	**433**	**21**
	Developed	**799**	**40**



Parametrix City of Duvall 553-3240-006/01(02) 5/05 (B)

Figure 3-6
2002 Land Cover and Sub-basins within Duvall

3.3.1 Hydrology

Alterations to hydrologic mechanisms in the Snoqualmie Watershed include decreased infiltration/recharge because of increases in impervious surface, channelization, and disconnection of streams from their floodplains; decreased storage capacity due to bank armoring, channelization, and wetland loss; increased peak flows resulting from vegetation clearing and an increase in impervious surface; and groundwater withdrawals and groundwater contamination.

The amount and rate of infiltration lessens as the transit time of surface water through a watershed decreases. Several reaches of the river below Snoqualmie Falls have armored banks or flap gates, disconnecting the channel from its floodplain. In an assessment of habitat conditions along the Snoqualmie River and tributary streams, Solomon and Boles (2002, 2004) documented bank hardening and channel straightening, as well as loss of wetlands and channel complexity for a number of streams including the Snoqualmie River.

Collins and Sheikh (2002) documented an 81 percent decrease in Snoqualmie floodplain riparian wetlands between 1870 and 2000 and also concluded that the mainstem Snoqualmie River has been disconnected from its floodplain. Most of the historic wetland area has been converted to agricultural lands. Figure 3-7 shows historic and current Snoqualmie floodplain wetlands.

The historic extent of wetlands above the Snoqualmie floodplain in Duvall is not known, although given the steepness of the topography and relative impermeability of the predominant soils, it is assumed the loss of water storage capacity has not been significant. Solomon and Boles (2002) identified bank armoring at 2 sites and water diversion structures (flap gates, pumps) at two sites along the right-bank of the mainstem Snoqualmie in the Duvall area. They also found three large pools (pool length equal to or greater than channel width) within this section of the river (Solomon and Boles 2002).

Overbank flows from the reaches of Thayer, Coe-Clemmons, and Cherry Creeks within Duvall above the Snoqualmie floodplain has not been significant. The lower reaches of these streams are within the Snoqualmie floodplain and are subject to flooding from the Snoqualmie River. Sandbagging, apparently to limit overbank flows, was reported along a reach of Coe-Clemmons Creek within the Snoqualmie floodplain (Herrera Environmental Consultants, Inc. 2002).

Developed land use in the Coe-Clemmons and Cherry Creek tributary sub-basins exceeds 35 percent of land cover and is 20 percent of the Thayer Creek sub-basin (see Table 3-4). Forest cover is less than 50 percent in all of these sub-basins and is less than 20 percent (0 percent for Thayer Creek) of the mapped cover within 200 feet of these streams. Decreasing proportions of forest cover and increasing development (impervious surfaces) are associated with higher peak flows (see Table 3-3). Although overbank flows are not a major issue for these low-order streams, increased peak flow frequency and duration have affected their channel morphology. Herrera Environmental Consultants, Inc. (2002) assessed stream habitat in Thayer, Coe-Clemmons, and two Cherry Creek tributaries within the city limits and identified reaches within all of these streams with deeply incised channels and bank failures caused by altered runoff patterns. Excessive sedimentation was also seen in reaches of Thayer Creek and Cherry Creek Tributary B.

As well as altering hydrology, floodplain disconnection and decreased storage capacity can impair stream habitat suitability for fish. Infiltration and recharge can be important sources of stream baseflow during summers and side channels and backwaters offer fish rearing habitat.

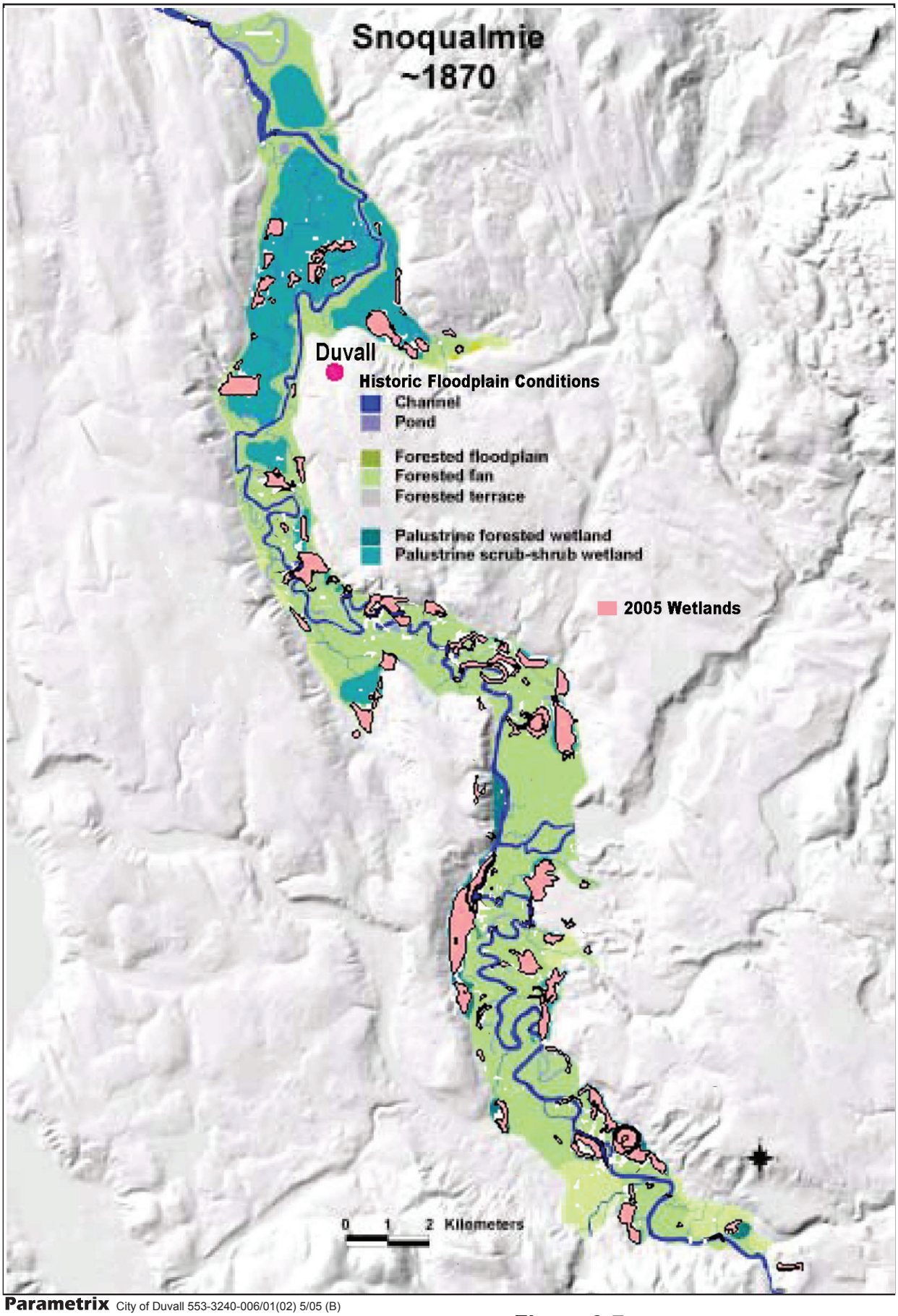
In addition to floodplain disconnection and loss of storage capacity, road crossings and culvert placement have also affected a number of potential fish-bearing streams in the watershed and Duvall (Herrera Environmental Consultants, Inc. 2002; Solomon and Boles 2002, 2004; SBSRF 2004). Culverts are potential barriers to fish passage because of associated changes to stream flows and channel morphology (Solomon and Boles 2002, 2004; SBSRF 2004; Stockard and Harris 2005). has been identified as a management issue in the Snoqualmie Watershed (Solomon and Boles 2002, 2004; Adolfson and Associates, Inc. 2004; SBSRF 2004). Restoring floodplain hydrologic connectivity and removing or modifying man-made barriers to fish passage, specifically culverts, have been identified as important for restoration of salmonid habitat within the Snoqualmie Watershed (Solomon and Boles 2002, 2004; Adolfson and Associates, Inc. 2004; SBSRF 2004) and also Duvall (Herrera Environmental Consultants, Inc. 2002; Solomon and Boles 2002, 2004).

Groundwater flow in the watershed has been impacted by development in urban areas and by groundwater withdrawals in rural and agricultural areas. Development can impact the hydrology of sites downslope by altering the amount and delivery path of surface water and shallow groundwater. Groundwater extraction in the Snoqualmie Watershed occurs in lowland areas where population and agriculture predominate. Proposed water withdrawals of 20 to 40 million gallons per day have been proposed for the Snoqualmie Aquifer, although the water would be pumped into the Snoqualmie River during the summer, with a predicted flow augmentation of up to 8 percent (CPSWSF 2001).

3.3.2 Sediment Supply

Alterations to sediment supply in the Snoqualmie Watershed include elevated sedimentation rates and deposition in the Snoqualmie River and tributary streams. The Snohomish Basin Salmonid Recovery Technical Committee (2000, as reported in Solomon and Boles 2002) examined Chinook salmon habitat conditions in 25 Snoqualmie Watershed sub-watersheds (basins) and reported that sediment regimes are impaired or at risk of impairment in 24 of the basins.

Increased impervious surface (decreased infiltration and surface water storage) within a contributing area is associated with higher volumes of runoff. Increased runoff can produce higher peak flows and may cause scouring and bank failures, accelerating erosion and sediment loads. Solomon and Boles (2002) identified bank armoring and erosion at three sites along the right-bank mainstem Snoqualmie in the Duvall area. The sediment supply to reaches of Thayer, Coe-Clemmons, and two Cherry Creek (within Duvall) has been altered, apparently from increased peak flows. Reaches of all these streams were found with deeply incised channels and failing banks; reaches of Coe-Clemmons Creek (see Appendix B for figures showing stream segments) (Segments 1 and 3) and Cherry Creek Tributary B (Segment 2) were braided (Herrera Environmental Consultants, Inc. 2002). Excessive sedimentation, particularly fines, was seen in reaches of Thayer Creek, from a wetland upslope of the creek, Coe-Clemmons Creek, and Cherry Creek tributary B. The sediment in Cherry Creek Tributary B had partially filled a culvert under NE Rupard Road, limiting salmonid access to upstream reaches of the stream (Herrera Environmental Consultants, Inc. 2002).



Parametrix City of Duvall 553-3240-006/01(02) 5/05 (B)

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Figure 3-7
Snoqualmie Floodplain Wetlands circa 1870 (Collins and Sheikh 2002) and 2005

3.3.3 Water Quality

Land use alterations and loss of forest cover, wetlands, floodplains, and hyporheic zones can cause changes in nutrients (nitrogen and phosphorous), oxygen, pH, temperature, turbidity, and introduce pathogens and toxins (metals, hydrocarbons, pesticides). Changes in land use and forest cover may decrease infiltration and increase the volume and rate stormwater runoff. Alteration of wetlands and floodplains decreases storage capacity and shortens the transit time of water across the landscape. Increased stormwater volumes and shortened transit times are associated with increased contaminant loads (Minton 2002). Land use changes from native plant communities to agricultural or urban land use is also associated with elevated nutrient and contaminant loads.

Water quality issues identified within the Snoqualmie River and tributaries include temperature, pH, turbidity, dissolved oxygen, nutrients, and fecal coliform contamination (Solomon and Boles 2002, 2004; Adolfson and Associates, Inc. 2004; Onwumere and Batts 2004; SBSRF 2004). Elevated nitrate levels (greater than 2.0 mg/L) were found in groundwater throughout the lower Snoqualmie Valley, particularly in the Falls City area, by Turney et al. (1995).

Documented water quality concerns in the Duvall area include temperature, pH, dissolved oxygen, nutrients, and fecal coliform contamination in the mainstem Snoqualmie River and temperature and fecal coliform contamination in Cherry Creek (beyond the Duvall city limits) (Solomon and Boles 2002, 2004; Onwumere and Batts 2004).

Lack of riparian vegetation is associated with increased water temperatures as a result of greater insolation; access to streams by livestock with elevated turbidity and fecal coliform, and reduced dissolved oxygen. Three sites where cattle had direct access to the Snoqualmie River in the Duvall reach were documented by Solomon and Boles (2002). The Ecology 1998 list of 303(d) impaired waters (2000) included an exceedance for fecal coliform in the Duvall reach of the Snoqualmie River. Solomon and Boles (2002) recorded a 7-day moving average water temperature of 20.5 degrees Celsius. They cite Berman (1998) who found that water temperatures above 18 degrees Celsius were harmful to salmonids (Solomon and Boles 2002).

Water quality parameters were not studied in the Duvall stream assessment (Herrera Environmental Consultants, Inc. 2002), but water quality problems in urban streams are well documented (Minton 2002; EPA 2003). Beschta (1978) found a significant increase in sedimentation in streams and wetlands within 200 feet of roads following logging in Oregon. In Duvall, road density within 200 feet of streams is highest along Coe-Clemmons Creek (approximately 2,000 linear feet) and Thayer Creek (approximately 1,200 linear feet). These streams as well as Thayer Creek include a number of road crossings, which may be an additional source of runoff and contaminants (Herrera Environmental Consultants, Inc. 2002). Rasmussen Lake was the wetland with the highest road density nearby. A residential neighborhood is located immediately to the west of the wetland. Elevated levels of nitrogen and phosphorous, from lawn and garden fertilizer, have been found in runoff from residential areas (Minton 2002).

Stream reaches with relatively low road density (no paved roads) within 200 feet included Thayer Creek and Coe-Clemmons Creek within the Snoqualmie floodplain. There were no paved roads within 200 feet of wetlands within the Snoqualmie floodplain and in the southeastern portion of Duvall (Snoqualmie SE and Cherry Creek D sub-basins).

Turney et al. (1995) found elevated arsenic levels (greater than 20 mcg/L) in two Duvall area groundwater wells (Well 13D03 and 24D01), nitrate (0.6 to 1.0 mg/L) in Well 13J01, and pesticides in Well 13D03. The water level in Well 13D03 was approximately 250 feet deep

and Turney et al. (1995) thought it was unlikely that the source of the pesticide contamination was local. There were no groundwater wells monitored by Turney et al. (1995) in the porous soils found in northeastern Duvall that have been mapped as a high recharge area by King County (King County GIS 2005). As a high recharge area, these soils may be a potential source of groundwater contamination from pollutant-laden (nutrients, contaminants) surface waters.

3.3.4 Organic Inputs

Alterations to organic inputs include conversion of native plant communities to agricultural or developed land use and changes in the density or species composition (i.e., forest to scrub-shrub or native shrub to non-native shrub) of riparian vegetation. Organic inputs have been altered throughout the lower Snoqualmie Valley. Overall, riparian habitat quality in the Snoqualmie Watershed is relatively intact (dense native, woody vegetation within the riparian zone) because a large proportion of the watershed is forested. Above Snoqualmie Falls the SBSRF (2004) report 73 percent of the watershed is mature forest. Within this portion of the watershed, as well as uplands in the remainder of the watershed, the potential for LWD recruitment remains relatively high. However, recruitment potential along valley bottoms is mixed in the watershed and is low along the Snoqualmie River and tributaries below Snoqualmie Falls. Downstream of North Bend, conditions generally worsen as land use intensity increases moving down the drainage (Solomon and Boles 2002).

Solomon and Boles (2004) assessed habitat conditions along 14 Snoqualmie tributaries and rated habitat quality as poor in the lower reaches of seven of these tributaries (Raging and Tolt Rivers; Canyon, Patterson, Langlois, Ames Lake, and Cherry Creeks) due to lack of riparian vegetation and LWD. Poor quality riparian habitat and lack of instream LWD have been identified as two of the most important issues for salmon habitat restoration in the Snoqualmie Watershed (Adolfson and Associates, Inc.; SBSNFR 2004; Solomon and Boles 2004).

In the Duvall reach of the Snoqualmie River (RM 9 to 11), Solomon and Boles (2002) found that right bank riparian habitat was in relatively good condition. Deciduous trees were found throughout the reach and dense native shrubs were dominant along more than half of the reach. The mainstem Snoqualmie was wide enough in this reach that trees were not able to shade the full width of the channel. They also found low amounts of instream LWD and few mature riparian trees available for future LWD recruitment (Solomon and Boles 2002).

Organic inputs, and thus land cover, is relevant to aquatic resources only in the riparian zone and slide areas that may contribute organic matter via debris flows. Intact riparian vegetation (herbs, shrubs, immature trees) was seen along Thayer, Coe-Clemmons, and Cherry Creek within the city limits but there was a lack of mature trees and large coniferous LWD in all of these streams (Herrera Environmental Consultants, Inc. 2002). The widest riparian zone with woody vegetation on Thayer Creek, approximately 400 feet wide, was found in Segment 6 (see Appendix B for figures showing stream segments). During the cover classification for this study, this area was mapped as tree/shrub cover. Along Coe-Clemmons Creek, Segment 4 had the widest forested riparian zone (approximately 400 feet wide). A forested riparian zone, up to 1,300 feet in width, covered most of the area between Cherry Creek Tributaries A and B directly north of Rasmussen Lake (Segment 3 for both streams). However, this riparian zone was approximately 50 feet wide to the west of Tributary A and 80 feet wide to the east of Tributary B. Emergent vegetation and non-native shrubs were dominant in the riparian zones along Segments 1, 2, 4, and 5 of Thayer Creek; Segments 1, 3, and 6 of Coe-Clemmons Creek; Segments 1 through 5 of Cherry Creek Tributary A; and Segments 1 and 2 of Cherry Creek Tributary B. Although, for all of the streams, immature and mature deciduous forest

were the predominant riparian community reported (Herrera Environmental Consultants, Inc. 2002).

Thayer and Coe-Clemmons Creeks, and the Cherry Creek tributaries within Duvall do not provide suitable Chinook salmon spawning habitat. Adult coho salmon were observed spawning in Thayer and Coe-Clemmons Creek in 2001. No coho salmon were seen in the Cherry Creek tributaries surveyed. Fish passage barriers have been documented downstream of the city limits in Cherry Creek (Herrera Environmental Consultants, Inc. 2002). Washington Department of Fish and Wildlife (WDFW) priority habitats identified in Duvall include four wetlands (also identified in King County and NWI data) and one riparian zone along the Snoqualmie River in southern Duvall. There were no data points for terrestrial priority species within Duvall (WDFW 2005).

Table 3-5 summarizes the functional responses of aquatic resources within the Duvall analysis area.

3.3.5 Summary

In summary, aquatic resources and landscape processes within the Snoqualmie Watershed are generally in good condition. A large proportion of the watershed remains forested and impervious surfaces represent a very small percentage of the total watershed area. Groundwater infiltration, flow, and water quality are largely intact. High peak flows and flooding have been altered for the Snoqualmie River and major tributaries in the lower valley. Sediment supply in the upper watershed has not been appreciably altered from historic conditions, although channel aggradation has been documented for the lower Tolt and Raging Rivers. Alterations to landscape processes and aquatic resources have been concentrated in the lower valley and along the mainstem Snoqualmie River. In the lower valley the principal alterations include: a significant loss of wetlands (storage capacity), instream LWD, and riparian vegetation (organic input, shading) within the Snoqualmie floodplain; bank armoring along the mainstem Snoqualmie and channelization of tributary streams; and placement of fish passage barriers (culverts) throughout the lower watershed (Herrera Environmental Consultants, Inc. 2002; Solomon and Boles 2002, 2004; Adolfson Associates, Inc. 2004; SBSRF 2004).

Aquatic resources and processes in Duvall have been altered but are, for the most part, intact. Riparian vegetation along the Duvall reach of the mainstem Snoqualmie is in better condition than reaches upstream and downstream of Duvall (Solomon and Boles 2002). The primary alterations to landscape processes in Duvall parallel those of the Snoqualmie Watershed. In the Snoqualmie floodplain, Duvall area streams have been disconnected from their CMZs, and there has been a loss of wetlands and riparian vegetation. Above the Snoqualmie floodplain, elevated peak flows and sediment loads as well as fish passage barriers have been identified as important management concerns (Herrera Environmental Consultants, Inc. 2002; Solomon and Boles 2002, 2004). In Duvall, management of aquatic resources should address the following alterations:

- Maintain existing riparian forests and trees along the Snoqualmie River, Coe-Clemmons, and Cherry Creeks to maintain and improve water quality (temperature and turbidity), sediment supply, and provide organic and LWD input;
- Restore riparian forests along reaches of the Snoqualmie River, Coe-Clemmons (Segments 1, 3, and 6) and Thayer (Segments 1 to 6) Creeks, and Cherry Creek tributaries A (Segments 1 to 5) and B (Segments 1 and 2) that are currently not forested to improve water quality (temperature and turbidity), sediment supply and provide organic and LWD input;

- Maintain and restore surface water storage (wetlands and off-channel habitat) along Coe-Clemmons, Thayer, and Cherry Creeks to reduce peak flows and improve sediment supply and water quality in these first-order streams. Restoration of, or increasing surface water storage capacity should be emphasized in sub-basins with over 35 percent developed land use (Cherry Creek A, Cherry Creek B, Cherry Creek C, Snoqualmie South, Snoqualmie North, and Coe Clemons Creek Sub-basins). Maintenance and restoration of surface water storage capacity should be emphasized in sub-basins with less than 35 percent developed land use (Snoqualmie SE, Cherry Creek D, Snoqualmie East, Thayer Creek, and Snoqualmie River Sub-basins);
- Reconnect Coe-Clemmons, Thayer, and Cherry Creeks to their floodplains and off-channel habitat to restore surface water storage and channel migration (sediment supply and organic input); and
- Remove or modify fish passage barriers on Coe-Clemmons and Thayer Creeks and Cherry Creek tributaries to allow fish access to upstream reaches (see Herrera Environmental Consultants, Inc. 2002 for specific restoration priorities) in support of organic inputs and habitat improvement; and
- Limit development and protect existing forest cover on high recharge areas (porous soils) in northeastern Duvall to protect infiltration/recharge, sediment supply and water quality. These high recharge areas have also been mapped by King County as a high landslide hazard area (King County GIS 2005).

Table 3-5. Functional Reponses of Aquatic Resources to Process Alterations in the City of Duvall

Process	Mechanism	Snoqualmie River	Streams	Wetlands
Hydrology	Infiltration/Recharge	No information	No information; high recharge area mapped on porous soils in northeastern Duvall	No information
	Surface Water Storage	Overbank flows; loss of wetlands and off-channel habitat within floodplain	Loss of wetlands and off-channel habitat in Snoqualmie floodplain	Loss of wetlands within Snoqualmie floodplain; no specific information on wetland loss above floodplain within Duvall
	Peak Flows	Overbank flows, bank armoring along mainstem	Incised channels and failing banks in Segments 1, 3, 5, and 6 of Thayer Ck; Segments 1, 3, 4, 5, and 6 of Coe-Clemmons Ck; Segments 1, 2, and 3, of Cherry Ck Trib A; Segments 1, and 3, of Cherry Ck Trib B	Excessive sedimentation in Thayer Creek from upstream mitigation wetland
	Groundwater Flow	Groundwater wells throughout lower Snoqualmie Valley and tributaries	No information	No information
Sediment Supply	Substrate Condition	Not properly functioning or at risk for Chinook salmon spawning habitat in mainstem, excessive sedimentation in many tributaries	Fines comprise 74, 24, 40, 100% of dominant substrate in Thayer, Coe-Clemmons, and Cherry Ck Trib A & B, respectively. Braided channel in Segments 3 and 4 of Coe-Clemmons Ck and Segment 2 of Cherry Ck Trib B	N/A
Water Quality	Temperature/pH/DO	Temperature and pH 303(d) exceedance in mainstem Snoqualmie River	No information, likely degraded due to proportion of urban land use and road density within contributing area	No information
	Nutrients	Groundwater arsenic and nitrate contamination upstream of Duvall (Fall City)	No information	Groundwater arsenic contamination
	Contaminants	Pesticides in Duvall groundwater Well 13D03	No information, likely degraded due to proportion of urban land use and road density within contributing area	No information, likely degraded due to proportion of urban land use and road density within contributing area
Organic Inputs	Riparian Vegetation/LWD	Degraded due to agricultural and urban land use, moderate tree and shrub cover in Duvall reach; low instream LWD, recruitment	Degraded along Thayer Ck due to low percentage of mature trees in riparian zone, degraded reaches but generally intact for Coe-Clemmons Creek and Cherry Creek tributaries	Variable, site-specific

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APPENDIX A

Groundwater Figures

APPENDIX B

Duvall Stream Segment Figures