1. INTRODUCTION

This study was initiated by the recognition that Newaukum Creek (Fig. 1; #09-0114) plays a vital role in supporting the productivity of threatened fish species (i.e., Chinook salmon *O. tshawytscha* and steelhead *O. mykiss*). Newaukum Creek also supports biological production in the Green River by contributing water, sediments, organic matter, food energy, and nutrients. In addition to its ecological value, the Newaukum Creek basin supports important rural and urban economies and communities that rely on agriculture and forestry.

Sustaining and improving the biological productivity of the Newaukum Creek basin in this growing community requires an understanding of the basin as a 'system'. This understanding can be achieved through the work of interdisciplinary scientific teams, but also by drawing on the extensive knowledge base of local citizens and landowners. In this report, we attempt to synthesize this knowledge to explain how ecological patterns, structures, and the underlying processes have been changed by a long history of human influences. Our hope is that the results will guide decisions about how best to ensure the vitality of Newaukum Creek and inform investments in conservation and restoration that will result in meaningful improvements.

1.1. PURPOSE

This report is intended to strengthen the scientific understanding of the Newaukum Creek watershed (hereafter, basin). This understanding can be used to inform the planning and implementation of fish and wildlife habitat restoration projects in the basin. Accordingly, our general goals are to:

- Characterize the present condition of the Newaukum Creek basin;
- Identify ecological impairments to inform restoration;
- Identify major gaps in our understanding of how the basin functions;
- Anticipate how conditions in Newaukum Creek may change in the future.

This report is an important step forward, but knowledge of the basin must evolve and improve over time, especially through information provided by residents and through additional studies.

1.2. INTENDED AUDIENCE

This is a technical report, but it is intended to support the activities of a diverse interest groups and agencies working to sustain productive habitat in the Newaukum Creek basin. This includes, but is not limited to:

- People who may affect or be affected by the condition of Newaukum Creek;
- People interested in learning how the basin functions and in improving habitat;
- Non-profit organizations, especially those involved in restoration activities;
- Public and tribal agencies involved in resource management, protection, and recovery.

Figure 1. Map of Newaukum Creek Basin

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We hope that most readers will find the report accessible, interesting, and useful. However, the scope of the report is relatively broad. Readers seeking detailed information at very small scales are encouraged to use this report as a ‘springboard’ for further investigation.

1.3. APPROACH

Our general approach is to blend site-specific data on historical and current conditions with relevant principles of terrestrial and fluvial ecology, geology, and hydrology. We emphasize an understanding of the Newaukum Creek ‘system’ as well as its parts. We explain the nature and consequences of the long history of human activities throughout the report, when sufficient information exists. The framework for this report is adapted from a time-tested ‘state factor’ model of ecosystems (Jenny 1941; Admundson and Jenny 1997), focusing on main drivers and secondary drivers of ecosystem structure and processes. Refer to Section 1.4 (below) for more detail.

In this report, we subdivide the Newaukum Creek basin (26 square miles) into three parts representing abrupt shifts in basin topography along the channel network (Fig. 2):

Ravine (RM 0 to 5.7)

Plateau (RM 5.7 to 11, including Big Spring Creek and Watercress Creek)

Upper Basin (RM 11 to 16, including the North Fork and Stonequarry Creek)

These divisions are ecologically relevant, but are mostly for convenience. Hydrological analyses are an exception, based on 29 individual sub-watersheds. Note that we describe analytical methods in footnotes or in appendices to improve readability.

This report is organized by 11 chapters (for example, 9.0 Plants and Animals) consisting of variable numbers of sections (9.1. Special Status Wildlife Species) and subsections (9.1.1. Chinook salmon). The report can also be navigated from the Figure List and Table List. Note that there are also five appendices containing important information.

1.4. MAIN DRIVERS VS. SECONDARY DRIVERS

We begin with the ‘big picture’ by identifying and describing the main drivers (also called ‘state factors’; Jenny 1941; Admundson and Jenny 1997) affecting the basic structure and functioning of the Newaukum Creek basin. Main ecosystem drivers include: (1) climate; (2) geologic setting (or parent material); (3) topography; (4) potential organisms (plants and animals); and (5) time, including key changes in the human culture within the basin. These factors are relatively independent. They represent primary controls on the range of ecological processes evident in the basin.

Figure 2. Stream courses and sub-watersheds.

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Second, we explain the secondary drivers, which are influenced by the main drivers (above) and interact with one another. Examples include: (1) disturbances; (2) aquatic resources[1]; (3) riparian and terrestrial soils; and (4) plant and animal (including fish) communities. These are sometimes called 'interactive controls' (Chapin et al. 2003). These drivers affect patterns in the availability of the fundamental ecological resources (i.e., light, water, nutrients, sediments and soils) that support biological production and provide useful insight into how the system 'works'.

Recognizing that the 'parts' of a system are also important, we provide 'snapshots' of the life histories of individual species in special management categories (threatened species, for example). Plants and animals are mostly described in groups according to where they live (streams, wetlands, riparian areas, and uplands) or how they 'make a living' (their biological roles in the community). We discuss wildlife separately because many use a variety of habitats throughout their life cycle.

1.5. ECOREGIONS

The main drivers described in the preceding section can be integrated by classifying landscapes into ecological regions, or 'ecoregions'; "areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources" (USEPA 2007). Many different classifications exist (e.g., USEPA, USFS, NRCS, WAGAP[2]) have developed systems to suit various purposes[3].

In one system, Newaukum Creek exists within the Pacific Coastal ecoregion. This ecoregion runs from southeast Alaska to northern California, and is bounded to the east by the Cascade and Coastal mountain ranges (Naiman and Bilby 1998). In this report, we refer to classifications developed by the Environmental Protection Agency (EPA) to achieve finer spatial resolution (see below; Omernik 1987; Pater et al. 1998).

The EPA mapped ecoregions across North America and classified them into four hierarchical levels of increasing complexity and detail (i.e., Levels I, II, II, IV). We focus on Level III and IV regions which allow identification of locally defining characteristics and formulation of specific management strategies. Level IV classifications identify "potential natural vegetation," which facilitates characterization of historic conditions, in lieu of other data.

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[1] Here we use the term 'resources' in reference to the energy and materials (and space) in the environment used by organisms (mostly plants and animals) to support their growth, maintenance, and reproduction.

[2] U.S. Environmental Protection Agency (USEPA), U.S. Forest Service (USFS), National Resources Conservation Service (NRCS), Washington Gap Analysis Program (WAGAP).

[3] See comparison summary of three systems on Native Seed Networks web page: http://www.nativeseednetwork.org/article_view?id=27 (note: does not include WAGAP ecoregions in summary).

Newaukum Creek contains two Level III and three Level IV ecoregions[4] (Table 1). The Puget Lowlands Ecoregion is defined as having the following distinguishing characteristics (EPA 2002):

> This broad rolling lowland is characterized by a mild maritime climate. It occupies a continental glacial trough and is composed of many islands, peninsulas, and bays in the Puget Sound area. Coniferous forest originally grew on the ecoregion's ground moraines. outwash plains, floodplains, and terraces. The distribution of forest species is affected by the rainshadow from the Olympic Mountains.

In contrast, the Cascades Ecoregion has other distinguishing characteristics (U.S. EPA, 2002):

> This mountainous ecoregion is underlain by Cenozoic volcanics and has been affected by alpine glaciations. It is characterized by steep ridges and river valleys in the west [Newaukum Creek is here], a high plateau in the east, and both active and dormant volcanoes. Elevations range upwards to 4,390 meters. Its moist, temperate climate supports an extensive and highly productive coniferous forest. Subalpine meadows occur at high elevations.

Table 1. Characteristics of Level III and IV ecoregions represented in the Newaukum Creek basin.

Level III Ecoregion (Omernik 1987)*	Level IV Ecoregion (Pater et al. 1998)	Physiography	Elevation (ft)	Potential Natural Vegetation	Land Use and Land Cover (current conditions)
Puget Lowland Region	Eastern Puget Riverine Lowlands	Floodplains and terraces with meandering rivers, oxbow lakes, and meander scars. Freshwater and estuarine wetlands	0-800	Western redcedar, western hemlock; some red alder, black cottonwood, bigleaf maple, Sitka spruce.	Crop and pastureland (e.g., reclaimed wetland); some riparian deciduous woodland, coniferous forests, wetlands; rural/residential/suburban/urban/ industrial activity
	Eastern Puget Uplands	Rolling moraines and foothills with lakes and sinuous streams and rivers	0-2677	Western hemlock western redcedar; some Douglas-fir.	Douglas-fir/western hemlock forests. Forestry, pasture and cropland, rural residential/suburban/urban development
Cascade Region	Western Cascades Lowlands and Valleys	Westerly trending ridges and valleys with reservoirs and medium gradient rivers and streams. U-shaped, glaciated valleys in the east	800-4000	Western hemlock, western red cedar, Douglas-fir.	Douglas-fir/western hemlock/western redcedar/vine maple/red alder forests are widespread. Forestry and recreation are important land uses and pastureland occurs in lower valleys

[4] The EPA mapped ecoregions across North America and classified them into four hierarchical levels of increasing complexity and detail (i.e., Levels I, II, II, IV). We focus on Level III and IV regions which allow identification of locally defining characteristics and formulation of specific management strategies. Level IV classifications identify "potential natural vegetation", which facilitates characterization of historic conditions, in lieu of other data.

1.6. LIMITATIONS

This report represents our best attempt to synthesize the existing knowledge of the Newaukum Creek basin within existing constraints, but is not without substantial limitations, omissions, and speculations. Whereas general patterns in climate, geology, topography, land cover and hydrology are well-documented, substantial uncertainty remains in the physical condition of specific locations, especially in regards to stream and wetland habitats and the distribution and abundance of the plants and animals that inhabit them. Much of this uncertainty can be attributed to three interrelated factors: (1) time constraints; (2) difficulties in reaching private landowners to request permission to conduct field studies on private lands; and (3) some landowners that were contacted refused to grant permission to study their lands. Accordingly, we provide clear statements regarding data quality and identify significant uncertainty where it exists (see the summary for a synthesis).

Management agencies and local landowners both possess considerable, but incomplete knowledge of the rivers, lands, and wildlife. A more complete understanding of the basin will require coupling field surveys that meet established scientific standards with the unique local knowledge and long-term perspective of basin residents and landowners. This coupling is needed for the following reasons:

- To improve the level of scientific rigor in future assessments;
- To better reflect the extent of the local knowledge base and history of the basin;
- To ensure future management actions are biologically effective; and
- To ensure restoration dollars are spent wisely.

Additional work is necessary. In the meantime, we suggest using an appropriate level of deliberation when enacting new strategies based on the information herein.

2.0. CLIMATE

Climate (temperature and precipitation, for example) influences the distribution of plants and animals and shapes basin hydrology. Regional climate patterns are typified by relatively warm and wet winters and cool, dry summers. Climate within Newaukum Creek basin varies along an elevation gradient. In general, precipitation increases from the Ravine towards the Upper Basin, whereas mean annual temperatures decline. Details are provided in Sections 2.1 and 2.2. below.

Table 2. Average seasonal air temperatures for the Plateau.

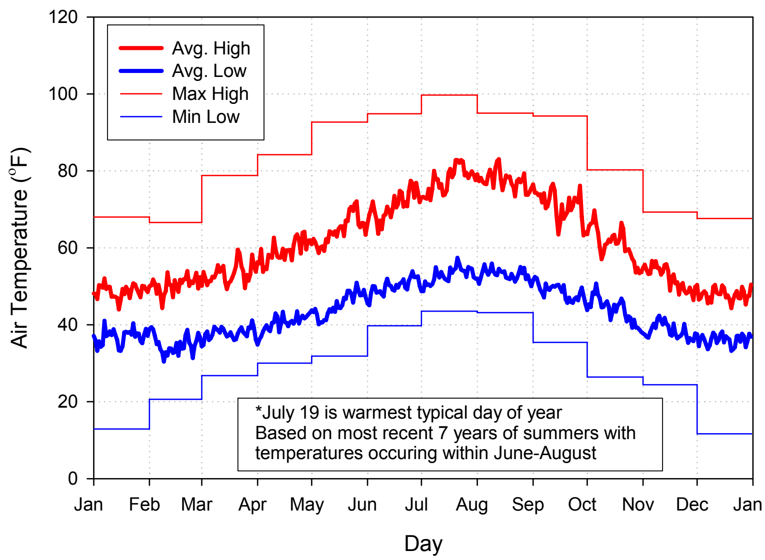
Season	Max (˚F)	Min (˚F)
Winter (Dec-Feb)	49	36
Spring (Mar-May)	59	41
Summer (June-Aug)	75	52
Fall (Sept-Nov)	61	44

2.1. TEMPERATURE

Mean annual air temperature is 52.2˚F, based on observations from a station[5] on the Plateau. Mean seasonal temperature extremes range from a low of 36˚F in winter to 75˚F in summer (Table 2). Within-day temperature fluctuations are very similar among spring and fall, though exceed 23˚F in summer (Fig. 3).

Mean annual temperatures in the Newaukum Creek basin are expected to rise in the future. The period of record (1999-2006) is obviously insufficient to conduct climatic trend analyses for Newaukum Creek basin, alone. However, regional climate forecasting efforts, including the work of the University of Washington Climate Impacts Group[6] indicate a continued trend of regional warming.

Figure 3. Seasonal variation in mean maximum (red) and minimum (blue) daily temperatures (bold lines) in the Newaukum Creek basin. Historical monthly maximum and minimum temperatures are depicted as thin lines. Note that the annual maximum temperature will occur on July 19, on average, whereas this is estimated to occur in the first week of August when longer term records from Sea-Tac are used.



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[5] King County monitoring station 44U is located near the foothills east of Enumclaw (see Fig. 5). Near real-time data is available at (http://dnrp.metrokc.gov/WLR/Waterres/hydrology/DataDownload.aspx?G_ID=656).

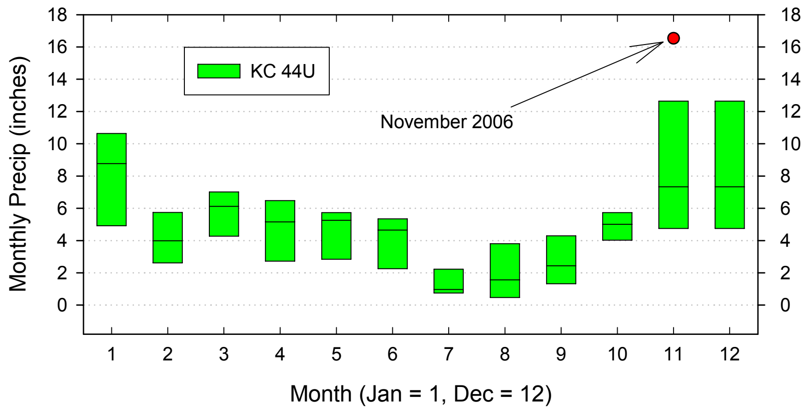
[6] (http://www.cses.washington.edu/cig/)

2.2. PRECIPITATION

Rain is the dominant form of precipitation in Newaukum Creek basin, though snow plays an important role in the upper basin near Boise Ridge. The amount and form of precipitation is strongly influenced by air temperature and 'orographic effects' caused by the Cascade foothills.

Total monthly precipitation ranges from a low of 0.33 inches (July) to a high of 13.8 inches (January) (Fig.4). The maximum amount measured in any month over the period of eight years occurred during November 2006, when massive storms consistently set historical records around the Puget Sound region.

Figure 4. Monthly precipitation observed at King County Gauge 44U. Box plots depict the median (50th) and 25th/75th percentiles of monthly precipitation volumes. The red dot indicates the total precipitation for November 2006, which was the highest on record.



Mean annual precipitation at King County gauge 44U (Fig.4) was 58.1 inches. Unlike air temperature, precipitation levels in the Newaukum Creek basin are *not* similar (i.e., 49% greater) to those at Sea-Tac, where annual precipitation is only 39 inches.

The weighted basin average annual precipitation[7] is 54.5 inches though annual levels vary widely within the basin according to the proximity of the Cascade mountain range (Fig. 5). Estimates for mean annual precipitation volumes for coincident locations differ by 10%. We attribute this divergence to differences in the period of record among the data sources used to compute weighted basin averages. PRISM estimates are based on a period of record 1971-2000, whereas King County records used in this analysis range from 10/1/1998 through the end of water year 2006 (i.e. 9/30/2006).

[7] Significant efforts have gone into quantifying spatial variation in the magnitude of rainfall; taking into account most known and quantifiable influences on climate. The Oregon climate group known as PRISM (not to be mistaken with UW PRISM consortium; http://www.prism.washington.edu/), staffed by Oregon State University personnel, is a regional leader in this technology (http://www.ocs.orst.edu/prism/index.phtml). They have analyzed and estimated variations in annual precipitation quantities throughout the United States.

Figure 5. Map of average annual precipitation.

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Six percent of the Newaukum Creek basin receives seasonal snowfall (i.e., where elevation exceeds 1,500 ft) and is therefore sensitive to hydrological impacts of regional warming trends. Storms that drop rain on existing snowpacks (i.e., rain-on-snow events) will likely become more frequent in these areas. This would amplify the annual number of storm run-off events, which also affect downstream areas along the stream. Moreover, higher elevations that would normally retain snow cover through May or June will lose their snowpack earlier, and higher spring flows, and lower summer flows would result. However, given the small percentage of the basin in those higher elevations, these phenomena likely will be less significant than in the greater Green River watershed, where snowmelt runoff is more important.

3.0. GEOLOGIC SETTING

The geologic setting – including the character and arrangement of both bedrock and non-lithified sediment – influences topography, soil development, drainage patterns, and erosional and depositional processes. The geology of the Newaukum Creek watershed includes volcanic rock in the Upper Basin, glacial and volcanic mudflow deposits across the Plateau and alluvial sediments near the mouth. Note that soils are discussed in Section 8.

3.1. BEDROCK GEOLOGY

Newaukum Creek basin originates on the western slopes of Boise Ridge (elevation 2,980 ft), which is entirely composed of volcanic rocks. These rocks have been divided into two geologic units; the Fifes Peak and Ohanapecosh formations (Tabor et. al., 2000) (Fig. 6). The Fifes Peak formation consists primarily of andesite, a dark gray porphoritic rock characteristic of Cascade volcanos. The Ohanapecosh consists of volcaniclastic rocks including tuff[8] and volcanic breccia[9], rocks that form during explosive volcanic eruptions. A number of prominent bedrock knobs protrude through Quaternary deposits (Fig. 7) on the eastern side of the Plateau (west of Boise Ridge). These knobs are composed of andesite which is locally quarried for crushed rock and rip-rap.

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[8] Rock composed of the finer kinds of volcanic detritus usually fused together by heat.

[9] A rock composed of sharp fragments embedded in a fine-grained matrix

Figure 6. Map of basin geology.

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Figure 7. Map of glacially sculpted bedrock knobs near Boise Ridge

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3.2. QUATERNARY GEOLOGY - GLACIAL AND POST-GLACIAL DEPOSITS

The Puget lowland, including the Newaukum Creek basin has been covered by *continental glaciers* repeatedly during the Quaternary Period, which lasted from approximately 1.8 million to 8,000 years ago. These glaciers formed in the mountains of British Columbia and Vancouver Island and extended south, filling the Puget Lowland between the Olympic and Cascade Mountains, stopping near where the City of Olympia now exists.

The Vashon Stade of the Fraser Glaciation was the most recent of these glacial advances, reaching a maximum extent approximately 17,000 BP (before present), but persisted less than a thousand years in the Enumclaw area (Porter and Swanson, 1998). During the Vashon advance glacial ice reached a maximum elevation of approximately 2300 ft in the Enumclaw area (700 m) (Thorson, 1980). As the ice sheet extended and retreated, it formed sculpted bedrock exposures and transported and deposited sediments, forming advance outwash, glacial till, ice-contact deposits, and glacial recessional deposits, which are explained below.

As the Vashon glacier was advancing south into the Puget lowland, a broad expanse of sandy sediment was deposited in front of the ice as it moved forward. These sediments were subsequently over-ridden by the ice sheet and covered by other sediments as the glacier continued to move south. In the Newaukum basin, this deposit, called (Vashon advance outwash (Qva)) is only visible in limited exposures on the walls of the Ravine along lower Newaukum Creek, but probably underlies much of the Plateau.

As the glacier continued to move south distinctive sediment called glacial till (Qvt) was deposited directly at the base of the ice. Glacial till, commonly known as hardpan, is a dense, poorly sorted mixture of silt, sand and gravel that is relatively impervious to water. Till underlies much of the ground surface in the western portion of the Plateau.

At the glacial maximum, and especially as the glacier began to retreat, wedges of sediment would accumulate between the glacial ice and the adjoining hillsides. These texturally heterogeneous deposits formed are called ice-contact deposits (Qvi) They locally show evidence of collapse and displacement resulting from melting of the adjacent ice. Below its volcanic headwaters, Newaukum Creek crosses an irregular bench composed of Vashon-age ice-contact sediments (Qvi) at the base of Boise Ridge.

More than 10,000 years after Vashon glacial retreat the White River valley and surrounding areas, including the Enumclaw area were buried under sediment carried by the Osceola mudflow. This massive volcanic mudflow (or lahar) occurred approximately 5600 years ago. Starting as a landslide on the northeast flank of Mt. Rainier, the mudflow grew to an estimated volume of one cubic mile (3.8 km^3) as it traveled down the White River Valley. Transported material filled the White River Valley upstream of the present Mud Mountain Dam to a depth of 450 feet above the present valley bottom (Crandell, 1971). When the mudflow reached the approximate location of modern dam site it overflowed the White River valley walls and spilled north toward the Green River. Much of the ground surface on the Plateau is directly underlain by sediment deposited during this event. The mudflow deposits consist of gravel to boulder-sized clasts of Mt. Rainier volcanics, largely andesite in a fine-grained, clay-rich matrix.

After crossing the Osceola mudflow on the Plateau, down through the Ravine, Newaukum Creek flows onto floodplain deposits of the Green River. These floodplain deposits extend from the confluence to a point roughly 1200 feet upstream. The modern Creek traverses floodplain that is forested and appears static. However, much of the ground surface underlying this section of the creek consists of gravelly alluvium that was once a part of the (then wider) active channel of the Green River, prior to completion of Howard Hansen Dam in 1961 (see Appendix B, Fig. B1).