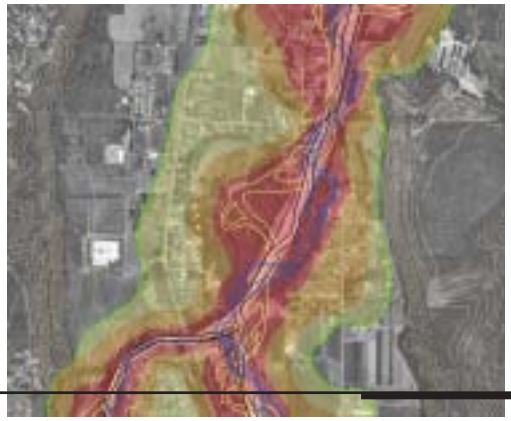

Report

Geomorphic Evaluation and
Channel Migration Zone Analysis
Puyallup, Carbon and White Rivers

for

Pierce County

Public Works and Utilities
Environmental Services, Water Programs Division

June 19, 2003

GeoEngineers

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GEOMORPHIC EVALUATION AND CHANNEL MIGRATION ZONE ANALYSIS

INTRODUCTION

The purpose of this project is two-fold: 1) map the extent of the channel migration zone (CMZ) for portions of three major streams in the Puyallup River watershed, and 2) identify severe, moderate and low Migration Potential Areas (MPAs) within each CMZ. The streams included in the study area are the Puyallup River from River Mile (P-RM) 10.3 (confluence with the White River) to approximately P-RM 28.6, the White River, from W-RM 0.0 (confluence with the Puyallup) to the Pierce County boundary at approximately W-RM 5.4, and the Carbon River from C-RM 0.0 (confluence with the Puyallup River) to approximately C-RM 8.3 (see Plate 1).

PROJECT OBJECTIVE

The Puyallup, White and Carbon rivers are presently confined by levees and revetments. However, based on historic and present conditions, most sections of the Puyallup and Carbon Rivers and portions of the White River are subject to potential future channel migration. Channel migration is the gradual or abrupt movement of a channel within its floodplain. The extension of levees, almost continuously, along both the Puyallup and Carbon River channels was completed throughout the project area in the mid-1960's. However, since their completion, levees on both rivers have been damaged by erosion associated with channel migration. White River confinement has resulted primarily in incision; however, the upper portion of the river in the project area is subject to potential migration.

The Pierce County Public Works and Utilities, Water Programs Division (Water Programs) contracted GeoEngineers, Inc. to identify the lateral extent of the CMZs for the three rivers over the length of the project area. The County is particularly interested in identifying limits of migration that could occur under unconfined river conditions. Consequently, the CMZ analysis is based on the unconfined channel condition, that is, **in the absence of** levees, revetments and other confining structures adjacent to the channel. We understand that the County intends to use the resulting channel migration zone delineation as a decision making tool regarding the following:

1. Maintaining existing levees, revetments, roads, bridges,
2. Floodplain management,
3. Revising floodplain ordinances,
4. Identifying future levee setback project sites.

PROJECT APPROACH AND SCOPE

Our approach to identifying the CMZ boundaries and three (low, moderate, severe) MPAs within the CMZ involved four major elements: 1) Data Collection, Review, and Selection, 2) Geographic Information Systems (GIS) Data Preparation 3) Geomorphic Evaluation, and 4) CMZ and MPA Delineation.

Detailed descriptions of methods and technology used in completing overall project goals are provided in Appendix A. Tasks and activities involved in accomplishing project goals are summarized below.

- Conduct a review of literature and other materials provided in the References section,
- Research, collect and evaluate available aerial photographs for the study area,
- Collect and assess existing GIS information and compile a comprehensive, linked project database.
- Select 4 sets of aerial photos to be added to the GIS. A total of 140 aerial photos were selected based on both the quality and extent of the photo coverage, and the channel conditions represented in the photo.
- Review and evaluate the comprehensive database. The database includes primarily topographic, geologic and soils maps, and air photos.
- Conduct preliminary stream reconnaissance on the three rivers in two site visits. The site visits were conducted in February and May of 2002.
- Evaluate geomorphic processes; this task included dividing the three main stem channels into geomorphic reaches and measuring rates of migration for each reach using the GIS database (Appendix B).
- Conduct additional site visits on August 1 and 2, 2002 to verify the results of our data evaluation.
- Delineate CMZs for each river based on the results of preceding tasks using GIS tools.
- Identify MPAs within the CMZ for each river. In coordination with Pierce County Water Programs staff, we developed criteria by which to delineate migration potential areas. The criteria document, 'Delineation Criteria for Low, Moderate, Severe Migration Potential Areas for the Puyallup, Carbon, and White Rivers', is provided in Appendix D.

Deliverables for the project include (1) this report; (2) GIS layers including CMZ boundaries, migration potential areas, dated channel locations, historical channel occupation tracts (HCOT), and, (3) selected aerial photos for 1931, 1940, 1965, 1970, 1978, 1987, 1991 and 1996 in GIS compatible format. GIS layers and documentation are provided on a CD-ROM, which accompanies this report.

REGIONAL SETTING

LOCATION

The project area is situated within the greater Puyallup River Watershed (Figure 1), which drains the west and northwest sides of Mount Rainier. Historically, the watershed consisted of two major sub-basins, the Puyallup and Carbon River sub-basins. However, in November of 1906 the White River was diverted away from its historic channel to a new course through the Stuck Valley and a new confluence with the Puyallup River, thereby adding a large portion of the White River sub-basin to the Puyallup watershed.

The Puyallup River serves as the primary drainage channel for the watershed. The Carbon and White Rivers are major tributaries to the Puyallup River. Combined, the three sub-basins drain an approximately 900 square mile area that varies from rugged mountainous terrain in the

upper basin areas, to the low-relief flood-plains and terraces of the Puget Lowlands comprising the lower basin areas.

Each of these rivers originates in the glacial terrain of Mount Rainer and from their sources flow out of the Cascades and across the eastern flank of the Puget Plateau and Lowland (Figure 1). Of the three, the Puyallup sub-basin is the longest, extending a total distance of about 50 miles from glacial source areas to Puget Sound where the river discharges water and sediment into Commencement Bay. The Carbon River flows into the Puyallup between the towns of Orting and McMillan, at Puyallup river mile (P-RM) 17.4. The confluence between the White and Puyallup Rivers is located near the town of Sumner (P-RM 10.3).

CLIMATE

The basin climate is typical of the mild temperatures and wet conditions of the west slope of the Cascade Mountains. The mean annual precipitation in the basin varies from approximately 40 inches in the lower basin to as much as 120 inches in the upper basin. Roughly 75 percent of the total annual precipitation within the basin falls from October through March, primarily as rain in lower elevations and as both rain and snow in higher elevations.

Winter storms produced by warm fronts often cause rapid melting of the transient snow pack between Elevations 1500 and 4500 feet, producing large runoff events. These heavy rain-on-snow events are the likely cause of most of the region's floods.

BASIN HYDROLOGY

The topography and hydrology of the Puyallup Watershed is typical of other Western Cascade drainage basins in that it encompasses several discrete sub-basins, each of which respond differently to given climatic events. To better understand channel migration in each sub-basin, we evaluated the hydrologic response of each sub-basin to specific storm events, including dates and relative magnitudes of floods, annual peak flow patterns, and relationships between the three sub-basins. Based on historical data from the U.S. Geological Survey (USGS), the Federal Emergency Management Agency (FEMA) and published documents we deduced the following: 1) a large percentage of total stream discharge is collected in the higher elevations above 1,500 feet, 2) annual peak flows and floods usually occur in the fall or early spring, 3) the Puyallup, Carbon, and White Rivers are subject to diurnal flow-rates, controlled primarily by the daily freeze and thaw of glaciers and snow fields, 4) the scale of flooding across the watershed can vary greatly depending on local storm intensity and sub-basin characteristics.

We calculated the 1.25-, 2-, 5-, 10-, 25-, 50- and 100-year peak flows using available data from all known USGS gage stations on the Puyallup, Carbon, and White Rivers. The locations of gage stations used in our evaluation are shown on Figure 1. The calculations were conducted using the Log-Pearson III distribution method (Log-Pearson) for the Puyallup, Carbon and White Rivers and compared against modeled data used by FEMA and the USGS. The results of our calculations and comparisons are provided on Tables 1, 2 and 3. Given the relatively short period of available data, we concluded that the Log-Pearson method best predicts the flow magnitudes of large floods (greater than a 25-year recurrence interval).

The Log-Pearson calculated recurrence flow rates for the various gage stations were used to estimate the relative magnitudes of historic floods within the watershed. The results of the evaluation (presented in Table 4) confirm that, for the same storm event, each sub-basin will likely experience a different scale of flooding. This information was used qualitatively in our geomorphic assessment of channel conditions and migration character.

REGIONAL GEOLOGY

The terrain comprising the Puyallup Watershed, which includes a portion of the Puget Sound lowlands and the west and northwest flanks of Mount Rainier and adjacent Cascade Mountains (Cascades), is derived in large part from the geology comprising the area. Within the watershed, the Cascades are composed of uplifted Tertiary and Quaternary aged volcanic and sedimentary rocks (35 million years ago to present). The Puget Sound lowlands are generally underlain by a thick sequence of relatively unweathered glacial and interglacial sediments. The study area lies within the margin between these two terrains, where older volcanic and sedimentary rocks derived from the Cascades are covered by glacial sediments.

The last glaciation, the Vashon Stade of the Fraser Glaciation, is responsible for most of the existing topography in the study area. Most noticeable are the trough-like valleys (the Puyallup, Carbon, Orting, and Stuck Valleys) and the relatively flat plateau, the Puget Sound Plateau, situated above the valleys.

Over the last 10,000 years, rivers and volcanic mudflows have deposited sediment in the trough-like valleys in the study area. The Puyallup, Carbon, and White Rivers have eroded the Cascade uplands and deposited a thick sequence (up to 200 feet thick) of sediments in the valleys. However, volcanic mudflows from Mount Rainer periodically coursed down the Puyallup and White River Valleys depositing a mixture of mud and rock that inundated the valley floors, covered floodplains and terraces and filled-in river channels and other low-lying areas. The deposits of the last two mudflow events are present throughout the study area. The oldest of the two mudflows, the Osceola (dated about 5,600 years ago), underlies the White River (Stuck) Valley. The Electron mudflow (dated about 560 years ago) coursed down the Puyallup River and is present primarily on Puyallup River floodplains.

The Electron mudflow deposited 15-50 feet of clay-rich mud and rock throughout much of the Puyallup and Orting Valleys. Since the Electron mudflow occurred, the Puyallup and Carbon Rivers (downstream of Orting) have created a new channel corridor within the mudflow deposits.

Eight geologic and surface soil units are found within the study area and are described below. For discussion purposes, we use the units mapping by Walsh and others (1987) unless otherwise noted. These units are described from oldest to youngest:

Bedrock units consist of Miocene-Eocene volcanic and sedimentary rocks. The volcanic rocks are mainly massive andesidic lava with columnar joints. The sedimentary rocks are primarily highly jointed siltstone and mudstone with coal bearing layers. Typically, these rocks are resistant to stream erosion. They are locally exposed along valley walls of the Puyallup River in the upper reaches of the Puyallup and Carbon Rivers.

Pre-Vashon, glacial drift (Orting and Salmons Springs Formation) consists of layered silt, sand, gravel and cobbles deposited by glacial meltwater streams. Individual layers are well sorted and may exhibit cross-beds and cross-cutting features. Pre-Vashon glacial outwash is well compacted as a result of having been overridden by continental glaciers. These deposits are exposed along portions of the Orting and Stuck Valley Walls. In some places, outcrops of drift overlain by Vashon continental glacial till, comprise vertical cliff faces adjacent to the river. Pre-Vashon glacial outwash is moderately resistant to river erosion.

Glacial till (Vashon) consists of well-consolidated silt, sand, gravel and cobbles deposited directly by glacial ice. The deposits are exposed along the Puyallup and Orting Valley Walls and on the Puget Sound Plateau. The deposits are generally resistance to river erosion. However, the presence of joint sets (planes of weakness) in the glacial till often result in the calving-off of blocks of till from cliff faces due to erosional undercutting of valley walls.

Glacial drift (Vashon) consists of silt, sand, gravel and cobbles deposited during the most recent episode of continental glacial retreat. Deposits can vary in thickness and exhibit a wide variety of sedimentary characters (from well to poorly sorted, bedded and massive). In general, glacial drift is unconsolidated and is moderately sensitive to river erosion. The deposits are exposed along the Puyallup and Orting Valley Walls and on the Puget Sound Plateau.

Glacial outwash (Vashon) consists of layered silt, sand, gravel and cobbles deposited by glacial meltwater streams. The outwash mantles older glacial deposits and can vary in thickness from 10 to 120 feet. The deposits are exposed alongside the Orting Valley Wall and on the Puget Sound Plateau. Glacial outwash is moderately susceptible to river erosion.

Cohesive mudflow deposits (Osceola and Electron) consist of an unsorted mixture of sub-angular to sub-rounded volcanic rock fragments in a consolidated matrix of sand, silt, and clay. It generally exhibits a gradation of sediment-sizes from coarse material at the base to fine material at the top. These mudflows originated on the flanks of Mount Rainier and raced down river valleys. Remnants of the Electron mudflow underlie much of the Puyallup River valley floor from the town of Electron northward to the outskirts of Sumner. These deposits are exposed primarily in the floodplains and along the channel floor. The degree of cohesion and compaction of this deposit changes more-or-less proportionally to the thickness of the deposit. Consequently, erosion resistance ranges from relatively high in upstream areas, where deposit thickness is greatest, to moderate in the lower portions of the study area, where deposits are much thinner.

Riverwash (Alluvium) consists of sand to boulder-sized sediment transported and deposited relatively recently by stream flow. These deposits include both active and former riverbeds and gravel bar deposits. Riverwash is generally heterogeneous throughout the project area, but can be moderately well sorted locally. Riverwash is relatively loose and unconsolidated, and therefore highly susceptible to erosion.

Silty Loam (Overbank Alluvium) consists primarily of silt and sand with organic material deposited by floodwater. They are commonly reworked for agriculture. Silty loam is relatively loose and unconsolidated, and therefore highly susceptible to erosion.

TOPOGRAPHY

The Puyallup River originates from the Mowich, Puyallup and Tacoma Glaciers, located on the west flank of Mount Rainier (Figure 1) between Elevations 5400 and 6000 feet. Within the first 20 miles of its source areas, the river drops roughly 5,000 vertical feet and passes from U-shaped glacial valleys to a deeply incised, tightly confined canyon with steep channel gradients. At about Elevation 540 feet the valley widens and the channel gradient decreases abruptly. Below Elevation 280 feet the river flows through a wide flat-bottomed valley onto the Puget Plateau where it joins with both the Carbon River (P-RM 17.4) and White River (PRM10.6) near the town of Sumner. From Sumner, the Puyallup River flows another 10 miles to the northwest where it discharges water and sediment into Commencement Bay. Other major tributaries entering the Puyallup River upstream of the Carbon Confluence include the North and South Mowich Rivers, Kapowsin Creek, Fox Creek, and Fiske Creek. Fennel Creek enters the Puyallup River downstream of the Carbon River.

The Carbon River originates from the Carbon and Russell Glaciers (Elevation 4,000 to 5,000 feet) on the Northwest slope of Mount Rainer (Figure 1). Like the Puyallup River, it flows through rugged mountainous canyons along its course to a flat-bottomed valley at Elevation 420 feet. Below Elevation 290 feet, the Carbon River flows along the eastern side of the valley to its confluence with the Puyallup River approximately 2.5 miles northeast of Orting. Major tributaries entering the Carbon mainstem include Ipsut, Tolmie, South Prairie and Voight Creeks.

The main branch of the White River is formed by the junction of its east and west forks on the northern slope of Mount Rainier. The two forks collect flow from the Emmons, Frying Pan, and Winthrop Glaciers (Elevation 5000-7000 feet) (Figure 1). The river flows west to Buckley, collecting flow from the Greenwater River, Boise Creek and several smaller drainages. Approximately 4 miles east of Buckley, the river flows through the U.S. Army Corps of Engineers Mud Mountain Retention Dam. The dam is designed to pass most sediment and discharge up to 15,000 cfs. Floodwaters in excess of 15,000 cfs and debris are held back by design. From Buckley the river flows southwest, exiting a steep, tightly confined valley near Auburn. From Auburn the river flows southward through a wide, flat-bottomed valley to the confluence with the Puyallup near Sumner.

REACH-SCALE GEOMORPHIC PROCESSES

INTRODUCTION

Reach scale channel forming processes include erosion, transport and deposition of sediment within a channel, and flow dynamics through each reach. The extent to which these processes influence channel development are generally determined by channel gradient, flow volume, transport capacity (the ability of the stream to move sediment), composition of channel banks,

and the volume and composition of sediment entering the stream from external source areas. For example, in upper stream reaches where channel gradient is steepest, the hydraulic action of fast flowing water results in the net erosion of the streambed, forming a deep, narrow, V-shaped valley wherein the stream channel occupies all or most of the valley floor. As channel gradient decreases and the valley becomes wider, a point is eventually reached where the action of the stream changes from erosion and vertical down cutting to a more complex system involving deposition, bank erosion, channel widening and development of bends and floodplains.

CONTROLS ON CHANNEL FORMING PROCESSES

As mentioned above, factors controlling channel-forming processes include regional topography, channel gradient, flow volume and transport capacity, composition of bank soils, and sediment delivery. The influence of each on channel form and process is briefly discussed below.

Topography

Channel patterns (straight, meandering, etc.) throughout the Puyallup, Carbon and White River project areas are controlled in large part by the presence of nearly continuous levees and revetments that artificially confine the river channels. Under unconfined conditions, however, channel pattern is typically controlled by local topography and geology that may confine the river channel, or protrude into the channel, altering the flow direction. For example, reach-scale bedrock ravines develop as straight, non-migrating channels. Channel pattern is also affected where portions of valley walls, local landslides and alluvial fans extend into channels, effectively directing, or steering, the course of the flow away from the feature and toward another part of the channel, thus altering flow dynamics. Changes in flow dynamics often result in changes in the patterns of erosion and deposition and can lead to changes in the direction of channel migration.

Additional topographic controls on channel pattern include channel constrictions, or partial obstructions. Channel constrictions occur where the width of the high flow corridor is reduced from upstream and downstream corridor dimensions. Typically, the channel through the constriction is straight, or contains high-angle bends. Constrictions may be formed by bedrock outcroppings, valley walls, landslide deposits and alluvial fan deposits that protrude into the active corridor. A constriction in the channel will usually cause a backwater condition upstream of the constriction. The backwater condition is one in which flow velocity decreases substantially due to a backing up of the flow behind the constriction. Sediment moving as bedload toward the constriction typically drops out of transport in the backwater area, eventually resulting in streambed aggradation, widening of the high flow corridor and development of a braided channel system upstream of the constriction.

Transport Capacity

The ability of the river system to transport sediment is referred to as its ‘transport capacity’. Transport capacity, coupled with sediment and woody debris supplied to the system, is a deterministic factor in the development of channel morphology. These three factors affect bar formation and channel form, as well as the shape and dimensions of the channel, and ultimately,

its behavior and relative stability. River reaches in which sediment delivery and transport capacity are well balanced tend to be relatively stable with respect to channel form. In systems where the volume of sediment delivery continually exceeds transport capacity, deposition can lead to reach- or valley-scale streambed aggradation, likely resulting in channel widening. In these reaches, channel form typically consists of sinuous meander bends or multi-threaded braided channels with high width-to-depth ratios.

Where transport capacity exceeds sediment delivery, erosional conditions prevail resulting in an increase in the mean size of bedload materials, lack of bed forms and reduction of channel complexity. Under these conditions, channel form is often straight and incised, yielding smaller width to depth ratios.

In our discussion of channel conditions, we address reach-scale transport capacity in terms of the percent change in average reach gradients between two adjacent reaches. The change is derived from the difference in gradient from one reach to the next (see Table 5). Negative difference values indicate decreased gradient in the downstream direction, and represents areas where a portion of the bed load is more likely to drop out of transport. A positive difference indicates increased gradient in the downstream direction, and represents areas where bedload is more likely maintained in transport. Decreasing percent gradient change values ranging from 20 percent and greater typically indicate a strong potential for bedload deposition. Figure 2 presents a graphic comparison of streambed gradients and associated percent gradient changes from one reach to the next for the Puyallup, Carbon and White.

CHANNEL MIGRATION

In natural drainage systems, stream channels entering lower gradient reaches are seldom straight, except over short distances. Lower gradients usually encourage deposition of a portion of the sediment load in transport, which causes small to large changes in the flow patterns, often resulting in erosion along the outside bank of channel bends. In a state of dynamic equilibrium, erosion along the outside bank of a meander bend and deposition on the point bar at the inside bank of a meander bend both occur simultaneously, and at more or less similar rates. A result of this process is the lateral movement, or migration, of the channel across the floodplain.

The extent to which channels can migrate is highly dependent on the materials comprising the channel floor and banks. These materials may be grouped into three categories: bedrock, semi-controlled, and alluvial channels. Channels formed in bedrock, which is essentially erosion resistant, are defined as stable over time and do not change their position appreciably unless weaker (less resistant) bedrock sections are subject to erosion. Semi-controlled channels commonly have local controls that resist channel movement, such as bedrock outcrops. Channel sections without local erosion controls are more prone to erosion and migration. Alluvial channel banks and streambeds are composed of sediment previously transported and deposited by the stream. These deposits are usually highly prone to erosion and allow for higher rates of migration.

Types Of Channel Migration

Prior to confinement of the channels in the lower Puyallup Watershed three principle types of migration occurred most commonly: meander bend migration, braided channel migration, and avulsion. A fourth, less common, type of migration, referred to as vertical migration, is also noted in the project area.

Meander Bend Migration

Meander bend migration involves erosion of the outside bank of the river bend coupled with concurrent deposition of sediment along the inside bank of the bend. This process results in the lateral movement of the channel, while maintaining consistent channel shape and width. However, the area of most pronounced migration usually occurs where flow converges against the outer bank near the downstream end of a bend, resulting in both lateral and downstream migration of the bend. Prior to confinement of project area channels, highly sinuous meander bends tended to develop in low to moderate gradient areas subject to sandy bedload and erosion prone riverbanks. Highly sinuous bends are typically the product of both lateral and downstream migration.

Braided Channel Migration

Braided channel sections typically consist of multi-thread channels separated by gravel and cobble bars. The channels are typically shallow and migrate rapidly within the braided area as bars are eroded and redeposited within the channel corridor. Prior to confinement of the project area, braided channel sections tended to develop in areas with a decreasing gradient and where the channel was subject to an influx of large volumes of coarse sediment.

Avulsion

Avulsion is the abrupt movement of an active channel to a new location in the river corridor. This process usually occurs in response to sudden deposition and infilling of the active channel by sediment or debris, causing the stream to erode a new channel or reoccupy a formerly abandoned channel. Avulsion is most common in braided channel sections, where the active channel may abruptly abandon its location for a new channel within the active area during a single high flow event.

Avulsion is also observed in meander bend areas. Under these conditions avulsion typically occurs as a meander bend cutoff, wherein a highly sinuous, looping bend is pinched off at the neck, thus abandoning the bend and straightening the channel pattern. Avulsion by meander bend cutoffs is common in lower gradient reaches.

Vertical Migration

Vertical migration involves the downward vertical movement of the channel floor, generally resulting in a deeply entrenched channel detached from its floodplain. Vertical migration usually occurs in channel sections situated in generally erosion-resistant geologic materials, such as bedrock or glacial till, or where the channel has been held in place by artificial structures such as revetments. Vertically migrating channel sections are generally straight, single thread channels exhibiting virtually no observable lateral migration.

GEOMORPHIC EVALUATION

This section of the report summarizes the results of the geomorphic analysis conducted for the Puyallup, Carbon and White Rivers. The summary is based on a detailed description of geomorphic conditions for each reach in the project area, including valley- and reach-scale physical features, channel conditions, channel forming processes and migration characteristics. The geomorphic reach descriptions are provided in Appendix B of this report. The following summary is presented in order of the Puyallup, Carbon and White Rivers. Each river discussion includes the following topics:

- 'Pre-confined River Environment'; a summary of river and valley floor conditions prior to confinement by levees and revetments.
- 'Un-confined Channel Condition'; a summary of channel conditions and migration character prior to confinement.
- 'History of Development'; a summary of changes in land use, bridge and railroad construction, river protection and improvement measures, gravel mining in the river, and suburbanization of watersheds. Additional historic information is provided in Table 6.
- 'Developed Channel Character'; a summary of present, confined river conditions.

PUYALLUP RIVER

Introduction

The study area begins at P-RM 28.6 and ends at the confluence of the White River (P-RM 10.3). Throughout the project area, the channel corridor resides in a trough-like valley with steeply inclined valley walls. Between P-RM 25.4 and P-RM 23.6 the river flows through a straight, narrow bedrock constriction. At P-RM 23.4 the valley floor widens considerably, and converges with the Carbon River valley, to form the Orting Valley. From P-RM 23.4, the Puyallup River flows parallel with the Carbon River over a distance of about 4 miles, to the confluence of the two rivers, located about 2.5 miles northeast of Orting. The Puyallup River flows northward another 7 miles, past the towns of McMillin, Alderton, and Sumner to the confluence with the White River, the downstream end of the project area. Throughout the project area, the channel gradient decreases steadily from about 1.14 percent at P-RM 28.6 to roughly 0.17 percent at the confluence with the White River.

In addition to the Carbon and White Rivers, the other major tributaries to the Puyallup within the project area include Fox Creek (P-RM 27.9), Kapowsin Creek (P-RM 26.1), Fiske Creek (P-RM 25.4), and Fennel Creek (P-RM 15.0). The Carbon River confluence is located at P-RM 17.4, between the towns of Orting and McMillan, and the White River confluence is located at P-RM 10.2.

Pre-Confined River Environment

Throughout the lower portion of the project area, in the vicinity of the White River confluence, the Puyallup River valley bottom was forested, but was by all accounts, swampy and prone to flooding. The flooding was largely in response to the shallow channel depth and low lying terrain. Alders, vine maple and other deciduous trees grew in the riparian areas adjacent to

river edges, changing to cedar and spruce with increasing distance upstream. Elevated portions of the floodplain and terraces were densely forested by cedars, spruce and Douglas fir.

Prior to confinement, the mainstem Puyallup was a freely migrating channel. Migration was the natural response of the river to high sediment loads, which entered the mainstem channel primarily from high sediment yield reaches upstream of the project area and from the Carbon River.

Un-Confined Channel Condition

The upper-most reaches of the Puyallup River, from P-RM 28.2 to P-RM 20.1, were complexly braided. The complexity of the braid bars and channels indicate that large volumes of sediment entered the project area from upstream reaches. The influx of sediment was clearly in excess of local transport capacity, resulting in multiple shallow, unstable channels separated by numerous braid bars.

From P-RM 20.1 to the confluence with the Carbon River, the channel formed a series of large-radius unvegetated meander bends, indicating that sediment influx is high, although channel stability and the balance between sediment influx and transport capacity had both increased.

The reaches immediately downstream of the Carbon confluence (P-RM 17.4 to 14.2) are severely braided. The braiding is a direct response of the channel to a significant decrease in channel gradient, and the sudden high influx of sediment discharge from the Carbon River. The results of our evaluation indicate that this area was particularly sensitive to Carbon River sediment discharge, which clearly exceeded Puyallup transport capacity, resulting in channel aggradation, widening, and braiding.

The river transitions back to a meander bend channel pattern downstream of P-RM 14.2. The meander bends in this area are highly sinuous, indicating a generally even balance between transport capacity and sediment influx.

The extent and character of ancient braided and meander bend migration is preserved in floodplain and terrace deposits. Upstream of the Carbon confluence, (P-RM 28.2 to P-RM 17.4), the width of the ancient migration belt is defined by the remnants of the Electron mudflow, which was deposited as a thick layer of mud that blanketed the Puyallup valley bottom as far north as P-RM 12. The mudflow remnants, now buried in recent alluvium, are scalloped by stream erosion and thus appear to have bounded the ancient channel at some point. The distance between right and left mudflow deposits is approximately the same through the reaches upstream of the Carbon confluence, and represent a loosely defined corridor. The corridor may represent the width of a former braided channel section, or the bi-directional shifting of a less complex channel system.

A wide migration belt also formed downstream of the Carbon confluence as aggrading channel bars forced the stream to the sides of the active channel area, forming large scalloped cutbanks in the mudflow deposits. The apparent width of the ancient migration belt downstream of the Carbon confluence is much greater than noted upstream of the confluence. The increase is perhaps due to the composition and thickness of the mudflow deposit.

Abandoned channels situated near the mainstem channel may indicate episodes of channel avulsion. The most pronounced abandoned channel is situated along the west valley wall between P-RM 22.7 and 19.2. Mudflow deposits separate the ancestral channel from the mainstem Puyallup channel at Reaches P-13, P-12 and P-11. The abandoned channel is presently utilized by a small under-fit creek. The large size of the abandoned channel, and its separation from the main channel by an Electron mudflow remnant suggests that the Puyallup River may have moved thousands of feet as a result of avulsion.

Two other abandoned channels also representing possible ancient mainstem avulsion, are located downstream of the confluence with the Carbon River. The first is located on the west side of State Route 162, near McMillin (P-RM 16.6). The second is situated along the right valley wall near P-RM 14.2, east of Alderton and the present location of the mainstem channel. In our opinion these channels are unlikely to capture stream flow due to significant altering of channel morphologies.

History of Development

Based on the results of our aerial photo and historical maps review we deduced the following history of development. A summary of historical events is listed in Table 6. Plat maps from the 1860's indicate the land north of McMillin was plated for farms and small residences near the river. The Northern Pacific Railroad including two bridges over the Puyallup River and through Orting was completed by 1877.

By 1931 most of the Puyallup River bottom and surrounding hills had been harvested for timber and the valley was cleared for agriculture northward of P-RM 23.8.

In the 1920's two river engineering policies were employed: 1) driven piles and revetments were used to direct flow and 2) strings of concrete blocks wired together (concrete/wire debris catchments) were placed to capture wood debris and sediment as a means to divert the river to a desired course. In the 1930's and 1940's riprapped levees were constructed to prevent the migration of channels through agricultural lands.

River improvement policies were changed in the 1960's. The river channel was straightened and confined with man-made levees and revetments, decreasing channel width to an average of 250 feet. Levees and revetments were designed to prevent sediment sources on ravine walls from entering the mainstem channel, and thus increase transport capacity through the system.

The new levees changed land use practices in many areas adjacent to the river. Seasonal and residential developments occupy portions of historic zone of channel occupation, and low-lying areas previously subject to flooding have been cleared and presently used as pasture lands. The conversion of lands from rural to suburban land use started in the 1970's and continues today with the conversion of large tracts of farmland to residential developments.

Developed (Present) Channel Character

A direct result of development over the past several decades is the nearly complete confinement of Puyallup River reaches comprising the project area. As of 1998, nearly 100 percent of the total channel length is tightly confined by some combination of levees,

revetments and valley walls. In most areas, the levees are either set back short distances from, or placed adjacent to, channel edges. In addition, revetments composed of riprap or other erosion resistant materials line lengthy sections of stream to help prevent erosion of the riverbanks and levees.

Construction of levees over the past four decades produced a generally straight, narrow channel corridor. Placement of the levees cut-off and by-passed several major meander bends resulting in a general shortening and straightening of the channel. In addition, levee placement greatly reduced the width of the active channel corridor by as much as 60 percent upstream of the Carbon confluence, and up to 80 percent downstream of the Carbon. These changes in corridor width and channel pattern rendered a profound effect on geomorphic processes operating throughout the project area. The most profound change was a forced transition from highly complex braided (P-RM 28.4 to 24 and P-RM 17.6. to 16.0) and multiple thread meandering (P-RM 20.2 to 19.2 and P-RM 14.6 to 10.2) stream sections to an essentially straight, single thread channel.

The changes in channel pattern and character were accompanied by increased channel gradient, higher transport capacity, and very likely, deepening of the channel resulting from increased erosion of the streambed. Changes in gravel deposition followed the changes in the channel dynamics. Sand and gravel deposits no longer form braid bars and/or meander point bars, but instead form sidebars that build out from the channel edges. The sidebars develop as terraces alongside the levees and revetments, reducing available channel cross sectional area, and further constricting the low-flow channel.

Sediment discharge from high yield source areas higher in the watershed, and from the Carbon River have not changed appreciably from pre-confined conditions. Sediment deposition in lower gradient reaches causes aggradation of gravel sidebars, resulting in overtopping and breaching of the levees. A comparison of calculated percent changes in gradient (Table 5, Figure 2) with the results of our reach-scale geomorphic indicates several areas likely to experience aggradation and flooding, including portions of Reaches P-16, P-12 through P-9, P-7, and P-4. Depending on the volume and suddenness of bedload deposition within these reaches, the confining levees may be more susceptible to damage from erosion, bedload battering and flooding than in other reaches. Of all reaches identified, P-8 is most likely at risk of significant aggradation and flooding, due primarily to its location as a receiving reach from both the Puyallup and Carbon Rivers. Compared to upstream Puyallup and Carbon Reaches, the percent gradient change from P-9 is 27 percent, and 113 percent from C-01.

For many years, the primary solution to unwanted aggradation was the mining of gravel from strategic sites on the Puyallup, which worked to varying degrees. However, since 1997 all gravel mining in the river ceased, subjecting the confined river corridor to increased sediment loads, the full effects of which are yet unknown.

CARBON RIVER

Introduction

The study area begins at C-RM 8.3 and ends at the confluence with the Puyallup River (C-RM 0.0). Throughout the project area, the channel corridor resides in a relatively narrow trough-like valley, the north slope of which is a steep sided bluff. At C-RM 4.0 the valley floor widens considerably and converges with the Puyallup River valley. The channel passes on the north side of Orting, where it turns to the northwest through a large radius bend. The Carbon River flows along the north side of the valley until it discharges into the Puyallup River about 2.5 miles northeast of Orting. Throughout the project area, average channel gradients decrease steadily from about 1.2 percent to roughly 0.5 percent near the Puyallup confluence.

Two major tributaries, South Prairie and Voight Creek, supply water and sediment to the Carbon River. South Prairie Creek, the major drainage basin between the Carbon and White River watersheds, flows into the Carbon River at C-RM 5.6. Voight Creek, a smaller tributary, collects runoff from the foothills to the south and west and flows across the valley floor before entering the Carbon River at C-RM 4.2.

Pre-Confined River Environment

Descriptions of the Carbon River Valley prior to development are spotty at best. Aerial photographs indicate that the river occupied half or more of the valley floor throughout the project area. The valley floor and uplands were densely forested with conifers, and deciduous trees grew along the riparian corridor.

The majority of the Carbon River Valley was a broad floodplain with small discontinuous terraces along the south side of the valley. From C-RM 4.0 to the Puyallup confluence, the Carbon River was generally directed toward the right valley wall by the Electron Mudflow, which came down the Puyallup River around 1440 AD and deposited more than 15 feet of clay-rich mud across the Orting valley.

Un-Confined Channel Condition

Prior to development the entire length of the project area consisted of a nearly continuous complex of braided and multi-thread meandering channels. The channel pattern transitioned from a primarily shallow, multi-thread braided system in the upper project reaches (C-RM 8.3 to C-RM 3.2) to combined braided and sinuous multi-thread meander bends throughout the remaining length of channel (C-RM 3.2 to C-RM 0.0). Downstream of South Prairie Creak, the stream entered a broad corridor that extends to the confluence with the Puyallup River. The corridor developed as growing braid bars forced stream flow to the sides of the corridor, leading to the erosion of large scalloped cutbanks in the mudflow deposits and ravine walls.

History of Development

Aerial photographs and historical maps indicate that the first development along the Carbon River centered around coal mining. The Northern Pacific Railroad built a rail line up both the Carbon River (to Carbonado) and South Prairie Creek in the late 1870 or 1880's. Orting was a center of commerce in the area, first for the mining industry, and then later, for the timber and

agriculture industries. By 1931 most of the timber in the valley on surrounding hillsides had been harvested and the valley west of the South Prairie/Carbon confluence was cleared for agriculture.

The 1931 aerial photographs show at least two bridges crossing the river that may have obstructed stream flow, and caused sediment deposition and channel braiding. The first bridge was located at C-RM 3.1; the other was the Northern Pacific Railroad crossing at C-RM 5.9. The aerial photograph shows a complexly braided channel, approximately 1,000 feet wide and 3,000 to 4,000 feet long upstream of the bridge. The 1931 photos also indicate that riprap groins and concrete/wire debris catchments were in place, presumably to direct flow around Orting, and away from the railroad and county roads near the confluence with the Puyallup River.

Beginning in the 1960's, river improvement policies changed throughout the Puyallup River watershed. Levee and revetment placements were designed to move sediment through the system as well as prevent valley wall sediment from entering the river. The design involved straightening and confining the channel to an average width of 250 feet, and placing the structures to intercept sediment accumulating at the base of valley walls.

To date, only a small fraction of this subbasin has been developed. However, since the completion of the 1960's era levees, small residential homes and the Orting Wastewater Treatment Plant have been built adjacent to the river in areas historically occupied by the river. More recently, floodplains downstream of Orting have been cleared and used for pastures.

Developed (Present) Channel Character

Existing levees and revetments tightly confine the Carbon River channel against the north valley wall. In most areas, the levees are either set back short distances from, or placed adjacent to channel edges. Construction and maintenance of levees over the past four decades significantly altered channel alignment and pattern in Reaches C-6 and C-5 (C-RM 6.6-C-RM 5.6) and in Reaches C-1 and C-2, downstream of Orting (C-RM 3.1 to C-RM 0.0). Placement of the levees shortened and straightened the channel and reduced the width of the high flow channel corridor by 10 to 50 percent. These changes in channel pattern and width rendered a profound effect on geomorphic processes operating throughout the project area. The most profound change observed was the forced transition of a large section of the channel from a complexly braided and multi-thread meandering channel to an essentially straight, single thread stream.

The changes in channel pattern and character were accompanied by increased channel gradient, higher transport capacity, and very likely, deepening of the channel resulting from increased erosion of the streambed. Similar to the Puyallup River, changes in bedload deposition followed the changes in channel dynamics. Throughout Reaches C-1 and C-2 (C-RM 3.1 to C-RM 0.0) gravel and cobble bedload is deposited as side bars that build out from channel edges. The sidebars develop as terraces alongside the levees and revetments, reducing available channel cross sectional area, and further constricting the low-flow channel.

Sediment influx from high yield source areas higher in the watershed and along project area valley walls has not changed appreciably from pre-confined conditions. Similar to conditions before confinement, sediment deposition in low gradient reaches causes aggradation of the

streambeds, however, reduced channel width from confining structures has effectively decreased the total channel area available for sediment deposition, resulting in overtopping and breaching of the levees. A comparison of calculated percent changes in gradient (Table 5, Figure 2) with the results of our reach-scale geomorphic indicates several areas likely to experience aggradation and flooding, including portions of Reaches C-4, C-3, and C-2. Depending on the volume and suddenness of bedload deposition within these reaches, the confining levees may be more susceptible to damage from erosion, bedload battering and flooding than in other reaches. Reach C-2 is likely at greatest risk of significant aggradation, due to the tight confinement of the channel and its high percent gradient change. Reaches C-4 and C-3 are presently high deposition reaches, primarily the result of a wider stream corridor and relatively high percent changes in gradient.

WHITE (FORMERLY STUCK) RIVER

Introduction

The White River project area extends from the Pierce/King County boundary (W-RM 5.6) to the Puyallup River (W-RM 0.0). Throughout the project area average channel gradients gradually decrease from 0.23 percent to 0.03 percent near the confluence with the Puyallup River.

Noteworthy tributaries within the study area include Salmon Springs Creek, a substantial drainage ditch, and the engineered discharge outfall from the White River Diversion/Dieringer hydroelectric project. Salmon Springs Creek collects water from a series of springs on the east valley wall and enters the White river at W-RM 2.0. Jovita Creek and several small, unnamed creeks collect and convey run-off from the west valley wall and valley floor to a large drainage ditch which enters the river at W-RM 1.1. The White River Diversion/Dieringer hydroelectric project outfall enters the river at W-RM 3.6.

Pre-development River Environment

Prior to development, the Stuck Valley was a flat, swampy lowland positioned between two large, sediment-laden river systems. Prior to 1904, the White River was mapped as flowing northward past Auburn, where it joined the Green River. As mapped, the ancestral Stuck Creek originated from a swamp in Jovita Canyon, situated at about the intersection of 8th Avenue and Valentine Road SE, and flowed southward to the Puyallup River, much like the White River does today. Historical reports indicate that, occasionally, the White River was diverted southward into the Stuck Valley by wood debris dams. Stuck Valley soils are composed of fine sand, silt and peat, suggesting the area was subject to periodic flooding and backwater ponding. To our knowledge, however, no evidence to date suggests that the White River had developed an ancestral connection with the Puyallup River.

History of Development

Based on the results of our aerial photographs and historical maps review we deduced the following history of development. Agricultural development in the Stuck Valley began in the 1860's. Plat maps dating from the 1860s indicate the valley was platted for farming. The Northern Pacific Railroad (now Burlington Northern Santa Fe Railroad Company) completed an alignment up the right side of the Stuck valley in 1880's. By 1900, a second railroad alignment,

including a spur across the White River, was constructed by the Chicago, Minneapolis, and St. Paul Railroad (now used by the Union Pacific Railroad Company).

A disastrous flood and channel avulsion in 1906 caused the White River to flow permanently south into the Stuck Valley and to the Puyallup River. The avulsion led to a series of engineering projects intended to protect lands adjacent to both the White/Stuck and the lower Puyallup River. In 1907, the Puyallup River was dredged, straightened, and reveted downstream of the White River confluence (1907-1910's). In 1914, the Inter-County River Improvement office (ICRI) constructed a diversion dam to prevent the White River from avulsing back into its pre-1906 channel, and partially channelized the White River from the diversion dam to the Puyallup River confluence (1914-1920's). Aerial photographs in 1931 and 1940 indicate that riprap and concrete levees were constructed to protect cutbanks and three bridges near Sumner.

Two upstream dam projects alter the hydrology of the river. In 1912, Puget Sound Energy (PSE) constructed the White River Diversionary Dam, and the Dieringer Hydroelectric Plant began diverting water from the White River near Buckley, WA, located upstream of the study area. The diverted flow was temporarily detained to allow settling of the sediment load prior to routing the sediment free water back into the White River at Dieringer. In 1945 the Army Corps of Engineers completed a flood protection dam, the Mud Mountain Dam, on the White River east of Buckley. The dam is designed to pass a maximum of 15,000 cubic feet per second of water and sediment through the dam. Excess flow and woody debris is detained behind the dam.

In the 1970's, land use in the Stuck Valley was converted from primarily rural farm use to industrial/warehouse land use. As of 2002, warehouses occupy roughly 30 percent of the valley.

Based on our review of 1931, 1940, and 1976 aerial photographs gravel mining was conducted periodically upstream of the Dieringer Hydroelectric outfall from the 1920's to the mid 1990's. All gravel mining ceased in 1997. The effects of starting and stopping the gravel mining operation are unknown.

Developed (Present) Channel Character

Upstream of the Dieringer Plant outfall, the White River consists of several large radius meander bends. Channel gradient decreases steadily in the downstream direction from Reaches W-7 to W-5, although the calculated percent change in channel gradient (Table 5) is relatively high. Based on aerial photo review, the meander bends appear to be relatively stable over the period of record, suggesting that the sediment influx and transport capacity are in balance.

Immediately upstream of the Dieringer Hydroelectric Plant outlet, the channel character changes from a meandering channel with active channel side bars in a reveted channel corridor, to a meander channel with vegetated mid-channel and side channel bars (W-RM 5.4 to 3.6). Downstream of the outfall, the channel is generally straight and incised. Base on field evaluations, the depth of incision increases in the downstream direction. Throughout Reaches W-1 and W-2, the river is entrenched by as much as 15 feet, and thus detached from its floodplain. The depth of channel entrenchment is apparent from 1920's era concrete slabs placed to protect the now elevated upper banks, and from remnants of stabilized sand bars situated along the base of the concrete slabs.

CHANNEL MIGRATION ZONE (CMZ) ANALYSIS AND RESULTS

INTRODUCTION

A principle objective of this project is the delineation of channel migration zones **in the absence of** levees, revetments and infrastructure presently confining project area channels. This objective requires evaluating each channel from the perspective of a freely migrating system subject to existing reach-scale channel conditions and existing geomorphic processes. Problematic to this approach is the fact that nearly all project-area river reaches were confined by 1965, rendering them unrepresentative of free migration.

Our approach to delineating the probable extent of migration assumes that, in the absence of existing channel constraints, the future rate and character of migration will be similar to that of the past, given similar water and sediment discharge conditions. Consequently, our approach depends heavily on our understanding of the relationships between channel topography, sediment influx, transport capacity and the type and character of migration occurring in each reach prior to confinement. To achieve this objective, migration character and rates were documented only from 1931 to 1940/1965, the unconfined period of record, since rates averaged over a longer period of record would strongly favor confined conditions. Migration distances were measured only at sites that reflected observed reach-scale migration type and character, and appeared not to have been influenced by local artificial structures.

CALCULATION OF UNCONFINED MIGRATION RATES

Average rates of migration were calculated for each reach by dividing measured distances between observed channel positions by the number of years between channel positions. Measurements were made directly from channel positions digitized from dated aerial photographs scanned and rectified into our comprehensive GIS. Selection of areas for migration measurements excluded artificially confined (revetted, etc.) areas to obtain representative unconfined migration conditions. Both lateral and downstream migration was noted throughout the study area, however, only lateral rates were used in the analysis. Downstream migration was not used because the scale and frequency of occurrence was generally very low to negligible compared to lateral rates.

Wherever possible, migration rates were measured from 1931 to 1940 on unconfined sections of each reach. This time frame includes the flood of winter 1933, one of the three largest floods in the watershed on record. Older maps were not used in the calculation due to scaling and accuracy considerations. The 1940 aerial photographs indicate that several portions of the Puyallup and Carbon River channels were already confined or reveted. In those cases we deduced the distance of migration by comparing the 1931 channel position to the locations of bars and freshly abandoned channels observed on the 1940 aerial photographs. For those reaches lacking 1940 aerial photograph coverage, we inferred the distance of migration from evidence of abandoned channels observed on 1965 aerial photos.

The calculated maximum unconfined migration rates for each reach in the project area are presented in Table 7. Unconfined migration rates for the Puyallup River are highest in Reaches P-15, P-13, P-12, P-10, P-8, and P-4; migration rates are low to un-measurable in reach P16, where the channel is confine by bedrock, and very low in Reach P2 where the channel is

entrenched. Carbon River rates are highest in Reaches C-7, C-4 and C-1, near the confluence with the Puyallup. White River rates are highest in Reaches W-7 and W-6, and very low to un-measurable in Reaches W-4, W-2 and W-1, where the river is entrenched. It should be noted that early engineered channel controls likely limited the extent of migration in Carbon River reaches C4 and C3, and in White River reaches W7 to W1. Based on the results of our geomorphic evaluation, these reaches are all subject to a high percent change in channel gradient, and high influxes of sediment.

CMZ DELINEATION

We delineated the CMZ in the absence of levees and revetments based on several factors including the following:

- The Historical Channel Occupation Tract (HCOT) over the observable period of record,
- The pre-confined character of migration identified in each reach,
- The maximum unconfined rate of lateral migration for each reach,
- The unconfined rate of migration measured through Electron mudflow deposits,
- The locations of ancient and historic abandoned channels.

As describe earlier, our delineation approach assumes that in the absence of channel constraints, the future rate and character of migration will be similar to those of the past, given similar water and sediment discharge conditions. Consequently, we used unconfined migration rates, which is represented by the period from 1931 to 1940 and/or 1965 (Table 7). The unconfined migration rates represent periods of only 9 to 34 years, which is clearly too short a period to accurately evaluate average long-term rates of past migration. Therefore, to avoid under-estimating annual average migration rates, we used the local maximum rate measured within each reach, rather than reach-averaged rates.

The width of the CMZ was delineated to identify the distance the channel could travel in a period of 50 years in the absence of artificial confining structures. Based on the character of pre-confined migration, the distance of lateral migration in each direction was calculated by multiplying the maximum annual rate of migration for each reach by 25 years in a single direction. The distance of migration over a 25-year period, calculated at maximum rates of migration for each reach in the project area is provided in Table 7. Migration distances were measured from the outside edges of the observed historic channel occupation (HCOT). It should be noted that, as measured, the resulting CMZ is much wider in most reaches than existing confined channel conditions could typically achieve over the 25 year time span, given regular maintenance of confining levee system.

RESULTS

The results of the CMZ analysis are shown on Plate 1. The resulting width of the CMZ varies widely throughout the project area. Reach-scale variations are a result of the following factors:

- Local maximum rates of migration measured for each reach,
- Proximity of the channel corridor to valley walls and/or hard, erosion resistant geologic units,
- The presence of abandoned channels in the floodplain,
- Reach scale channel characteristics and geomorphic processes.

In reaches where a migrating channel would encounter an Electron mudflow remnant buried in the floodplain, the maximum migration rate was used through floodplain alluvium and then reduced to the measured rate of erosion through the mudflow. In historically non-migrating reaches, such as those confined by bedrock sidewalls (Puyallup Reach P-16), or where the channel is deeply entrenched (White River Reaches W-2 and W-4) the CMZ boundary is situated at the edge of the channel corridor. White River reach W-1 is also deeply entrenched but is included in the Puyallup CMZ. Where the calculated CMZ boundary intersects valley walls composed of granular soil the boundary is situated at the approximate crest of the valley wall to compensate for possible erosion along the slope face. In reaches where abandoned avulsion channels are present in the floodplain, the channel was field verified and included in the CMZ on the premise that the river could reoccupy the abandoned channel by avulsion.

The resulting CMZ encompasses all ancient channel traces, including possible avulsion or secondary channels, as well as historic mainstem channels shown on Government Land Office maps dating back to 1865.

MIGRATION POTENTIAL AREA (MPA) ANALYSIS AND RESULTS

MPA DELINEATION

Our MPA delineation approach is similar to that employed in our CMZ analysis. It assumes that future rates and character of migration will be similar to those of the past for similar water and sediment discharge conditions. We assumed the absence of artificial confining structures and used maximum unconfined migration rates for each reach.

The analysis involved identifying severe, moderate and low migration potential areas within the delineated CMZ. The width of each MPA was measured, based on delineation criteria developed specifically for this project, and then adjusted to accommodate geomorphic conditions not accounted for in maximum migration rates. Criteria developed for mapping severe, moderate and low MPA are provided in the following paragraphs:

Severe Migration Potential Area

The area that includes 1) the HCOT, as determined by the results of our aerial photographic evaluation (from 1931 to 1998) and 2) an area representing the distance the channel could travel in 5 years of steady lateral migration **from the outside boundary of the HCOT.** The maximum rate of migration for each geomorphic reach was used in the calculation. The calculated distance of migration used for the severe MPA is shown Table 7.

Moderate Migration Potential Area

The area landward of severe migration potential area representing 1) the distance the channel could travel in 15 years of steady lateral migration **from the HCOT**, and 2) the distance the channel could travel in 5 years of steady lateral migration from geomorphic features capable of capturing stream flow. (i.e. ancient abandoned channels, oxbows, secondary channels, ditches). The calculated distance of migration used for the minimum (15 year) moderate MPA width is shown Table 7.

Low Migration Potential Areas

The area landward of moderate MPAs comprising the remaining area of the CMZ.

Exceptional Conditions

The width of CMZ and Severe and Moderate MPAs were modified from the minimum calculation defined above, as deemed necessary based on factors requiring geologic interpretation and professional judgment. These factors include the presence of significant abandoned channels capable of capturing main stem flow in an avulsion event, and the proximity of the channel to valley walls and hard, erosion resistant geologic units.

The most common adjustments typically involved widening the moderate MPA to include ancient abandoned channels, and reducing the width of MPA to accommodate the presence of native erosion resistant bank materials, such as bedrock. A detailed list of MPA adjustments is provided in Appendix D.

The MPAs are based on observed rates of unconfined migration. However, on the left back of the Carbon River RM 4.0 to 4.4 (reaches 3 and 4) the former BNSF railway revetment has confined the river throughout the period of record and likely influenced the measured rate of migration. The placement of the MPA is based on the observed rate of migration and therefore influenced by the railway revetment.

RESULTS

The resulting migration potential areas are shown on Plate 1 and the GIS CD. Reach-scale variations in the calculated width of severe and moderate zones are results of the following factors:

- The local maximum rate of migration measured for each geomorphic river reach,
- The Maximum rate of migration measured for Electron mudflow deposits along the Puyallup River (Reaches P-9 through P-18) and Carbon River (Reaches C-1 through C-3),
- The proximity of the channel corridor to valley walls and/or hard, erosion resistant geologic units.
- The presence of abandoned channels in the floodplain

In historically non-migrating reaches only the severe MPA was delineated; we identified such conditions along Puyallup Reach P-16, where the channel is confined by bedrock sidewalls, and White River Reaches W-2 and W-4, where the channel is deeply entrenched. In reaches where the channel is situated adjacent to a valley wall and the CMZ boundary is located approximately at the crest of valley wall, the face of the slope is mapped as a medium MPA.

COMPARISON OF CMZ AND MPA RESULTS WITH FEMA FLOOD ZONES

We compared the results of the CMZ and MPA analysis against published Federal Emergency Management Agency (FEMA) 100- and 500-year flood boundaries, modeled in 1989. Please refer to MPA and FEMA Flood GIS layers provided on the accompanying GIS CD.

CMZ/FEMA FLOOD ZONE COMPARISON

The results of the comparison indicate that CMZs are generally wider than both FEMA 100- and 500-year Flood Zones for the Puyallup and Carbon Rivers, but not for the White River.

Over the length of the Puyallup River, the width of the CMZ varies significantly depending on previously identified factors. From the upstream end of the project area (P-RM 28.5) through P-16 (P-RM 25.0) the CMZ is slightly wider than the FEMA 500-year Flood Zone. From P-RM 25.0 to the Carbon River confluence (Reaches P-15 through P-9) the CMZ is 2 to 4 times wider than the FEMA Flood Zones. Downstream of the Carbon River confluence (Reaches P-8 through P-1), the width of the CMZ, which is highly variable, is 2 to as much as 5 times greater than the FEMA Flood Zone widths.

The Carbon River CMZ also exceeds the width of both the FEMA 100- and 500-year Flood Zones. From the upstream end of the project area (C-RM 8.3) through C-RM 6 (C-RM 5.9), the CMZ varies from 1.5 to 2 times wider than the FEMA Flood Zone. From C-RM 6 to the Puyallup River Confluence (Reaches C-5 through C-1) the CMZ is roughly is 2 to 4 times wider than the FEMA Flood Zone.

In contrast to the Puyallup and Carbon Rivers, the White River FEMA 100-year Flood Zone is significantly wider than the CMZ throughout most project area reaches. From the upstream end of the project area at W-RM 8.3 to W-RM 1.2 (Reaches W-7 through the upstream portion of W-2) the width of the FEMA Flood Zone varies from 2 to 10 time greater than the CMZ. However, the width of the FEMA 100- and 500-year Flood Zones decreases abruptly to that of the CMZ downstream from W-RM 1.2 (White River Reach W-2), primarily in response to the deep entrenchment of the channel.

Results of the comparison indicate relatively close correlations between Severe MPA and FEMA flood zone boundaries for most Puyallup and Carbon River reaches, but not for White River reaches.

LIMITATIONS

We have prepared this report for use by the Pierce County Public Work and Utilities, Environmental Services, Water Programs Division. Conditions within the Puyallup River Watershed may change over time as a result of changes in land use and flood management policies and sediment delivery. Our report should not be construed as a guarantee of future conditions in the Puyallup watershed or within the Puyallup, Carbon, and White River project area.

GeoEngineers believes that the results of the CMZ and MPA analysis provided in this report are reasonable and appropriate; however, fluvial geomorphology is not an exact science, and conditions and interpretations can change with time and additional or different data. Changes in interpretation or conditions may require that our conclusion and recommendations be modified.

Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted geoscience practices in this area at the time the report was prepared. No warranty or other conditions express or implied, should be understood.

Please refer to Appendix E, titled “Report Limitation and Guidelines for Use,” regarding appropriate usage of this report.

We appreciate the opportunity to work with you on this project and look forward to providing further assistance as needed. Please call with any questions that you have regarding this report, or if there is anything else we can do to assist you.

Yours very truly,

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Attachments

Three copies submitted

REFERENCES

Abbe, T.B., 2000, Patterns, Mechanics and Geomorphic Effects of Wood Debris Accumulations in a Forest River System, Ph.D. dissertation, University of Washington, Seattle, Washington.

Anderson, I.E., 1948, Floods of the Puyallup and Chehalis River Basins, Washington, Water-supply paper 968-B, United States Geological Survey.

Borland, W.M., 1984, Puyallup River Basin Bed Load Studies: Channel Aggradation in the Puyallup River Basin, Memo to the Puyallup Tribe and Appendix.

Crandell, D.R., 1963, Surfical Geology and Geomorphology of the Lake Tapps Quadrangle Washington, Geological Survey Professional Paper 388-A, U.S. Geological Survey.

Cadastral Survey Plats: Washington [electronic resource], 2000, United States Bureau of Land Management, General Land Office, Portland, Oregon, distributed by Allied Vaughn, CD-28, CD-29.

Federal Emergency Management Agency, 1989, Pierce County, Washington, Flood Insurance Studies, Volumes 1 & 2.

Henshaw, F.F., & Parker, G.L., 1913, Water Powers of the Cascade Range, Part 2 -- Cowlitz, Nisqually, Puyallup, White, Green, and Cedar Drainage Basins, Water Supply Paper 0313, U.S. Geological Survey.

http://waterdata.usgs.gov/wa/nwis/peak/.

James M. Montgomery Consulting Engineers Inc, May 1991, Puyallup River Basin Comprehensive Flood Control Management Plan, Pierce County Department of Public Works, River Improvement Division.

Lewis, D.E., Comis, J.G., & Prych, E.A., 1987, Flood Protection in the Puyallup River Basin, Washington—Past, Present and Future, in Realistic Approaches to Better floodplain Management: 11th Annual Conference Proceedings of the Association of State Floodplain Managers, University of Colorado Natural Hazards Information Center Special Publication 18, p 298-304.

Mastin, M.C., 1999, Real-time Flood Alert and Simulation of River Flood Discharges in the Puyallup River Basin, Washington. Water Resources Investigation 98-4226, U. S. Geological Survey.

Montgomery, DR, & Buffington, JM, 1998, Channel Processes, Classification, and Response, in River Ecology and Management, Naiman, R and Bilby, R, eds, Springer-Verlag, New York, p 13-42.

Pauley, G.B., Thomas, G.L., Marino, D.A., & Weigand, D.C., March 1989, Evaluation of the Effects of Gravel Bar Scalping on Juvenile Salmonids in the Puyallup River Drainage, W68 MD9-86-251-01, AFRS #8766, Washington State Department of Fisheries.

Prych, E.A., 1988, Flood-carrying Capacities and Changes in Channels of the Lower Puyallup, White, and Carbon Rivers in Western Washington, Water Resources Investigation 87-4129, United States Geological Survey.

Roberts, W.J., 1916, Some of the Problems in the Flood Control of the White-Stuck and Puyallup Rivers, Pacific Northwest Society of Engineers, Proceedings, v. 15, no.3.

Roberts, W.J., 1920, Report on Flood Control of White-Stuck and Puyallup Rivers, Inter-County River Improvement, King and Pierce Counties, Washington, Inter-County River Improvement Board of Commissioners.

Schumm, S.A., 1986, Alluvial River Response to active Tectonics, in Active Tectonics, Geophysics Study Committee, Geophysics Research Forum, Commission on Physical Sciences, Mathematics, and Resources, National Research Council, National Academy Press, Washington, DC, p 80-94.

Sikonia, W.G., 1990, Sediment Transport in the Lower Puyallup, White, and Carbon Rivers of Western Washington, Water Resources Investigation 89-4112, United States Geological Survey.

Sumioka, S. S., Kresch, D. L., & Kasnick, K. D, 1998, Magnitude and Frequency of Floods in Washington, Water Resources Investigation 97-4277, United States Geological Survey.

U.S. Water Resources Council, 1976, Guidelines for Determining Flood Flow Frequency, Bulletin 17 of the Hydrology Committee, Water Resources Council, Washington, D.C.

U.S. Water Resources Council, 1981. Guidelines for Determining Flood Flow Frequency, Bulletin #17B of the Hydrology Committee, Water Resources Council, Washington, D.C

United States Army Corps of Engineers, 1940, Aerial Photographs of the Puyallup, White and Carbon Rivers.

United States Army Corps of Engineers, 1944, Enlargements of 1:20,000 Aerial Photographs of Washington State, United States Army Map Service.

United States Army Corps of Engineers, Puyallup River, Wash. 1924, Letter from the secretary of war transmitting, with a letter from the chief of engineers, a report on preliminary examination of Puyallup River, Washington, with a view to preparing plans and estimates of cost for the prevention and control of floods on said river and its tributaries, and to determining the extent to which the United States and local interests should cooperate in carrying out any plans recommended. United States Government Printing Office, House Document 220.

United States Geological Survey, Auburn, Washington 7.5 Minute Topographic Map, 1973, United States Geological Survey.

United States Geological Survey, Auburn, Washington 7.5 Minute Topographic Map, 1994, United States Geological Survey.

United States Geological Survey, Buckley, Washington 7.5 Minute Topographic Map, 1968, United States Geological Survey.

United States Geological Survey, Buckley, Washington 7.5 Minute Topographic Map, 1973, United States Geological Survey.

United States Geological Survey, Buckley, Washington 7.5 Minute Topographic Map, 1993, United States Geological Survey.

United States Geological Survey, Historical Peak Stream flow for Washington, database queries

United States Geological Survey, Orting, Washington 7.5 Minute Topographic Map, 1973, United States Geological Survey.

United States Geological Survey, Puyallup, Washington 7.5 Minute Topographic Map, 1961, United States Geological Survey.

United States Geological Survey, Puyallup, Washington 7.5 Minute Topographic Map, 1973, United States Geological Survey.

United States Geological Survey, Puyallup, Washington 7.5 Minute Topographic Map, 1994, United States Geological Survey.

United States Geological Survey, Sumner, Washington 7.5 Minute Topographic Map, 1973, United States Geological Survey.

United States Geological Survey, Tacoma, Washington 15 Minute Topographic Map, 1900, United States Geological Survey.

United States Geological Survey, Tacoma, Washington 15 Minute Topographic Map, 1944, United States Geological Survey.

United States Geological Survey, Wilkerson, Washington 7.5 Minute Topographic Map, 1973, United States Geological Survey.

Unknown. Puyallup River System Gravel Study, 1997, Scoping Issues, 2nd draft, October 1, 1997.

Viessman, Jr., W., Lewis, G.L., & Knapp, J.W., 1996, Introduction to Hydrology, 4th Edition, Harper Collins, New York.

Walsh, T.J., 1987, Geologic Map of South Half of the Tacoma Quadrangle, Washington, Open File Report 87-03,Washington State Department of Natural Resources.

Walsh, T.J., Korosec, M.A., Phillips, W.M., 1987, Geologic Map of Washington - Southwest Quadrant, GM-34, Washington State Department of Natural Resources.

Walters, K.L, Kimmel, G.E., Ground-Water Occurrence and Stratigraphy of Unconsolidated Deposits, Central Pierce County, Washington, Washington State Department of Ecology, ECOL WSB-22, 1968.

Washington Department of Natural Resources, 1964-65, Aerial Photographs of the Puyallup, White and Carbon Rivers.

GLOSSARY OF TERMS

active channel	The wetted portion of a channel at the time of observation..
aggradation	The process of building up a surface by sediment deposition.
avulsion	The process in which a stream abandoned a developed channel an creates a new one.
bank full conditions	The stage at which the elevation of the water surface of a stream flowing at channel capacity.
braided channel migration	A process where a stream forms a interlacing network of shallow short lived channels separated by channel bars
high flow channel	The wetted channel width that the stream can, or has recently, occupied during high flow events. As observed on aerial photographs the high flow channel consists of the low flow channel as well as active and exposed gravel bars.
channel capacity	The maximum flow that a given channel is capable of transmitting without overtopping its banks.
Channel gradient	The degree of inclination of a river channel. In this report, gradient is averaged over the length of river reaches.
channel migration	The lateral or downstream shifting of a river channel within a river valley.
CMZ	Channel Migration Zone
concrete/wire debris catchments	A linear assemblage of pyramid shape concrete (poured in place) weights cabled together. They were designed and constructed in the 1920's to ‘catch’ woody debris during high flow events.
Electron mudflow	A 500 year old volcanic deposit consisting of consolidated mud, rock and debris that covered much of the Puyallup River Valley.
entrenched channel	A channel that has cut vertically downward into streambed deposits, resulting in a channel that is much deeper than it is wide.
FEMA	Federal Emergency Management Agency
GIS	Geographic Information Systems
HCOT	Historical Channel Occupation Track
lag deposits	Coarse grained material deposited in the channel during waning storm flows. These deposits are typically devoid of finer sediment.
mainstem	A channel identified as carrying the majority of the flow.

meander bend migration	The lateral or downstream movement of a sinuous curve in a stream within a river valley.
meander scar	A crescentic cut in a bluff or valley wall produced by the sideward cutting of a meandering stream, indicating the former location of the channel.
MPA	Migration Potential Areas
multi-threaded channels	A section of a stream that is characterized by several discernable shallow channels separated by sediment bars.
Osceola mudflow	A 5,600 year old volcanic deposit, consisting of consolidated mud, rock and debris that originated in the White River system and is found at depth in the Sumner area.
Map projection	A method of converting a three-dimensional surface of the Earth to a two-dimensional representation.
Puget Plateau	A remnant of the most recent continental glaciations in the Puget Sound area. It consists of a relatively flat landscape, 400 to 600 feet above sea level, dissected by steep walled valleys.
rectification	The operation of matching a scanned photograph or map with projected electronic data (I.e. parcel lines or an Ortho-photograph). In this report the scanned data was rectified to a 1998 Orthophotograph.
reprojected	Changing the projection of digital data to a common projection, in this case North American Datum 1983, Washington State Plane South Coordinates in feet.
river reaches	A length of a river channel that is uniform with respect to discharge, gradient, channel shape, bank composition, valley shape, sediment supply and other factors.
stade	A substage of a glacial stage marked by the readvance of a glacier.
transport capacity	The ability of the river system to transport sediment.
under fit stream	A stream that appears too small to have eroded the valley through which it flows.
USGS	United States Geological Survey (Department of Interior)
WDNR	Washington Department of Natural Resources
X-year flood	A predicted size of a storm event; based on a model that uses historical data to estimate the size of a flood based on is probability to reoccur (i.e. a 100-year flood, has a one percent chance of occurring in any given year).

TABLE 1
FLOOD FREQUENCY DISCHARGES
PUYALLUP RIVER
PIERCE COUNTY

GAGE NO.	LOCATION	DRAINAGE AREA (SQ. MILES)	METHOD	YEARS OF DATA	SOURCE	FLOOD FREQUENCY DISCHARGES (cfs)						
						1.25-Year	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
12092000	NR ELECTRON, WA	92.8	USGS Computer Program J407 [1]	59	USGS	--	4,310	--	8,470	10,900	12,800	14,800
12092000	NR ELECTRON, WA	92.8	Log-Pearson III [2]	62	GEI	2,900	4,377	6,723	8,478	10,917	12,888	15,012
--	U/S CONF KAPOWSIN	138	FEMA Regression Equations [3]	--	FEMA	--	--	--	9,860	--	14,200	16,000
12093500	NR ORTING, WA	172	USGS Computer Program J407 [1]	65	USGS	--	6,500	--	11,700	14,200	16,000	17,800
12093500	NR ORTING, WA	172	Log-Pearson III [2]	69	GEI	4,352	6,649	9,748	11,715	14,090	15,777	17,387
--	U/S CONF CARBON	186	FEMA Regression Equations [3]	--	FEMA	--	--	--	11,700	--	16,400	18,400
--	CONF CARBON	416	FEMA Regression Equations [3]	--	FEMA	--	--	--	24,400	--	33,200	36,800
12096500	AT ALDERTON, WA	438	USGS Computer Program J407 [1]	27	USGS	--	13,200	--	21,000	25,200	28,500	31,900
12096500	AT ALDERTON, WA	438	Log-Pearson III [2]	27	GEI	9,829	13,161	18,762	23,182	29,664	35,187	41,361
--	CONF WHITE	934	FEMA Regression Equations [3]	--	FEMA	--	--	--	36,000	--	45,000	45,000
12101500	AT PUYALLUP, WA	948	USGS Computer Program J407 [1]	27	USGS	--	21,000	--	40,500	51,400	59,900	68,800
12101500	AT PUYALLUP, WA (1915-1941)	948	Log-Pearson III [2]	27	GEI	13,584	21,018	32,341	40,426	51,209	59,605	68,262
12101500	AT PUYALLUP, WA (1942-2000)	948	Log-Pearson III [2]	59	GEI	14,767	21,997	31,523	37,476	44,581	49,583	54,328

Notes:

[1] USGS computer program J407 (Kirby, 1981) involves fitting data for each station to a log-Pearson Type III distribution using the method of moments as described by the U.S. Water Resources Council (1981).

[2] Log-Pearson III (Bulletin 17B Frequency Method) as described in Viessman and Lewis (1996). The skew coefficient was not weighted. Calculations by GeoEngineers.

[3] Regression Equations used for the FEMA Study are described in the Flood Insurance Study, Pierce County, Washington (1987).

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TABLE 2
FLOOD FREQUENCY DISCHARGES
CARBON RIVER
PIERCE COUNTY, PUBLIC WORKS AND UTILITIES, ENVIRONMENTAL SERVICES, WATER PROGRAMS DIVISION

GAGE NO.	LOCATION	DRAINAGE AREA (SQ. MILES)	METHOD	YEARS OF DATA	SOURCE	FLOOD FREQUENCY DISCHARGES (cfs)						
						1.25-Year	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
12093900	AT FAIRFAX, WA	76.2	USGS Computer Program J407 [1]	13	USGS	--	4,440	--	9,380	12,200	14,300	16,600
12093900	AT FAIRFAX, WA	76.2	Log-Pearson III [2]	13	GEI	2,115	3,878	6,521	8,283	10,439	11,975	13,442
12094000	NR FAIRFAX, WA	78.9	USGS Computer Program J407 [1]	55	USGS	--	4,200	--	8,520	11,000	12,900	14,800
12094000	NR FAIRFAX, WA	78.9	Log-Pearson III [2]	59	GEI	2,509	4,390	6,933	8,475	10,223	11,383	12,427
--	U/S CONF S.PRAIRIE	97	FEMA Regression Equations [3]	--	FEMA	--	--	--	6,650	--	9,350	10,500
--	U/S CONF VOIGHT	191	FEMA Regression Equations [3]	--	FEMA	--	--	--	11,300	--	15,300	17,000
--	AT MOUTH	230	FEMA Regression Equations [3]	--	FEMA	3888[4]	6804[4]	10746[4]	13100	15500[4]	17,600	19,500

Notes:

[1] USGS computer program J407 (Kirby, 1981) involves fitting data for each station to a log-Pearson Type III distribution using the method of moments as described by the U.S. Water Resources Council (1981).

[2] Log-Pearson III (Bulletin 17B Frequency Method) as described in Viessman and Lewis (1996). The skew coefficient was not weighted. Calculations by GeoEngineers.

[3] Regression Equations used for the FEMA Study are described in the Flood Insurance Study, Pierce County, Washington (1987).

[4] Values were interpolated by GeoEngingers, and should only be used for reference within this study.

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TABLE 3
FLOOD FREQUENCY DISCHARGES
WHITE RIVER
PIERCE COUNTY, PUBLIC WORKS AND UTILITIES, ENVIRONMENTAL SERVICES, WATER PROGRAMS DIVISION

GAGE NO.	LOCATION	DRAINAGE AREA (SQ. MILES)	METHOD	YEARS OF DATA	SOURCE	FLOOD FREQUENCY DISCHARGES (cfs)						
						1.25-Year	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
12454000	NR PLAIN, WA	150	Log-Pearson III [2]	29	GEI	3,920	4,348	5,736	7,272	10,127	13,120	17,079
12097000	AT GREENWATER, WA	216	USGS Computer Program J407 [1]	48	USGS	--	4,750	--	10,200	14,000	17,200	20,800
12097000	AT GREENWATER, WA	216	Log-Pearson III [2]	48	GEI	2,933	4,519	7,306	9,588	13,006	15,980	19,344
--	CONF GREENWATER	294	FEMA Regression Equations [3]	--	FEMA	--	--	--	18,600	--	25,800	28,900
12097850	BELOW CLEARWATER R	375	USGS Computer Program J407 [1]	15	USGS	--	9,450	--	20,200	26,400	31,200	36,200
12097850	BELOW CLEARWATER R	375	Log-Pearson III [2]	16	GEI	5,859	10,204	16,702	21,097	26,601	30,611	34,510
12098500	NEAR BUCKLEY, WA	401	Log-Pearson III [2]	69	GEI	6,311	8,749	11,526	13,057	14,711	15,776	16,721
12100000	AT BUCKLEY, WA	427	USGS Computer Program J407 [1]	18	USGS	--	11,500	--	19,200	22,600	25,100	27,500
12100000	AT BUCKLEY, WA	427	Log-Pearson III [2]	41	GEI	4,935	8,505	13,500	16,664	20,400	22,980	25,388
--	AT BUCKLEY	427	FEMA Regression Equations [3]	--	FEMA	--	--	--	13,800	--	14,800	15,500
12100496	NR AUBURN, WA	464	Log-Pearson III [2]	13	GEI	4,194	7,036	11,544	14,819	19,223	22,657	26,195
12100500	NR SUMNER, WA	470	Log-Pearson III [2]	28	GEI	5,360	8,323	11,927	13,974	16,205	17,642	18,911
--	AT MOUTH	494	FEMA Regression Equations [3]	--	FEMA	--	--	--	16,400	--	18,300	19,100

Notes:

[1]USGS computer program J407 (Kirby, 1981) involves fitting data for each station to a log-Pearson Type III distribution using the method of moments as described by the U.S. Water Resources Council (1981).

[2]Log-Pearson III (Bulletin 17B Frequency Method) as described in Viessman and Lewis (1996). The skew coefficient was not weighted . Calculations by GeoEngineers.

[3]Regression Equations used for the FEMA Study are described in the Flood Insurance Study, Pierce County, Washington (1987).

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TABLE 4
ESTIMATED FLOOD SIZE BASED ON HISTORICAL PEAK FLOW RATES[1]
PUYALLUP, CARBON, AND WHITE RIVERS
PIERCE COUNTY, PUBLIC WORKS AND UTILITIES, ENVIRONMENTAL SERVICES, WATER PROGRAMS DIVISION

	ESTIMATED FLOOD SIZE PER WATERSHED[2]			PUYALLUP RIVER GAGE STATIONS				CARBON RIVER GAGE STATIONS		WHITE RIVER GAGE STATIONS			
DATE OF MAJOR FLOODS	Upper Puyallup	Carbon River	White River	Puyallup, City of	Alderton	Orting	Electron	South Prairie, Town of	Fairfax	Auburn[3]	Buckley[3]	Greenwater	Greenwater Creek, Below
Nov. 14, 1906				nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Dec. 18, 1917				40,500	19,300	nd	nd	nd	nd	nd	nd	nd	nd
Jan. 23, 1919				36,500	17,200	nd	nd	nd	nd	nd	nd	nd	nd
Dec. 13, 1921				35,600	20,000	nd	nd	nd	nd	nd	nd	nd	nd
Nov. 13, 1932	10-year		50-year	37,800	nd	11,800	nd	nd		nd	16,500	nd	nd
Dec. 9-10, 1933	10-year	10-year	100-year	57,000	nd	12,800	nd	nd	11,000	nd	28,000	18,100	nd
Oct. 25, 1934				39,500	nd		nd	nd		nd	nd		nd
Apr. 18, 1938				33,900	nd		nd	nd		nd	nd		nd
Feb. 15, 1939				13,000	nd		nd	nd		nd			nd
Dec. 11, 1946			10-year	33,800	22,600	11,200	nd	nd		nd	12,300		nd
Dec. 11-12, 1955	10-year	10-year	10-year		23,300	12,100		6,850		nd	13,700	10,100	nd
Nov. 22-23, 1959	10-year		10-year	35,600	nd	12,900	10,800			nd	13,000	14,300	nd
Nov. 20, 1962	25-year			22,900	nd	15,300	10,600			nd			nd
Jan. 29, 1965				41,500	nd					nd			nd
Jan. 18, 1975			10-year	32,600	nd			nd		nd	12,700	13,900	22,800
Dec. 2, 1975				33,300	nd			nd		nd			
Dec. 1-2, 1977	10-year		50-year	40,600	nd	12,100		nd	10,000	nd	14,800	17,800	
Jan. 25, 1984		10-year	10-year	37,100	nd			5,930		nd	13,400	nd	
Feb. 24, 1986			10-year	34,400	nd					nd	14,000	nd	14,100
Nov. 24, 1986			25-year	43,800	nd	11,000		8,170		nd	15,200	nd	14,900
Jan. 9, 1990	10-year		10-year	44,800	nd	11,600	9,900	nd		14,500	14,100	nd	17,200
Nov. 24, 1990		100-year		41,900	nd				13,000			nd	18,400
Feb. 8-10, 1996	100-year	50-year		46,700	41,500	18,300	16,000		12,000	15,000	29,700	nd	20,500
Dec. 30, 1996										13,600		nd	

Notes:

[1]Peak mean flow data (< 10 year flood event) from USGS Water Resource 'peak mean flow' database. All values are in cubic feet per second.

[2]Based off of flood frequency discharge calculations using Log-Pearson III model of data available for respective gage stations.

[3]Peak mean flows reflect flows before and after the completion of Army Corps of Engineers' flood control Mud Mountain Dam located east of Buckley.

purple'= less than 10 year flood event

black' = 10 to 25 year flood event

blue' = greater than 25 year flood event

blank' = peak mean flow value for calendar year different than the <10 year flood event being tracked

'green' = greater than 50 year flood event

'red' = greater than 100 year flood event

'nd' = no data that year

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TABLE 5
CHANNEL GRADIENTS BY REACH
PUYALLUP, CARBON AND WHITE RIVERS
PIERCE COUNTY

	River Reaches	Reach Length (in feet)	Elevation[1] (in feet)	Rise (in feet)	Reach Gradient (%)	Gradient Difference from Upstream to Downstream (%)	Percent Change in Gradient Difference (%)
White River	**W7**	3152	63.0	7.4	0.23		
	W6	6779	55.6	12.8	0.19	-0.05	24
	W5	3334	42.8	3.5	0.10	-0.08	80
	W4	2231	39.3	2.0	0.09	-0.02	17
	W3	6105	37.3	4.6	0.08	-0.01	19
	W2	5943	32.7	2.1	0.04	-0.04	113
	W1	2087	30.6	0.6	0.03	-0.01	23
Puyallup River	**P18**	9117	561.0	104.0	1.14		
	P17	8353	457.0	90.6	1.08	-0.06	5
	P16	1336	366.4	11.8	0.88	-0.20	23
	P15	9173	354.6	75.7	0.83	-0.06	7
	P14	2916	278.9	24.9	0.85	0.03	3
	P13	3281	254.0	24.5	0.75	-0.11	14
	P12	13314	229.5	71.5	0.54	-0.21	39
	P11	4619	158.0	20.0	0.43	-0.10	24
	P10	8187	138.0	26.2	0.32	-0.11	35
	P09	2248	111.8	3.6	0.16	-0.16	100
	P08	3161	108.2	6.9	0.22	0.06	27
	P07	786	101.3	1.4	0.18	-0.04	23
	P06	7435	99.9	18.9	0.25	0.08	30
	P05	3921	81.0	9.0	0.23	-0.02	11
	P04	7861	72.0	14.0	0.18	-0.05	29
	P03	5258	58.0	9.4	0.18	0.00	0
	P02	2605	48.6	4.4	0.17	-0.01	6
	P01	8061	44.2	14.2	0.18	0.01	4
Carbon River	**C7**	9914	443.0	114.0	1.15		
	C6	3163	329.0	32.0	1.01	-0.14	14
	C5	1273	297.0	14.0	1.10	0.09	8
	C4	8007	283.0	58.0	0.72	-0.38	52
	C3	6482	225.0	38.8	0.60	-0.13	21
	C2	10728	186.2	49.0	0.46	-0.14	31
	C1	6223	137.2	29.0	0.47	0.01	2
		Gradient Difference Between C1 and P8				-0.25	113
		Gradient Difference Between W1 and P1				0.15	513

Notes:
[1]Elevation is from the upstream end of reach.
[2](-) indicates a decrease in gradient.
P = Puyallup River
W = White River
C = Carbon River
Shading = Percent change in Gradient Difference greater than 20%.

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TABLE 6 (Page 1 of 2)
HISTORICAL EVENTS IN THE PUYALLUP WATERSHED
PUYALLUP, CARBON, AND WHITE RIVERS
PIERCE COUNTY, PUBLIC WORKS AND UTILITIES,
ENVIRONMENTAL SERVICES, WATER PROGRAMS DIVISION

Dates	Finding
1904	Puget Sound Power Co (PSE's) Electron Diversionary Dam and Hydroelectric Project was completed.
November 14, 1906	Large flood, no gage stations in place. Avulsion of the White River to the Puyallup Valley.
1907	Washington State legislature gave county governments the authority to do flood-protection work on rivers.
1907	Pierce County River Improvement began to straighten and deepen reaches of Puyallup River between the mouth and the White/Puyallup confluence (note: outside project area).
1912	Puget Sound Power Co (PSE) Lake Tapps Diversionary Dam and White River Hydroelectric Project completed (removing 0.4-1.2 mil tonnes/year of suspended sediment).
1913	Inter-County River Improvement (ICRI), formed in 1913 by an act of state legislature. ICRI was administered by the Pierce County Department of Public Works, but operated in Pierce and King Counties east of Tacoma City limits to a “point” east of Auburn.
1914	ICRI constructed a diversion dam to prevent the White River from returning to its pre-1906 channel (north flowing).
1914-1915	ICRI constructed a debris barrier to trap floating debris upstream of Auburn diversion dam.
1914 - 1920	ICRI began to channelize the White River from the Auburn diversion dam to its mouth (note: this work was not completed).
December 17-18, 1917	Flood, Puyallup Gauge Station logged 40,000 cubic feet per second (cfs), the only station in operation.
Late 1920s	ICRI stopped all channel realignment work on the rivers.
Late 1920s to 1939	PCRI focused on Puyallup and Carbon River channelization and bank stabilization using wooden bulkheads and debris barriers.
1930s and 1940s	WPA involved with channel clearing/dike repair/new dikes.
December 10, 1933	Flood throughout watershed (White River watershed =100-year flood event [1]) Puyallup gauged at 57,000 cfs.
June 22, 1936	US Flood Control Act signed into law.
1936	US Flood Control Act authorized US Army Corps of Engineers to construct the Mud Mountain Dam on the White River (29.6 RM) five miles east of Buckley. Project completed in 1947.
1936	US Army Corps of Engineers authorized to channelize and construct dikes along the lower three miles of the Puyallup River.
1939	Pierce County June 5th, 1939 (resolution No 686) approved a plan for flood control for the upper Puyallup and Carbon Rivers. The flood plan was to establish a channel on the Carbon River and Puyallup River (upstream of the White River confluence) by excavating gravel and river sediments and side casing them to form dikes that were armored with rock riprap. This was the standard practice until the 1970s.
1942	US Army Corps Aerial Photographs taken.
1948	Mud Mountain Dam completed. US Flood control Act authorized US Army Corps of Engineers to construct the Flood control Dam on the White River (29.6 RM) five miles east of Buckley. Project completed in 1947.
January 29, 1965	Mild Flooding throughout the watershed.
May 11 and July 1, 1965	DNR Aerial Photographs taken.
May 24, 1970	DNR Aerial Photographs taken.

Notes appear on page 2 of 2.

TABLE 6 (Page 2 of 2)

Dates	Finding
Early 1970s	Maximum of channelization, 45 river miles channnelized, included 14.7 miles of concrete armored dikes and 57.3 miles of dikes and riprap riverbank armor.
1974	River channel capacity maintained by the removal of deposited materials, not by building up the dikes.
December 2, 1977	Mild flooding throughout watershed (Upper White River = 50-year flood event).
June 2, 1978	DNR aerial photographs taken.
1981	Change in hydraulics permitted for gravel removal.
1985	ICRI-PCRI agreement with the Puyallup Tribal Nation for all their vegetation removal and trimming.
November 24, 1986	Mild flooding throughout the watershed (South Prairie Creek= 50-year flood event) (Carbon River was not gauged).
June 11, 1987	Aerial photographs taken.
1988	Flood control practices included vegetation management, debris removal (i.e., logs, stumps) (8,000 cubic yards annually), dike repair (30,000 tons of rock annually), and gravel removal.
January 9, 1990	Flooding throughout watershed (Lower Puyallup = 50-year flood event).
November 24, 1990	Flooding on the Carbon (100-year flood event) and Upper White Rivers.
September 26, 1991	Aerial Photographs taken.
February 10, 1996	Flooding on the Puyallup (100-year flood event) and Carbon Rivers (50-year flood event).
1998	Orthophotographs obtained.

Notes:

[1] =x-year flood event is based off of flood frequency discharge calculations using Log-Pearson III model of data available for the respective gage stations.

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TABLE 7 (Page 1 of 2)
MAXIMUM MIGRATION RATE CALCULATIONS BY REACH
PUYALLUP, CARBON AND WHITE RIVERS
PIERCE COUNTY, PUBLIC WORKS AND UTILITIES, ENVIRONMENTAL SERVICES, WATER PROGRAMS DIVISION

	River Reach	Maximum Migration Distance Observed (in feet)	Period of Observation	Number of Years Between Observations	Maximum Migration Distance Averaged per Year (in feet)	Reaches Affected by the Electron Mudflow[1]	Potential Travel over 5 Years in One Direction[2] (in feet)	Potential Travel over 15 Years in One Direction[3] (in feet)	Potential Travel over 25 Years in One Direction[4] (in feet)
White River	W6-W7	227	1931-1940	9	25.2		126	378	631
	W5	85	1931-1940	9	9.4		47	142	236
	W4	0	1931-1940	9	0.0		0	0	0
	W3	40	1931-1940	9	4.4		22	67	111
	W2	10	1931-1940	9	1.1		6	17	28
	W1	0	1931-1940	9	0.0		0	0	0
Carbon River	C7	505	1931-1965	34	14.9		74	223	371
	C6	48	1987-1998	11	4.4		22	65	109
	C5	51	1987-1998	11	4.6		23	70	116
	C4	580	1931-1940	9	64.4		322	967	1611
	C3	390	1931-1940	9	43.3	yes	217	650	1083
	C2	442	1931-1940	9	49.1	yes	246	737	1228
	C1	305	1931-1940	9	33.9	yes	169	508	847
	Mudflow	250	1931-1940	9	27.8		139	417	694

Notes appear on page 2 of 2.

TABLE 7 (Page 2 of 2)

	River Reach	Maximum Migration Distance Observed (in feet)	Period of Observation	Number of Years Between Observations	Maximum Migration Distance Averaged per Year (in feet)	Reaches Affected by the Electron Mudflow[1]	Potential Travel over 5 Years in One Direction[2] (in feet)	Potential Travel over 15 Years in One Direction[3] (in feet)	Potential Travel over 25 Years in One Direction[4] (in feet)
Puyallup River	P18	460	1931-1965	34	13.5	yes	68	203	338
	P17	460	1931-1965	34	13.5	yes	68	203	338
	P16	0	1931-1965	34	0.0		0	0	0
	P15	730	1931-1940	9	81.1	yes	406	1217	2028
	P14	326	1931-1940	9	36.2	yes	181	543	906
	P13	395	1931-1940	9	43.9	yes	219	658	1097
	P12	590	1931-1940	9	65.6	yes	328	983	1639
	P11	265	1931-1940	9	29.4	yes	147	442	736
	P10	520	1931-1940	9	57.8	yes	289	867	1444
	P09	136	1931-1940	9	15.1	yes	76	227	378
	P08	365	1931-1940	9	40.6		203	608	1014
	P07	194	1931-1940	9	21.6		108	323	539
	P05	151	1931-1940	9	16.8		84	252	419
	P06	330	1931-1940	9	36.7		183	550	917
	P04	1200	1931-1940	9	133.3		667	2000	3333
	P03	248	1931-1940	9	27.6		138	413	689
	P02	35	1931-1940	9	3.9		19	58	97
	P01	300	1931-1940	9	33.3		167	500	833
	Mudflow	250	1931-1940	9	27.8		139	417	694

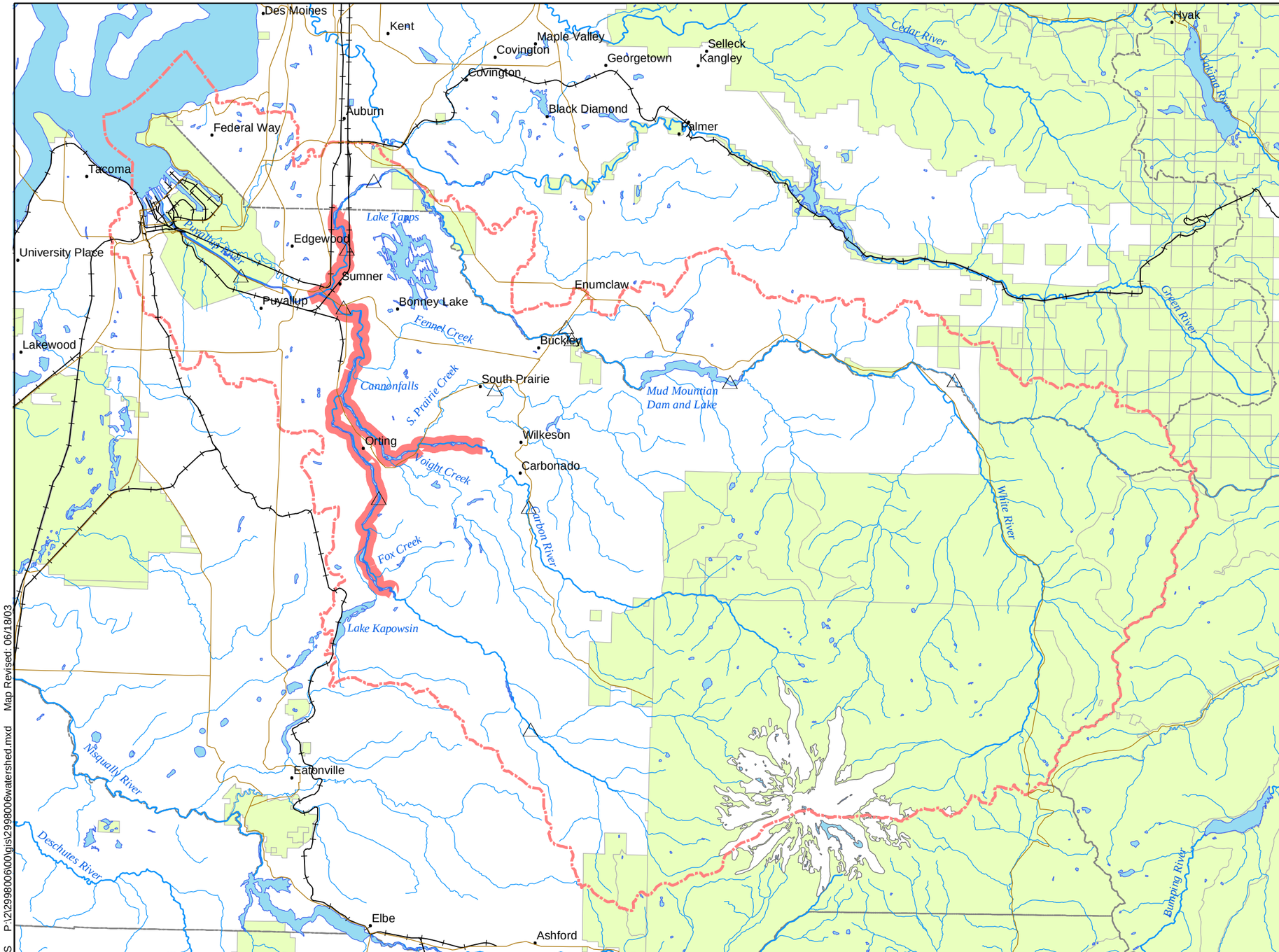
Notes:

[1] These reaches have resistant mudflows that could decrease migration rates. For these reaches, the rate of migration through a mudflow is used to create the MPA and CMZ.

[2] These values are used in part to create the severe MPA. Distances on Plate 1 measured from the historical channel occupation track boundary.

[3] These values are used to create the moderate MPA. Distances on Plate 1 measured from the historical channel occupation track boundary.

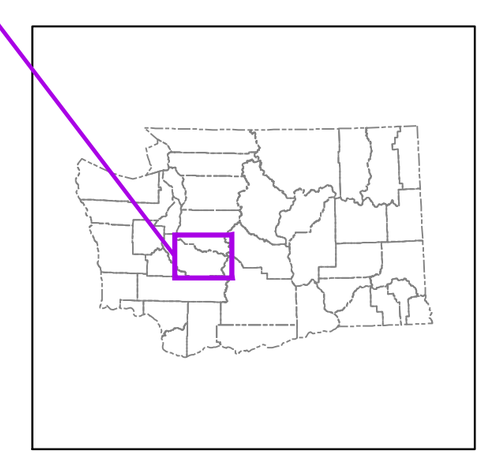
[4] These values are used to create the CMZ. Distances on Plate 1 measured from the historical channel occupation track boundary.



Puyallup Watershed Boundary
Study Area
USGS Gage Stations
Towns
State Highways
Railroad Lines
Major Public Lands
County Boundaries
Rivers
Glaciers
Waterbodies

5
Miles

N



Geo Engineers

PUYALLUP WATERSHED
CHANNEL MIGRATION ZONE STUDY
PUYALLUP, CARBON, AND
WHITE RIVERS
PIERCE COUNTY

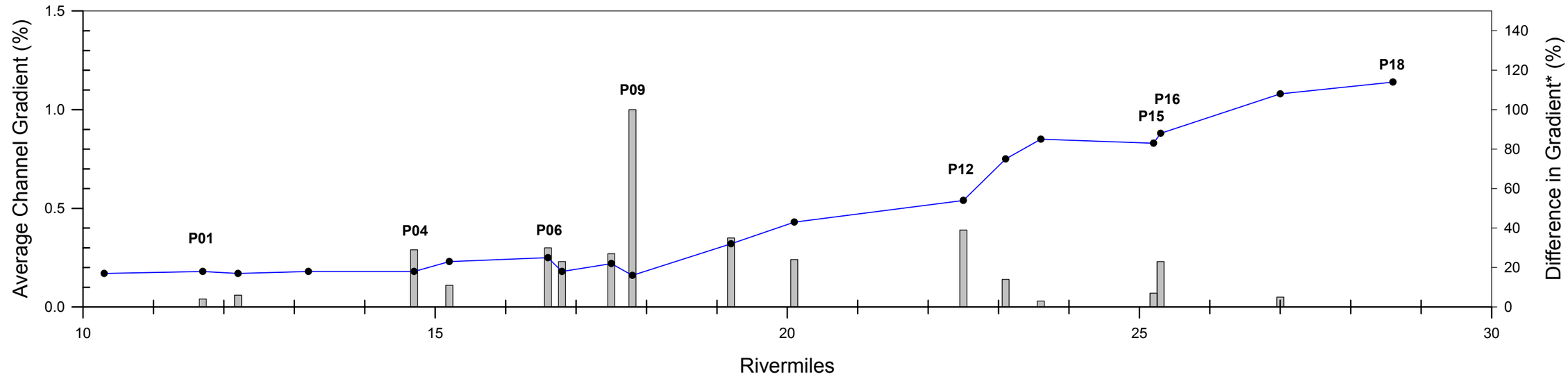
FIGURE 1

Data Sources: Rivers, waterbodies, state highways, railways, and political boundaries are provided by the Washington Department of Transportation. Watershed, glaciers, and major public lands are from the Washington Department of Natural Resources. Study area, gage stations, and towns locations were created by GeoEngineers.

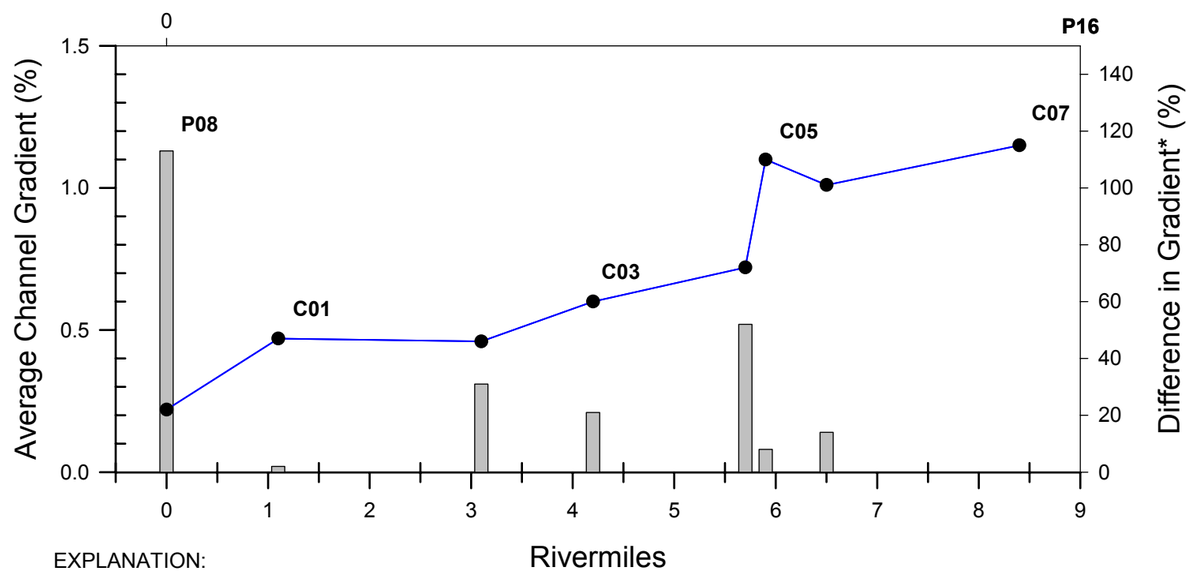
This map is for information purposes. Data were compiled from multiple sources as listed on this map. The data sources do not guarantee these data are accurate or complete. There may have been updates to the data since the publication of this map. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication. The locations of all features shown are approximate.

02998-006-00TAC DJS P:\2\2998006\00\gis\2998006watershed.mxd Map Revised: 06/18/03

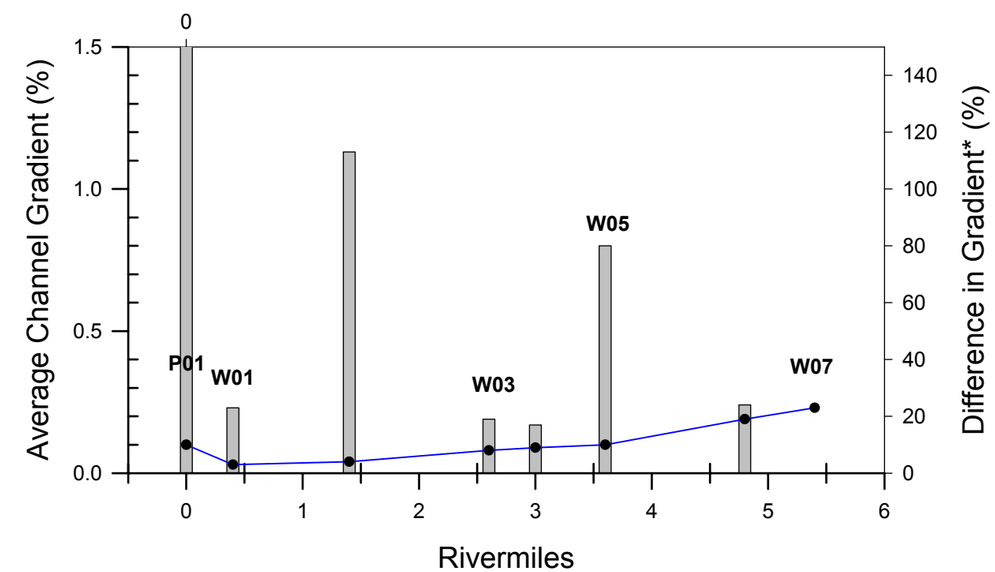
PUYALLUP RIVER



CARBON RIVER



WHITE RIVER



EXPLANATION:

Percent change in channel gradient between two reaches.

The average gradient (%) for each reach.

Notes: 1) *All the gradients are calculated from 1998 2-foot contours provided by Pierce County, Water Programs.
2) P01 = Puyallup River Reach number 01.
3) All data is provided in Table 5.

Geo Engineers

COMPARISION OF AVERAGE GRADIENT AND PERCENT CHANGE IN GRADIENTS
PUYALLUP, CARBON, AND WHITE RIVERS

FIGURE 2

6/18/2003

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DJS

APPENDIX A

METHODS

APPENDIX A

METHODS

INTRODUCTION

The scope of this project required the project team to work with large volumes of historical information dating back to the early 1900s. The information included historical and recent aerial photographs, printed topographic and geologic maps, and digitized data, all of which are published in different scales and formats. Our evaluation necessitated bringing the information into a common coordinate system in order to facilitate seamless comparison and review of the river reaches at variable scales. In order to achieve the flexibility required, our project approach utilized Geographic Information Systems (GIS) technology for review and evaluation of the database, and as an analytical tool. GIS also provided the tools for generating the CMZ boundaries that were further delineated into low, moderate and severe migration potential areas (MPAs).

DATA COLLECTION, REVIEW, AND SELECTION

Information collected for this project falls into three categories, 1) written reports, 2) maps and aerial photographs, and 3) GIS data layers. The information includes historic and recent aerial photograph and orthophographs, published and unpublished topographic, soils, and geologic paper maps, technical reports, and papers and GIS electronic data. The data sources included, but were not limited to: Pierce County, Washington Department of Natural Resources (WDNR), US Geological Survey (USGS), Army Corps of Engineers, Federal Emergency Management Agency (FEMA), King County and GeoEngineers' files.

We reviewed written reports to identify key information with regard to geology, flooding, topography, soils, land use, roads and planning. The information provided a framework for evaluating channel changes, land use changes and construction of channel constraints (e.g., revetments).

We reviewed all available maps and photographs dating from the 1870s through 1998. During our review we conducted a preliminary evaluation of progressive channel conditions. To manage the volume of available data for the analysis, we selected aerial photographs and maps suitable to project goals for conversion to our GIS database via electronic rectification. Our criteria for selection and inclusion of aerial photographs and maps in the GIS data base include 1) obtaining the earliest and most recent flight year coverage, 2) the available extent of coverage, 3) changes in channel position or other significant features, and 4) condition and visual quality of photographs and maps. Based on these criteria, we selected and scanned photographs from flight years 1931, 1940 and 1998 for the complete study area. We also selected aerial photographs covering specific channel sections from flight years 1965, 1970, 1978, 1987 and 1991 to capture observed geomorphic changes important to the analysis. A total of 157 photographs were rectified into the GIS.

GIS data layers were obtained from several different data sources including Pierce County GIS, USGS, FEMA and the WDNR. These GIS data layers were reprojected to the Washington State Plane coordinate system and added to the GIS.

GIS DATA DEVELOPMENT

Three major types of GIS data were developed; 1) digital rectified aerial photographs, 2) digitized features from historical data sets, and 3) delineated HCOT, CMZ and MPA boundaries. All GIS data development and analysis were completed using ESRI's ArcGIS version 8.2 software.

The aerial photographs were scanned and rectified to 1998 orthophotography. Due to inherent distortions when rectifying older photographs to current orthophotographs, our target Route Mean Square (RMS) error of all the control points was equal to or less than 14 feet. In some cases, only a portion of the photograph was rectified. Some aerial photographs were highly distorted. In these cases, the photograph was rectified with the lowest RMS error possible, and the RMS error was documented for reference. Additional information regarding specific RMS errors and data processing is available in the associated metadata included on the CD-ROMs.

The development of GIS data included digitizing and attributing points, lines and polygons with critical information from scanned aerial photographs. Digitizing was completed at a scale of approximately 1:12,000 (or 1 inch = 1000 feet). Critical information was digitized into four GIS shape files, also referred to as GIS layers: 1) active channel locations; 2) high flow channels; 3) historical channel occupation tracts (HCOTs); 4) CMZ boundaries, and, 5) Migration Potential Areas (MPAs).

Active channels are defined as the wetted channel width observed on aerial photographs of a selected year, and are generally correlative with the 'low flow' channel. Active channels are attributed within the GIS to distinguish the different aerial photograph year set (1931, 1940, 1965, 1978, 1987, and 1998).

The active channels are mapped from scanned and rectified photos. The rectification process has a small but measurable amount of distortion, as compared with other data formats (i.e. topography and other photo-years). The active channels were not adjusted to account for any distortion and, therefore, may not match precisely with other GIS layers (HCOT, CMZ and MPA).

High flow channels are defined as corridor width most likely occupied by recent high flow events, as observed on dated aerial photographs. The high flow channel generally includes the active channel, exposed alluvial side bars, and channel scour features. High flow channels are attributed within the GIS to distinguish the different aerial photograph year set (1931, 1940, 1965, 1978, 1987, and 1998).

HCOT is defined as the zone within which the active channel has been located between 1931 and 1998. The width of the HCOT is typically equal to or greater than the width of any single high flow channel. Reaches displaying overlapping high flow channels and HCOT lines typically identify reaches where the channel position has not moved appreciably over the period of record.

HCOT boundaries have been adjusted with respect to the topographic contours to account for distortion from photos and, therefore, may not precisely match digitized active and high flow channels. HCOT boundaries are also adjusted to account for circumstances where levies were constructed within the high flow corridor. In such cases, channel scares located outside of the levies have been included in the HCOT.

CMZ boundaries are defined as the distance the channel edge could migrate laterally away from the HCOT at a measured rate of erosion in 25 years. (Please see CMZ Analysis in Appendix A).

MPAs include severe, moderate or low migration potential areas and are defined as the distance the channel edge could migrate laterally away from the HCOT at a measured rate of erosion in a specific period of time (please see MPA Analysis in Appendix A).

GEOMORPHIC EVALUATION

A key element of our CMZ analysis included identifying the geomorphic processes operating throughout the project area, and evaluating the affects of those processes on migration. Channel migration is a dynamic process driven by the interaction of physical characteristics and geomorphic processes operating at both local and watershed scales. Physical characteristics include topography, geology, regional and local channel gradients, channel dimensions, and the composition of riverbank and stream bed materials. Principle geomorphic processes include local and reach-scale flow dynamics, sediment supply and delivery, sediment transport capacity, and erosion and deposition within the channel.

A principle objective of our geomorphic evaluation was to identify the type and character of migration operating at both local (river reach) and regional scales. This task was complicated by changes in channel character resulting from the placement of levees and revetments. Our approach involved the following steps; 1) define reach boundaries, 2) conduct a geomorphic evaluation on a reach scale, 3) calculate the river gradient per reach, 4) measure maximum migration rates for each reach, and 5) evaluate reaches for regional geomorphic changes.

For the purposes of our evaluation, we divided each river channel into reaches, based on the presence and continuity of specific physical features, geomorphic characteristics and channel conditions. Physical features and geomorphic characteristics used in the delineation include the following:

- Valley and floodplain configuration,
- Dominant channel pattern (meander, braided, straight channel),
- Average channel gradient,
- Size and abundance of sand and gravel bars,
- Rate and continuity of lateral channel movement,
- Floodplain features indicative of historic/ancient channel activity (abandoned channels).

The features and characteristics summarized above were identified from aerial photographs, topographic maps, geologic maps and field reconnaissance. A complete list characteristics used

to describe and interpret the condition of the reaches is provided in Appendix B-1. Reach delineations are shown on Plate 1 and included in the GIS database, both of which accompany this report.

CMZ ANALYSIS

A principle objective of this project is the delineation of channel migration zones **in the absence of** artificial structures presently confining project area channels. This objective required evaluating each channel from the perspective of a freely migrating system subject to existing reach-scale channel conditions and existing geomorphic processes. Problematic to this approach is the fact that many project-area river reaches were confined by 1965, rendering them unrepresentative of free migration.

Achieving project objectives necessitated using migration rates measured from the unconfined period of record, which extends from 1931 to 1940/1965. Measured rates averaged over a longer period of record would strongly favor confined channel conditions and were therefore not used.

CALCULATION OF UNCONFINED MIGRATION RATES

Average rates of migration were calculated for each reach by dividing measured distances between observed channel positions by the number of years between channel positions. Measurements were made directly from channel positions digitized from dated aerial photographs scanned and rectified into our comprehensive GIS database. Migration distances were measured at sites deemed representative of the dominant type and character of channel migration observed throughout the reach. Both lateral and downstream migration were noted throughout the study area, however, only lateral rates were used in the analysis. Downstream migration was not used because the scale and frequency of occurrence is very low to negligible, compared to lateral rates. For the purposes of the following discussions, the term ‘migration rate’ refers only to the lateral migration of a channel.

Wherever possible, migration rates were measured from 1931 to 1940 on unconfined sections of each reach. This time frame includes the flood of winter 1933, one of the three largest floods recorded in the watershed. Older maps were not used in the calculation due to scaling and accuracy considerations. The 1940 aerial photographs indicate that several portions of the Puyallup and Carbon River channels were already confined or reveted. In those cases we deduced the distance of migration by comparing the 1931 channel position to the locations of bars and freshly abandoned channels observed on the 1940 aerial photographs. For those reaches lacking 1940 aerial photograph coverage, we inferred the distance of migration from evidence of abandoned channels observed on 1965 aerial photographs.

CMZ DELINEATION

We delineated the CMZ in the absence of levees and revetments based on several factors including the following:

- The HCOT over the observable period of record
- The pre-confined character of migration identified in each reach,

- The maximum unconfined rate of lateral migration for each reach,
- The unconfined rate of migration measured through Electron mudflow deposits,
- The locations of ancient and historic abandoned channels.

Our delineation approach assumes that in the absence of channel constraints, the future rate and character of migration will be similar to those of the past, given similar water and sediment discharge conditions. Within the available period of record, unconfined migration was observable only from 1931 to 1940 or 1965. This period represents only 9 to 34 years, depending on the reach, and is clearly too short a period to evaluate average long-term rates of past migration. To compensate for the short period of unconfined migration and avoid under-estimating annual average migration rates, we used the local maximum rate measured within each reach.

The width of the CMZ was delineated to identify the distance the channel could travel in a period of 50 years in the absence of confining structures. Based on the character of unconfined migration, the distance of lateral migration in each direction was calculated by multiplying the maximum annual rate of migration for each reach by 25 years in a single direction. The distance of migration over a 25-year period, calculated at maximum rates of migration for each reach in the project area is provided in Table 7. Migration distances were measured from the outside edges of the observed HCOT.

MIGRATION POTENTIAL AREA (MPA) ANALYSIS

Our MPA delineation approach is similar to that employed in our CMZ analysis. We assumed the absence of artificial confining structures and used maximum unconfined migration rates for each reach.

The analysis involved identifying severe, moderate and low migration potential areas within the delineated CMZ. The width of each MPA was measured, based on delineation criteria developed specifically for this project, and then adjusted to accommodate geomorphic conditions not accounted for in maximum migration rates. Criteria developed for mapping severe, moderate and low MPA are provided in the following paragraphs:

Severe Migration Potential Area

The area that includes 1) the HCOT, as determined by the results of our aerial photographic evaluation (from 1931 to 1998) and 2) an area representing the distance the channel could travel in 5 years of steady lateral migration **from the outside boundary of the HCOT.** The maximum rate of migration for each geomorphic reach was used in the calculation. The calculated distance of migration used for the severe MPA is shown Table 7.

Moderate Migration Potential Area

The area landward of severe migration potential area representing 1) the distance the channel could travel in 15 years of steady lateral migration **from the HCOT**, and 2) the distance the channel could travel in 5 years of steady lateral migration from geomorphic features capable of

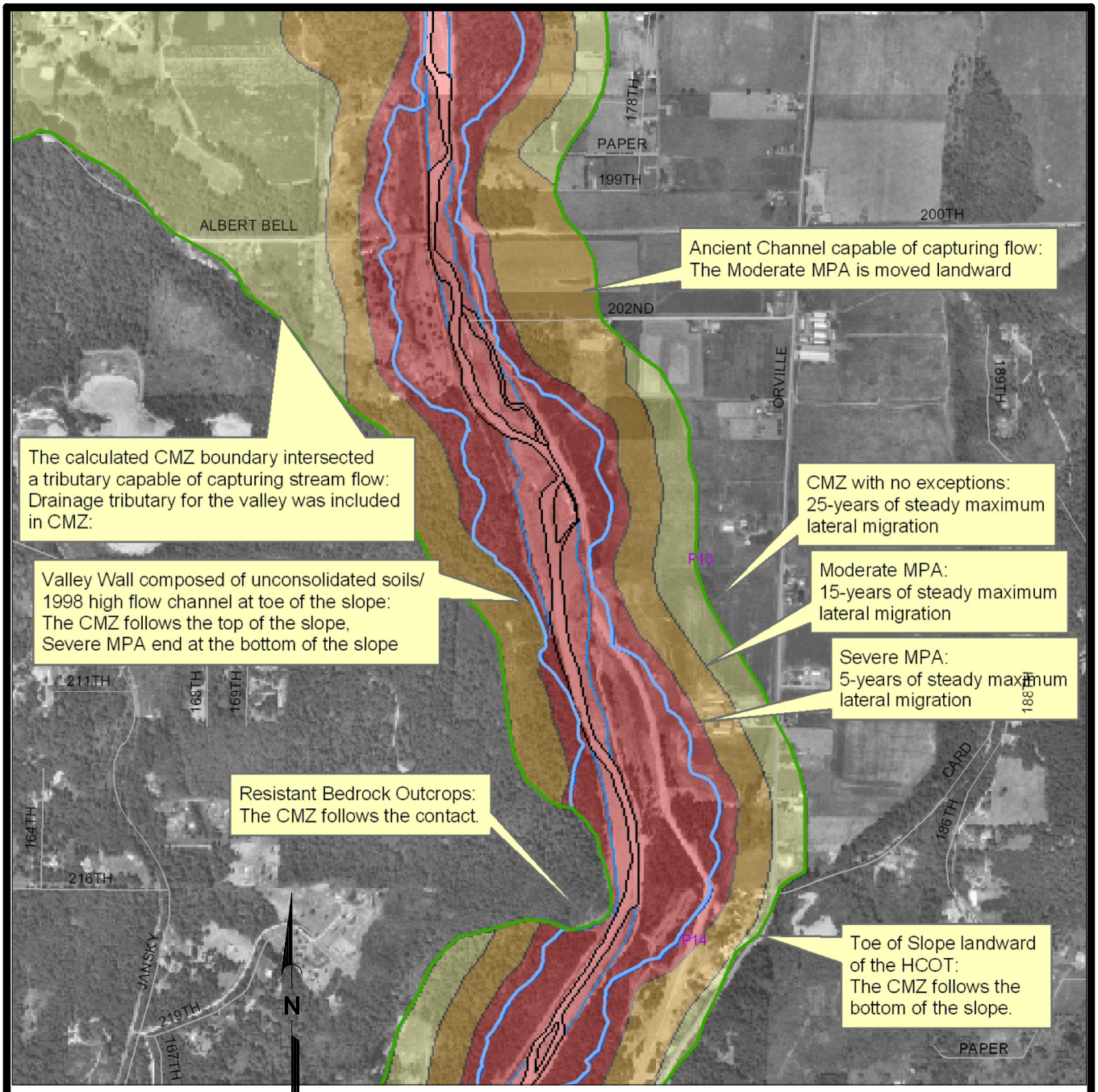
capturing stream flow (i.e. ancient abandoned channels, oxbows, secondary channels, ditches). The calculated distance of migration used for the minimum (15 year) moderate MPA width is shown Table 7.

Low Migration Potential Areas

The area landward of moderate MPAs comprising the remaining area of the CMZ.

Exceptional Conditions

The width of Severe and Moderate MPAs may be modified from the minimum calculation defined above, as deemed necessary based on factors requiring geologic interpretation and professional judgment. These factors include the presence of significant abandoned channels capable of capturing main stem flow in an avulsion event, and the proximity of the channel to valley walls and hard, erosion resistant geologic units. Please see Figure A-1 for an example of CMZ and MPAs delineations based on our stated criteria, with modification based on the above exceptional conditions. A log of the exceptions used to create the MPAs is found in Appendix D.



NOT TO SCALE

EXPLANATION:

- 1998 ACTIVE CHANNEL
- 1998 HIGH-FLOW CHANNEL
- HCOT
- CMZ

MPA (COLOR CODED)

- SEVERE
- MODERATE
- LOW

Note: This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document. Data were compiled from sources as listed in this figure. The data sources do not guarantee these data are accurate or complete. There may have been updates to the data since the publication of this figure. This figure is a copy of a master document. The master hard copy is stored by GeoEngineers, Inc. and will serve as the official document of record.

Reference: 1998 Washington DNR orthophotograph.

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EXAMPLE OF CMZ AND MPZ MAPPING

FIGURE A-1

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APPENDIX B

GEOMORPHIC REACH DESCRIPTION

APPENDIX B
GEOMORPHIC REACH DESCRIPTION

INTRODUCTION

Key elements of our CMZ analysis include identifying the geomorphic processes operating throughout the project area, and evaluating the affects of those processes on channel migration. For the purposes of our evaluation, we divided each river channel into geomorphic reaches based on the presence and continuity of specific physical features, geomorphic characteristics and channel conditions. Physical features and geomorphic characteristics used in the delineation include the following:

- Valley and floodplain configuration,
- Dominant channel pattern (meander, braided, straight channel),
- Average channel gradient,
- Size and abundance of sand and gravel bars,
- Rate and continuity of lateral channel movement,
- Floodplain features indicative of historic/ancient channel activity (abandoned channels, oxbow lakes)

The features and characteristics summarized above were identified from aerial photographs, topographic maps, geologic maps and field reconnaissance. Reach delineations are shown on Plate 1 and included in the GIS CD, both of which accompany this report.

In order to be consistent with river mile stationing convention, the reaches are numbered in the upstream direction, with Reach 1 located at the downstream end of the channel. However, to better evaluate the influence of fluvial and bedload transport on channel migration, all reach descriptions are provided in the downstream direction, beginning at the upstream end of the project area. The descriptions generally focus on a single reach. However, wherever applicable, two or more successive reaches are combined in a description. Tributary channels are not included in this evaluation.

Each of the following descriptions contains three sections: Existing Geomorphic Character, Historic Information Review, and Erosion Potential. The Existing Geomorphic Character section describes the current condition of the reach based on review of 1998 orthophotographs and other information from the last decade. The Historic Information Review section summarizes the history of the reach from the pre-confined to the post-confined condition. The Erosion Potential section briefly describes channel and floodplain soils with regard to sediment production, sensitivity to erosion, and migration.

Specific characteristics used to describe and interpret the condition of the reaches are provided in Appendix B-1. The reach descriptions begin with Puyallup River, followed by the Carbon and White Rivers.

PUYALLUP RIVER CORRIDOR

Introduction

The Puyallup River project area extends from the confluence with the White River at P-RM 10.3 to P-RM 28.6. We identified 18 geomorphic reaches throughout the project area.

PUYALLUP REACH 18

Existing Geomorphic Character

Reach 18 extends roughly 9,100 feet through a steep trough-shaped valley with steep walls. Discontinuous levees and revetments, and the valley walls confine the channel corridor. Within the high flow channel corridor the river transitions from a system of complexly braided channels to a system of one to two straight channels bounded by continuous mid- and side-channel gravel bars. The braided section is situated in the upper portion of the reach, where active channels shift around large bars and woody debris.

Throughout this reach, the channel gradient decreases abruptly from 4.0 percent, just upstream of the project area, to about 1.3 percent in the middle of the reach. The pronounced decrease in channel gradient identifies an area prone to significant sediment deposition. Within the high flow channel corridor, the channel floor and bar deposits consist of boulders up to 5 feet in diameter, large cobbles, gravel, and trace amounts of sand. The right valley wall is composed of Fraser continental drift. The left valley-wall is composed of andesitic bedrock. Flood terrace deposits situated outside high flow high flow channel corridor consist of alluvial gravel and/or cohesive Electron mudflow deposits. Existing levees, revetments and a railroad embankment are generally composed of quarry riprap and angular quarry spall.

The results of our aerial photograph evaluation indicate that bedload entering Reach 18 is supplied primarily from upstream source areas and Fox Creek, a small tributary entering the main stem from the right. The creek, which drains a portion of the steep valley wall, is likely transporting moderate to large volumes of sediment to the valley floor where it is entrained into Puyallup River bedload during high stage flows. The creek presently occupies an abandoned Puyallup River channel and joins with the main stem at P-RM 27.9.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Railroad alignment present on right bank. Multiple thread, braided stream in wide high flow channel.
1940 air photos (low flow conditions)	No aerial photograph coverage.
1965 air photos (low flow conditions)	Left bank revetment completed.
1978 air photos (low flow conditions)	Right bank partly levied. Levee reduces width of high flow corridor.
1987 air photos (low flow conditions)	Upstream levees not observable on aerial photo; downstream levees still observable.
1996 air photos (bank full conditions)	Levees in lower reach damaged.
1998 air photos (low flow conditions)	
Pierce County, Water Program Staff	

The upper one-half of the reach was partially confined by levees and revetments in 1965. Confinement was completed throughout the reach by 1978. The revetments effectively decreased the width of the high flow channel from an average of 800 feet in 1931 to about 300 feet in 1978.

Prior to confinement, the upstream end of the reach was a complexly braided river consisting of shallow, multi-thread channels separated by numerous gravel bars. Aerial photographs from 1931 to 1978 clearly show that gravel bars and channels shifted frequently, indicating that the channel floor was aggrading. The dominant migration style observed consisted of rapid lateral and downstream shifting of channels through braid bars within the high flow corridor, and lateral migration of channels into adjacent floodplains and terraces. Aerial photographs also indicate the occurrence of periodic channel abandonment and reoccupation (avulsion) within heavily braided sections. Ancient abandoned channels and channel traces are observable in alluvial floodplain deposit on both sides of the channel corridor, not including the Electron mudflow deposits, suggesting that the Electron Mudflow impeded migration of the braided channels.

Since confinement was completed in the 1970s, several levee sections have been destroyed during flood events. Portions of levees in upper reach areas were destroyed by 1978. Portions of the levees in the lower reach were destroyed or damaged in the 1996 floods. A likely cause of the damage is the high rate of channel aggradation, which has greatly reduced the flow capacity of the channel.

Erosion Potential

Erosion potential within Reach 18 varies with levee and revetment materials, native soils comprising valley walls, and the composition of gravel bars. Alluvial gravel bars inside the confined corridor are highly susceptible to erosion. The maximum distance of lateral migration measured through an alluvial deposit between 1931 and 1965 is 460 feet (at P-RM 27.2). Portions of the left valley wall composed of hard sedimentary and andesitic bedrock are very resistant to erosion and therefore represent a barrier to migration. The right valley wall consists of Fraser continental drift, generally considered to be moderately resistant to erosion. Several sections of the levies on both sides of the channel are composed of quarry spall and small riprap, and have been subject to frequent damage. Field observations indicate the quarry rock and riprap comprising the levees is subject to downstream transport and, therefore, cannot be expected to prevent erosion. Remnants of Electron mudflow deposits, located in the floodplains landward of existing levees and revetments, are moderately resistant to erosion.

PUYALLUP REACH 17

Existing Geomorphic Character

Nearly 100 percent of this reach is confined by man-made levies, revetments, or valley walls. The existing reach is characterized by a dominantly straight, single to multi-threaded low-flow channel with several large radius bends. The outside banks of the bends are generally positioned against levees or revetment-reinforced riverbanks, and straight portions of the low-flow channel(s) move around and between large aggrading gravel bars extending from the edges of the confined corridor.

The channel gradient decreases in the downstream direction from 1.2 to 0.70 %. The riverbed and adjacent gravel bars are composed largely of large cobbles and gravel with, occasional boulders and trace amounts of sand. The valley walls are generally composed of advance outwash, older

glacial till and other glacially derived sediments. The levies and revetments are constructed of quarry rock and/or riprap, depending on the age of the structure.

The results of our evaluation indicate that sediment entering Reach 17 is supplied primarily from upstream sources. Although Kapowsin and Fiske Creeks both drain portions of the steep valley walls, these creeks appears to contribute relatively small volumes of sediment to the main stem. Kapowsin Creek drains a sizeable sub-basin (25.9 mi^2) on the west side of the Puyallup River, and is capable of transporting relatively large sediment loads. However, prior to entering the Puyallup River Valley the creek flows into Kapowsin Lake, where virtually all-incoming sediment is deposited. Little sediment is entrained between the lake outlet and the Puyallup Valley floor, accounting for the apparently low sediment discharge volumes. Fiske Creek drains a much smaller sub-basin, and thus transports much smaller sediment loads. This creek flows onto and across the Puyallup River floodplain, where the creek channel is deeply entrenched in steep vegetated banks.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Railroad alignment on the left bank. Multi-thread, braided stream in wide high flow corridor.
1940 air photos (low flow conditions)	No Coverage.
1965 air photos (low flow conditions)	Left bank revetment complete.
1978 air photos (low flow conditions)	Right bank partly leveed. Levees reduce the width of the high flow corridor.
1987 air photos (low flow conditions)	Levee is not observed on aerial photo.
1996 air photos (bank full conditions)	
1998 air photos (low flow conditions)	
Pierce County, Water Program Staff	

The upper one-half of the reach was partially confined by levees and revetments in 1965. Confinement was completed throughout the reach by 1978. The revetments effectively decreased the width of the channel from roughly 700 feet in 1931, to about 250 feet in 1978. In 1996 numerous sections of the levees and revetments in Reach 17 failed. Pierce County's Water Programs' staff reported that the levee section between P-RM 27 and P-RM 26.8 has been repaired several times. In 2002 a section of the left valley wall was armored were the river undercut the slope and potentially threatened the Kapowsin Highway at MP 26.1.

Prior to 1965, Reach 17 was a complexly braided river section composed of shallow multi-threaded channels separated by numerous gravel braid bars. The dominant migration style observed consisted of lateral and downstream migration of shallow multi-thread channels through gravel braid bars within the high flow corridor, and into alluvial floodplain deposits The aerial photograph review also indicates that periodic channel avulsion also took place within heavily braided sections. Aerial photographs and geologic maps show much older abandoned channels and channel traces in floodplain deposits on both sides of the channel channel, but not through Electron mudflow deposits, indicating that upon contact, the Electron Mudflow impeded migration of the braided channels. Aerial photographs dating from 1931 to 1978 clearly show that gravel bars and channel locations

shifted frequently during that period indicating that the channels and braid bars were aggrading and unstable.

Erosion Potential

Erosion potential within Reach 17 varies with levee and revetment materials and construction, native soils comprising valley walls, and the composition of gravel bars. Alluvial gravel bars inside the confined corridor are highly susceptible to erosion. Portions of the left valley wall, composed of hard sedimentary and andesitic bedrock, are very resistant to erosion and offer a barrier to migration. The right valley wall consists of Fraser continental drift, which is considered moderately resistant to erosion. Several sections of the levees on both sides of the channel are composed of quarry spall and small riprap, and have been subject to frequent flood damage. Recent field observations identified quarry spall well downstream of their apparent origin indicating, along with specific damage reports, that the levees cannot prevent erosion. Electron mudflow deposits located in the floodplain landward of existing confining structures are moderately resistant to erosion.

PUYALLUP REACH 16

Existing Geomorphic Character

Reach 16 is characterized by a short, straight, narrow channel section tightly confined on both sides by steep valley walls. This reach is a constriction to flow arriving from upstream. The constriction is formed by outcroppings of bedrock on the left and Fraser continental drift on the right. The base of the right wall is buttressed with riprap from an abandoned railroad grade and an engineered revetment associated with the Orville Bridge overpass. With the exception of structures protecting the Orville Bridge, levees and revetments are not present in this reach.

Through the reach, the river flows as a single channel with an average channel gradient of 0.88 percent. The riverbed is composed primarily of bedrock with discontinuous side bar deposits composed of cobbles, gravel and occasional boulders. This reach is virtually devoid of sand.

The results of our aerial photograph evaluation indicate that sediment is supplied to this Reach primarily as bedload exiting Reach 17. The relatively clean riverbed, suggests that most sediment entering the Reach is transported directly through it.

Historic Information Review

The Orville Bridge and revetment appear to have been placed sometime prior to 1931. The river channel has been relatively stable since at least 1931. Virtually no significant changes in channel alignment were observed between 1931 and 1998, and only minor lateral fluctuations were detected at the upstream and downstream ends of the reach.

Erosion Potential

The sedimentary and andesitic bedrock comprising the left valley wall is very resistant to erosion, and is an effective a barrier to migration. The right valley wall consists of Fraser continental drift, which is considered moderately resistant to erosion. Based on information provided above, the erosion and migration potential of this reach is deemed very low.

PUYALLUP REACH 15 AND 14

Existing Geomorphic Character

This reach is almost completely confined by levees and revetments. From the outlet of the Reach 16 constriction, the valley floor widens to form a broad U-shaped trough. Throughout the reach, width of the high flow channel corridor has been reduced by confining structures to less than one-third of its former width. Based on the 1998 orthophotograph, the existing channel is characterized by a series of large radius meander bends in the upper portion of the reach, and a generally straight channel through the lower reach. The meander bends are defined by a set of shallow, multi-thread channels that combine to form a straight channel of unknown depth. Throughout the reach, channel gradient decreases steadily downstream from .90 percent to 0.80 percent. The riverbed and adjacent gravel bars consist of large cobbles and gravel, with sand and occasional boulders. Levees and revetments along the left valley wall bound most of the channel. Riverbanks exposed below levees consist of alluvial gravel deposits or floodplain soils. Exposed valley walls are primarily composed of glacially outwash overlying patches of andesitic bedrock.

The results of our aerial photograph evaluation indicate that bedload entering Reach 15 is supplied primarily from upstream reaches, mass wasting along the left valley wall and bank erosion. Small tributary streams such as Mint Creek (P-RM 23.7) and an unnamed tributary (P-RM 25.0) may also contribute sediment to the river during high flow events. These tributaries drain portions of the steep Puyallup valley slopes, however, the volume of supplied sediment is unknown. No alluvial fan is present at the Mint Creek confluence, indicating that sediment discharge from the creek is entrained into Puyallup River bedload during most flows. The unnamed tributary likely contributes only very small sediment volumes because it flows through a swampy area on the floodplain where most of the sediment load is deposited.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Railroad in place. Multi-thread, braided stream in wide high flow corridor with forested floodplain. Channel likely migrating toward RR. Landslide scars noted on valley walls.
1940 air photos (low flow conditions)	HCOT 500 to 800 feet wide.
1965 air photos (low flow conditions)	River channel was confined and straitened. High flow channel 250 to 350 feet wide. Saw mill noted on west side of road.
1978 air photos (low flow conditions)	Levees failed in upper half of Reach 15. Channel regained sinuous bends following the failure. Houses noted encroaching on HCOT downstream of damaged levees.
1987 air photos (low flow conditions)	No coverage.
1996 air photos (bank full conditions)	Numerous levee and revetment failures following winter storm flows. Structures not repaired. Flooded properties on west bank purchased by County.
1998 air photos (low flow conditions)	Channel formed large meander bends. Set back levee constructed. 1960s era levees abandoned.
Pierce County, Water Program Staff	Revetments between milepost 23 and 25 repaired numerous times.

Aerial photographs indicate that the entire reach was confined and straightened by 1965. Revetment placements decreased the width of the 1940 high flow channel from as much as 800 feet, to roughly 300 feet by 1965. In 1978 the confining structures failed along both sides of the river in the upper portion of the reach. The failures allowed for expansion of the channel corridor and development of highly sinuous braided channels. The levees were repaired, but failed again during winter flooding in 1996, wherein the river quickly formed a series of meander bends roughly 800 feet wide. The revetments between P-RM 23 and P-RM 25 have been repaired multiple times. In response to these events the County purchased flood prone properties on the west side of the river and set the levee back through portions of Reaches 15 and 14. We understand that Pierce County does not plan to maintain the remaining section of 1960s era levees in this reach within the set back levee project limits.

Prior to confinement, Reach 15 was a complexly braided river section roughly 500 to 800 feet wide, and composed of numerous shallow channels separated by braid bars. Aerial photographs indicate the presence of high flow secondary, and abandoned main stem channels within the high flow corridor. Aerial photographs and geologic maps also show much older abandoned channels and channel traces on both sides of the historic channel occupation tract (HCOT). Similar to conditions in Reach 17, remnants of Electron mudflow deposits separate the river channel from the valley walls. The locations of the mudflow remnants indicate that the mudflow deposits once bounded the channel. Within the high flow channel, gravel bars and channels alike shifted frequently prior to confinement, indicating that the channels and braid bars were aggrading and unstable.

Following completion of the levees, continued sediment deposition and streambed aggradation was likely a significant cause of levee damage and failure. Since the levees were set back in 1996, the river began reverting to a wider, more sinuous multi-thread channel pattern. By 1998, meander bends had developed within the newly expanded high flow, displaying both downstream and lateral migration trends.

Erosion Potential

Alluvial gravel bars inside the confined corridor are highly susceptible to erosion, as noted during 1996 when hundreds of lateral feet of alluvium eroded in a matter of days. The maximum rate of migration measured within the alluvium between 1931 and 1940 is 81 feet per year. Portions of the left valley wall, composed of hard sedimentary and andesitic bedrock, are very resistant to erosion and thus offer a barrier to migration. The right valley wall consists of Fraser continental drift, which is moderately resistant to erosion. Electron mudflow deposits located in the floodplains on both sides of the channel are moderately resistant to erosion.

PUYALLUP REACHES 13, 12, AND 11

Existing Geomorphic Character

Throughout Reaches 13, 12 and 11, 1960s era levees and revetments confine the river channel. The three reaches are characterized by a dominantly straight, single to double thread low-flow channel defined by continuous side-channel bars building out from the toes of levees and revetments. Over the length of these reaches, the Puyallup River emerges from a relatively narrow U-shaped valley onto a broad, flat valley shared with the lower reaches of the Carbon River and the City of Orting, situated between the Puyallup and Carbon River channels. Between Reaches 13 and 11, the

valley floor widens from roughly 3,500 feet to nearly 9,000 feet at the widest point. At the upstream end of Reach 13, an ancient abandoned channel branches away from the main stem. The abandoned channel follows the base of the valley wall to an intersection with the existing active main stem in Reach 11. A small stream presently utilizes the abandoned channel.

Nearly 100 percent of the river channel is bounded by man-made levies and revetments. The levees consist of quarried rock and/or riprap, depending on the age of the structures; the revetments are composed primarily of riprap. River bank soils exposed beneath the levees generally consist of alluvial gravels and Electron mudflow deposits. The alluvial soils are composed of former gravel bar deposits and fine-grained overbank deposits. Electron mudflow deposits comprise roughly 80 percent of the floodplain on both sides of the Puyallup River, and separate the existing main stem from the ancient abandoned channel on the west floodplain.

Within the confined corridor, channel gradients decrease steadily downstream through the three reaches from 0.75% in Reach 13, to 0.54 percent in Reach 12, and 0.43 percent in Reach 11. The riverbed and adjacent gravel bars consist generally of large cobbles and gravel with sand and occasional boulders. Most of the sediment entering Reach 13 is supplied almost entirely from upstream sources and erosion of exposed riverbanks.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Multi-thread braided channels and bars in wide high flow corridor. Concrete/wire debris diversion structures placed both sides of Calistoga Road Bridge (MP 21.3). Trestle at 159th Avenue East crossed main stem channel at about P-RM 20.5.
1940 air photos (low flow conditions)	High flow channel 500 - 700 feet wide. Trestle bridge (P-RM 20.5) not found. Additional debris diversion structures placed at Calistoga Bridge.
1965 air photos (low flow conditions)	Levees confine entire channel section. High flow channel width reduced to 300 feet.
1978 air photos (low flow conditions)	Meander bars cleared for pasture.
1987 air photos (low flow conditions)	
1996 air photos (bank full conditions)	Numerous failures of 1960s era levees.
1998 air photos (low flow conditions)	
Pierce County, Water Program Staff	

The entire length of Reaches 13, 12, and 11 was confined by levees in 1965. The placement of the levees reduced the width of the high flow channel from an average of roughly 700 feet in 1940 to about 250 feet in 1965. In 1996 numerous sections of the levee failed during winter storm events. The failures allowed the high flow channel to widen significantly and develop braided channels. In response to local and upstream events of 1978 and 1996, the county purchased flood prone properties and set the levee back through portions of Reaches 15, 14 and 13. We understand that Pierce County does not plan to maintain the remaining section of 1960s era levees in these reaches within the setback levee project limits.

Prior to confinement, Reaches 13, 12 and 11 were complexly braided river sections composed of numerous shallow channels separated by gravel bars. Aerial photographs indicate the presence of high water secondary and abandoned main stem channels within the high flow corridor. Aerial

photographs clearly show that gravel bars and channels shifted frequently prior to confinement, indicating that the channels and braid bars were aggrading and unstable. Aerial photographs and geologic maps also show a much older abandoned channel corridor situated in the left floodplain adjacent to the west valley wall. Similar to conditions in Reach 17, remnants of Electron mudflow deposits separate the main stem Puyallup River channel from the ancient abandoned channel. A large remnant deposit of Electron mudflow also separates the Puyallup from the Carbon River. The locations of these remnants indicate that the mudflow deposits once bounded the channel and impeded migration of the braided channels.

Following completion of the levees, sediment deposition and streambed aggradation was likely a significant cause of levee erosion and failure. Since the right levee was set back and the channel corridor widened in 1996, the river has reverted to a wider, more sinuous multiple treaded pattern.

Erosion Potential

Erosion potential within Reach 13, 12 and 11 varies with levee/revetment materials and construction, native soils comprising valley walls exposed to stream flow, and the composition and clast size of gravel bars. Alluvial gravel bars inside the confined corridor are highly susceptible to erosion. Remnants of the 1960s era levees are poorly constructed and likely to fail. The recently built set back levee is constructed to withstand the 100-year flood event, and is not likely to succumb to erosion or breaching. Electron mudflow deposits are moderately resistant to erosion.

PUYALLUP REACH 10 AND 9

Existing Geomorphic Character

Roughly 95 percent of Reaches 10 and 9 are tightly confined by levees and revetments. The channel corridor turns northward and extends along the west valley wall through Reach 10, and turns back towards the northeast through Reach 9 to join with the Carbon River. Two bridges span the river in Reach 9, an old railroad trestle bridge (now part of a walking trail) and the State Route 162 Bridge. An outfall structure from the Tacoma Water Public Utilities McMillin Reservoir is also located in Reach 9 on the left bank of the river at P-MP 17.75. We understand that flow rates through Reach 9 can vary greatly, depending on the outfall discharge, which is controlled by the Tacoma Water facility. We also understand that outfall discharge is typically sediment-free.

These reaches are characterized by a single, straight channel in the upper portion of Reach 10, and a series of large radius bends that extend from the lower portions of Reach 10 through the downstream end of Reach 9. The straight channel section is situated along the west valley wall, which does not appear to be protected by revetments. The channel bends are generally meander type bends with stable channels and bars.

The channel gradient decreases steadily through the two reaches from 0.43 to 0.16 percent. The streambed and meander bars are composed of gravel, cobbles and increasing amounts of sand in the downstream direction. Native soils underlying the levees consist of alluvial gravel and sand, and cohesive Electron mudflow deposits. The west valley wall in Reach 10 is composed of Orting Drift overlain by Vashon recessional outwash, both of which are subject to mass wasting.

Our evaluation indicates that bedload entering the two reaches is supplied from upstream sources, failures along the west valley wall and erosion of exposed soil underlying the levees.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Reach 10 river unconfined. Reach 9 channel confined. Single threaded meander bend channel in wide corridor with forested floodplain. Land-slide scars noted on left valley wall. Railroad and highway in place.
1940 air photos (low flow conditions)	High flow channel 500 to 800 feet wide. Meander bend at P-RM 17.9 leveed and reveted to protect road.
1965 air photos (low flow conditions)	River channel confined and straightened. One section moved 850 feet west of the 1940 channel location. High flow channel reduced to 300 feet wide.
1978 air photos (low flow conditions)	No channel changes observed. A golf course was constructed on the floodplain.
1987 air photos (low flow conditions)	No observed changes
1996 air photos (bank full conditions)	Several levee sections breached during winter storm flows. Structures repaired.
1998 air photos (low flow conditions)	No observed changes
Pierce County, Water Program Staff	

Sections of Reach 9 were confined by levees and revetments prior to 1931. Construction of levees through both reaches was completed in the mid-1960s. Confinement included diverting a portion of the 1940 river channel roughly 850 feet west to a new alignment along the west valley wall. It also includes extending levees along the right riverbank and building discontinuous revetments along of the base of the west valley wall. Placement of the levees cut off several large radius meander bends, resulting in significant shortening and straitening of 1940 channel. Levee placement also decreased the width of the high flow channel from 700 feet to about 250 feet. We understand that portions of the levees have failed periodically since 1965, most notably during 1996 winter high stage flow events.

Prior to confinement, Reaches 10 and 9 were complexly braided river sections. Similar to Reaches 13, 12 and 11, remnants of Electron mudflow deposits separate the main stem Puyallup River channel from the Carbon River. The locations of the remnants indicate that the mudflow deposits once bounded the channel and impeded migration of the braided channels. Aerial photographs clearly show that gravel bars and channels shifted frequently prior to confinement, indicating that the channels and braid bars were aggrading and unstable.

Since completion of the confining structures, the straight channel along the left valley wall has not migrated; however, the outside banks of meander bends periodically erode unprotected portions of the west valley wall, causing localized mass wasting events.

Erosion Potential

The streambed, point bars and side channel bars situated within the high-flow corridor consist of highly erodable alluvial sand and gravel. The left valley wall is composed of Vashon Recessional Outwash, which is highly sensitive to erosion and subject to mass wasting. The Electron mudflow deposit in this section of the valley is moderately resistant to erosion.

The maximum erosion observed in alluvium between 1931 and 1940 was about 520 feet. The rate of migration within the mudflow is estimated at 250 feet over 9 years, or 27.8 feet per year.

PUYALLUP REACH 8

Existing Geomorphic Character

This reach is characterized by a generally straight channel pattern with occasional bends. The Carbon River confluence is situated at the upstream end of the reach. Both sides of the existing channel throughout the reach are confined by levees and revetment structures. The active channel consists of a single dominant channel positioned between large, continuous, aggrading gravel bars extending from the edges of the confined corridor. Periodically, the observed active channel appears to shift from one side of the high flow channel to the other, remobilizing and redistributing the gravel bars along the way.

Reach 8 receives water and sediment from upstream Puyallup Reaches and the Carbon River. Based on our aerial photo review, it is clear that Reach 8 is aggrading, and that the majority of the sediment entering Reach 8 is discharging from the Carbon River. Compared against Puyallup Reach 8, the average channel gradient increases slightly from 0.16 percent in P-8 to 0.22 percent in P-8, indicating a potential increase in transport capacity that is not representative of observed aggradational conditions. Reach 8 conditions are more likely a result of the change in channel gradient between Puyallup Reach 8 and Carbon Reach 1, which decreases significantly from 0.46 to 0.22. This abrupt decrease in channel gradient, coupled with the large volume of Carbon River sediment discharge, identifies Reach 8 as an area subject to significant deposition.

The streambed and bars throughout Reach 8 are composed of gravel, cobbles and sand. Native soils underlying the existing levees consist of alluvial gravel and sand. Alluvial soils comprise much of the floodplain and are bounded by terraced Electron mudflow deposits, which are situated along the edges of the floodplain.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Floodplain and riparian zone previously cleared for agriculture. Railroad and highway in use. Portions of the reach already confined. Highly sinuous multi-thread, braided stream in wide high flow corridor. Concrete/wire diversion structures visible in channel and on floodplain (river left). Very large alluvial fan (2700 feet wide) formed at Carbon River mouth.
1940 air photos (low flow conditions)	Levee built on right bank reducing high flow channel width to 1,500 feet.
1965 air photos (low flow conditions)	Left bank revetment complete. High flow channel width reduced to 650 feet.
1978 air photos (low flow conditions)	Right bank levee replaced. High flow channel width reduce to 300 - 450 feet wide.
1987 air photos (low flow conditions)	
1996 air photos (bank full conditions)	Levees overtopped.
1998 air photos (low flow conditions)	
Pierce County, Water Program Staff	

Aerial Photographs indicate that Reach 8 was partly confined in 1931, and completely confined by the mid-1960s. Confinement effectively decreased the width of the high flow channel from over 1,500 feet in 1940 to roughly 400 feet in 1965.

Prior to complete confinement this reach was a zone of significant sediment deposition. Bedload entering the reach from both the Puyallup and Carbon River clearly exceeded Puyallup transport capacity, resulting in pronounced riverbed aggradation and channel widening. In response to the rapid deposition, the reach developed a highly sinuous, multi-thread braided system with frequent episodes of avulsion. Aerial photographs also indicate the presence of ancient abandoned channels and old channel traces in the floodplain, indicating a history of free migration.

Following confinement, the levees have experienced repeated episodes of erosional damage, failure and overtopping. The damage is likely due to a combination of factors, including the significant loss of channel corridor width, voluminous sediment influx from both Puyallup and Carbon River sources, and high rates of sediment deposition and channel aggradation.

Erosion Potential

The erosion potential within Reach 8 varies depending on the type of bank soils and levee construction. The alluvial sand and gravel bars within the confined channel corridor are highly susceptible to erosion. The maximum distance of migration through alluvium between 1931 and 1940 was about 365 feet. Electron mudflow deposits present in the floodplain are deeply scalloped, indicating that they bounded braided channels. The right valley wall consists of stratified post-glacial lacustrine sand and silt, which is susceptible to erosion.

PUYALLUP REACH 7

Existing Geomorphic Character

Within this reach, the existing channel corridor is completely confined by levees and revetments. The reach is characterized by a single, straight active channel situated between large continuous (over the length of the reach) and relatively stable side-channel bars. Two bridges cross the river within this reach; an old trestle-style pipeline bridge used to convey water for the Tacoma Public Utilities, and the McMillin Bridge, which extends from 128 Street.

The average channel gradient throughout the reach is 0.18 percent, representing a decrease from the upstream reach. The riverbed consists of lag deposits composed primarily of small cobbles and gravel. The west side of the channel corridor is positioned against a wedge shaped terrace elevated approximately 20-feet higher than the elevation of the east floodplain surface. This terrace is composed of alluvium and an Electron mudflow remnant.

The results of our aerial photograph evaluation indicate that bedload entering Reach 8 is supplied almost entirely from upstream source areas.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Floodplain and riparian zone previously cleared for agriculture. Two bridges cross the channel. Portions of reach were reveted to protect the bridges. Straight channel pattern is present in partly confined high flow channel.
1940 air photos (low flow conditions)	A portion of the west terrace slope has receded 20 feet. Revetments extend the length of the west terrace slope.
1965 air photos (low flow conditions)	Levees completely confine the reach.
1978 air photos (low flow conditions)	Upstream and downstream reaches leveed. High flow channel width reduced to about 300 feet.
1987 air photos (low flow conditions)	No changes observed.
1996 air photos (bank full conditions)	Levees at P-RM 16.7 breach during winter storm event. Levees repaired.
1998 air photos (low flow conditions)	
Pierce County, Water Program Staff	

Prior to 1965, Reach 7 was a straight, narrow channel with a high flow channel roughly 780 feet wide. In contrast, the reaches upstream and downstream of Reach 7 comprised broad, complexly braided river sections, rendering Reach 7 as somewhat of a historical channel constriction. Government Land Office Plat Maps indicate that the channel has maintained its position for at least the last 110 years. Over that period of time, the channel has been statically positioned with virtually no lateral movement. The lack of lateral movement is likely a result of two factors; 1) the presence of low relief terraces on the east and west sides of the channel, which effectively trap the channel, and 2) installation of heavily reinforced revetments along the channel and adjacent terrace slopes. Aerial photographs indicate that the riverbanks have been armored since at least 1931. The revetments were likely constructed to protect bridge structures from stream erosion. Since 1940, the riverbank and bridge revetments have been significantly reinforced.

In 1996, levees in the vicinity of P-RM 16.7 breached in response to super-elevation of flood waters behind (landward) of the levees. The levees were repaired to their original condition, but not reinforced to withstand return flood-flow conditions.

Erosion Potential

The potential for erosion throughout Reach 7 is low due the presence of reinforced bridge revetments and levee structures.

PUYALLUP REACH 6 AMD REACH 5

Existing Geomorphic Character

Roughly 90 percent of Reaches 6 and 5 are confined by levees, bank revetments and the right valley wall. Combined, the reaches measure roughly 11,300 feet long. Two major tributaries, Canyonfalls Creek and Fennel Creek, and a smaller unnamed creek, enter the river from the right side. The existing high flow channel is generally straight through the upper and middle portions of

Reach 6, with large radius bends in the lower portion of Reach 6 and throughout Reach 5. Historically, the bends in Reaches 5 and 6 were initiated by deflection of the flow around a pronounced alluvial fan situated at the mouth of Fennel Creek. The fan is now separated from the high flow corridor by levees. The corridor alignment follows the perimeter of the fan around to the east, where it impinges against the east valley wall and is deflected sharply northward.

The existing low-flow channel consists of a straight to slightly meandering, single channel bounded by aggrading bars building out from the toes of levees and revetments. Bar aggradation is particularly prominent in the upper portion of Reach 6, and less so in the lower portion of the reach where bars appear to be relatively stable.

The average channel gradient decreases from 0.30 percent at the upstream end of Reach 6 to about 0.23 percent. Streambed and bar deposits are generally composed of gravel and cobbles with increasing amounts of sand in the downstream direction. The east valley wall is composed of compacted glacial outwash interbedded with thin mudflow and peat deposits (the Pre-Fraser Alderton Formation). Valley wall erosion is most notable at P-RM 15.0, where the active channel impinges on an approximately 8-foot high portion of the east valley wall. The impingement has caused erosional undercutting and over-steepening of the slope face, resulting in a relatively unstable bluff subject to periodic episodes of mass wasting.

The results of our evaluation indicate that most of the sediment entering Reach 6 is supplied as bedload from upstream Puyallup reaches, erosion and mass wasting along the east valley wall, and sediment discharging from both Canyonfalls Creek and Fennel Creek. The magnitude of sediment contribution from the tributaries is not well known.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Complexly braided channel observed. Floodplain and riparian zone cleared for agriculture prior to 1931. Concrete/wire diversion structures and groins placed to train channel. The river split around a heavily forested island at RM 16.2. Total width of braided area about 2000 feet.
1940 air photos (low flow conditions)	Two channel branches migrate laterally and downstream. A channel reroute is partly excavated.
1965 air photos (low flow conditions)	Two channel branches routed to a single, excavated channel. High flow corridor width reduced to 250 feet.
1978 air photos (low flow conditions)	Single-family homes noted adjacent to left side of levees.
1987 air photos (low flow conditions)	Gravel mining operation observed.
1996 air photos (bank full conditions)	Single-family homes noted adjacent to right side of levees. Levees damaged in winter flooding event. Flood damages recorded at properties on right bank.
1998 air photos (low flow conditions)	
Pierce County, Water Program Staff	East bank property buy-outs presently in progress.

Channel erosion and migration control measures were in place as early as 1931. Observed measures include the use of concrete-and-wire debris catchment structures and rock groins (MP 16.4). The structures were used to induce sediment deposition as a means of redirecting flow from one portion of the braid plain to another. As with previously described reaches, Reach 5 was completely confined by the mid-1960s, and Reach 6 was confined by the mid-1970s. Confinement effectively decreased the width of the former high flow channel corridor from over 2,300 feet in the upper and middle portions of Reach 6 (1931), to roughly 270 feet in 1978. However, in the river bend sections of Reaches 6 and 5, we noted little change in high flow channel width between 1931 and 1998.

Prior to complete confinement, these reaches consisted of complexly braided river sections. In 1931, several wide, shallow channels separated by large mid- and side channel bars occupied the upstream half of the area. In the middle of the reach two prominent channels formed around a densely forested gravel bar. Combined, the two active corridors and the vegetated bar measured roughly 2,000 feet wide. The two branch channels joined together at P-RM 15.9, forming a single channel that curved around the Fennel Creek alluvial fan and impinged upon the east valley wall in Reach 5.

The upper and middle portions of Reach 6 have long been known as an area of significant sediment deposition and streambed aggradation. Permitted mining of river gravel took place within Reach 6 for many years (a mining operation is visible in the 1987 photograph), but was discontinued in 1997 in response to changes in environmental regulations. Since gravel mining stopped, we understand that the size of gravel side bars has generally increased.

Flooding in 1996 eroded and breached levees at P-RM 16.1 and along 153rd Ave East. The river overtopped the revetments around MP 14.8. Between 1931 and 1940 17-feet of lateral migration was observed on the cut-bank at MP 15.3.

Erosion Potential

Alluvial sand and gravel deposits are highly susceptible to erosion and high migration rates. In Reach 6, the maximum observable distance of lateral migration is 330 feet between 1931 and 1940. Gravel deposition forced the channel to migrate laterally through cleared alluvial floodplain soils at a rate of 37-feet in nine years. The rate of erosion though forested land was measured at 20-feet in 9 years. In Reach 5, lateral migration of 17 feet was measured between 1931 and 1940 along a valley floor terrace. No erosion rates along the east valley wall could be obtained. Geologic maps and aerial photographs indicate that Electron mudflow deposits are present only along western edge of the floodplain, and have not been encountered by the main stem river channel in the course of the 70 year period of record.

PUYALLUP REACH 4

Existing Geomorphic Character

The existing reach is roughly 7,900 feet long. The channel was partly confined as early as 1931, and nearly completely confined in the early 1960s by levees and reinforced revetments. A total of two small, unnamed tributaries enter the river, one from each side of the channel.

The existing high flow channel consists of three large radius bends. Inside the confined corridor, the low flow channel consists of a single thread channel with bends bounded by side-channel bars situated along the inside edges of the bends. The floodplains on both sides of the channel contain several prominent ancient and historic abandoned oxbow channel features as well as several less distinctive channel traces. The presence of these features indicates a characteristic pattern of significant lateral migration and possible avulsion well prior to 1931.

The channel gradient decreases dramatically from 0.23 percent at the upstream end of the reach to 0.18 percent downstream, inducing sediment deposition throughout the reach. Accordingly, the streambed and bars throughout the upper one-half of the reach appear subject to aggradation and periodic shifting, causing similar shifting of the active channel. This condition is particularly noticeable downstream of the 96th Avenue Bridge. Bars throughout the lower portion of the reach appear to be smaller and more stable. Existing channel banks are generally protected by revetments and riprap bank protection.

The results of our aerial photograph evaluation indicate that bedload entering this reach is supplied primarily from upstream sources.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Channel is unconfined. Single to multi-thread meander bends observed throughout reach. Ancient abandoned and oxbow channel features in floodplain. Floodplain utilized for agriculture in 1931. A trestle bridge spanned the channel at P-RM 14.6
1940 air photos (low flow conditions)	Lateral migration of 1200 feet noted. Rock groins placed along both banks.
1965 air photos (low flow conditions)	Rock groins connected to form revetments. No significant migration from 1940 channel location noted. High flow channel width reduced to 250 feet. 1940s era bars vegetated and stabilized.
1978 air photos (low flow conditions)	In-channel gravel mining in progress.
1987 air photos (low flow conditions)	96th Street bridge replaced older trestle bridge.
1996 air photos (bank full conditions)	Gravel mining stopped.
1998 air photos (low flow conditions)	The left revetment at MP 13.4-3 failed.
Pierce County, Water Program Staff	

Efforts to control channel migration within Reach 4 began sometime between 1931 and 1940 with the placement of rock groins. The reach was completely confined by 1965. Confinement decreased the width of the former high flow channel from roughly 1,000 or 1,200 feet in 1931 to about 250 feet in 1965.

Prior to confinement, the channel throughout this reach was characterized by highly sinuous laterally migrating meander bends consisting of a single channel and very pronounced un-vegetated point bars with back bar channels. The presence of these features generally indicates high rates of deposition on the bars and relatively high rates of migration. This condition likely persisted well prior to 1931, based on the presence of numerous ancient abandoned meander loops observed in the 1931 aerial photograph.

Following a significant lateral channel shift of 1,200 feet between 1931 and 1940, rock groin revetments were installed to prevent migration. Use of these structures appears to have been very successful; the channel has remained virtually static since 1940 in spite of the combined effects of low channel gradient and high influxes of sediment into the reach. However, since gravel mining ceased in 1978, at least one gravel bar has begun to grow. The effect of bar growth on channel confinement in this area is not yet known.

Erosion Potential

Historically, bank erosion rates in Reach 4 vary depending on the types of bank soils and local vegetation. Prior to confinement, erosion of alluvial soil was typically rapid, particularly in areas subject to pronounced aggradation and channel widening. Between 1931 and 1940, rapid deposition and aggradation resulting in lateral migration of the channel through roughly 1,200 feet of floodplain soils. Measured rates of migration though forested land was slower, about 200-feet in 9 years. Rates of migration though mudflows and valley wall sediment were not observed in the period of record.

PUYALLUP REACH 3

Existing Geomorphic Conditions

Reach 3 is roughly 5,200 feet long and is completely confined by reinforced levees and revetments. The reach is characterized by a series of tightly engineered right-angle bends, which divert the channel from a northward to westward course. Based on our aerial photograph review, the bends have been statically positioned over the entire period of record.

The channel gradient for the reach is about 0.18 percent, roughly the same as that recorded for Reach 4. The gradient appears to be generally constant throughout the reach and subject to only small local variations. The active channel is bounded by a few stable, continuous side channel bars along the inside banks of the bends. Traces of ancient meander bends are present in the floodplains in the vicinity of the engineered bends. However, these features are elevated above the present channel floor, clearly indicating that the existing channel has incised downward and is now entrenched within the reveted channel. Given the low gradient throughout the reach and the apparently high sediment discharge entering the reach from upstream sources, the depth of incision suggests that the channel has been statically located much longer than our period of record. The degree of incision also suggests that the channel has probably not utilized the floodplains for equally long periods.

The results of our aerial photograph evaluation indicate that bedload entering this reach is supplied primarily from upstream reaches. An unnamed creek flows into the Puyallup River at P-RM 12.8. The creek, which occupies an ancient abandoned channel, drains the valley floor east of Reaches 4 and 3 and is likely contributing only small volumes of sediment to the main stem channel. The water in the unnamed creek was silty at the time of our August field investigations, and likely does not supply bedload to the Puyallup River.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Channel partly confined by revetments. Two right angle bends divert the stream from north to west. Floodplains and riparian zones cleared for agriculture prior to 1931.
1940 air photos (low flow conditions)	Channel confinement completed. Channel width similar to 1931 width.
1965 air photos (low flow conditions)	
1978 air photos (low flow conditions)	Single-family homes and a trailer park built on north side of channel.
1987 air photos (low flow conditions)	No changes observed.
1996 air photos (bank full conditions)	
1998 air photos (low flow conditions)	Flooding of trailer homes on north side of channel
Pierce County, Water Program Staff	

Efforts to control channel erosion and migration in Reach 3 began prior to 1931 with the construction of riprap revetments and rock groins adjacent to the right angle bends. The reach was completely confined by 1965. Aerial photographs dated 1940 indicate that the width of the confined high flow corridor was approximately the same as the 1931 high flow channel.

Prior to confinement, the channel bore similar characteristics to the present day channel. Differences between pre-and post-confined channel conditions are represented primarily in the size and distribution of gravel bars. In 1931 the active channel appears to have shifted from side to side within the high flow channel. The gravel bars were larger and more abundant in 1931 than those observed in 2002. The combined effects of confinement and channel incision likely caused the observed changes.

Erosion Potential

Drilling logs from subsurface explorations on the north side of the channel indicate that a relatively resistant mudflow, the Osceola mudflow, is present at depth and overlain by alluvial overbank deposits. The presence of the mudflow may have impeded northward migration of the channel prior to channel confinement. Given the confined and entrenched condition of the river, the channel has not migrated appreciably since 1931.

PUYALLUP REACHES 2 AND 1

Existing Geomorphic Character

The combined length of Reaches 2 and 1 is about 10,600 feet. Both reaches are completely confined by reinforced revetments, some of which date back to about 1910. The revetments restrict the river to a generally straight, northwest-tending channel, which extends to the confluence with the White River.

Through both reaches the channel gradient is approximately 0.18 to 0.17 percent, changing little from the measured gradient in Reach 3. The channel floor and adjacent floodplain are underlain at shallow depths by Osceola mudflow deposits. Thin, discontinuous side channel bars composed primarily of sand with small gravel confine the existing low-flow channel. As with the previous

reach, traces of ancient meander bends present in the floodplains are elevated above the present channel floor, indicating incision and entrenchment of the channel into the Osceola mudflow deposits. The degree of entrenchment indicates that the channel is detached from its floodplain, and can no longer migrate laterally.

The results of our aerial photograph evaluation indicate that bedload entering these reaches is supplied primarily from upstream sources.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	The reach transitions from a straight channel in Reach 2 to a meander channel in Reach 1. Bridge abutments are heavily reveted. Floodplain and riparian zones were cleared for agriculture prior to 1931.
1940 air photos (low flow conditions)	The channel is further confined by revetments. Reach 2 channel has been straightened.
1965 air photos (low flow conditions)	Channel confinement is complete.
1978 air photos (low flow conditions)	Suburban development on north floodplain.
1987 air photos (low flow conditions)	No changes observed.
1996 air photos (bank full conditions)	Floods overtopped the channel banks.
1998 air photos (low flow conditions)	
Pierce County, Water Program Staff	

Efforts to control channel migration began in the early 1900s. The channel was completely confined by revetments and levees by 1965. Through Reach 2, little change in the width of pre- and post-confined high flow channels is observed. However in Reach 1, confinement reduced the width of the high flow channel from 1,000 feet in 1931 to roughly 200 feet in 1965.

Prior to confinement, Reach 1 was a laterally migrating meander channel with broad un-vegetated point bars. The presence of these features generally indicates high rates of deposition on the bars coupled with relatively high migration rates. This condition likely persisted well prior to 1931, based on the presence of numerous ancient abandoned meander loops preserved in the 1931 floodplain.

Confining structures straightened, and thus shortened the channel, which probably increased both the channel gradient and its transport capacity. One of the primary differences observed between pre- and post channel conditions is the sharp reduction in both the size and distribution of gravel bars. From 1965 on, the size of the bars decreased slightly with each set of dated photographs. In addition to the changes in channel dynamics, the general reduction of sediment bars may also be caused by the combined effects of channel incision, and the possible loss of bedload materials resulting from upstream gravel mining operations.

Erosion Potential

Drilling logs from boring on the north side of the channel indicate that the Osceola mudflow is present at depth and overlain by alluvial overbank deposits. The presence of the mudflow may have impeded northward migration of the channel prior to channel confinement. No appreciable lateral migration was observed over the period of record.

CARBON RIVER CORRIDOR

The Carbon River project area extends from the confluence with the Puyallup River at C-RM 0.0 to MP 8.3. We divided the project area into seven geomorphic reaches.

CARBON REACHES 7 AND 6

Existing Geomorphic Reach Character

Reaches 7 and 6 extend roughly 13,000 feet through a relatively steep, trough-shaped valley with steep sidewalls. Throughout these reaches, over 90 percent of the channel corridor is presently confined to a relatively narrow corridor by levees, revetments and the north valley wall. Within the confined channel corridor, the river transitions from a system of complexly braided shallow channels, to a system of one to two straight channels bounded by continuous mid- and side-channel gravel bars. The braided section is situated in the upper portion of Reach 7. Based on our review of 1998 orthophotographs, the width of the high flow channel decreases by roughly one-half at about C-RM 7.2, along with a change in channel character from dominantly braided to generally straight.

Throughout these reaches the channel gradient decreases abruptly from about 3.0 percent just upstream of the project area to 1.15 percent in Reach 7, and 1.0 percent at the downstream end of Reach 6. The channel floor is composed of boulders, up to 3 feet in diameter, and bar deposits composed of large cobbles and gravel with very little sand. Throughout Reach 7, the right (north) side of the channel corridor is confined by the north valley-wall. The valley wall is composed of poorly consolidated sand and gravel (Orting Drift), which is highly prone to mass wasting events. Revetments extend discontinuously along the toe of the valley wall and thus offer only partial protection from erosion. Consequently, slope erosion and mass wasting events periodically deliver soil and uprooted trees directly to the river channel. The left (south) riverbank consists of terraced flood deposits composed of alluvial gravel and cobbles. The flood terraces on the south side of the channel contain several ancient abandoned channels.

The results of our aerial photographic evaluation indicate that bedload entering these reaches are supplied from three sources: bedload from upstream reaches, mass wasting and erosion along the north valley wall, and erosion of braid bars inside the confined channel corridor.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Railroad in place on south bank. Revetment noted along railroad. Multiple threaded, braided stream with forested floodplain. High flow channel about 800 feet wide. Landslide scars noted on valley wall.
1940 air photos (low flow conditions)	No photograph coverage available.
1965 air photos (low flow conditions)	River channel completely confined and straightened. High flow channel confined to about 250 feet wide. Valley floor development downstream of RM 7.2.
1978 air photos (low flow conditions)	Revetments along north valley wall damaged and repaired. Suburban development increasing. Houses noted adjacent to levees and revetments.
1987 air photos (low flow conditions)	No coverage.
1996 air photos (bank full conditions)	Numerous levee and revetment failures following winter storm flows. Structures not repaired. Flooded properties on west bank purchased by County.
1998 air photos (low flow conditions)	Channel formed large meander bends. New set back levee constructed. 1960s era levees abandoned.
Pierce County, Water Program Staff	Levees set back downstream of RM 8.2.

Aerial photographs indicate that Reaches 7 and 6 were partly confined in 1931 and completely confined by the mid-1960s. Confinement effectively decreased the width of the high flow channel from roughly 800 feet in 1931 to about 250 feet in 1998.

Prior to the completion of confinement structures both reaches consisted of complexly braided systems with shallow, shifting channels and numerous braid bars. Most of the sediment comprising the braid bars entered the project area as bedload from upstream reaches, and from mass wasting along the north valley wall. Combined, the influx of sediment clearly exceeded the local transport capacity of the Carbon River, resulting in aggradation of the streambed, channel widening and complex braiding. Aerial photographs show ancient abandoned channels and old channel traces in the floodplain, indicating that braiding has likely characterized these reaches on the order of centuries.

Aerial photographs and field reconnaissance also indicate that channel movement throughout these reaches has been avulsive and chaotic since the mid-1960s. Rapid sediment deposition and streambed aggradation was likely a significant cause of levee and revetment damages and breaching. Since the levee was set back, the channel corridor widened and channel braiding has become more complex.

Erosion Potential

Erosion potential within Reaches 7 and 6 varies with levee/revetment materials and construction, native soils comprising valley walls exposed to stream flow, and the composition and clast size of gravel bars. The most rapid erosion is observed in valley floor alluvial soils where the channel migrated 505 feet between 1931 and 1965. The soils comprising the north valley wall are prone to erosion and mass wasting from basal undercutting.

The county road (177th Street East) and former railroad grade is armored with rock in some locations. Pierce County Water Programs levee inventory indicates that the railroad embankment armoring near MP 6.4 experienced a toe slope failure in 1996. The former railroad grade is poorly compacted and not resistant to erosion.

CARBON REACH 5

Existing Geomorphic Character

Reach 5 is approximately 1,300 feet long. The reach is situated immediately downstream of two bridges presently spanning the river; the old railroad trestle bridge and the newer SR162 bridge, located downstream of the trestle. Levees confine nearly 100 percent of the channel corridor in this reach. South Prairie Creek enters the Carbon River from the north – northwest at about C-RM 5.7. At the confluence, a riprap groin extends from the left bank of the creek into the Carbon River channel.

The existing channel corridor consists of a single large radius bend that directs the channel from a westerly to a southwesterly course. The channel gradient throughout this reach is 1.10 percent, which is steeper than the measured gradient of Reach 6. The low flow channel consists of two shallow threads that bend around a large bar situated along the inside edge of the bend. The riverbed and bars

are composed of large cobbles, gravel and occasional sand. Traces of abandoned ancient channels are observable on the north floodplain, but not on the south floodplain. South Prairie Creek enters the main stem Carbon as a meandering stream with a measured channel gradient of 0.27 percent. The creek is likely utilizing a historic channel of the Carbon River.

The results of our evaluation indicate that bedload entering Reach 5 is supplied primarily from upstream Carbon River reaches and the north valley wall downstream of the South Prairie Creek.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Channel is confined by levees. Railroad and County Road trestle bridges in place. High flow channel about 300 feet wide.
1940 air photos (low flow conditions)	No coverage available.
1965 air photos (low flow conditions)	Three riprap groins observed along right bank.
1978 air photos (low flow conditions)	No changes observed.
1987 air photos (low flow conditions)	No changes observed.
1996 air photos (bank full conditions)	No changes observed.
1998 air photos (low flow conditions)	Channel migrated 51 feet west.
Pierce County, Water Program Staff	No problems with levees reported.

Aerial photographs indicate that by 1931, this reach was completely confined by engineered structures. The structures included levees on both sides of the channel, two trestle-type bridge crossings and reinforced revetments in the vicinity of the bridge pilings. In about 1978, the new SR 162 Bridge replaced the county road, and the old bridge was converted to a trestle-style bridge with a concrete span. Three riprap groin structures have been constructed along the right bank since 1965 to deflect streamflow towards the left bank. The purpose of the deflection structures is unknown.

Erosion Potential

The erosion potential within Reach 5 is limited due to the presence of engineered groins and revetments. The 2002 visit revealed that the river is entrenched along the right valley wall at MP 5.7. Valley wall sediments are mapped as Orting Drift (Crandell (1963), a compacted stratified sand and gravel that is moderately resistant to erosion. Pierce County Water Programs staff did not report any problems regarding the revetments in this reach.

CARBON REACHES 4 AND 3

Geomorphology of the River Reach

Carbon River Reaches 4 and 3 include an approximately 14,500-foot channel section bounded on the right by the north valley wall and on the left by a slightly elevated flood terrace. Roughly 100 percent of the length of both reaches is confined by levees and revetments along the south side of the channel, and discontinuous revetments along the north valley wall. The channel corridor bends from southwest to northwest around a protruding bulge in the valley wall. The width of the high flow channel through these reaches is considerably greater than adjacent upstream and downstream

reaches; Reach 4 is roughly 1.5 times wider than upstream reaches and Reach 3 is approximately three times wider than downstream reaches.

The 1998 orthophotographs indicate that the confined corridor through Reaches 4 and 3 includes an extensive continuous gravel bar situated along the base of the north valley wall, and a much smaller discontinuous bar located alongside the levee at the upstream end of Reach 4. The low flow channel consists of two shallow channels bounded by the continuous bar on the right and the levee/revetment structures on the left. The smaller discontinuous bar at the upstream end of Reach 4 is presently diverting flow against the north valley wall, causing erosion and mass wasting. The large bar on the right then deflects the low flow channels away from the north valley wall and against the levees.

The channel gradient through the two reaches decreases steadily in the downstream direction from 1.0 percent at the upstream end of Reach 4 to about 0.6 percent near the downstream end of Reach 3. The streambed and bars are composed of large cobbles and gravel with woody debris. The north valley wall is composed of the glacially compacted Orting Drift and ice-contact deposits, both of which are prone to mass wasting. The floodplain on the left is composed of alluvial gravel, cobbles and sand deposits overlying a large remnant of the Electron Mudflow.

Two tributaries flow into the Carbon River within Reaches 4 and 3. The larger Voight Creek drains a sizeable watershed of about 22 square miles on the north slope forming the drainage divide between the Carbon and Puyallup Rivers. Voight Creek sediment discharge has formed an alluvial fan at the base of the south valley wall where the creek enters the river at C-RM 4.0 via an ancient Carbon River meander channel. The smaller Patterson Creek enters the Carbon at C-RM 5.4 discharging comparatively smaller sediment volumes.

The results of our aerial photograph evaluation indicate that sediment entering Reaches 4 and 3 is supplied from upstream sources, (including South Prairie Creek), Voight Creek, and mass wasting of the right valley wall within Reach 4.

Historic Map and Aerial Photograph Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Railroad and County Road embankments partly confine south side of high flow channel. Concrete/wire debris catchment structures observed along side channels on south side of Reach 3. Low flow channel consists of multi-thread braid channels. 1 large landslide scarp observable on north valley wall (Reach 4).
1940 air photos (low flow conditions)	County Road and Railroad embankments confine south side of high flow channel. No levees observed. Fresh landslide scarps on north valley wall in Reach 4.
1965 air photos (low flow conditions)	Revetments and levees completely confine south side of the channel. SR 12 replaces County Road. Single-family homes observed adjacent to levees.
1970/788 air photos (low flow conditions)	Tightly braided channels develop. Fresh landslide scarps observed on North Valley wall. Possible channel avulsion noted.
1987 air photos (low flow conditions)	No coverage available.
1996 air photos (bank full conditions)	No changes observed.
1998 air photos (low flow conditions)	Channel edge migrated 51 feet west.
Pierce County, Water Program Staff	Numerous failures along left levees during winter storms.

The 1931 aerial photographs indicate that reinforced railroad and county road embankments partly confined Reach 4 and the upstream portion of Reach 3. By 1965 the south side of both reaches was completely confined by levees. We observed no evidence of levee or revetment construction along the north side of the high flow channel. The width of the pre-confined high flow channel varied from 450 to 1,100 feet in Reach 4, and from 420 to 1,550 feet in Reach 3. The post-confined corridor width varies from 200 to 700 feet in Reach 4, and from 500 to 900 feet in Reach 3.

Prior to complete confinement both reaches were complexly braided systems with numerous shallow channels separated by braid bars. Many of the largest bars were vegetated and relatively stable, but virtually all other bars appear subject to remobilization. The active channel was situated along the base of the north valley wall in Reach 4. Large patches of exposed soil and landslide scarps are observable on the slope face where the active channel was in direct contact with the slope.

Most of the sediment entering the two reaches was likely delivered as bedload from upstream reaches and mass wasting along the north valley wall in Reach 4. Based on the distribution of gravel bars and the width of the high flow channel throughout these reaches, it is clear that sediment delivery exceeded reach-scale transport capacity. This condition resulted in streambed aggradation, channel widening and development of complex, unstable channels. Aerial photographs show abandoned channels and old channel traces in vegetated bar surfaces and on the left bank floodplain south of the railroad grade. Concrete and wire debris catchment structures placed along the south side of the observed low flow channel were likely intended to induce sediment deposition as a means of diverting the channel away from the town of Orting.

Since confinement along the south edge of the channel was completed in the 1960s the active channel has moved closer to the right valley wall in Reach 4, resulting in a general increase in the number of erosion and landslide scarps along the north valley wall. The change in channel alignment also resulted in movement of the channel through Reach 3 much closer to the town of Orting. It is unclear whether the levees and revetments were extended through Reach 4 to protect Orting from encroachment of the redirected channel. It is, however, clear from 1931 and 1940 aerial photographs that Orting City limits have been threatened by periodic encroachment of major braid channels in the past. Given the high influx of sediment into Reach 3 it is highly likely that the City and its levee will again be threatened by encroachment of a major braid channel.

Erosion Potential

The erosion potential throughout Reaches 4 and 3 vary with levee/revetment materials and construction, native soils comprising the north valley wall, and the composition of braid bars. Gravel bars within the high flow corridor are highly susceptible to erosion during high flow events. Maximum migration rates through alluvial bar and flood terrace soils between 1931 and 1940 vary from 64.4 to 43.3 feet per year. The right valley wall, which is composed of Orting Drift soils overlain by Fraser glacial drift, is moderately resistant to erosion and is subject to mass wasting from basal undercutting. Most of the 1960s era levees are composed of quarry rock and are subject to erosion. The Pierce County levee inventory indicates that several sections of these levees are presently over-steepened from basal erosion. Washington DNR surficial geologic map indicates the

presence of a mudflow deposit approximately 0-300 feet from the left side of the river in Reach 3. The mudflow deposit is considered moderately resistant to erosion.

CARBON REACHES 2 AND 1

Existing Geomorphic Character

Reaches 2 and 1 are confined by a combination of 1960s area levees and revetments, and the north valley wall. The two reaches are characterized by one to two straight, low-flow channels defined by relatively continuous side-channel bars building out from the toes of the confining structures. Over the length of these reaches the Carbon and Puyallup River Valleys merge to form a broad, flat valley varying from 3,500 to 9,000 feet wide. Levees and revetment on the left bank have effectively confined the existing Carbon River channel along the eastern edge of the Puyallup Valley between Orting and the Puyallup confluence, a distance of about 3 miles.

Levees and revetments confine nearly 90 percent of river channel. The levees consist of quarried rock and/or riprap, depending on the age of the structure; the revetments are composed primarily of riprap. River bank soils exposed beneath the levees consist primarily of alluvial gravels and Electron mudflow deposits. Electron mudflow deposits are also present in the left bank floodplain throughout both reaches. One smaller mudflow remnant is situated along the eastern edge of the floodplain near the confluence with the Puyallup River.

Within the confined high flow corridor channel gradients decrease steadily downstream through the two reaches from 0.60 to 0.46 percent. The riverbed and adjacent gravel bars consist largely of large cobbles and gravel with sand. Most of the sediment entering Reach 2 is supplied from upstream sources, although occasional failures on the right valley wall also deliver sediment directly to the streambed. Other smaller sediment sources likely include small tributaries and erosion of exposed riverbanks.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Valley floor partly cleared. Left bank partly levied. Concrete/wire debris catchment structures on left bank near confluence. Low flow channel consists of multi-thread braid channels.
1940 air photos (low flow conditions)	Migration of 450 feet observed on left bank near Orting. Left bank levied continuously from C-RM 0.6 to Puyallup confluence, and at Orting.
1965 air photos (low flow conditions)	Revetments and levees completely confine east side of channel.
1970/78 air photos (low flow conditions)	Orting wastewater treatment plant completed by 1978, partly located in former high flow channel. Tightly braided channels develop within confined corridor. Levee and revetment toe-slope failures reported.
1987 air photos (low flow conditions)	No coverage available.
1996 air photos (bank full conditions)	No changes observed.
1998 air photos (low flow conditions)	Several failures along left bank levees during winter storm. Basal erosion of valley wall.
Pierce County, Water Program Staff	

Reaches 1 and 2 were completely confined by 1965. The placement of the levees reduced the width of the high flow channel from roughly 700 feet in 1931 to about 250 feet in 1965. In 1996 numerous sections of the levee failed during winter storm events.

Prior to confinement, Reaches 1 and 2 were complexly braided river sections composed of numerous shallow channels separated by gravel bars. The 1931 and 1940 aerial photographs show the river shifting back and forth across the high flow channel. The photographs also indicate the presence of ancient abandoned side channels preserved in the floodplain. A large remnant of the Electron mudflow separates the Puyallup and Carbon Rivers at the town of Orting. The location of the remnant indicates that the mudflow deposits once bounded active channels and likely slowed the rate of migration. Aerial photographs clearly show that both gravel bars and river channels shifted frequently, indicating that the channels and braid bars were likely aggrading and unstable.

Following confinement, the high flow channel corridor was reduced to approximately 300 feet wide, decreasing the area available for storing sediment. Pierce County has reported numerous episodes of erosional damage to levees and revetments on both sides of the river in Reach 1. The damage is a likely response of the channel to streambed aggradation and reduced sediment storage capacity.

Aerial photographs suggest that right valley wall in Reach 2 has been relatively stable over the period of record. However, a few mass wasting scars are visible near the old Bridge Street bridge-crossing site at C-RM 3.1, and site visits in 2002 indicate that the soils on the slope are presently exposed and undercut.

Erosion Potential

The streambed, point bars and side channel bars situated within the high-flow corridor consist of highly erodable alluvial sand and gravel. Migration rates in alluvial soils between 1931 and 1940 were measured at 49.1 ft per year in Reach 2, and 33.9 ft per year in Reach 1. The right valley wall is composed of pre-Fraser glaciations Orting Drift, which is considered moderately resistant to erosion. The Electron mudflow deposit in this section of the valley is moderately resistant to erosion. Pierce County observations indicate the quarry rock used as riprap has over-steepened and failed during high flow events and, therefore, cannot be expected to contain the river over the long term.

WHITE RIVER CORRIDOR

The White River project area extends from the confluence with the Puyallup River at W-RM 0.00 near Sumner to W-RM 5.4. We divided the project area into seven geomorphic reaches.

WHITE REACHES 7 AND 6

Existing Geomorphic Condition

Reaches 7 and 6 extend approximately 9,900 feet from the upstream end of the project area to about the location of the Dieringer Hydroelectric Plant outfall. The channel was partly confined as early as 1931 and nearly completely confined in the early 1960s by levees and reinforced revetments.

The existing channel corridor consists of two large radius bends. Inside the confined channel corridor, the low flow channel consists of a single thread channel with occasional shallow bends

bounded by side-channel bars. The floodplains on both sides of the channel contain no observable ancient or historic channel features.

The channel gradient decreases steadily in the downstream direction from 0.23 percent at the upstream end of the project area to 0.19 percent at the downstream end of Reach 6. The streambed and bars consist primarily of sand, gravel and small cobbles (in Reach 7), grading in the downstream direction to sand and gravel in Reach 6. Existing channel banks are generally composed of alluvial floodplain soils and are not protected by revetments. Most levees are composed of poorly compacted silty soils likely dredged from the channel.

The low gradient has induced sediment deposition throughout the reach. The deposition is apparent from aggradation and periodic shifting of gravel bars. Deposition is particularly noticeable in the lower portion of Reach 7, and through the 'S-turn section of Reach 6. Bars in the lower portion of Reach 6 appear to be smaller and more stable. The results of our aerial photograph evaluation indicate that bedload entering these reaches is supplied primarily from upstream sources and from riverbank and streambed erosion.

Historic Information Review

Source of Historical Information	Historical Observation
1931 air photos (low flow conditions)	Channel is partly confined. Single to multi-thread braid channels with meander bends observed throughout the reach. Floodplain utilized for agriculture in 1931. County Road Bridge spanned the channel at W-RM 4.7.
1940 air photos (low flow conditions)	Rock groins placed along both banks in Reach 7 and along left bank through S-turn in Reach 6. High flow channel 200 to 450 feet wide.
1965 air photos (low flow conditions)	Both reaches completely levied. High flow channel confined to a 250 foot wide corridor.
1978 air photos (low flow conditions)	No change observed from 1965 photograph.
1987 air photos (low flow conditions)	No photograph coverage.
1996 air photos (bank full conditions)	No photograph coverage.
1998 air photos (low flow conditions)	
Pierce County, Water Program Staff	

Serious efforts to confine the channel in Reaches 7 and 6 began between 1931 and 1940 with the placement of rock groins. The reaches were completely confined by 1965. Confinement decreased the width of the former high flow channel from 200-500 feet in 1931, and later again to about 200 feet wide in 1965.

Prior to confinement, the channel throughout these reaches was characterized by straight to sinuous multi-threaded channels that shifted laterally between continuous mid- and side-channel bars. Streambed deposition appears to have been relatively high in the upper portion of Reach 7 based on the presence of shallow channels and un-vegetated bars. The channel was subject to measurable migration at the S-turn between 1931 and 1940. This migration likely provoked the placement of rock groins in 1940, along with the installation of revetments and levees.

Since confinement of the channel was completed in the 1960s, the channel alignment has remained virtually the same with no observable evidence of lateral migration.

WHITE REACH 5 AND 4

Existing Geomorphic Character

Reaches 5 and 4 extend roughly 2,400 feet downstream from the Dieringer/Lake Tapps Hydroelectric Power Plant Outfall. The channel was at least partly confined in 1931, and completely confined by levees and revetments by 1965.

The existing channel corridor is generally straight, with a single large radius bend located in Reach 5. The channel gradient decreases through both reaches from 0.10 percent at the upstream end of Reach 5, to about 0.07 percent at the downstream end of Reach 4. Throughout both reaches the active channel extends the full width of the confined corridor and is deeply entrenched. No side channel bars are observable on the 1998 orthophotograph and the floodplains on both sides of the channel contain no observable ancient or historic channel features.

Earthen levees composed of silt and sand are present on both sides of the river. In some locations landowners have reinforced the levees with construction materials and riprap. On average, the levees increased bank heights by about 4 feet. Native bank soils underlying the levees consist of silty sand. The levees are partly to completely vegetated by relatively mature deciduous trees, blackberry vines, and grasses. Most native banks display erosional surfaces, many of which include basal undercutting.

Sediment entering Reaches 5 and 4 is supplied primarily from upstream sources, but also from erosion of the riverbanks and streambed. Much of the in-channel erosion is attributable to discharge entering the reach from the hydroelectric power plant outfall. The discharge, which can be large, typically carries no sediment. The absence of sediment in large flows is known to increase transport capacity and erosion, often resulting in streambed erosion, channel entrenchment and the general absence of side-channel bars.

Historic Information Review

Source of Historical Information	Historical Observation
1913	White River diversion and Dieringer Hydroelectric Power Project completed.
1920	Channel corridor dredged and banks hardened.
1931 air photos (low flow conditions)	Channel is partly confined. Single active channel fills width of channel corridor.
1940 air photos (low flow conditions)	Point bar formed on inside of large bend. Lateral migration noted. Revetments placed along outside bank.
1965 air photos (low flow conditions)	Revetment placed along inside bend adjacent to point bar. No further migration observed.
1978 air photos (low flow conditions)	No change observed from 1965 photographs.
1987 air photos (low flow conditions)	No photo coverage.
1996 air photos (bank full conditions)	No photo coverage.
1998 air photos (low flow conditions)	No changes observed.
Pierce County, Water Program Staff	

River valley maps prior to 1904 show the ancestral Stuck River channel located somewhat west of the existing channel. Accounts of the 1904 flood suggest that the ancestral Stuck River channel was abandoned during the White River avulsion, when the new channel formed farther to the east. By 1920, the lower portion of the river was being dredged up to Reach 5, and major cut banks had been hardened and levied. In 1913 the White River diversion and Dieringer Hydroelectric Power Projects were completed.

The general alignment of the river has not changed appreciably since 1931, although it is highly likely that the channel has deepened significantly. The 1931 aerial photographs show the formation of a point bar on the east side of the river downstream of the outfall. By 1940 the point bar had grown measurably and a revetment was in place along the west bank, opposite the outfall. By 1965 the point bar had been cutoff by the placement of a levee/revetment, and has since become occupied by farm buildings. The channel has not migrated from its 1940 position,

Erosion Potential

The native soils located adjacent to the existing channel pose no significant barrier to lateral channel migration. The riverbanks and levees, composed of loose silty sand, are highly to moderately susceptible to erosion. Although the growth of mature deciduous trees and ground cover plants on the levee tend to increase erosion resistance, the levees and native soils are still quite sensitive to erosion. NSCS soil descriptions indicate that the valley floor is composed of silty sand or peat deposits, which are also moderately to highly susceptible to erosion. Measurable lateral migration, however, has not occurred since 1965. The lack of lateral migration is likely a result of the downward incision of the streambed. As the channel floor continues to descend the channel will likely widen slightly.

WHITE REACHES 3, 2 AND 1

Existing Geomorphic Character

Reaches 3, 2, and 1 extend from W-RM 2.5 to W-RM 0.00, at the confluence with the Puyallup River near Sumner. The channel was completely confined in a dredged channel by 1931. The channel was completely levied by 1965.

The existing channel corridor is generally straight with a single large radius bend located in Reach 3. The channel gradient decreases through all reaches from 0.08 percent in Reach 3, to 0.04 percent in Reach 2 and 0.02 percent in Reach 1. Throughout these reaches the active channel extends the full width of the confined corridor. Similar to Reaches 5 and 4, no side-channel bars are observable on the 1998 orthophotograph and the floodplains on both sides of the channel contain no observable ancient or historic channel features.

Throughout this river section the channel is deeply entrenched. The severity of the entrenchment is such that modeled 100- and 500-year floods are contained entirely within existing channel dimensions. Concrete slabs and riprap revetments built at the water edge between 1910 and 1920 are presently situated 6 to 10 feet above the surface elevation of the annual averaged flow level. Exposed bank soils consist of silty sand, which is moderately sensitive to erosion.

Our evaluation indicates that most sediment entering these reaches is supplied from upstream sources, riverbank and streambed erosion, floodplain drainage ditches and from Salmon Springs Creek.

Historic Information Review

Source of Historical Information	Historical Observation
1920	Channel corridor dredged and banks hardened.
1931 air photos (low flow conditions)	Channel is partly confined. Single active channel fills width of channel corridor.
1940 air photos (low flow conditions)	Point bar formed on inside of large bed. Migration noted. Revetments placed along outside bank.
1965 air photos (low flow conditions)	Revetment placed along inside bend adjacent to point bar. No further migration observed.
1978 air photos (low flow conditions)	No change observed from 1965 photograph.
1987 air photos (low flow conditions)	No photo coverage.
1996 air photos (bank full conditions)	No photo coverage.
1998 air photos (low flow conditions)	No change observed.
Pierce County, Water Program Staff	

Dredging in 1917 effectively entrenched the channel, greatly reducing its potential to move laterally. Streambed erosion and dredging are generally considered to be the primary causes of the incision. No appreciable lateral channel movement was noted after 1940, and by 1978 no side channel bars were visible in aerial photographs.

Historical information indicates that the riverbanks were armored discontinuously by concrete slabs or riprap revetments in the early 1900s. Many of the concrete slabs are still present and buried beneath 1 to 6 feet of fine sand.

Erosion Potential

The native soils located adjacent to the existing channel pose no significant barrier to lateral channel migration. The native riverbanks are composed of loose silty sand that is highly to moderately susceptible to erosion. NSCS soil descriptions indicate that the valley floor is composed of silty sand or peat deposits, also moderately to highly susceptible to erosion. However, measurable lateral migration has not occurred since 1940. The lack of lateral migration is likely a result of the downward incision of the streambed. As the channel floor continues to descend, the channel will likely widen slightly.

APPENDIX B1 (Page 1 of 6)
PUYALLUP RIVER CMZ ANALYSIS
GEOMORPHIC REACH DESCRIPTIONS

Reaches:	**Puyallup 18**	**Puyallup 17**	**Puyallup 16**	**Puyallup 15**	**Puyallup 14**	**Puyallup 13**
River Miles :	27.0-28.6	25.3-27.0	25.2-25.3	23.6-25.2	23.1-23.6	22.5-23.1
Length: (Feet)	9,117	8,353	1,336	9,173	2,916	3,281
Gradient: (%)	1.14	1.08	0.88	0.83	0.85	0.75
Valley configuration:	The river flows into a trough-like valley, 2,500 to 3,000 feet wide valley floor. Puyallup River runs on the east-side, Kapowsin Creek occupies the west-side.	Valley narrows slightly, 2,500-1,800' wide. River cross valley floor and hugs the west side.	Valley narrows to 300 feet due to a bedrock outcrop.	Valley widens (1300-2000'). River remains in the center.	Valley walls narrow to 1,400- 3,500'; river hugs the west side of the valley.	Valley opens (3500-6500'). River flows of the left half of the valley.
Floodplain and Terraces: (presence, and character)	Large, discontinuous floodplains on both sides of channel, a young mudflow terrace in the middle of the valley floor.	Large continuous floodplains on both sides of channel upstream of confluence with Kapowsin Creek. Downstream there is a moderate floodplain on the right.	No floodplains	Moderate floodplains (discontinuous, on both sides) with young terrace on the right.	Floodplains (continuous, on river right) with young terrace on the right.	Floodplains (narrow, discontinuous, both sides) young terrace on the right
Floodplain Features:	Ancient channel scars on left floodplain	Ancient channel swales on the right	None	Oxbows (left flood plain) and ancient channel scars (both) on floodplains	Oxbows (right) and ancient channel scars on both floodplains.	Oxbows (right) and ancient channel scars (both) on floodplains
Dominant Channel Pattern:	Historically: braided, Existing: single and multiple braided treads.	Historically: braided Existing: transitional and straight single thread.	Historically: single threaded Existing: single threaded.	Historically: braided, multiple-threads Existing: transitional meander/braided	Historically: braided multiple-threads Existing: straight single-thread with side bars.	Historically: braided multiple-threads Existing: transitional meander/braided.
Measured Maximum Migration Rate: (feet/year)	13.5	13.5	0.0	81.1	36.2	43.9
Width of Observed Active Channel to High Flow Channel:	15-33%	25-40%	50-95%	20-60%	40-60%	30-50%
Gravel Bar Character (within the Channel Corridor):	Large, abundant, active mid-channel and side bars	Large, abundant, active side bars	Small, discontinuous, stable bars	Large, abundant, and active mid-channel and side bars	Moderately large, abundant, stable side bars	Large abundant, and active mid-channel and side bars
Tributaries: Name, confluence location (side of the river it enters)	Fox Creek, RM 27.9 (right)	Kapowsin Creek, RM 26.1 (left); Fiske Creek, RM 25.4 (right)	None	Unnamed creek/swamp, RM 25.0 (left); Mint Creek, RM 23.7 (left)	None	None
Primary Bank Soil:	Alluvial gravel bars overbank deposits cohesive mudflow deposit andesitic bedrock	Alluvial gravels cohesive mudflow deposit bedrock, shale and andesite	Alluvial gravel overbank deposits andesite bedrock	Alluvial sand and gravel bars overbank deposits cohesive mudflow deposit	Alluvial sand and gravels bars overbank deposits bedrock shale and andesite	Alluvial sand and gravels cohesive mudflow deposit
Bedload: listed order of observed composition	Cobbles and gravel with boulders and sand	Cobbles and gravel with boulders and sand	Cobbles and gravel with sand	Cobbles and gravel with sand	Cobbles and gravel with sand	Cobbles and gravel with sand
Sediment Source Area	Primarily upstream mass wasting and glacial run-off. Mass-wasting of in-reach valley wall sediments.	Upstream, tributaries, in-reach mass wasting of valley wall	Upstream	Upstream, tributaries, banks	Upstream and banks	Upstream
Existing Infrastructure:	Champion Bridge (RM 28.6) Railroad alignment and private timber road (left) Orville Road E (left)	Abandoned Railroad Alignment and Neadham Road (right) Orville Road E (left)	Abandoned Railroad Alignment and Orville Road E (right) Orville Road High Bridge	Abandoned Railroad Alignment and Orville Road E (right)	Abandoned Railroad Alignment and Orville Road E (right)	None
Revetments and Levees: (presences)	Left side is reveted (riprap is incorporated into the bedload)	1960's era levee/revetment remains in spots.	Engineered riprap embankment Remains of the abandon railroad grade	1960's era levee/revetment remains in spots. Set-back levee is constructed along the right side.	1960's era levee/revetment remains in place. Set-back levee is constructed along the right side.	1960's era levee/revetment remains in place Set-back levee is constructed along the right side.

PUYALLUP RIVER CMZ ANALYSIS
GEOMORPHIC REACH DESCRIPTIONS

Reaches:	Puyallup 12	Puyallup 11	Puyallup 10	Puyallup 9	Puyallup 8	Puyallup 7
River Miles :	20.1-22.5	19.2-20.1	17.8-19.2	17.5-17.8	16.8-17.5	16.6-16.8
Length: (Feet)	13,314	4,619	8,187	2,248	3,161	786
Gradient: (%)	0.54	0.43	0.32	0.16	0.22	0.18
Valley configuration:	The Puyallup and Carbon River valleys merge forming a broad valley 7000-9000' wide. The Puyallup River is in the middle of the valley floor.	Overall Valley width decreases to 5000- 6000' (river is not affected).	The Puyallup River valley is over 5000 feet wide. The river flows along the left side of the valley wall.	The Puyallup River valley is approximately 5400 feet wide. River moved to the center of the valley.	The Puyallup River valley is over 5000 feet wide. River is located in the center of the valley.	The Puyallup River valley is over 5400 feet wide. River located on the eastern half of the valley.
Floodplain and Terraces: (presence, and character)	Floodplains (broad, continuous, on both sides)	Floodplains (discontinuous both sides) young terrace on the right	Floodplains (large on the right, and small discontinuous on the left.) young terrace on the right	Floodplains (discontinuous, on both sides) terraces (discontinuous, on both sides)	Extensive floodplains (continuous, both sides), with adjacent terraces	Floodplain on the right, terrace on the left
Floodplain Features:	Oxbows, ancient channels on floodplains (both sides)	Oxbows, ancient channel on floodplains (both sides)	Oxbows (both sides); ancient channels scars (left only)	None	Oxbows, swales, ancient channel scars (both sides)	None
Dominant Channel Pattern:	Historically: braided multiple-threads Existing: straight with transitional bars and tightly braided.	Historically: transitional braided meanders Existing: straight with transitional bars and tightly braided.	Historically: meandering single-threads Existing: straight with transitional bars and tightly braided.	Historically: straight single-thread Existing: straight single-thread.	Historically: braided multiple-threads Existing: straight with transitional bars and tightly braided.	Historically: straight single-thread Existing: straight single-thread.
Measured Maximum Migration Rate: (feet/year)	65.6	29.4	57.8	15.1	40.6	21.6
Width of Observed Active Channel to High Flow Channel:	25-60%	35-90%	20-100%	40-100%	40-60%	40-80%
Gravel Bar Character (within the Channel Corridor):	Moderately large, abundant, and active side bars	Moderately, abundant, and active mid-channel and side bars	Moderately, discontinuous, and active mid-channel and side bars	Small, discontinuous, stable bars	Large, abundant, active, and aggrading side bars	Large, abundant, active, and aggrading side bars
Tributaries: Name, confluence location (side of the river it enters)	None	None	Unnamed Creek, RM 19.1 (left)	None	Carbon River, RM 16.8 (right)	None
Primary Bank Soil:	alluvial sand and gravels cohesive mud flow deposit	Alluvial sand and gravels cohesive mud flow deposit	Alluvial sand and gravels cohesive mud flow deposit Pre-Vashon "Orting' Glacial Drift (valley wall)	Alluvial sand and gravels cohesive mud flow deposit	Alluvial sand and gravels cohesive mudflow deposit Vashon pro-glacial delta gravel (valley wall)	Alluvial sand and gravels cohesive mudflow deposit Vashon pro-glacial delta gravel (valley wall)
Bedload: listed order of observed composition	Cobbles and gravel with sand	Cobbles and gravel with sand	Gravel with sand and cobbles	Gravel with sand and cobbles	Cobbles and gravel with sand	Cobbles and gravel with sand
Sediment Source Area	Upstream	Upstream	Upstream, tributary, in-reach mass wasting of valley wall	Upstream	Carbon River and Upstream	Upstream
Existing Infrastructure:	Calistoga Street Bridge (RM 21.3)	None	None	Tacoma Water outfall structure (RM 17.7) State Route 162 and abandoned railroad bridges (RM 17.5)	McCutcheon Road (right) State Route 162 (left) Concrete/wire debris catchments	128th Street E and Tacoma Water Pipeline bridges (RM 16.7) McCutcheon Road (right) State Route 162 (left)
Revetments and Levees: (presences)	1960s era and earlier levee/revetment system remains in place. Section repaired in the last 5 years are up to US Army Corps specifications for 100 year flood.	1960s era levee/revetment system remains in place.	1960s era and earlier levee/revetment system remains in place.	1960s era and earlier levee/revetment system remains in place.	1960s era and earlier levee/revetment system remains in place.	1960s era and earlier levee/revetment system remains in place.

PUYALLUP RIVER CMZ ANALYSIS
GEOMORPHIC REACH DESCRIPTIONS

Reaches:	Puyallup 6	Puyallup 5	Puyallup 4	Puyallup 3	Puyallup 2	Puyallup 1
River Miles :	15.2-16.6	14.7-15.2	13.2-14.7	12.2-13.2	11.7-12.2	10.3-11.7
Length: (Feet)	7,435	3,921	7,861	5,258	2,605	8,061
Gradient: (%)	0.25	0.23	0.18	0.18	0.17	0.18
Valley configuration:	The valley is 5400 - 5800 feet wide (river located on the eastern half of the valley)	The valley is 5800 feet wide (river runs along the toe of the eastern valley wall).	Valley Widens to 8800 feet (river is located in the center of the valley).	The Puyallup and Stuck valleys merge forming a flat broad valley 10,000 feet wide. The river is located in the center of the valley.	The River is located in the center of the valley.	The River is located in the center of the valley flowing towards Tacoma.
Floodplain and Terraces: (presence, and character)	Broad floodplains (continuous, on both sides), adjacent terrace on the left.	Narrow floodplain (discontinuous, on both sides) with terrace on the left.	Extensive floodplains (continuous, both sides)	Broad floodplains (continuous, both sides) with a terrace north of the river	Broad detached floodplains on both sides of the river.	Broad detached floodplains on both sides of the river
Floodplain Features:	Oxbows, swales and ancient channels	Ancient channels	Oxbows, swales and ancient channels	Oxbows on the left.	None	Oxbow, ancient channels and swales on the left. Oxbow on the right
Dominant Channel Pattern:	Historically: braided multiple-threads Existing: straight with transitional bars and tightly braided.	Historically: straight single-thread Existing: straight with transitional bars.	Historically: meandering single-thread Existing: straight single-thread with transitional bars.	Historically: meandering Existing: straight with transitional bars (beginning of incised channel).	Historically: Straight single-thread Existing: straight, incised single-thread.	Historically: meandering single-thread Existing: straight, incised single-thread.
Measured Maximum Migration Rate: (feet/year)	16.8	36.7	133.3	27.6	3.9	33.3
Width of Observed Active Channel to High Flow Channel:	30-45%	60-100%	30-100%	60-100%	40-100%	40-100%
Gravel Bar Character (within the Channel Corridor):	Large, abundant, active, aggrading side bars	Small, discontinuous stable side bars	Moderate, discontinuous point bars	Small, discontinuous, stable, point bars	Single, small, stable bar	Small, infrequent, fairly stable side bars
Tributaries: Name, confluence location (side of the river it enters)	Cannonfalls Creek, RM 15.9	Fennel Creek, RM 15.0 (right) Unnamed Creek, RM 14.7 (left)	None	Unnamed Creek, RM 12.8 (right)	none	None
Primary Bank Soil:	Alluvial sand and gravels cohesive mudflow deposit Fraser pro-glacial delta gravel (valley wall)	Alluvial sand and gravels cohesive mudflow deposit Pre-Fraser "Alderton Formation" compacted sand and gravel "Fraser" kame-terrace gravel	Alluvial sand and gravels cohesive mud flow deposit	Alluvial sand and silt	Alluvial sand and silt	Alluvial sand and silt
Bedload: listed order of observed composition	Gravel with cobbles and sand	Gravel with sand and cobbles	Gravel and Sand	Gravel and Sand	Sand and Gravel	Sand
Sediment Source Area	Upstream, tributary	Upstream, tributary, mass wasting of valley wall	Upstream	Upstream, tributary	Upstream	Upstream
Existing Infrastructure:	McCutcheon Road (right) State Route 162 (left)	McCutcheon Road (right) State Route 162 (left)	96th Street E bridge (RM 14.2) Riverside Road (right) State Route 162 (left)	Riverside Road (right)	State Route 162 Bridge at Alderton (RM12.1)	Linden Avenue and Burlington Northern Santa Fe Railroad Bridges (RM10.7) State Route 410 (right)
Revetments and Levees: (presences)	1960s era and earlier levee/revetment system remains in place.	1960s era and earlier levee/revetment system remains in place.	1960s era and earlier levee/revetment system remains in place.	1960s era and earlier levee/revetment system remains in place.	1960s era and earlier levee/revetment system remains in place.	1960s era and earlier levee/revetment system remains in place.

APPENDIX B1 (Page 4 of 6)
CARBON RIVER CMZ ANALYSIS
GEOMORPHIC REACH DESCRIPTIONS

Reaches:	**Carbon 7**	**Carbon 6**	**Carbon 5**	**Carbon 4**	**Carbon 3**
River Miles :	6.5-8.4	5.9-6.5	5.7-5.9	4.2-5.7	3.1-4.2
Length: (Feet)	9,914	3,163	1,273	8,007	6,482
Gradient: (%)	1.15	1.01	1.10	0.72	0.60
Valley configuration:	The river flows into a trough-like valley, with a 1100 to 1800 foot wide valley floor. Carbon River occupies the north-half of the valley floor up to the an actively mass wasting valley wall.	The valley floor is approximately 1250 to 1350 feet wide. Carbon River confined on the left by a resistant glacial till and historical railroad bed.	Carbon river is historical confined by rail and highway bridges. Area is highly engineered. The confluence of the Carbon and South Prairie Creeks is located within this reach .	The valley floor is approximately 2300 to 3400 feet wide. The river occupies the northern third of the valley up to the an actively mass wasting valley wall.	The Puyallup and Carbon River valleys merge forming a broad valley 8000-9000' wide. Carbon River is in the north quarter of the valley floor.
Floodplain and Terraces: (presence, and character)	Large floodplain (continuous, left) with adjoining terrace (discontinuous, left)	Extensive floodplain on the right, moderate floodplain on the left	Large floodplain (continuous, right) with terrace (discontinuous, left)	Large floodplain (discontinuous, on both sides) and adjoining terrace on the left.	Large floodplain (continuous, on both sides) and adjoining terrace on the left.
Floodplain Features:	Swales and ancient channels (in old photos)	Ancient channels	South Prairie Creek follows an oxbow (right)	Patterson Creek (left), oxbows and swales on (left)	Voight Creek (left), oxbows and swales on (left)
Dominant Channel Pattern:	Historically: braided multiple-threads Existing: braided multiple-threads.	Historically: braided multiple-threads Existing: straight with transitional bars and tightly braided.	Historically: braided multiple-threads Existing: straight with transitional bars and tightly braided.	Historically: braided multiple-threads Existing: straight with transitional bars and tightly braided.	Historically: braided multiple-threads Existing: straight with transitional bars and tightly braided.
Measured Maximum Migration Rate: (feet/year)	14.9	4.4	4.6	64.4	43.3
Width of Observed Active Channel to High Flow Channel:	20-50 %	30-40%	40-60 %	15-60 %	20-50%
Gravel Bar Character (within the Channel Corridor):	Large, abundant, active bars	Large, abundant, active bars	Moderate, discontinuous, active bars	Large, abundant, active, aggrading bars	Large, abundant, active, aggrading bars
Tributaries: Name, confluence location (side of the river it enters)	None	None	South Prairie Creek, RM 5.7 (right)	Patterson Creek, RM 5.4 (left)	Voight Creek, RM 4.0 (left)
Primary Bank Soil:	Alluvial sand and gravel Pre-Vashon "Orting' Glacial Drift, overlain by Vashon ice-contact and pro-glacial drift (valley wall)	Alluvial sand and gravel Pre-Vashon "Orting' Glacial Drift (right valley wall) Vashon ice-contact and pro-glacial drift (left valley wall).	Alluvial sand and gravel Pre-Vashon "Orting' Glacial Drift (right valley wall)	Alluvial sand and gravel Pre-Vashon "Orting' Glacial Drift (right valley wall)	Alluvial sand and gravel cohesive mudflow deposits Vashon ice-contact stratified drift (right valley wall).
Bedload: listed order of observed composition	Cobbles and gravel with boulders and sand	Cobbles and gravel with boulders and sand	Cobbles and gravel with boulders and sand	Cobbles and gravel with sand	Gravel and cobbles with sand
Sediment Source Area	Upstream mass wasting and glacial run-off. Mass-wasting of valley wall sediments.	Upstream	Upstream, South Prairie Creek and in-reach valley wall mass wasting.	Upstream, in-reach valley wall mass wasting.	Upstream, Voight Creek, and erosion of floodplains
Existing Infrastructure:	Riprap from former railroad alignment now 177th Street E (left)	Riprap from former railroad alignment now 177th Street E (left)	Pioneer Highway (State Route 162) and former Burlington Northern Railroad bridges, RM 5.9	Riprap from former railroad alignment	Concrete drift barriers and former railroad alignment
Revetments and Levees: (presences)	1960s era levee/revetment system was constructed on both side of the river. The right side is not maintained and large sections had completely failed. The left side remains, although sections were destroyed in 1996 and were reconstructed to ACE specs.	1960s era levee/revetment system remains in-place. PC levee inventory indicated small sections of the revetment had toeslope failures in 1996.	The Bridges and railroad approach from the north were rip-raped in the 1930's. Beginning in the 1960's various rip-rap levees were constructed that separated the two river systems. Modification were observed in 1965, 1970, and 1998.	The Railroad grade is rip-raped, and serves as a levee on the left side of the river. 1960s era levee/revetment system further confined the river, this system remains in-place.	The left side of the river is confined by a revetment /railroad grade riprap system. PC levee inventory indicated sections of the revetment had failures in 1996. A section near RM 3.8 was repaired by field visit in 2002.

CARBON, WHITE RIVER CMZ ANALYSIS
GEOMORPHIC REACH DESCRIPTIONS

Reaches:	Carbon 2	Carbon 1	White 7	White 6	White 5
River Miles :	1.1-3.1	0-1.1	4.8-5.4	3.6-4.8	3.0-3.6
Length: (Feet)	10,728	6,223	3,152	6,779	3,334
Gradient: (%)	0.46	0.47	0.23	0.19	0.10
Valley configuration:	The Puyallup River Valley is over 7,000 feet wide. The Carbon River flows along the right valley wall.	Overall Valley width decreases to 5,000 to 6,000 feet. The Carbon River remains on the east half of the valley floor.	The Stuck Valley is a flat bottom, trough-like valley. The valley floor is over 7,000 feet wide. The White River is in the center of the valley.	The valley remains over 7,000 feet wide. The White River moved to the east half of the valley.	The valley remains over 7,000 feet wide. The river remains on the east half of the valley.
Floodplain and Terraces: (presence, and character)	Extensive floodplain on the left, with adjoining terrace	Large floodplain (continuous, on both sides), with adjoining terraces	Extensive floodplains (continuous, both sides)	Extensive floodplains (continuous, both sides)	Extensive floodplains (continuous, both sides)
Floodplain Features:	Oxbows and swales on (left)	Oxbows and swales on both sides	Ancient channels west of banks (in right floodplain)	Ancient channels west of banks (in right floodplain)	Ancient channels west of banks (in right floodplain)
Dominant Channel Pattern:	Historically: braided meander multiple-threads Existing: straight with transitional bars and tightly braided.	Historically: braided meander multiple-threads Existing: straight with side bars.	Historically: braided meander multiple-threads Existing: meandering single-thread	Historically: meander bends Existing: straight with transitional bars	Historically: meander bends Existing: vertically, incised single-thread
Measured Maximum Migration Rate: (feet/year)	49.1	33.9	25.2	25.2	9.4
Width of Observed Active Channel to High Flow Channel:	25-70%	25-70%	30-100%	20-100%	100%
Gravel Bar Character (within the Channel Corridor):	Moderate, discontinuous active bars	Moderate, discontinuous active bars	Large, abundant, active bars	Large, abundant, active bars	Small, discontinuous, stable sand bar is located near the hydroelectric inflow
Tributaries: Name, confluence location (side of the river it enters)	None	None	Unnamed Ditch RM 5.2 (right)	Unnamed Ditch RM 3.8 (right)	PUGET SOUND ENERGY Dieringer/Lake Tapps Hydroelectric plant Outfall RM 3.6 (left)
Primary Bank Soil:	Alluvial sand and gravel cohesive mudflow deposits Pre-Fraser "Orting' Glacial Drift, overlain by Vashon ice-contact stratified drift (right valley wall).	Alluvial sand and gravel cohesive mudflow deposits Pre-Fraser "Orting' Glacial Drift, overlain by Vashon ice-contact stratified drift (right valley wall).	Alluvial silt, sand and gravel	Alluvial silt, sand and gravel	Alluvial silt, sand and gravel
Bedload: listed order of observed composition	Gravel and cobbles with sand	Gravel and cobbles with sand	Gravel with sand and small cobbles	Gravel with sand and small cobbles	Gravel and Sand
Sediment Source Area	Upstream, in-reach valley wall mass wasting.	Upstream	Upstream, tributary	Upstream, tributary	Upstream, erosion of cutbank
Existing Infrastructure:	State Route 162 (left)	State Route 162 (left)	8th Street E Bridge (RM 4.7) 138th Avenue E (right)	Valentine Rd E (right) Railroad alignments (both)	Unfinished Pedestrian Bridge (RM 3.4) Railroad alignments (both)
Revetments and Levees: (presences)	60s era levee/revetment system on the left side of the river remains in-place. PC levee inventory indicated three small sections of the revetment had toe and toeslope failures in 1996.	Section of the left side of the river has been reveted since the 1940's. A 60s era levee/revetment system confined both sides and remains in-place. PC levee inventory indicated numerous small sections of the revetment had toe and toeslope failures in 1996.	Rock groins and pilings along cut-banks. Private bank protection in local areas.	Rock groins and pilings along cut-banks. Private bank protection in local areas.	Private bank protection in local areas. Revetments and levee near Puget Sound Energy outfall. Interurban Bike Trail Bridge 1999.

WHITE RIVER CMZ ANALYSIS
GEOMORPHIC REACH DESCRIPTIONS

Reaches:	**White 4**	**White 3**	**White 2**	**White 1**
River Miles :	2.6-3.0	1.4-2.6	0.4-1.4	0-0.4
Length: (Feet)	2,231	6,105	5,943	2,087
Gradient: (%)	0.09	0.08	0.04	0.03
Valley configuration:	The valley is over 7,000 feet wide. The river remains on the east half of the valley.	The valley is over 7,000 feet wide. The river crosses the valley to the west side.	The valley widens to 8,000 feet wide. The river is close to the west valley wall.	The Puyallup and Stuck Valleys merge forming a flat broad valley 10,000 feet wide. The White River remains close to the northwest valley wall.
Floodplain and Terraces: (presence, and character)	Extensive floodplains (continuous, both sides)	Extensive floodplains (continuous, both sides)	Narrow floodplains (discontinuous, on both sides) terraces (discontinuous, on both sides)	Moderate floodplains (continuous, both sides)
Floodplain Features:	Ancient channel scars (right)	None	None	Oxbow right of the river
Dominant Channel Pattern:	Historically: straight single-thread Existing: straight, vertically, incised single-thread	Historically: straight single-thread Existing: straight, vertically, incised single-thread	Historically: straight single-thread Existing: straight, vertically, incised single-thread	Historically: straight single-thread Existing: straight, vertically, incised single-thread
Measured Maximum Migration Rate: (feet/year)	0.0	4.4	1.1	0.0
Width of Observed Active Channel to High Flow Channel:	100%	100%	100%	100%
Gravel Bar Character (within the Channel Corridor):	None	None	None	Small, Sand bars form at the confluence
Tributaries: Name, confluence location (side of the river it enters)	Unnamed Ditch RM 2.6 (right)	Salmon Creek, RM2.0 (right)	Jovita Creek (Ditch), RM 1.2 (right); Unnamed Ditch, RM 0.9 (left)	None
Primary Bank Soil:	Alluvial silt, sand and gravel	Alluvial silt, sand and gravel	Alluvial silt, sand and gravel	Alluvial silt and sand
Bedload: listed order of observed composition	Sand	Sand	Sand	Sand
Sediment Source Area	Upstream, tributary	Upstream, tributary	Upstream, tributary	Upstream
Existing Infrastructure:	Railroad alignments (left)	New Tacoma Ave East Bridge (1999), 145th Ave East bridge (removed by 1965) 142 Avenue E (right)	Bridge Street Bridge (RM 0.7) Abandoned Sumner Railroad Bridge (RM 1.1) 142nd Avenue E Street Bridge (RM 1.3)	State Route 410 Bridge (RM 0.2)
Revetments and Levees: (presences)	Private bank protection in local areas	Small rock groins and pilings along cut-banks. Private bank protection in local areas.	Concrete revetments/mats placed on the cut banks	Levees cut off oxbows and protect the sewage plant

APPENDIX C

DRAFT DELINEATION CRITERIA
LOW, MODERATE, SEVERE MIGRATION POTENTIAL AREAS
PUYALLUP, CARBON, WHITE RIVER

APPENDIX C

DRAFT DELINEATION CRITERIA
LOW, MODERATE, SEVERE MIGRATION POTENTIAL AREAS
PUYALLUP, CARBON, WHITE RIVER

SEVERE MIGRATION POTENTIAL AREA:

Definition: Areas adjacent to the outside edges of the historic channel occupation tract (HCOT) boundaries, as determined by the results of the historic aerial photographic evaluation. The width of the severe migration potential area will be determined for each individual geomorphic stream reach, based on the distance the channel edge could travel in 5 years of steady lateral migration. The rate of migration used in the calculation will be the maximum rate of migration measured for each geomorphic reach.

This distance will be measured from the outside boundary of the HCOT.

MODERATE MIGRATION POTENTIAL AREA:

Definition: Areas adjacent to the outside boundaries of severe migration potential areas. The width of the moderate migration potential area will be determined for each individual geomorphic stream reach, based on the distance the channel could travel in 10 years of steady lateral migration at the maximum rate of migration for each reach.

The width of the moderate migration potential area will be calculated from the outside boundary of the severe migration potential area. In areas where geomorphic features capable of capturing stream flow (i.e., ancient abandoned channels, oxbows, secondary channels, ditches, topographic lows) are present outside of the severe migration potential area, the width of the moderate migration potential area will be extended by a distance equivalent to an additional 5 years of migration (i.e., 15 years total). The outside boundary of the moderate migration potential area will be determined based on the calculated distance of migration, the presence of valley slopes and other obstructions representing barriers to migration.

LOW MIGRATION POTENTIAL AREAS:

Definition: Areas unlikely to experience channel migration within a 15- to 20-year period, depending on the presence of geomorphic features in the moderate migration potential area.

EXCEPTIONS:

- The width of Severe and Moderate Migration Potential Areas may be increased based on geologic interpretation and professional judgment, and agreement with county staff.
- Areas protected by hard geologic materials, such as volcanic bedrock and glacial till, with very low (non-measurable) rates of erosion will be designated as Moderate or Low Migration Potential Areas, based on our geologic interpretation and professional judgment.

APPENDIX D

LIST OF EXCEPTIONS USED TO CREATE THE CMZ AND MPAs

APPENDIX D
LIST OF EXCEPTIONS USED TO CREATE THE CMZ AND MPAS

PUYALLUP, CARBON, AND WHITE RIVERS
PIERCE COUNTY, PUBLIC WORKS AND UTILITIES, ENVIRONMENTAL SERVICES, WATER PROGRAMS DIVISION

River	Reach	River Mile	Side of the River*	Affected Area	Exceptional Condition	Basis for Exception
Puyallup	18	28.5-17.6	both	CMZ, MPA	Width of CMZ and MPA calculated based on rate of migration through mudflow deposit.	Electron mudflow more resistant to erosion, causes decrease in local migration rates.
Puyallup	18	28.2-28.5	right	CMZ, MPA	Width of CMZ and moderate and severe MPA's reduced. CMZ boundary placed along base of valley wall	Bedrock valley wall limits lateral migration
Puyallup	18	28.0-27.9	right	CMZ, MPA	Width of CMZ and moderate and severe MPA's reduced. CMZ boundary placed along base of valley wall	Bedrock valley wall limits lateral migration
Puyallup	18	27.6-27.2	left	CMZ, MPA	Width of CMZ and moderate MPA increased to include ancient abandoned channel.	Ancient channel capable of capturing mainstem flow
Puyallup	18	27.5-27.1	right	CMZ, MPA	CMZ boundary placed along top of valley wall.	1998 high flow channel located along base of valley wall. Valley wall composed of soils subject to erosion. wasting.
Puyallup	17	27.0-28.0	left	HCOT, CMZ, MPA	Left HCOT boundary extended in various locations to include area occupied by active channel between 1931 and 1965	Aerial photos indicate areas occupied by active channel between 1931 and 1965
Puyallup	17	26.3-25.4	left	CMZ, MPA	Width of CMZ and moderate and severe MPA's reduced. CMZ boundary placed along base of valley wall	Bedrock valley wall limits lateral migration
Puyallup	17	25.6-27.0	right	HCOT, CMZ, MPA	Right HCOT boundary extended in various locations to include area occupied by active channel between 1931 and 1965	Aerial photos indicate areas occupied by active channel between 1931 and 1965
Puyallup	16	25.4-25.1	both	CMZ, MPA	Width of CMZ and moderate and severe MPA's reduced. CMZ boundary placed along base of valley wall	Bedrock valley wall limits lateral migration
Puyallup	15	25.1-24.5	left	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow
Puyallup	15	24.6-24.3	right	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow
Puyallup	15	24.1-23.6	right	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow
Puyallup	14	23.6-23.4	left	CMZ, MPA	Width of CMZ and moderate and severe MPA's reduced. CMZ boundary placed along base of valley wall	Bedrock valley wall limits lateral migration
Puyallup	14-13	23.4-22.8	left	CMZ, MPA	CMZ boundary placed along top of valley wall.	1998 high flow channel located along base of valley wall. Valley wall composed of soils subject to erosion. wasting.
Puyallup	14-13	22.8-22.4	right	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow

River	Reach	River Mile	Side of the River*	Affected Area	Exceptional Condition	Basis for Exception
Puyallup	12-11	22.5-19.4	left	CMZ	Width of CMZ increased to include ancient abandoned channel.	Professional judgment; ancient channel is partly filled in and unlikely to capture main-stem flow, but should be included in CMZ
Puyallup	12	21.9-20.9	left	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow
Puyallup	12	20.8-20.7	right	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow
Puyallup	12	20.3-20.2	right	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow
Puyallup	11	19.6-19.4	right	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow
Puyallup	10	19.2-17.8	left	CMZ, MPA	CMZ boundary placed along top of valley wall, moderate MPA extends over slope face to CMZ boundary.	1998 high flow channel located along base of valley wall. Valley wall composed of soils subject to erosion. wasting.
Puyallup	10	19.1-18.5	left		Right HCOT and severe MPA boundaries placed along toe of valley wall. Severe MPA extended slightly to include ancient abandoned channel at base of slope.	Professional judgment; slope conditions and historic channel behavior do not support extension of severe zone onto slope face.
Puyallup	10	18.4-18.0	left	CMZ, MPA	CMZ boundary placed along top of valley wall.	Valley wall composed of glacially derived soils subject to erosion.
Puyallup	9	17.8-17.7	left	HCOT, CMZ, MPA	Left HCOT boundary extended to include area occupied by active channel between 1931 and 1940	Aerial photos indicate areas occupied by active channel between 1931 and 1940
Puyallup	8	17.4-17.1	right	CMZ, MPA	CMZ and MPA calculated based on rate of migration through mudflow deposit.	Electron mudflow more resistant to erosion, causes decrease in local migration rates.
Puyallup	7	16.8-16.7	right	CMZ	CMZ boundary is extended to base of valley wall	Professional judgment and continuity with upstream and downstream boundaries.
Puyallup	6	16.4-16.0	left	HCOT, CMZ, MPA	Left HCOT boundary extended to include area occupied by active channel between 1931 and 1940	Aerial photos indicate areas occupied by active channel between 1931 and 1940
Puyallup	6	16.4-15.9	right	CMZ, MPA	CMZ boundary placed along top of valley wall.	1998 high flow channel located along base of valley wall. Valley wall composed of soils subject to erosion. wasting.
Puyallup	5	15.4-15.0	right	CMZ, MPA	CMZ boundary placed along top of valley wall.	1998 high flow channel located along base of valley wall. Valley wall composed of soils subject to erosion. wasting.
Puyallup	4	14.8-13.8	right	CMZ	Width of CMZ increased to include ancient abandoned channels and floodplain drainage channels.	Ancient and/or drainage channels likely not capable of mainstem capture, but should be included in CMZ.
Puyallup	4	14.6-14.0	right	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow
Puyallup	4	14.4-14.0	left	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow
Puyallup	4	14.0-13.8	left	HCOT, CMZ, MPA	Left HCOT boundary extended to include area occupied by active channel between 1931 and 1940	Aerial photo indicates areas occupied by active channel between 1931 and 1940
Puyallup	4	13.8-13.2	left	MPA	Width of severe and moderate MPAs increased to include ancient abandoned channel (detached from main stem channel).	This area is subject to surface scour and channelization during significant flooding; possible future avulsion potential .

River	Reach	River Mile	Side of the River*	Affected Area	Exceptional Condition	Basis for Exception
Puyallup	3	13.2-12.8	right	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow
Puyallup	2, 3	13.2-12.0	left	MPA	Width of moderate MPA increased to include area inside right-angle bends in Reach 3.	Professional judgment; possible future bend cut off and proximity to left bank abandoned channels in Reach 4.
Puyallup	2	11.7-12.0	both	MPA	Width of severe and moderate MPAs reduced.	No lateral migration observed over period of record, channel is deeply incised and entrenched in Osceola Mudflow deposits.
Puyallup	1	11.4-11.0	right	CMZ	Width of CMZ increased to include ancient channels.	Professional judgment; ancient channels not capable of capturing streamflow, but should be included in CMZ
Puyallup	1	11.3-10.8	left	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow
Carbon	7	8.3-6.5	right	CMZ, MPA	CMZ boundary placed along top of valley wall.	1998 high flow channel located along base of valley wall. Valley wall composed of soils subject to mass wasting.
Carbon	7	8.2-6.4	left	HCOT, CMZ, MPA	HCOT moved landward in various locations to include areas occupied by active channel between 1931 and 1965	Aerial photos indicate areas occupied by active channel between 1931 and 1965
Carbon	5	5.8	right	CMZ	CMZ boundary excludes topographic knob.	Knob composed of bedrock and deflecting flow.
Carbon	5, 4	5.7-4.4	right	CMZ, MPA	CMZ boundary placed along top of valley wall, moderate MPA extends over slope face to CMZ boundary.	1998 high flow channel located along base of valley wall. Valley wall composed of soils subject to mass wasting.
Carbon	4	5.2-4.2	right	MPA	Right HCOT and severe MPA boundaries placed along toe of valley wall.	Professional judgment; slope conditions and historic channel behavior do not support extension of severe zone onto slope face.
Carbon	4	5.2-4.2	left	CMZ	Decrease width of CMZ; Boundary follows a break in slope on valley floor.	An alluvial fan originating from Voight Creek has created low-relief topography steering the river northward.
Carbon	4, 3	4.5-4.0	left	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing flow
Carbon	3, 1	4.2-0.0	left	CMZ, MPA	Width of CMZ and MPA calculated based on rate of migration through mudflow deposit.	Electron mudflow more resistant to erosion, causes decrease in local migration rates.
Carbon	3	3.5-3.1	left	HCOT, CMZ, MPA	HCOT moved landward to include areas occupied by active channel between 1931 and 1940	Aerial photo indicate areas occupied by active channel between 1931 and 1965
Carbon	2, 1	3.1-0.8	right	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow
White	7	5.4-5.1	left	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow
White	7	5.2-4.9	right	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow
White	6	4.5-4.4	right	HCOT, CMZ, MPA	Right HCOT boundary extended to include area occupied by active channel between 1931 and 1940	Aerial photo indicates areas occupied by active channel between 1931 and 1940
White	1	0.2-0.0	right	MPA	Width of moderate MPA increased to include ancient abandoned channel	Ancient channel capable of capturing mainstem flow

* (looking downstream)

APPENDIX E

CD-ROM PACKAGE

APPENDIX E

CD-ROM PACKAGE

GIS layers and documentation are provided on a CD-ROM package, which accompanies this report. The GIS layers include CMZ boundaries, migration potential areas, dated channel locations, historical channel occupation tracts (HCOT), and selected aerial photos for 1931, 1940, 1965, 1970, 1978, 1987, 1991, and 1996 in GIS compatible format. The CD-ROM package was delivered to Pierce County Department of Public Works and Utilities.

APPENDIX F

REPORT LIMITATIONS AND GUIDELINES FOR USE

APPENDIX F

REPORT LIMITATIONS AND GUIDELINES FOR USE[1]

This appendix provides information to help you manage your risks with respect to the use of this report.

GEOTECHNICAL SERVICES ARE PERFORMED FOR SPECIFIC PURPOSES, PERSONS AND PROJECTS

This report has been prepared for the exclusive use of Pierce County Department of Public Works and Utilities and their authorized agents. This report is not intended for use by others, and the information contained herein is not applicable to other sites.

GeoEngineers structures our services to meet the specific needs of our clients. For example, a geotechnical or geologic study conducted for a civil engineer or architect may not fulfill the needs of a construction contractor or even another civil engineer or architect that are involved in the same project. Because each geotechnical or geologic study is unique, each geotechnical engineering or geologic report is unique, prepared solely for the specific client and project site. Our report is prepared for the exclusive use of our Client. No other party may rely on the product of our services unless we agree in advance to such reliance in writing. This is to provide our firm with reasonable protection against open-ended liability claims by third parties with whom there would otherwise be no contractual limits to their actions. Within the limitations of scope, schedule and budget, our services have been executed in accordance with our Agreement with the Client and generally accepted geotechnical practices in this area at the time this report was prepared.. This report should not be applied for any purpose or project except the one originally contemplated.

A GEOTECHNICAL ENGINEERING OR GEOLOGIC REPORT IS BASED ON A UNIQUE SET OF PROJECT-SPECIFIC FACTORS

This report has been prepared for the Upper Cowlitz River and Rainey Creek. GeoEngineers considered a number of unique, project-specific factors when establishing the scope of services for this project and report. Unless GeoEngineers specifically indicates otherwise, do not rely on this report if it was:

- not prepared for you,
- not prepared for your project,
- not prepared for the specific site explored.

SUBSURFACE CONDITIONS CAN CHANGE

This geotechnical or geologic report is based on conditions that existed at the time the study was performed. The findings and conclusions of this report may be affected by the passage of time, by manmade events such as construction on or adjacent to the site, or by natural events such as floods, earthquakes, slope instability or groundwater fluctuations. Always contact GeoEngineers before applying a report to determine if it remains applicable.

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[1] Developed based on material provided by ASFE, Professional Firms Practicing in the Geosciences; www.asfe.org .

MOST GEOTECHNICAL AND GEOLOGIC FINDINGS ARE PROFESSIONAL OPINIONS

Our interpretations of subsurface conditions are based on field observations from widely spaced sampling locations at the site. Site exploration identifies subsurface conditions only at those points where subsurface tests are conducted or samples are taken. GeoEngineers reviewed field data and then applied our professional judgment to render an opinion about subsurface conditions throughout the site. Actual subsurface conditions may differ, sometimes significantly, from those indicated in this report. Our report, conclusions and interpretations should not be construed as a warranty of the subsurface conditions.

A GEOTECHNICAL ENGINEERING OR GEOLOGIC REPORT COULD BE SUBJECT TO MISINTERPRETATION

Misinterpretation of this report by others can result in costly problems. You could lower that risk by having GeoEngineers confer with appropriate members of the design team after submitting the report. Also retain GeoEngineers to review pertinent elements of the design team's plans and specifications. Contractors can also misinterpret a geotechnical engineering or geologic report. Reduce that risk by having GeoEngineers participate in pre-bid and preconstruction conferences, and by providing construction observation.

READ THESE PROVISIONS CLOSELY

Some clients, design professionals and contractors may not recognize that the geoscience practices (geotechnical engineering or geology) are far less exact than other engineering and natural science disciplines. This lack of understanding can create unrealistic expectations that could lead to disappointments, claims and disputes. GeoEngineers includes these explanatory "limitations" provisions in our reports to help reduce such risks. Please confer with GeoEngineers if you are unclear how these "Report Limitations and Guidelines for Use" apply to your project or site.

GEOTECHNICAL, GEOLOGIC AND ENVIRONMENTAL REPORTS SHOULD NOT BE INTERCHANGED

The equipment, techniques and personnel used to perform an environmental study differ significantly from those used to perform a geotechnical or geologic study and vice versa. For that reason, a geotechnical engineering or geologic report does not usually relate any environmental findings, conclusions or recommendations; e.g., about the likelihood of encountering underground storage tanks or regulated contaminants. Similarly, environmental reports are not used to address geotechnical or geologic concerns regarding a specific project.

CHANNEL MIGRATION ZONE BOUNDARY AND MIGRATION POTENTIAL AREAS PIERCE COUNTY, WASHINGTON CHANNEL MIGRATION ZONE STUDY FOR THE PUYALLUP, WHITE, AND CARBON RIVERS

PLATE 1

COMPILED BY

GeoEngineers

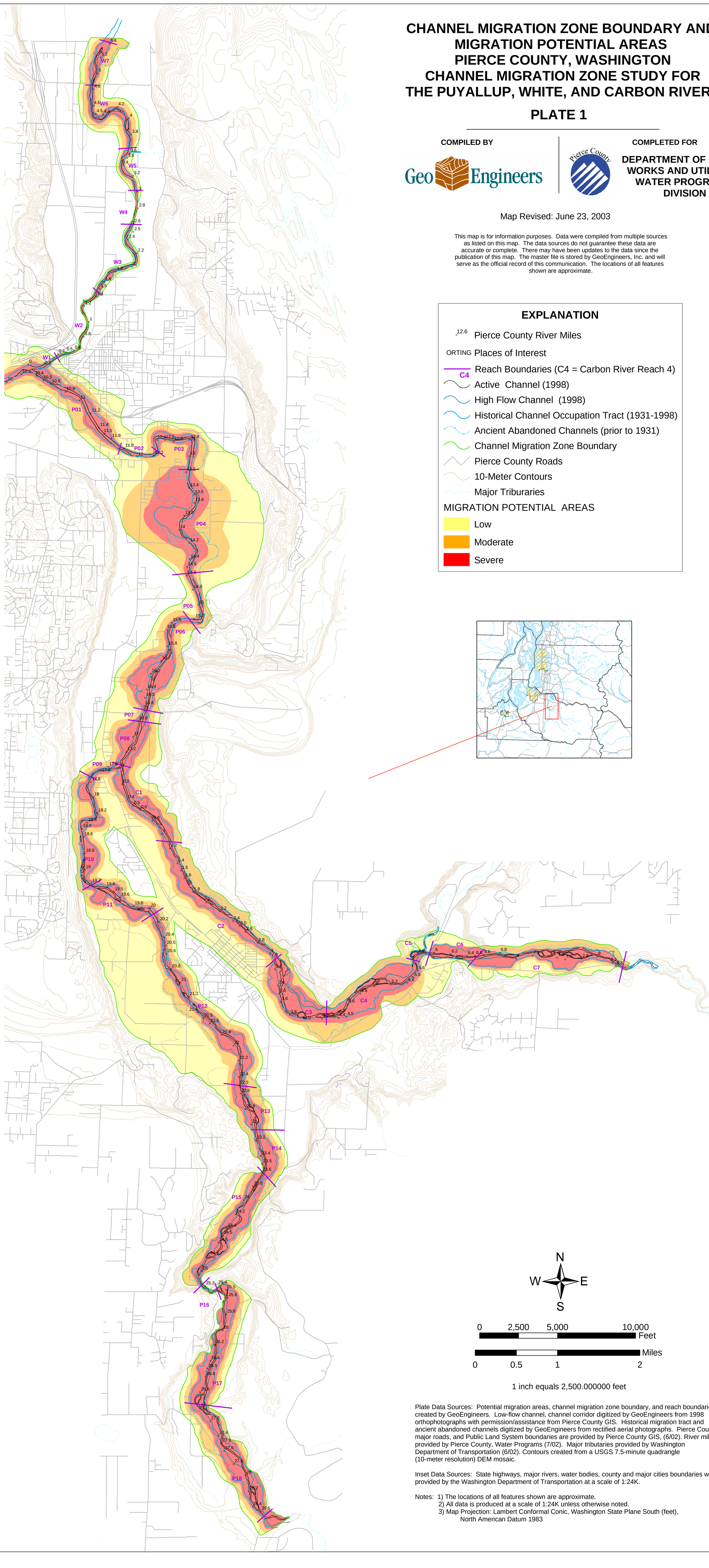
COMPLETED FOR

Pierce County

DEPARTMENT OF PUBLIC WORKS AND UTILITES, WATER PROGRAMS DIVISION

Map Revised: June 23, 2003

This map is for information purposes. Data were compiled from multiple sources as listed on this map. The data sources do not guarantee these data are accurate or complete. There may have been updates to the data since the publication of this map. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication. The locations of all features shown are approximate.



EXPLANATION

- 12.6 Pierce County River Miles
- ORTING Places of Interest
- C4 Reach Boundaries (C4 = Carbon River Reach 4)
- Active Channel (1998)
- High Flow Channel (1998)
- Historical Channel Occupation Tract (1931-1998)
- Ancient Abandoned Channels (prior to 1931)
- Channel Migration Zone Boundary
- Pierce County Roads
- 10-Meter Contours
- Major Triburaries

MIGRATION POTENTIAL AREAS

- Low
- Moderate
- Severe

1 inch equals 2,500.000000 feet

Plate Data Sources: Potential migration areas, channel migration zone boundary, and reach boundaries created by GeoEngineers. Low-flow channel, channel corridor digitized by GeoEngineers from 1998 orthophotographs with permission/assistance from Pierce County GIS. Historical migration tract and ancient abandoned channels digitized by GeoEngineers from rectified aerial photographs. Pierce County major roads, and Public Land System boundaries are provided by Pierce County GIS, (6/02). River miles provided by Pierce County, Water Programs (7/02). Major tributaries provided by Washington Department of Transportation (6/02). Contours created from a USGS 7.5-minute quadrangle (10-meter resolution) DEM mosaic.

Inset Data Sources: State highways, major rivers, water bodies, county and major cities boundaries were provided by the Washington Department of Transportation at a scale of 1:24K.

Notes: 1) The locations of all features shown are approximate.
2) All data is produced at a scale of 1:24K unless otherwise noted.
3) Map Projection: Lambert Conformal Conic, Washington State Plane South (feet), North American Datum 1983