SWANSON HYDROLOGY + GEOMORPHOLOGY

FINAL REPORT

Lower Gales Creek Enhancement Planning
Geomorphic Assessment - Technical Study

Tualatin River Watershed Council

July 28, 2006

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1. Introduction

1.1 Problem Statement

In March of 2003 the Tualatin River Watershed Council completed work on the Lower Gales Creek Habitat Enhancement Plan (LGCHEP). The purpose of the LGCHEP was to outline an anadromous fish habitat enhancement strategy for a four mile section of Gales Creek that was identified as a priority restoration area through the Gales Creek Watershed Assessment Project (Bruener, 1998). From this process, the LGCHEP identified nine potential restoration projects designed to improve habitat conditions for steelhead (*Oncorhynchus mykiss*) and other salmonids. The nine projects included diverse habitat enhancement measures such as widening riparian buffers, increasing channel complexity by installing engineered log jams, and enhancing floodplain and secondary channel dynamics. To move these projects forward to the design, permitting, and implementation phase, the Bureau of Reclamation has requested that a geomorphic analysis be conducted on the study reach to evaluate the following issues:

- How is the channel functioning geomorphically as compared to historic conditions?
- What is the expected long term stability of the channel?
- Are the recommended projects appropriate within the existing morphology and sediment transport regime?
- What effects would the proposed projects have on planform and profile stability and sediment transport conditions?
- Are there external factors, such as land-use change or changes in downstream base level that would affect the future success of the proposed enhancement activities?

1.2 Study Goals and Objectives

Swanson Hydrology and Geomorphology (SH+G), an environmental consulting firm located in the Portland area, was hired to address these questions through a field and modeling-based geomorphic and hydrologic analysis of the study area. The geographic scope of the study included the approximately four mile stretch of the mainstem of Gales Creek from the Stringtown Bridge near the confluence of Prickett Creek upstream to the Gales Creek Road Bridge near the Iler Creek confluence (Figure 1). Areas outside of the study area were evaluated, where necessary, to gain a better understanding of sediment supply to the study reach and overall planform stability.

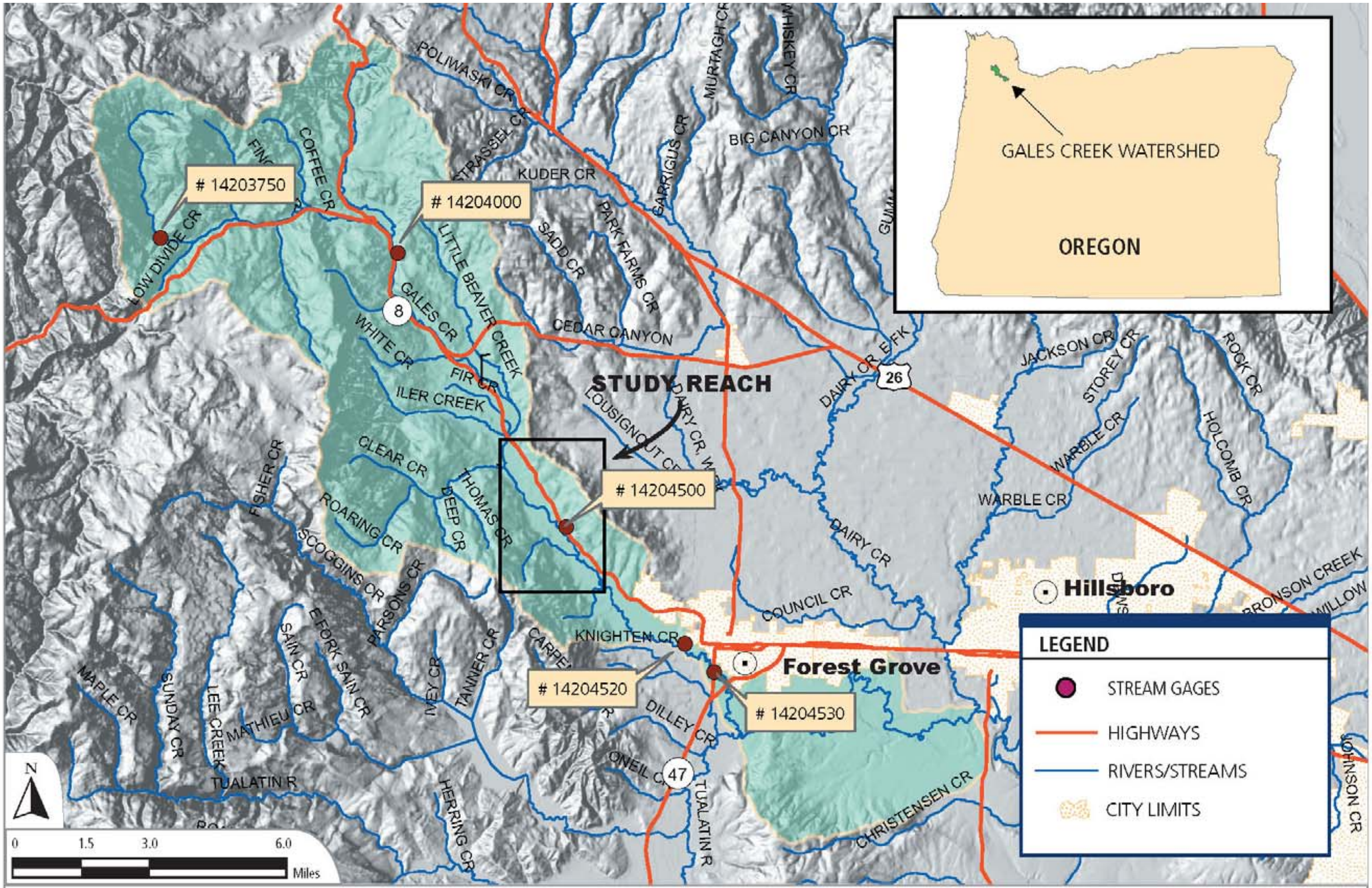

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FIGURE 1: General location map for the Gales Creek watershed and geomorphic assessment study area. Gales Creek is located in Washington County, on the Eastern side of the Oregon Coast Range.

The primary study objective was to develop an understanding of the geomorphology of the study reach so as to support and/or identify potential restoration efforts that will improve habitat conditions for salmonids in Gales Creek and the Tualatin River watershed. The tasks outlined by SH+G to meet the study objectives and prepare a technical document describing the results are as follows:

- Historic Geomorphic Analysis: An evaluation and description of geomorphic conditions and functions that were present prior to intensive land uses of the 19th and 20th centuries,

- Existing Conditions Analysis: An evaluation of current channel morphology and function, probable expected future conditions, and opportunities and constraints to restoration. Includes a brief analysis of existing hydrologic and sediment transport to support the analysis,

- Restoration Project Evaluation: Sites and techniques recommended in the LGCHEP were evaluated in relation to geomorphic conditions to determine their effectiveness in achieving the stated goals of the restoration effort,

- Technical Report – Draft and Final

2. Setting

Gales Creek is a major tributary to the Tualatin River and is located in Washington County, Oregon. The watershed encompasses approximately 78 square miles of primarily state owned and private forest land on the eastern side of the Coast Range. The lower watershed consists of a broad alluvial valley that opens up to the Tualatin Valley near the City of Forest Grove. Agricultural and rural residential uses dominate the lower valley. The City of Forest Grove owns a large portion of the Clear Creek watershed, which is used as a municipal water supply.

The climate of the Gales Creek watershed is characterized by a wet season and a dry season. The wet season typically runs from October to May with the dry season running from June to September. Rainfall totals in the western end of the watershed average up to 115 inches per year, whereas lower elevation areas on the eastern end near Forest Grove only receive an average of 45 inches of rainfall each year. This discrepancy is due to a phenomenon known as a “rain shadow” where rainfall gets squeezed out of storm systems on the western flanks of the Coast Range with less rain available for the eastern flanks and Willamette Valley. Most precipitation in the watershed falls as rain, though snowfall can occur.

Rock types within the Gales Creek watershed consist solely of young geologic material, primarily derived from the Eocene and Oligocene ages of the Tertiary period (Figure 2). Volcanic and sedimentary materials underlie much of the watershed creating highly erodible

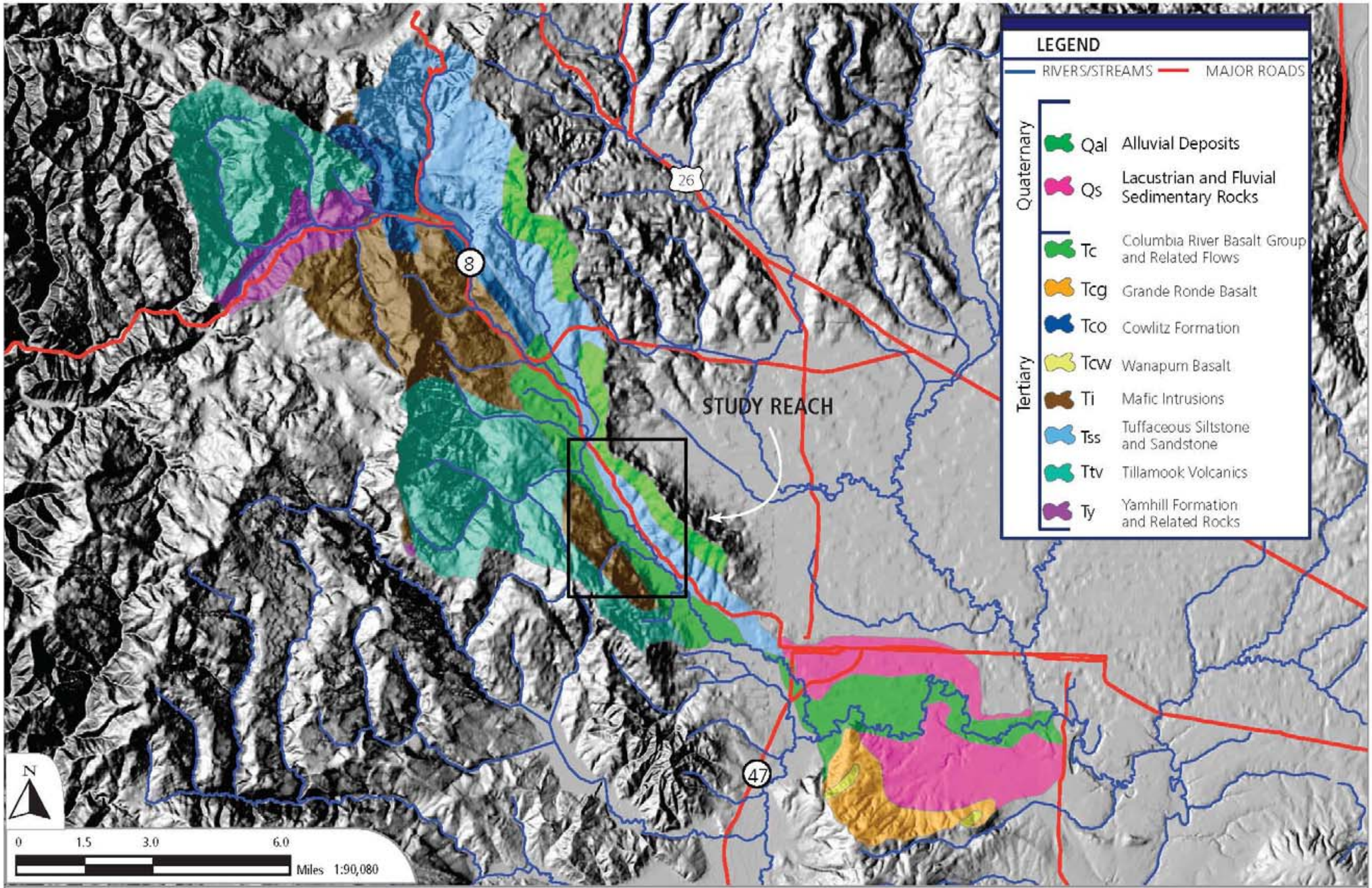

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FIGURE 2: Geologic rock types for the Gales Creek watershed. Mapping data was taken from the Tualatin River Watershed Information System (1998), and clipped to the Gales Creek Watershed. The study reach primarily consists of recent alluvial deoposits with tertiary outcrops of Tuffaceous mudstones and mafic intrusions.

conditions where slopes are steep (Figure 3). The study reach, located along a low gradient, wide valley bottom, consists primarily of recent alluvial deposits that appear to be fairly shallow in some areas. Where the channel has incised deeply into the valley bottom, bedrock outcrops have been exposed. Two types of bedrock outcrops were identified in the field and can be differentiated by their resistance to erosion. The softer material is a marine tuffaceous siltstone and sandstone (Tss) that appears susceptible to incision. The more resistant material is a Mafic intrusion consisting of a massive granophyric ferrogabbro. This material appears to resist incision, meaning erosion into a Mafic outcrop would likely result in longterm stability of the local channel profile or migration of the creek channel into less resistant material.

3. Channel Conditions

3.1 Historic Conditions

Stream channels function in a physical sense to transport watershed products, including water, sediment, woody debris, and nutrients, to the lower end of the catchment. All of the fundamental characteristics of the channel, such as planform, capacity, and width-depth ratio, are reflective of the quantity and characteristics of watershed products supplied to the channel, and eventually transported through it. Changes in the quantity or characteristics of watershed products supplied to the channel are likely to result in changes in fundamental channel characteristics, although the link between the watershed and the channel is complex and specific channel response to watershed changes may be difficult to predict (Lisle, 1999).

The supply of watershed products to the stream channel is to a great extent determined by geology and climate. Often termed independent variables in models of channel response, geology and climate do not respond to other factors governing channel behavior, and are not influenced by human management. The influence of these independent variables on channel behavior is felt across the entire watershed. Topography and watershed gradients, which sensitively control the rate of erosion, are dictated by tectonic activity and subsequent fluvial erosion. The quantity and size of bedload and suspended load sediments available for transport by the channel are a function of the erodibility of rocks in the watershed and their mode of transport from hillslope to stream channel. Climate-driven precipitation determines the amount and timing of water and sediment supplied to the channel. Geologic and climatic histories are also important influences on the delivery of watershed products; for example, the effects of higher past erosion rates, driven by a wetter climate, still influence how erosion occurs today.

The transport of watershed products through the stream system is also highly influenced by climate and geology. Large-scale geologic features such as faults, landslides or bedrock constrictions influence the stream profile gradient, the continuity of sediment transport down-valley during floods, and the storage of sediment and wood on the floodplain (Grant and Swanson, 1995; Benda, 1990; Miller, 1994). The magnitude, timing and duration of floods have significant influence over rates of sediment transport. The study area on Gales Creek that is the focus of this project is located at a point in the watershed where the gradient

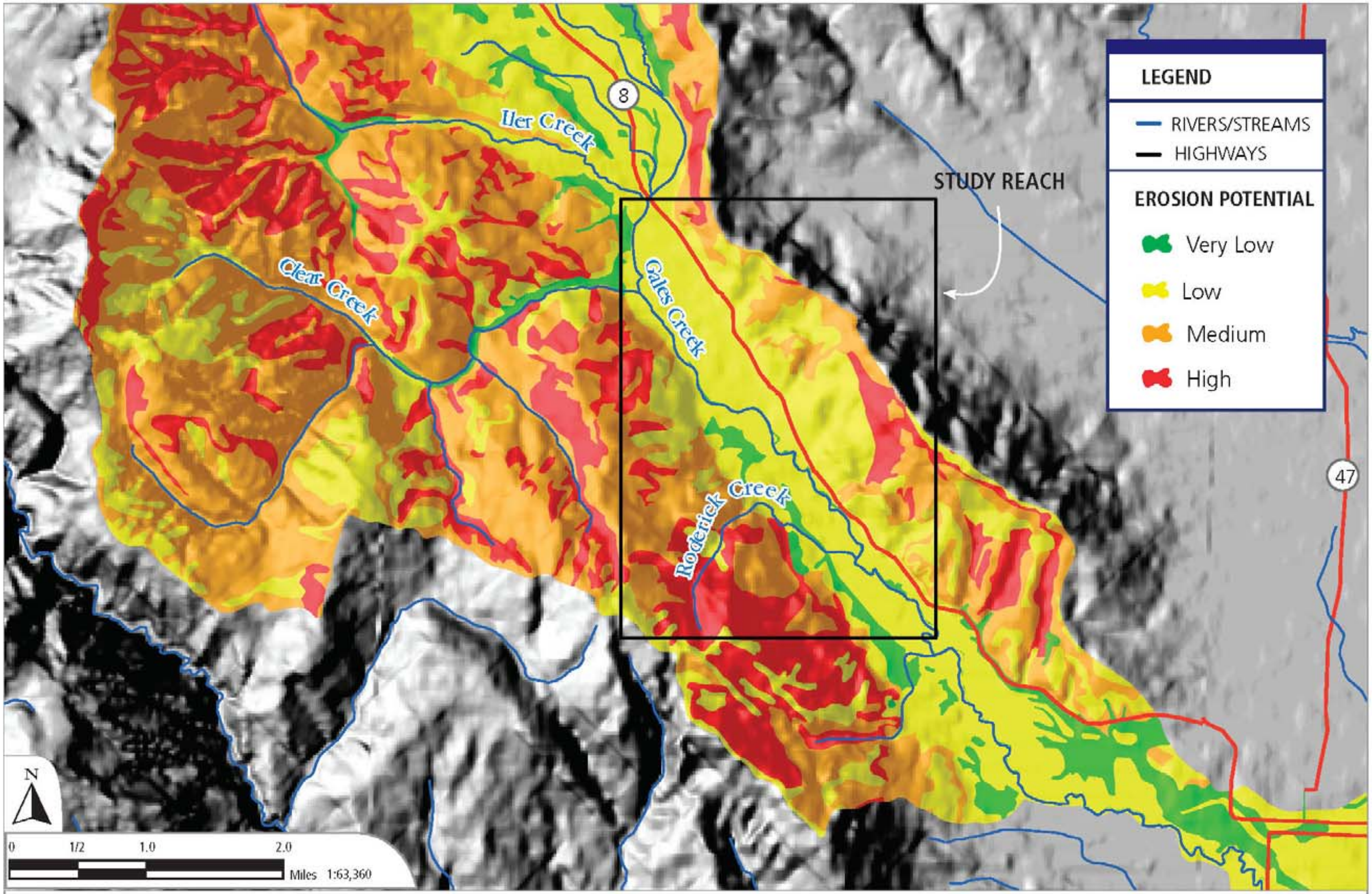

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FIGURE 3: Erosion potential for the central portion of teh Gales Creek watershed. Erosion potential is based on soil properties and slope, and was adapted from the Tualatin River Watershed Information System (1998).

declines slightly and the valley opens up into a broad alluvial plain that merges into the Tualatin Valley. Consequently, the upper portion of the study area was historically dominated by coarse sediment deposition that created a complex channel and floodplain valley form.

Channel morphology through the four mile study reach that is bounded by Prickett Creek on the downstream end and Iler Creek on the upstream end is much different today than it was when Europeans arrived in the 19th Century. Historically, the channel through the study reach most likely consisted of a mosaic of primary and secondary channels that avulsed and changed coarse in response to high flow events that delivered coarse sediment and debris. Gales Creek was most likely at, or nearly at-grade with the existing valley floor and had extensive backwater channels and wetlands that were formed by preceding flood events. The vegetation on the valley floor most likely consisted of a mix of hardwood and coniferous species that formed a dense understory and canopy. The dense understory was most likely thick with downed logs that created a rough channel and floodplain surface that obstructed flow, encouraged formation of new flow paths, and resulted in deposition of coarse sediment delivered from large landslides and debris flows in the upper watershed and adjacent tributaries.

Dunne and Leopold (1978) define the floodplain as the “flat area adjoining a river channel constructed by the river in the present climate and overflowed at times of high discharge”. Again, although this appears to be a simple definition, on closer examination the reality is more complex. For example, the flat area in this definition is a landform constructed primarily by slow lateral migration and overbank deposition. In developing a technique for channel classification, Rosgen (1994), working from the Dunne and Leopold concepts of bankfull discharge and floodplain formation, notes that the active floodplain is the area of the valley flat above bankfull discharge and below a flood prone stage, twice the maximum bankfull flow depth. He notes that this may include both active flood plain and low terrace (a former floodplain abandoned due to climatic or other changes) (Rosgen, 1994).

During floods, localized erosion and deposition occurs on the floodplain, resulting in a highly varied microtopography. Sediment deposition on the floodplain is a key element in establishing new riparian vegetation, as is localized erosion, which provides growing areas in proximity to the water table. Also, log jams and woody debris act as hydraulic controls in the channel, and influence groundwater elevation throughout the floodplain, increasing the amount of time that soil moisture is available during the growing season, and increasing the overall density of vegetation. Woody debris also plays a key role in stabilizing the floodplain by providing resistance to erosion in flood channels, storing and sorting sediment in localized areas, and preventing widespread erosion by resisting the tendency of flood flows to concentrate. Individual trees or downed logs break up floodplain flow paths.

The heterogeneous nature of the floodplain due to these processes contributes to the future recruitment of large trees and woody debris. Recent deposits of flood sediment deliver nutrient rich deposits of fine sediment onto the floodplain and thus provide suitable establishment areas for riparian vegetation. Areas of nutrient rich soil in areas of high roughness become favorable for the regeneration of large trees, providing for the next generation of large woody debris. This, then, perpetuates the long-term supply of woody debris, and provides for a steady state with respect to the level of resilience within the system.

Remnants of historic primary and secondary channels can be seen on the modern valley floor where the primary land use is agriculture. Today, several of these channel remain as small backwater channels dense with riparian vegetation that are cut off from their connection to the main channel by farm access roads. These channels, though not functioning biologically or morphologically as they did in the past, still provide some function by collecting and filtering farm runoff, thereby reducing pollutant loads to Gales Creek. These backwater channels also appear to have maintained a groundwater connection to the river and therefore may provide some wildlife benefit. Old primary channels can also be observed on the valley floor. They primarily persist today as dips in the valley floor and function primarily as drainage swales for farm runoff. Over time, these channels have been smoothed through filling and other modifications. Their form and relative depth provides indicators that they once were a primary flow paths for Gales Creek.

To generate a comparison of the spatial extent of the historic floodplain through the study area as compared to the present extent we used a combination of recent and historic aerial photos and USGS 1:24,000 topographic maps. Mapping historic floodplain extent was based on observed indicators in the field, assumptions about the relationship between the primary channel elevation and the elevation of the valley floor, and the presence of coarse scale morphological features of the valley floor such as its relative flatness, a marked break in slope between the adjacent hillsides and the valley floor, the presence of alluvial fan morphology at the mouths of tributary valleys, and its location relative to the larger Tualatin Valley landform. Based on these assumptions, the entire valley floor was mapped as floodplain producing the region presented in Figure 4. Between Iler and Pickett Creeks it was estimated that a total of 1,205 acres of floodplain used to exist on the valley floor.

The mid-19th century to the early 20th century was most likely a period of rapid change in land use and stream morphology on the lower Gales Creek valley floor. The large conifers that were present on the valley floor were often the first to be removed by an early wave of settlers to the area. The trees in the valley floor were large and grew quickly due to the presence of deep, fertile soils and year-round access to moisture in the valley bottom. Following removal of much of the marketable timber, agriculture took hold on the fertile soil. Development of agriculture requires clearing land, building levees, and controlling local and tributary drainage. Over time, this process affected most of the valley floor, confined Gales Creek to the edges of the valley to maximize usable farmland, and exacerbated future channel incision along much of lower Gales Creek. A morphology consisting of multiple channels, full of large woody material and high quality spawning and rearing areas for salmon, was confined to a relatively narrow corridor with a morphology that is efficient at moving both water and the watershed products that were delivered to it (e.g. – sediment, large woody material, etc). Consequently, the watershed products that historically created habitat complexity are now transported through the system, or have greatly reduced residence times, which results in simplified morphology and habitat.

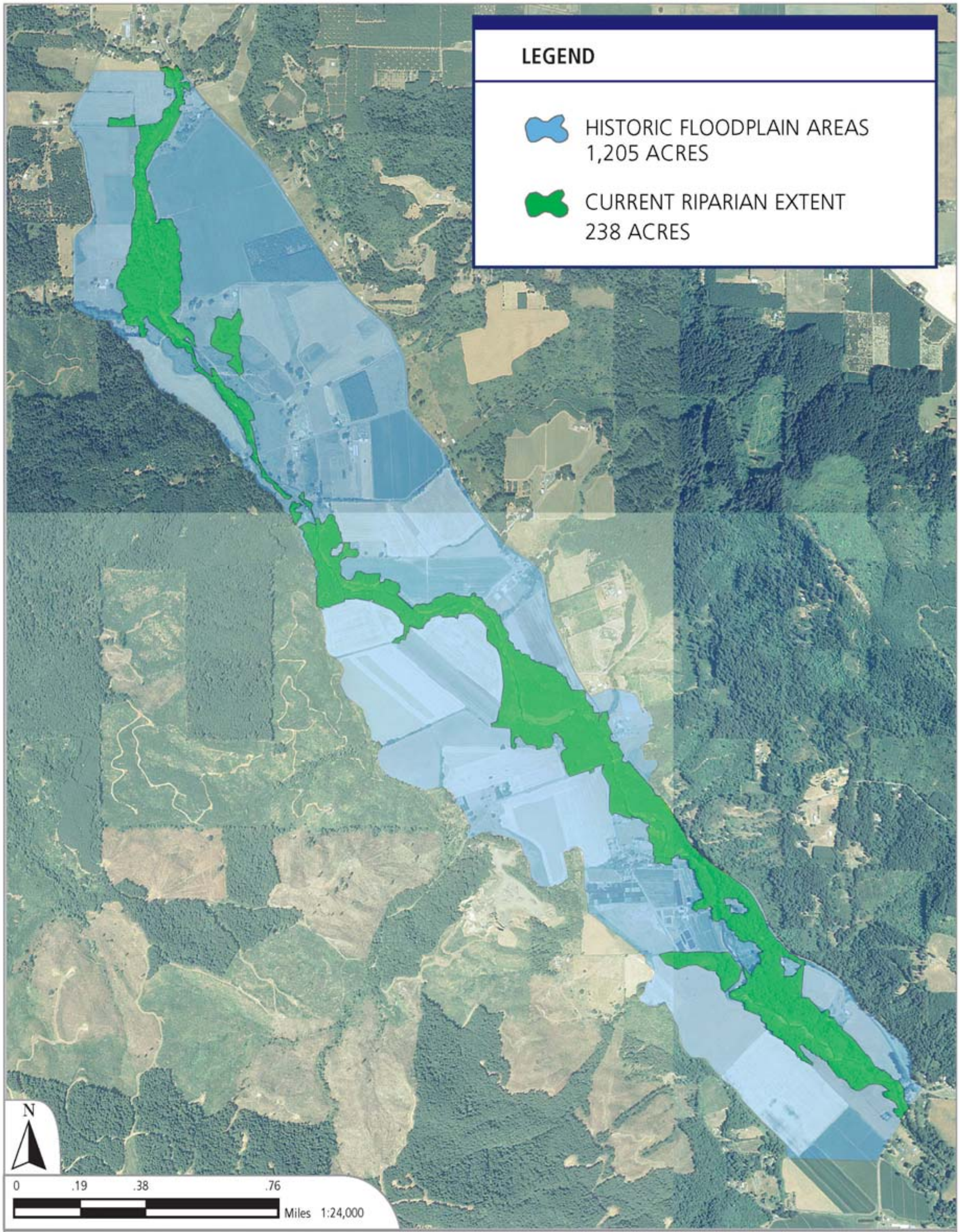

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FIGURE 4: Current and historic valley bottom areas. Historic refers to pre-European settlement. Current riparian extent was used as a proxy for areas that may have retained natural geomorphic function . Conversion of floodplain to farmland and confinement of the active channel has resulted in a marked change in how the Gales Creek study are functions geomorphically.

To evaluate the degree to which floodplain extent has been reduced over the last several decades, a series of aerial photos were obtained. Photos were obtained for 1974, 1989, and 2001 and the extent of riparian vegetation was mapped using each photo set. The extent of riparian vegetation was used as a proxy for floodplain extent since it was the most visible representation of where floodplain areas may be present and functioning. Though floodplain may occur outside of these areas, the additional floodplain most likely only floods during extremely high events and does not contain the elements necessary to allow for proper functioning of these areas as riparian or wetland habitat. Conversely, areas mapped as floodplain because they contained riparian vegetation may not be part of the functioning floodplain. They may in fact be fairly recently revegetated areas that are on terraces and therefore are not regularly flooded. Despite these limitations, we feel this approach provides the best means of estimating changes in floodplain extent over time.

Figure 5 shows floodplain extent for the 1974 and 1989 images. Riparian extent was mapped onto the 2001 aerial photos since those were digitally registered and therefore provided a way to compare acreages between photo sets. The 1974 and 1989 images were provided to us as hard copies by the Oregon Department of Forestry office in Salem. Figure 4 shows riparian extent overlain on the historic floodplain areas. The 1,205 acres of floodplain present in the early 19th century was reduced to approximately 292 acres by 1974, to 245 acres by 1989, and to 238 acres by 2001. Floodplain extent was reduced by 18% between 1974 and 2001, or a reduction of approximately 2 acres per year.

3.2 Implications of Morphologic Change on Stream Function

The historic Gales Creek channel and floodplain supported a healthy ecosystem by building and maintaining physical habitat that supported salmonids and other aquatic organisms. Physical habitat can be defined as the structure of the channel such as deep pools, clean riffles dominated by recently deposited gravel, and undercut banks. These physical habitat elements support salmonids in all stages of their life cycle by providing good quality spawning habitat, refuges from high flow conditions in the winter, and hiding places for both migrating adults and rearing juveniles. The key element in generating and maintaining good physical habitat relates primarily to two things: the channels morphologic response to discharge, sediment, and debris (Bellamy et al, 1992; Benda, 1990; Best and Keller, 1986; Grant and Swanson, 1995; Harris, 1988; Lanka and Hubert, 1987; Miller, 1994; Pitlick and Van Steeter, 1998), and the presence of roughness elements such as large woody material, bedrock outcrops, and boulders (Keller and MacDonald, 1995; Poff and Allan, 1995; Keller and Swanson, 1979; Keller et al, 1981).

In the Gales Creek study area, both of these key elements have been modified over time to maximize economic use of the valley floor. Constricting the channel and reducing total floodplain area has created a more homogeneous, less dynamic environment where the range of physical habitats necessary to support all life stages of salmonids have been greatly reduced. Flood flows are now focused into a single primary channel in most places, with the presence

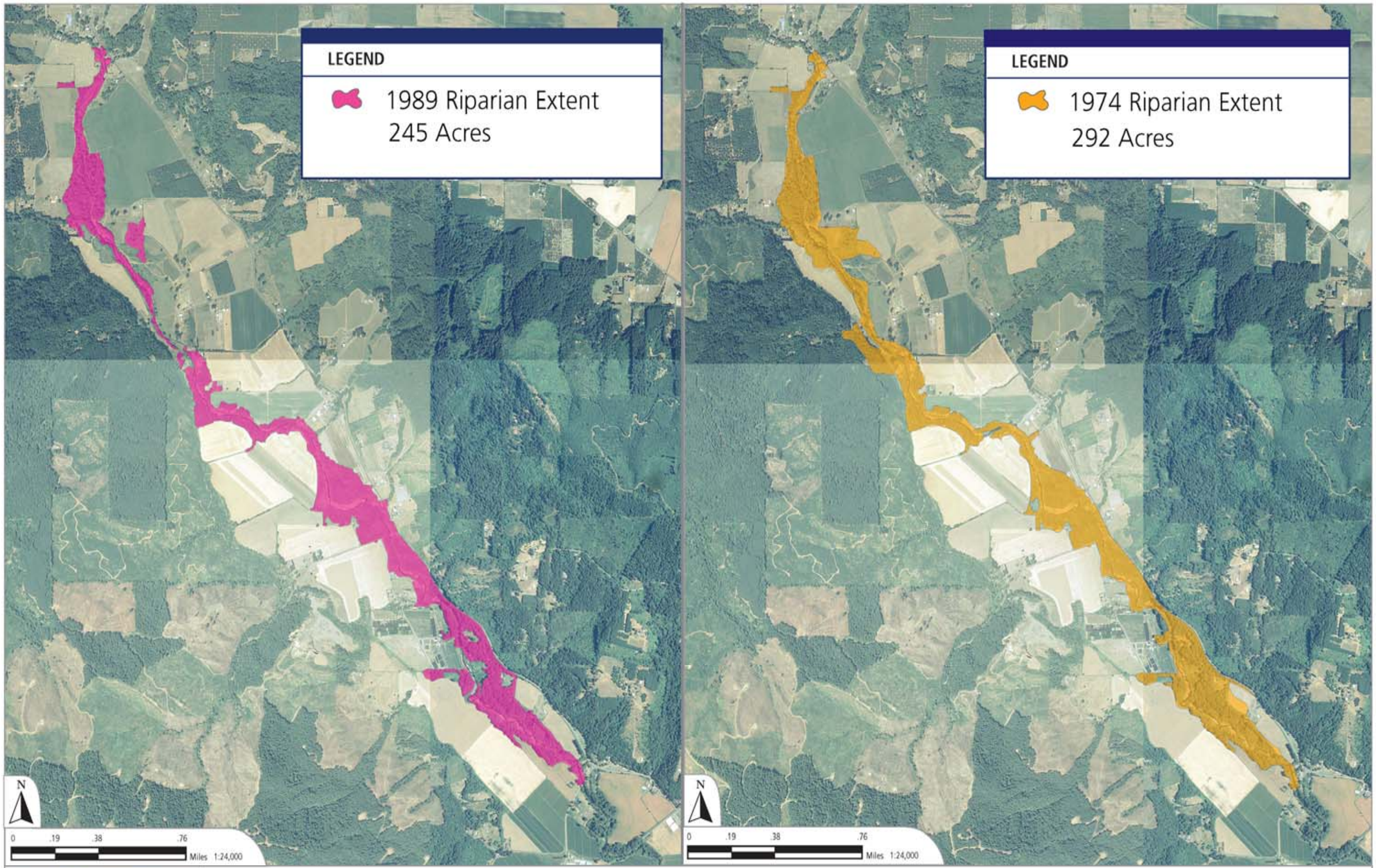

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FIGURE 5: Riparian extent based on aerial photos from 1989 and 1974 for the study reach. Riparian extent was used as a rough proxy of areas that may have retained a degree of natural geomorphic function. Detailed floodplain mapping was limited by the lack of high resolution topographic data.

of few physical obstructions. The lack of physical obstructions has resulted in higher flow velocities and more energy focused on the primary bed and banks of the channel. Consequently, the channel has incised, exposing steep banks that are prone to erosion. Channel incision and an increase in the energy focused on the bed and banks (referred to as shear stress) has created a channel system that is dominated by a muted pool and riffle sequence where the pools are fairly shallow and the riffles consist primarily of large gravel and cobble and are armored, limiting their usefulness as spawning areas. The high energy environment of incised channels has resulted in finer gravels being transported through the system rather than being deposited within these reaches.

Roughness elements, such as large cedar and Douglas fir logs are no longer present to the extent they were historically and do not play as much of a role in creating physical habitat. Historically, roughness elements, especially large woody material, were abundant, creating obstructions, diversity in the velocity field, and cover habitat for fish. Large woody material played a major role in creating a dynamic channel and floodplain dominated by avulsions, point bars, secondary channels, and backwater channels by creating obstructions to flow. These historic channel shifts were important in cleaning old spawning beds and creating new ones, limiting bed armoring, and scouring out deep pools and undercut banks. Without such obstructions present in the channel and on the floodplain, and limited potential for future recruitment due to the lack of large conifers on the floodplain, the opportunity to create physical habitat in the future through natural processes is limited.

The quantity and distribution of roughness elements in a channel also plays a role in dissipating energy. The amount of energy a given discharge exerts can be equated to the unit stream power. Stream power is a function of the discharge and the water surface slope. Roughness elements, such as large woody debris or bedrock outcrops, can resist or deflect flow, increasing the overall flow length and causing the flow to backwater as local velocities decrease. Both of these factors can reduce the local slope, thereby reducing local stream power. By reducing local stream power the stream is less likely to incise, less likely to erode banks, and more likely to deposit gravel which is important to anadromous fish populations.

3.3 Reach Delineation and Description

The 2003 Lower Gales Creek Habitat Enhancement Plan delineated a total of ten reaches (GL01 – GL10) along lower Gales Creek from the confluence of Prickett Creek upstream to the confluence of Clear Creek. The reach delineation for the LGCHEP was based on specific changes in channel type (Rosgen, 1994) and site specific geomorphic conditions such as bank condition, number and size of wood pieces, and primary flow characteristics. Though these delineations worked well for the analysis being conducted and will continue to be the primary delineations used by the Tualatin River Watershed Council to define locations of future enhancement and restoration projects, this study developed its own reach delineation that focused on morphologic character and sediment transport characteristics (Rosgen, 1994; Montgomery and Buffington, 1993). In addition, our study area was expanded to include the portion of Gales Creek between Clear Creek and Iler Creek.

For this study, a total of six reaches have been identified. Figure 6 and Table 1 delineate the reach breaks for both the current study and the LGCHEP work. The classifications and reach delineations are meant to represent average conditions within each reach with the goal of explaining the overall trend in channel form and function.

Table 1: Reach delineations and descriptions for the Gales Creek geomorphic assessment. Refer to Figure 6 for specific locations.

Reach #	LGCHEP Reach ID	Sediment Transport Regime	Sinuosity	Bankfull Width (ft)	Bankfull Depth (ft)	Width to Depth Ratio	Entrenchment	Slope (%)
1	None	Transport	1	58	2.9	20	1.9	.01
2	GL01	Aggradation	1.1	71	3.2	22	2.4	.004
3	GL02	Transitional	1.5	66	3.8	17	2.4	.003
4	GL03-06	Transport	1.2	58	3.6	16	2.4	.004
5	GL07-09	Aggradation	1.3	53	4.2	13	2.2	.001
6	GL10	Transport	1.1	60	5	12	1.3	.001

Reach 1

Reach 1 consists of a relatively steep, straight channel dominated by bedrock outcroppings and a cobble bed. The riparian corridor is intact and fairly wide through most of this reach, except in the upper portion where a farm field abuts the channel. Some floodplain exists in overbank areas to both the right and left of the channel and there are several abandoned meander bends on the floodplain that now support off channel wetland systems. Due to the relatively steep slope of this reach and bedrock exposures on the bank and bed of the channel it has been classified as a transport reach. This classification has been confirmed by the sediment transport calculations discussed in Section 4.3. Pool and riffle structure through this reach is fairly regular with very little in the way of meandering. The reach also has little to no woody material in the channel which is most likely the result of high velocities during peak runoff conditions. Spawning habitat may be limited through this reach given the lack of deposition and high velocities. This reach could provide good rearing habitat if large woody material is added and secured since the canopy cover provides good shade and there are several pools and undercut banks.

Reach 2

Reach 2 overlaps directly with GL01 and consists of a much wider channel and floodplain than in Reach 1. Clear Creek, a major tributary to Gales Creek, enters from the right bank at the upstream end of the reach, contributing both cold summer baseflow and a significant quantity of bedload in the form of gravel and cobble. There is a significant break in slope between Reach 1 and Reach 2 creating ideal conditions for bed load deposition which is the dominant feature within this reach. The fairly straight and narrow channel present in Reach 1

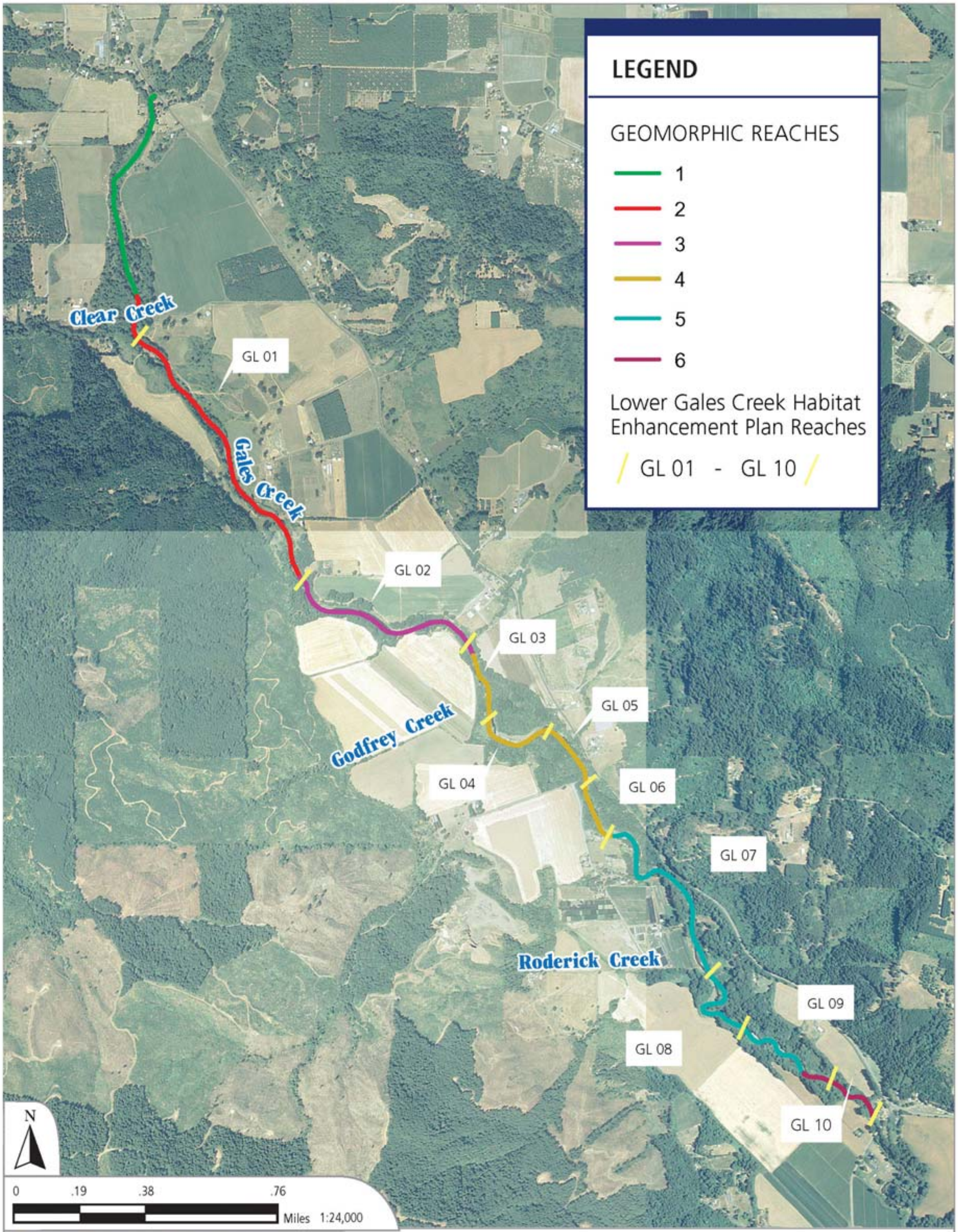

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FIGURE 6: Reach deliniations for the Gales Creek study reach. The Habitat Enhancement Plan deliniated reaches based on a Rosgen classification system. The geomorphic reaches were determined based on channel confinement and sediment transport dynamics.

changes to a meandering low flow channel with large bar forms. Active and abandoned off-channel gravel mines within this reach are a good indicator of the potential for sediment deposition through this reach. This reach may have historically been an important spawning area for salmonids.

Reach 3

Reach 3 overlaps fairly closely with GL02. Though this reach has the potential to deposit coarse sediment delivered from upstream, it is slightly more confined and incised than Reach 2. In addition, much of the sediment supplied to Reach 2 does not necessarily make it to Reach 3 to be deposited, which may explain the observed difference between the reaches. This reach runs primarily west to east as the main channel crosses the valley from being confined on one side to the other. Some bedrock is exposed on the banks and bed of the channel in the lower portion of this reach though the bedrock consists primarily of mudstones and is friable and unconsolidated. A bridge located at the downstream end of the reach shows evidence of from 1 to 2 feet of channel incision in the last 30-40 years. This reach may provide some spawning habitat in certain years where the gravel supply is adequate. The upper and middle portions of this reach may provide good rearing habitat if the canopy cover is improved and large wood is installed and secured.

Reach 4

Reach 4 has similar characteristics to Reach 1 in that it appears to be a transport reach, is relatively confined, and has bedrock exposures along the bed and banks of the channel. In particular, the bedrock exposure in the vicinity of the Roderick Road Bridge appears to be a Mafic outcrop consisting of material that is much more resistance to erosion. Based on this observation, much of the channel incision and headcut propagation occurring downstream of the Roderick Road Bridge would likely be arrested due to this outcrop and therefore not impact channel or bank conditions upstream. This is not to say that no incision or bank erosion will occur, but that this more resistant outcrop creates a barrier to significant impacts from downstream. Despite the overall incised nature of Reach 4, there are significant pockets floodplain and complex in-channel habitat. An abandoned channel upstream of the Roderick Road Bridge has potential as a restored secondary channel. The Reach has a wide and continuous riparian corridor, and some large wood has generated pool habitat upstream of the Roderick Road constriction. Though spawning habitat may be limited through this reach, there is potential to enhance rearing habitat due to some existing in-stream complexity and the continuous canopy.

Reach 5

Reach 5 can be classified primarily as a depositional reach. Reach 5 has experienced significant changes over the last several decades due to a series of headcuts that have moved through in succession, apparently due to channel changes downstream on Gales Creek and on the Tualatin River. As the headcuts have moved through the channel has incised. Though the incision appears to have ended, the system has moved to a new phase of channel widening, resulting in extensive areas of bank erosion. The bank erosion has introduced large quantities of sediment and debris into the channel that has resulted in the formation of point bars, thereby exacerbating the intensity of channel widening as new floodplain is created. Where debris has been deposited in the channel, pools have formed and gravel beds have been exposed creating pockets of what appears to be high quality spawning and rearing habitat. The bank erosion has also resulted in large gaps in the riparian canopy, thus limiting future recruitment of large wood. This reach historically appears to have provided spawning and rearing habitat for salmonids. It has the potential to provide both in the future if some of the mentioned issues are addressed.

Reach 6

Reach 6 is a short reach in the vicinity of the Stringtown Bridge. The channel through this reach is straight and incised, lacks channel complexity, and has a very narrow riparian corridor. Due to these conditions and the fact that is located downstream of a depositional reach, Reach 6 was considered a transport reach. It lacked bar forms and the characteristic pool and riffle sequence that characterize a meandering low flow channel. This reach may provide some rearing habitat if the canopy cover were improved but lacks much spawning habitat potential.

4. Existing Conditions

4.1 Bank Stability

An existing conditions assessment of bank stability was conducted for the entire study reach from the Iler Creek confluence downstream to the Stringtown Bridge. Bank stability was evaluated for both the right and left banks separately and each bank was assigned an erosion potential rating from very low to extreme. Erosion potential was determined using an assessment approach adopted from Rosgen (1994). The Rosgen method is based on the assumption that the ability of a stream bank to resist erosion is primarily determined by seven components:

- The ratio of streambank height to bankfull stage,
- The ratio of riparian vegetation rooting depth to streambank height,
- The degree of rooting density,
- The composition of streambank materials,
- Streambank angle,
- Bank material stratigraphy and presence of soil lenses, and
- Bank surface protection afforded by debris, vegetation, or resistant material such as boulders or bedrock.

These seven components are evaluated in the field by measuring reach length, flow distribution, erodibility, bankfull width, bankfull width at two times the bankfull depth (i.e. – channel entrenchment), bank height, bankfull depth, sinuosity, bank angle, percent bank face protected, percent root density, rooting depth from top of bank, bank material particle size, bank material sorting, bank soil stratification, streambed material, and stream gradient. Each field parameter was determined for relatively homogeneous stream and bank segments by averaging each parameter along the segment length. Bank parameters were determined for left and right banks (looking downstream) separately to determine the final index values for each stream segment. The bank erosion potential for each field segment is then determined based on the rating table developed by Rosgen and summarized in Table 2. Adjustments are made to the final score based on bank material and bank stratification to produce a final score for each segment. The final score is then assigned a erosion potential rating of very low, low, moderate, high, very high, and extreme.

Table 2: Bank erosion potential values for measured field parameters. A total score and rating is assigned to each field segment based on the following index values.

Bank Erosion Potential												
Criteria	**Very Low**		**Low**		**Moderate**		**High**		**Very High**		**Extreme**	
	Value	Index	Value	Index	Value	Index	Value	Index	Value	Index	Value	Index
Bank Height / Bankfull Height	1-1.1	1-1.9	1.1-1.19	2-3.9	1.2-1.5	4-5.9	1.6-2	6-7.9	2.1-2.8	8-9	> 2.8	10
Root Depth / Bank Height	1-0.9	1-1.9	0.89-0.5	2-3.9	0.49-0.3	4-5.9	0.29-0.15	6-7.9	0.14-.05	8-9	< 0.05	10
Root Density (%)	80-100	1-1.9	55-79	2-3.9	30-54	4-5.9	15-29	6-7.9	5-14	8-9	< 5	10
Bank Angle (Degrees)	0-20	1-1.9	21-60	2-3.9	61-80	4-5.9	81-90	6-7.9	91-119	8-9	> 119	10
Surface Protection (%)	80-100	1-1.9	55-79	2-3.9	30-54	4-5.9	15-29	6-7.9	10-15	8-9	< 10	10
Totals		5-9.5		10-19.5		20-29.5		30-39.5		40–45		46-50

Additional Adjustments and Considerations

<u>Bank Materials</u>:

- Bedrock - Bank erosion potential always very low
- Boulder - Bank erosion potential low
- Cobble - Decrease by one category unless mixture of gravel/sand is over 50%, then no adjustment
- Gravel - Adjust values up by 5-10 points depending on composition of sand
- Sand - Adjust values up by 5-10 points
- Silt/Clay - No adjustment

<u>Stratification</u>:

- Adjustment of 5-10 points (upward) depending on position of unstable layers in relation to bankfull stage

Results for each survey segment were then tied to a GIS layer representing the measured stream segments and are displayed on an aerial photograph of the area (Figures 7a, b, and c). Table 3 provides a statistical summary of the bank stability results. Though there appears to be problematic areas of high to moderate erosion potential, no banks were mapped as having a very high or extreme erosion potential. This is primarily due to the fact that the Rosgen system is meant to be a comprehensive assessment approach for all types of landscapes. Consequently, a very high or extreme bank erosion potential rating is often reserved for heavily incised stream channel located in arid watersheds where vegetation is sparse.

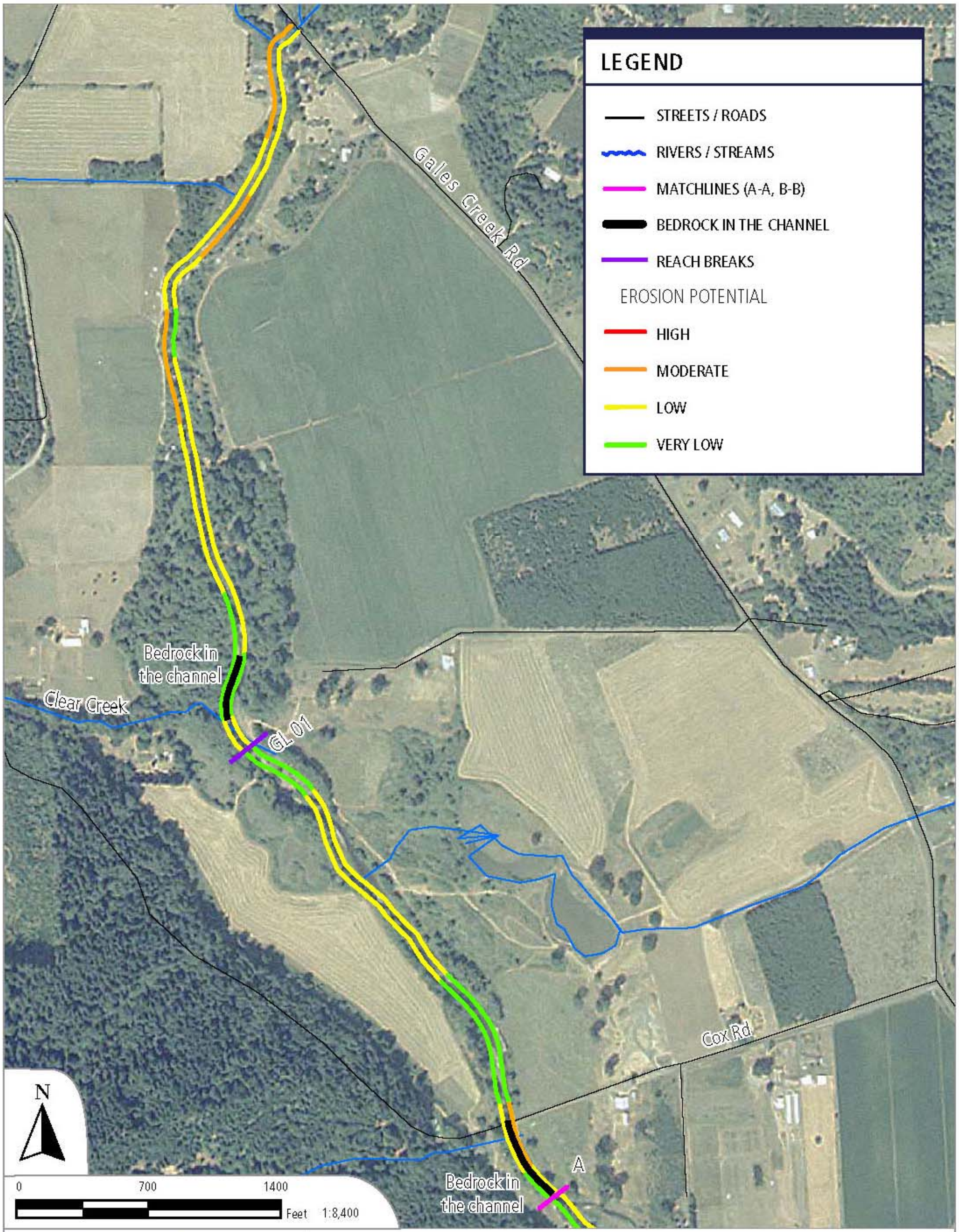

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FIGURE 7a: Erosion potential rating for banks along the geomorphic assessment study reach. Erosion potential was developed through field analysis of bank stability and the potential for future bank failure based on a method developed by Rosgen (1994).

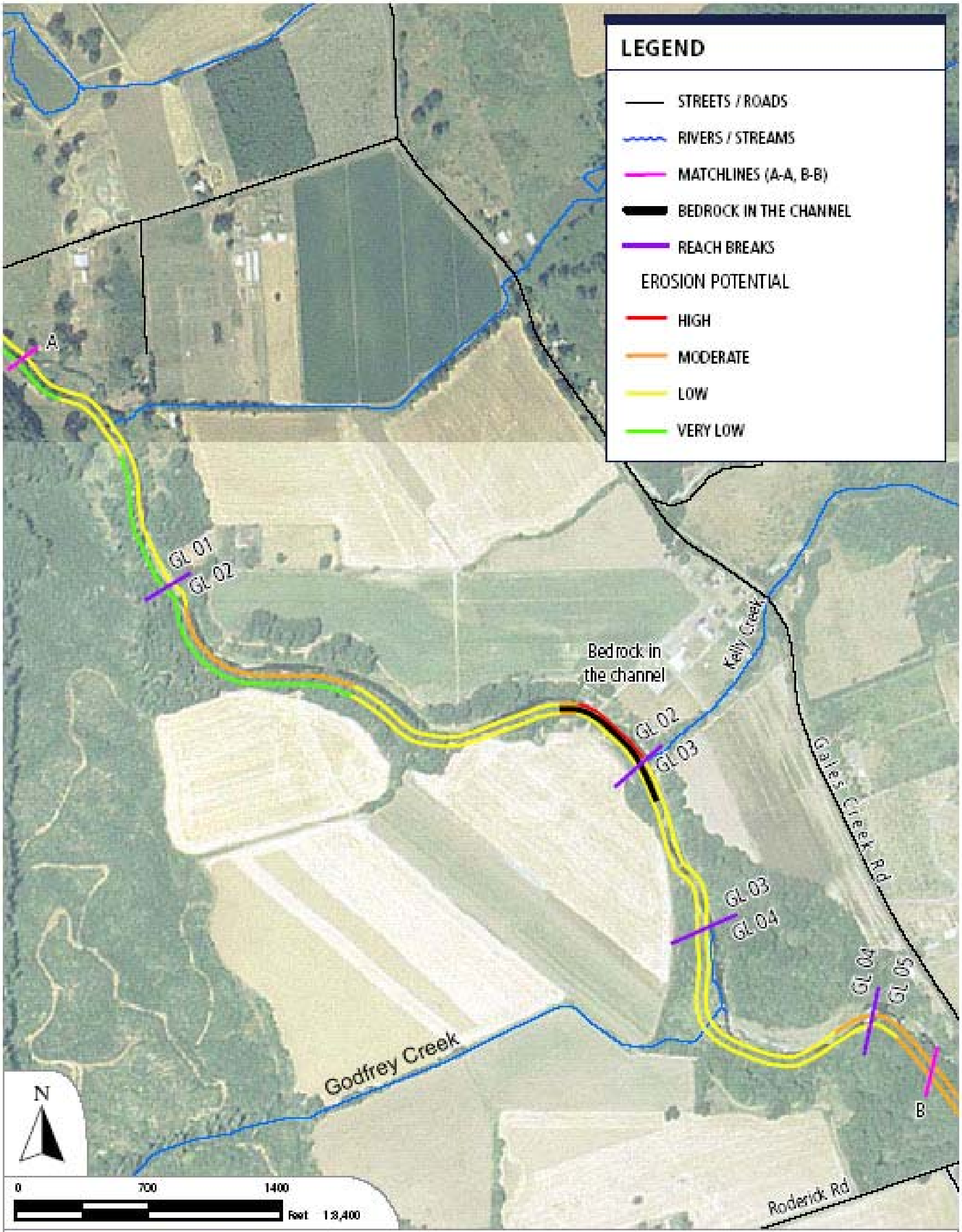

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FIGURE 7b: Erosion potential rating for banks along the geomorphic assessment study reach. Erosion potential was developed through field analysis of bank stability and the potential for future bank failure based on a method developed by Rosgen (1994).

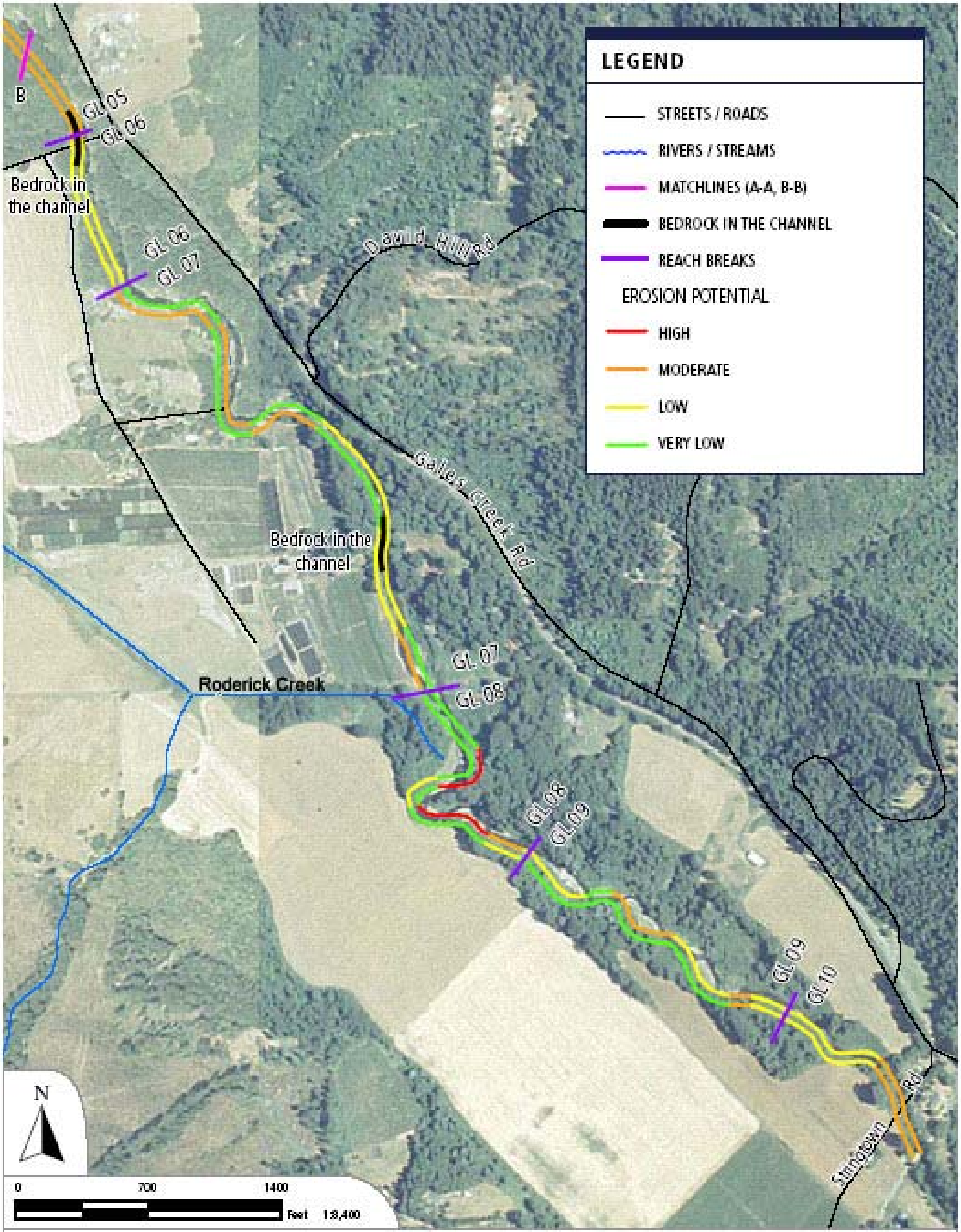

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FIGURE 7c: Erosion potential rating for banks along the geomorphic assessment study reach. Erosion potential was developed through field analysis of bank stability and the potential for future bank failure based on a method developed by Rosgen (1994).

Table 3: Summary statistics for bank erosion potential for right and left banks. The results suggest that many of the banks along the Gales Creek study reach are relatively stable, except in constricted channel segments or where headcuts have recently moved through.

Stream Bank	Bank Erosion Potential	Linear Feet	% of Subject Reach	Stream Bank	Bank Erosion Potential	Linear Feet	% of Study Area
Right	Very Low	6,945	32%	***Left***	Very Low	4,488	21%
	Low	7,954	37%		Low	10,766	50%
	Moderate	6,772	31%		Moderate	5,768	27%
	High	0	0%		High	649	3%
	Very High	0	0%		Very High	0	0%
	Extreme	0	0%		Extreme	0	0%
	Total	**21,671**	**100%**		**Total**	**21,671**	**100%**

Though the Gales Creek study reach has some very steep banks that are actively eroding, they often have some vegetation on them, are only moderately incised, or lack stratification. The primary areas of concern for significant bank erosion and retreat are associated with Reach 5 where relatively recent incision has occurred and the channel appears to be in a channel widening phase (Douglas, 1985). Bank erosion is evident elsewhere throughout the study area but appears to be confined to discrete locations such as on the outside of a meander bend or adjacent to bridges where the flow is constricted. In Reach 5, bank erosion is widespread and is likely to continue.

The Douglas model, which evaluates channel response to a series of land use disturbances, charts incision, bank erosion, and sediment production as a channel proceeds from undisturbed, through agricultural use, and on to urban development. Each of the phases contains a period of incision followed by accelerated bank erosion in response to the disturbance, whereby a new equilibrium is achieved. The period of time, known as the lag, that is required to achieve a new equilibrium depends on the degree of disturbance and watershed conditions that may result in additional hydrologic disturbance. In the Douglas model, the new disturbance is urbanization. Consequently, a new equilibrium is never achieved between the agricultural disturbance and the urban disturbance.

4.2 Hydrology

Though a number of measurement gages have historically measured streamflow on Gales Creek, there appear to be no active gages on the Creek today. The historic gages with the longest period of record on Gales Creek are gage 14204500 – Gales Creek nr Forest Grove, located near the Roderick Road Bridge, and 14204000 – Gales Creek nr Gales (Table 4). Both these gages combined constitute a record of mean daily and annual peak flow measurements that span the years 1935 to 1981. Unfortunately, as is the trend in hydrologic monitoring networks (Rodda, 1998; Lanfear and Hirsch, 1999), these gages were discontinued and do not provide a record of current streamflow conditions through the study reach.

Table 4: Streamflow data using in the geomorphic analysis for Gales Creek. Gage locations are shown in Figure 1.

Gage	Drainage Area (mi^2)	Period of Record	USGS Station ID
Gales Creek nr Forest Grove	66.1	1940-1956; 1970-1981	14204500
Gales Creek nr Gales	32.2	1935-1970	14204000
Gales Creek @ Old Hwy 47	78.6	1995 to present	14204530

Flood frequency values for a range of return periods and exceedence probability values were estimated for gage #14204500 and #14204000 and are presented in Table5 and Table 6, respectively. Flood frequency was calculated using historic annual peak discharge estimates for each of the gages according to a standard approach developed by the USGS and outlined in Bulletin 17B (USGS, 1982). Based on this approach, the 100-year discharge at the Roderick Road Bridge was estimated to be approximately 8,660 cfs. The bankfull discharge, which is typically assumed to have a 1.5-year recurrence (Rosgen, 1996; Dunne and Leopold, 1978; Leopold et. al., 1964), was estimated to be approximately 2,707 cfs for gage #14204500 and 1,660 cfs for gage #14204000. The statistical 1.5-year recurrence flow does not correspond with expected flows at bankfull indicators in the field suggesting that channel forming flows occur more frequently than the 1.5-year event. Castro and Jackson (2001) observed bankfull discharge in humid rivers in western Oregon and Washington on a 1.2 year recurrence based on gage records and infield measurements.

Table 6 summarizes mean daily flow data on Gales Creek, by month, as observed at gage sites #14204500 and #14204000. The data are presented as exceedence probabilities, by month and annually. Exceedence probability can be defined as the percentage of time a particular flow is exceeded. For example, in September at the Roderick Road gage, a flow of 13 cfs is exceeded 50% of the time. These data are very useful in analyzing summer low flow conditions, evaluating a range of options at fish passage improvement sites, and determining diversion methods for in-channel construction or restoration projects. They can also be useful when developing a rough IFIM-type analysis of instream flow and aquatic habitat relationships.

Table 5: Flood frequency discharge estimates for gages on Gales Creek. Flood frequencies were calculated using the methods developed by the USGS and published in Bulletin 17B (1982).

Station ID	DA (mi^2)	BF* (cfs)	2-yr (cfs)	MAF* (cfs)	5-yr (cfs)	10-yr (cfs)	25-yr (cfs)	50-yr (cfs)	100-yr (cfs)
14204500	66.1	2,707	3,232	3,479	4,593	5,533	6,759	7,700	8,664
14204000	32.2	1,660	1,970	2,116	2,799	3,392	4,191	4,823	5,485

*** MAF = Mean Annual Flood (2.33 year recurrence); BF = Bankfull Flood (1.5 year recurrence**

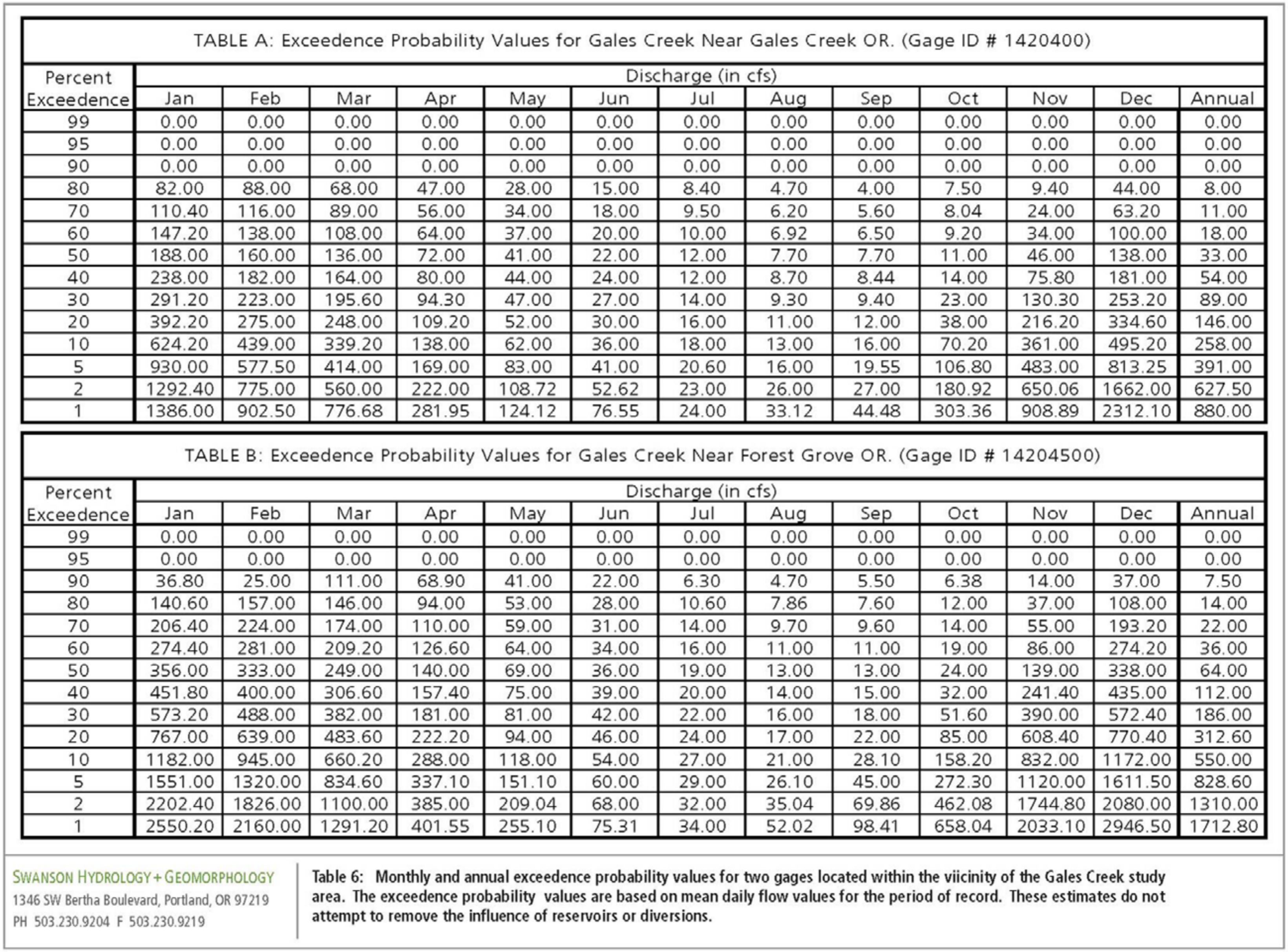

TABLE A: Exceedence Probability Values for Gales Creek Near Gales Creek OR. (Gage ID # 1420400)

Percent Exceedence	Discharge (in cfs)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	82.00	88.00	68.00	47.00	28.00	15.00	8.40	4.70	4.00	7.50	9.40	44.00	8.00
70	110.40	116.00	89.00	56.00	34.00	18.00	9.50	6.20	5.60	8.04	24.00	63.20	11.00
60	147.20	138.00	108.00	64.00	37.00	20.00	10.00	6.92	6.50	9.20	34.00	100.00	18.00
50	188.00	160.00	136.00	72.00	41.00	22.00	12.00	7.70	7.70	11.00	46.00	138.00	33.00
40	238.00	182.00	164.00	80.00	44.00	24.00	12.00	8.70	8.44	14.00	75.80	181.00	54.00
30	291.20	223.00	195.60	94.30	47.00	27.00	14.00	9.30	9.40	23.00	130.30	253.20	89.00
20	392.20	275.00	248.00	109.20	52.00	30.00	16.00	11.00	12.00	38.00	216.20	334.60	146.00
10	624.20	439.00	339.20	138.00	62.00	36.00	18.00	13.00	16.00	70.20	361.00	495.20	258.00
5	930.00	577.50	414.00	169.00	83.00	41.00	20.60	16.00	19.55	106.80	483.00	813.25	391.00
2	1292.40	775.00	560.00	222.00	108.72	52.62	23.00	26.00	27.00	180.92	650.06	1662.00	627.50
1	1386.00	902.50	776.68	281.95	124.12	76.55	24.00	33.12	44.48	303.36	908.89	2312.10	880.00

TABLE B: Exceedence Probability Values for Gales Creek Near Forest Grove OR. (Gage ID # 14204500)

Percent Exceedence	Discharge (in cfs)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	36.80	25.00	111.00	68.90	41.00	22.00	6.30	4.70	5.50	6.38	14.00	37.00	7.50
80	140.60	157.00	146.00	94.00	53.00	28.00	10.60	7.86	7.60	12.00	37.00	108.00	14.00
70	206.40	224.00	174.00	110.00	59.00	31.00	14.00	9.70	9.60	14.00	55.00	193.20	22.00
60	274.40	281.00	209.20	126.60	64.00	34.00	16.00	11.00	11.00	19.00	86.00	274.20	36.00
50	356.00	333.00	249.00	140.00	69.00	36.00	19.00	13.00	13.00	24.00	139.00	338.00	64.00
40	451.80	400.00	306.60	157.40	75.00	39.00	20.00	14.00	15.00	32.00	241.40	435.00	112.00
30	573.20	488.00	382.00	181.00	81.00	42.00	22.00	16.00	18.00	51.60	390.00	572.40	186.00
20	767.00	639.00	483.60	222.20	94.00	46.00	24.00	17.00	22.00	85.00	608.40	770.40	312.60
10	1182.00	945.00	660.20	288.00	118.00	54.00	27.00	21.00	28.10	158.20	832.00	1172.00	550.00
5	1551.00	1320.00	834.60	337.10	151.10	60.00	29.00	26.10	45.00	272.30	1120.00	1611.50	828.60
2	2202.40	1826.00	1100.00	385.00	209.04	68.00	32.00	35.04	69.86	462.08	1744.80	2080.00	1310.00
1	2550.20	2160.00	1291.20	401.55	255.10	75.31	34.00	52.02	98.41	658.04	2033.10	2946.50	1712.80

Table 6: Monthly and annual exceedence probability values for two gages located within the viicinity of the Gales Creek study area. The exceedence probability values are based on mean daily flow values for the period of record. These estimates do not attempt to remove the influence of reservoirs or diversions.

4.3 Channel Morphology / Sediment Transport

4.4.1 Sediment Transport Calculations

There are two distinct components of the sediment load in Gales Creek; these are gravel and sand/fines. Gravel (particles coarser than 2 mm diameter) generally move by sliding, rolling, or saltating (leaping or jumping) along the bed. Sand and fines (particles less than 2 mm diameter) can often be suspended by flow and kept in motion by turbulent eddies in the water column, being transported without significant grain-to-grain contact. These two components of the load are supplied from different sources, transported by different mechanisms, and deposited in different conditions. Because we are primarily interested in channel morphology and how modifications to the channel may influence formation of bed forms, such as bars, the main focus of our analysis was on the bed load portion of the overall sediment load. In addition, we were interested in understanding sediment transport dynamics within the study area with regard to delivery, transport, and deposition of coarse sediment into and out of the study area.

Bed load can be calculated in a variety of ways. The most accurate method would be to conduct detailed field investigations where bed load is measured directly during a range of storm events. Measurements are typically taken by lowering sampling equipment from a bridge and a rating curve, comparing bed load flux to discharge, is generated. This rating curve is then used to estimate daily, monthly, or annual bed load flux by applying the rating curve to a long term flow record. Though this is the preferred, and most accurate, method of estimating bed load flux, year to year variability, an inability to measure bed load during extremely high flows, and measurement variability due to hysteresis, makes this approach very expensive since it requires many years of data collection. Consequently, bed load data collected using these methods are often not available for most rivers. Long-term data sets are often only collected in intensively studied large river systems such as the Colorado, or in smaller water supply watersheds where reservoir sedimentation is a concern.

In the absence of field measured bed load data, the best approach to estimating bed load transport is to use one of a variety of bed load equations (e.g. – Meyer-Peter Muller, Ackers-White, Yang, Laursen, Tofaletti, Parker, etc). For the Gales Creek study reach, the most appropriate method for computing gravel flux is the surface-based relation of Parker (1990). This bed load transport relationship is based on the best available data set on gravel transport from a real gravel river, collected by Milhous (1973) in Oak Creek, Oregon. Parker's analysis of the Oak Creek data set is based on the understanding that it is the surface material, rather than the subsurface material, that directly exchanges sediment with the bed load. The Parker (1990) relation specifically excludes material less than 2mm in diameter from the analysis because those grain sizes are considered to be transported by a different mechanism. The model has a rather complicated form but accounts for the entire particle size distribution of the bed surface and bed load, and thus accounts for surface armoring, and predicts the composition of bed material and bed load. Details of this model are provided by Parker (1990) and are not elaborated here.

The parameters required to run the Parker model include cross-section geometry, channel slope, discharge, grain size distribution of the bed, and a roughness coefficient. These data were developed through collection of field data and use of a hydraulic model that was run at discrete locations in the channel. One location was chosen at a representative site at the upstream end of the study area (Reach 1), just upstream of the Clear Creek confluence, and another was chosen at a representative site downstream of the Roderick Road Bridge (Reach 4), just upstream of the Roderick Creek confluence (Figure 6). The Reach 1 site was chosen to model bed load transport conditions in the steeper, transport reach located at the upstream end of the study area and was meant to represent a relative estimate of the amount of bed load that was being delivered to the study area from upstream. The Reach 4 site was chosen to model bed load transport conditions within the lower gradient, depositional reach that makes up much of the study area and was meant to represent a relative estimate of the amount of bed load that was being transported downstream. The difference in bed load transport rates between the upstream and downstream site would determine the quantity of coarse sediment being deposited in the study area.

Once the sites were selected, longitudinal profile, cross-section, and bed material data (Wolman, 1954) were collected at each of the sites (Figures 8 and 9). At the Reach 1 site, 1000 feet of channel was surveyed. At the Reach 4 site a total of 750 feet of channel was surveyed. At both sites, cross-section data were collected at distinct changes in hydraulic conditions such as at the top of a riffle and the bottom of a riffle. Where large pools were present an additional cross-section was measured in the middle of the pool. These data were then input into the U.S Army Corps of Engineers HEC-RAS hydraulic modeling system to generate the necessary output parameters under a range of flow conditions.

Output data from the HEC-RAS model was used to as input parameters to the Parker bed load transport model. Bed load flux was computed for a range of discharges to provide an estimate of mean daily bed load flux as it relates to mean daily discharge[1]. We then fitted a regression to the data to compute bed load flux for mean daily flows greater than 150 cfs. Bed load flux was considered to be zero for flows less than 150 cfs. The result of the regression for Reach 1 and Reach 4 was a power-law relationship for flows less than 1,000 cfs and 2,000 cfs, respectively, and a linear relationship for flows greater than 1,000 cfs and 2,000, respectively (Figures 10 and 11).

These relationships were then used to compute daily, annual, and long-term bed load flux using mean daily flow data for the USGS 14204500 - Gales Creek near Forest Grove gage from 1941-1956 and 1971-1981 and the WRD 14204530 from 1995 to 2004. The data was adjusted for drainage area at each of the sites to reflect potential changes in flow due to

---

[1] Using mean daily discharge to estimate bed load flux may underestimate total bed load flux since the peak will move considerably more sediment than the daily average. Unfortunately, daily peak data is often not available. Consequently, the bed load estimated calculated for this project should only be used as a relative measure of flux.

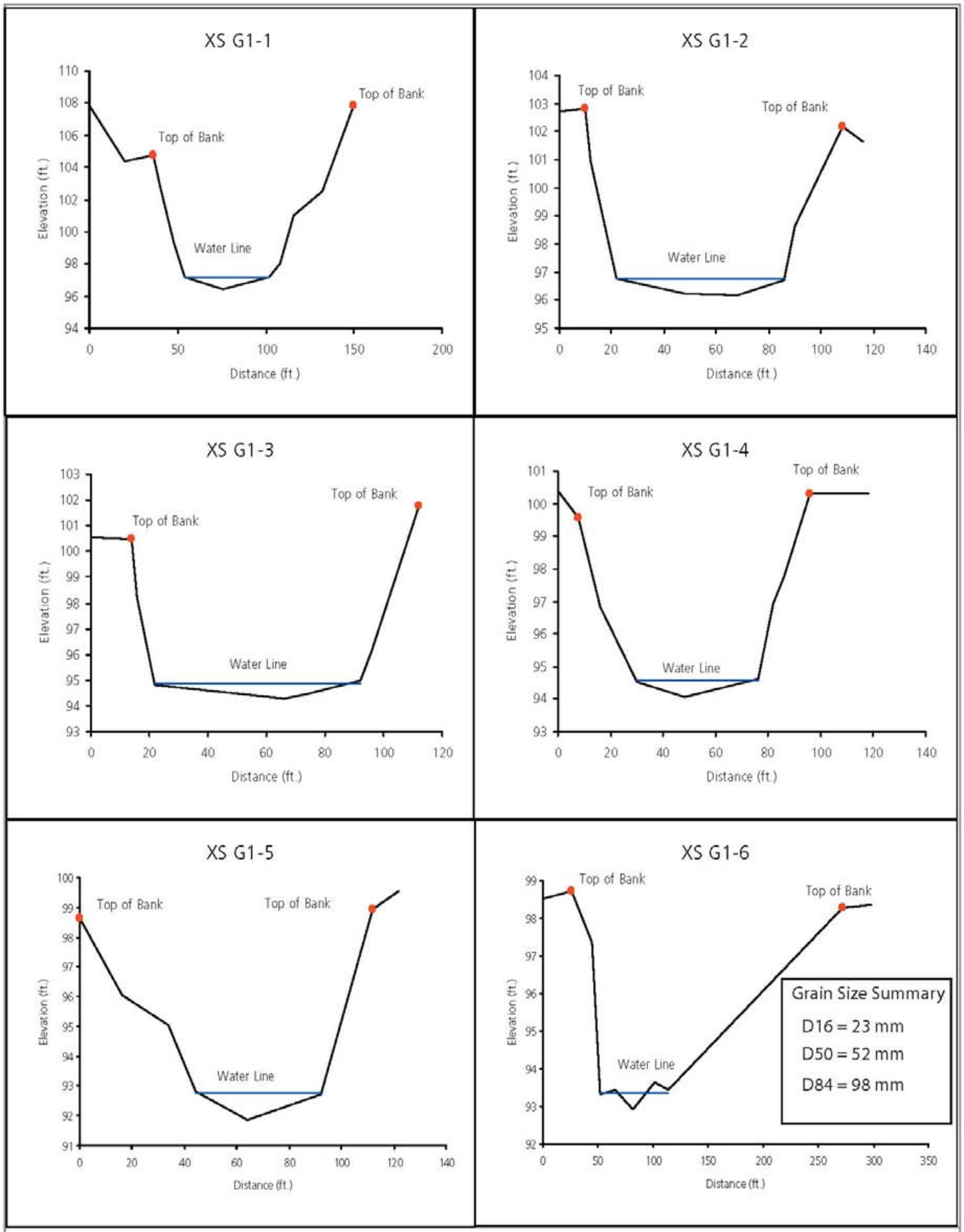

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FIGURE 8: Channel geometry for six cross-sections that were measured in Reach 1 of Gales Creek. Elevations are based on an assumed bench mark elevation of 100 feet, and do not represent true elevations. These data were used to generate a HEC-RAS model. Output from the HEC-RAS model was used to estimate sediment transport through the reach.

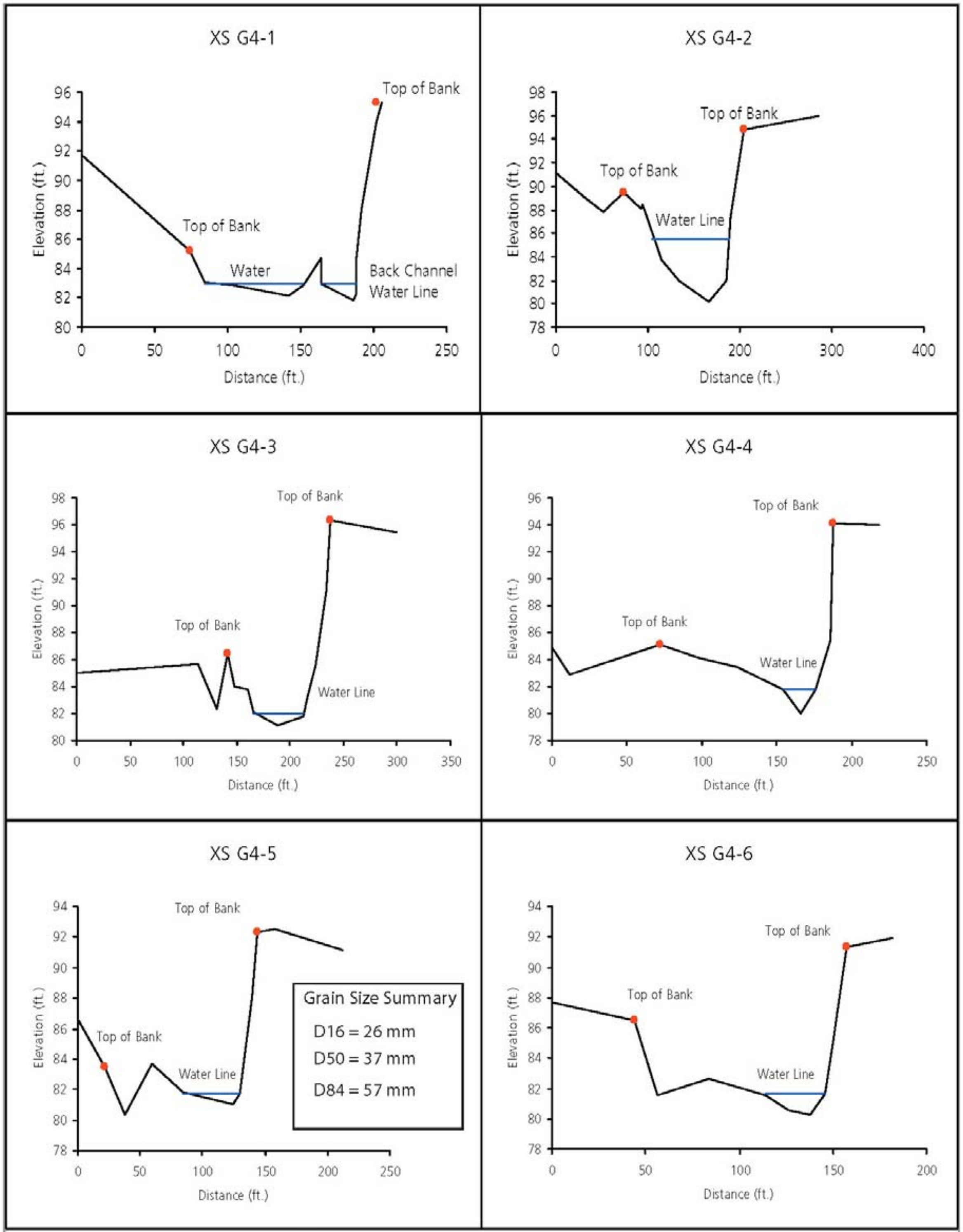

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FIGURE 9: Channel geometry for six cross-sections that were measured in Reach 4 of Gales Creek. Elevations are based on an assumed benchmark elevation of 100 feet, and do not represent true elevation. These data were used to generate a HEC-RAS model. Output from the HEC-RAS model was used to estimate sediment transport through the reach.

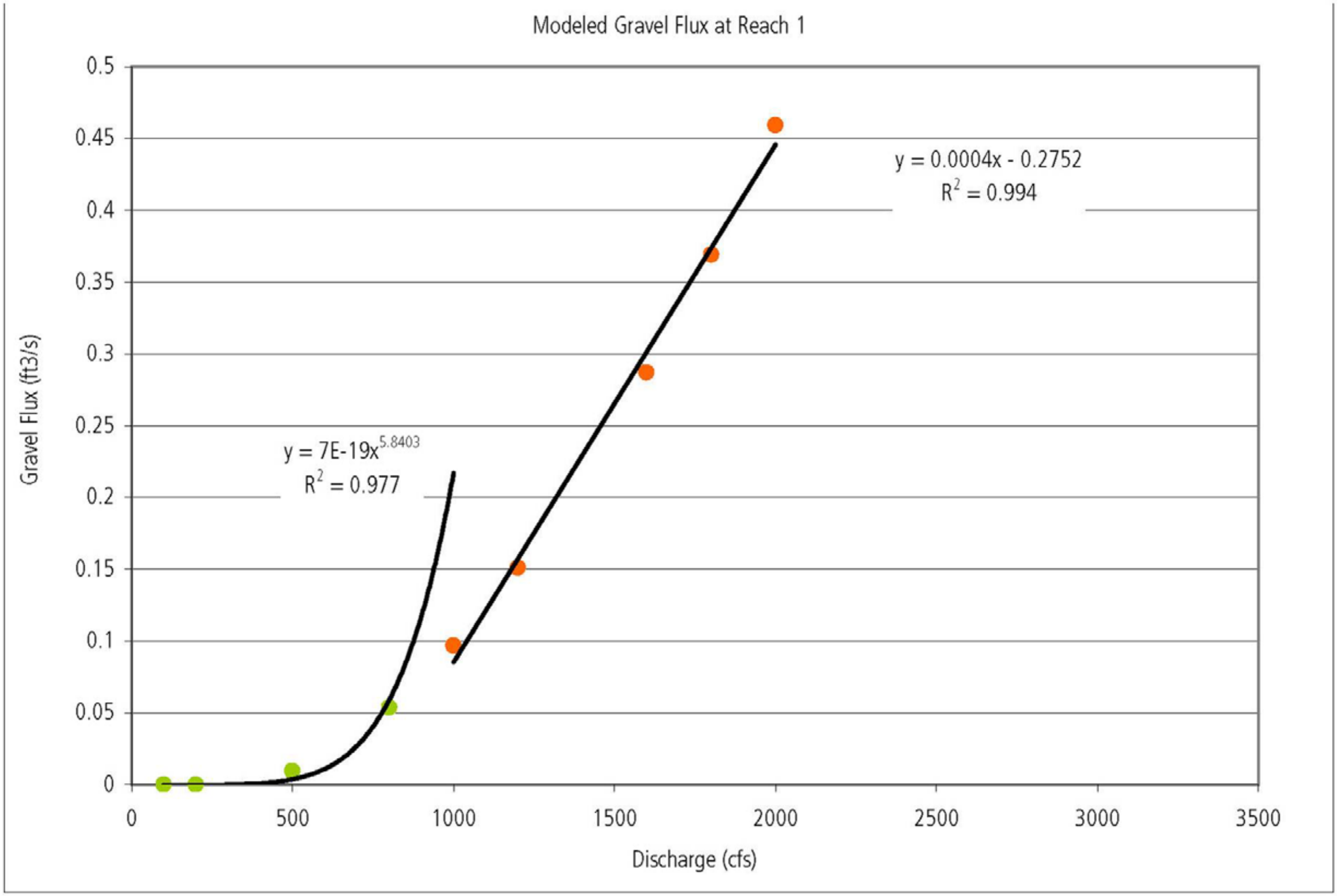

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FIGURE 10: Estimated bed load flux rating curve for Gales Creek. Bed load was estimated using Parker's (1990) surface based relationship and was modeled for Reach 1. A best line was fit through the data seperately for low and high flows.

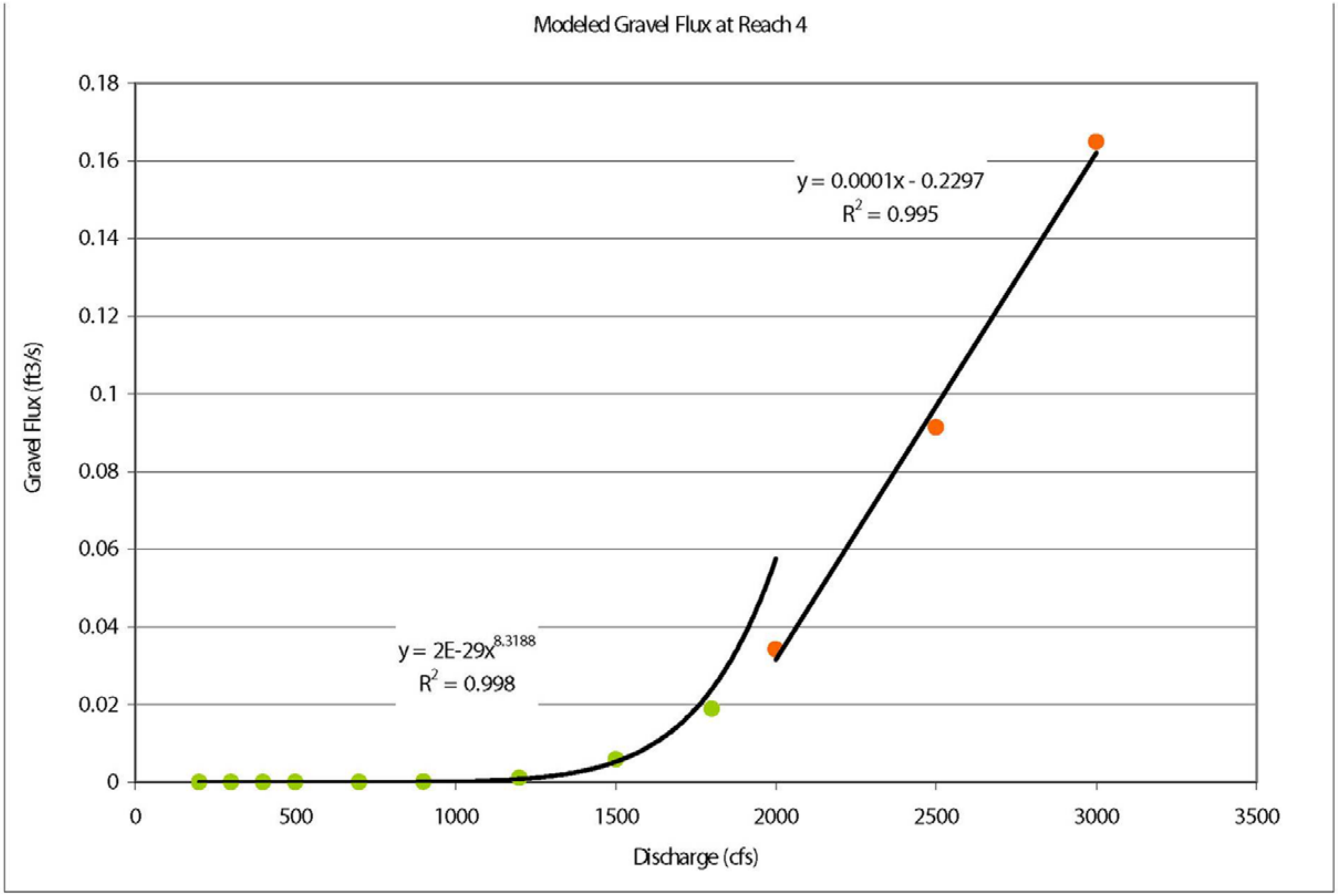

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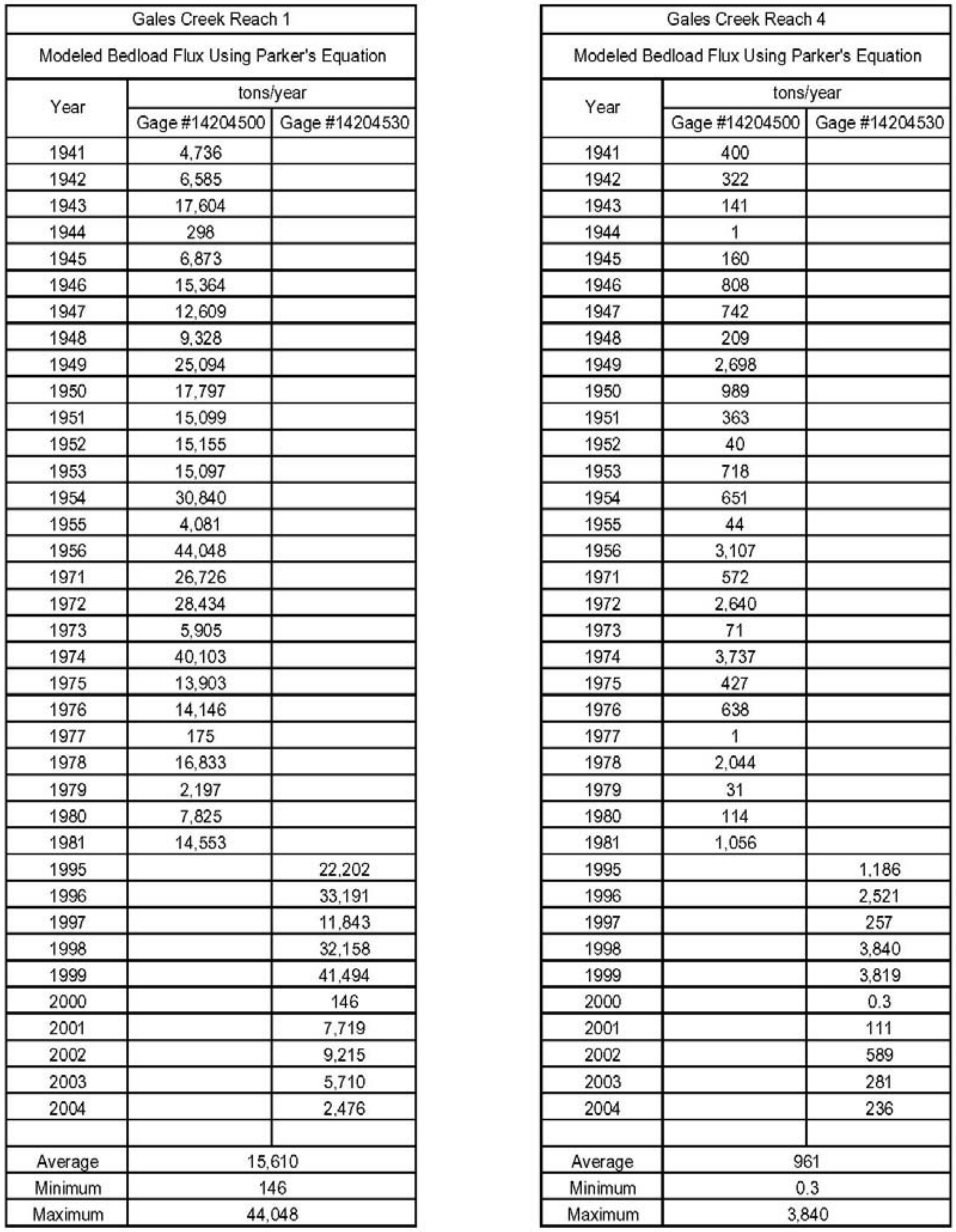
FIGURE 11:Estimated bed load flux rating curve for Gales Creek. Bed load was estimated using Parkers (1990) surface based relationship and was modeled for Reach 4. A best line was fit through the lower and upper data separately.



Gales Creek Reach 1		
Modeled Bedload Flux Using Parker's Equation		
Year	tons/year	
	Gage #14204500	Gage #14204530
1941	4,736	
1942	6,585	
1943	17,604	
1944	298	
1945	6,873	
1946	15,364	
1947	12,609	
1948	9,328	
1949	25,094	
1950	17,797	
1951	15,099	
1952	15,155	
1953	15,097	
1954	30,840	
1955	4,081	
1956	44,048	
1971	26,726	
1972	28,434	
1973	5,905	
1974	40,103	
1975	13,903	
1976	14,146	
1977	175	
1978	16,833	
1979	2,197	
1980	7,825	
1981	14,553	
1995		22,202
1996		33,191
1997		11,843
1998		32,158
1999		41,494
2000		146
2001		7,719
2002		9,215
2003		5,710
2004		2,476
Average	15,610	
Minimum	146	
Maximum	44,048	

Gales Creek Reach 4		
Modeled Bedload Flux Using Parker's Equation		
Year	tons/year	
	Gage #14204500	Gage #14204530
1941	400	
1942	322	
1943	141	
1944	1	
1945	160	
1946	808	
1947	742	
1948	209	
1949	2,698	
1950	989	
1951	363	
1952	40	
1953	718	
1954	651	
1955	44	
1956	3,107	
1971	572	
1972	2,640	
1973	71	
1974	3,737	
1975	427	
1976	638	
1977	1	
1978	2,044	
1979	31	
1980	114	
1981	1,056	
1995		1,186
1996		2,521
1997		257
1998		3,840
1999		3,819
2000		0.3
2001		111
2002		589
2003		281
2004		236
Average	961	
Minimum	0.3	
Maximum	3,840	

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TABLE 7: Long-term record of annual bed load for Gales Creek at Reach 1 and Reach 4 measured in Cubic Feet Per Second. Bed load was estimated using the bed load flux rating curve presented in Figures 10 and 11 and mean daily flow data recorded at the Gales Creek Gages Id 14204500 (USGS) and Id 14204530 (Washington Co.).

tributary inputs. The results for years 1940-1956, 1971-1981, and 1995-2004, presented in Table 7, show that movement of bed load is much higher in Reach 1 than in Reach 4. An average annual bed load flux of approximately 15,600 tons per year was estimated for Reach 1 and an average of 960 tons per year for Reach 4, using the Parker bed load transport equation. Typically, all bed load is transported during several discrete runoff events that may last on the order of a few days to a week. Actual bed load flux may be higher given that our calculations used mean daily flow rather than flow hydrographs.

4.4.2 Sediment Transport Dynamics

Our sediment transport analysis focused on two discrete locations in the channel to gain an understanding of the relative differences in bed load transport rates between reaches and how that might affect observed channel patterns, existing and future bank erosion, and past and future management of the study area. The results suggest that a significant amount of sediment delivered to the reach is deposited between the Clear Creek and Roderick Creek confluences, as postulated in Section 4.1 where we defined transport, transitional, and aggradational reaches (Table 1). Given the depositional nature of Reach 2, and the presence of historic and active off-channel gravel mining operations in this reach, much of the sediment being transported to and through Reach 1 is being deposited in this area.

Reach 5, downstream of the Roderick Road Bridge, can also be classified as a depositional reach, with increased sinuosity, presence of large bar forms consisting of gravel and cobble material, and areas of active bank erosion that's indicative of an area that's widening in response to aggradation. The difference between sediment deposition in Reach 2 and sediment deposition in Reach 5 is the source of the material. Reach 2 appears to be receiving coarse sediment from the upstream watershed and Clear Creek. This material is transported downstream during high magnitude, low frequency discharge events. The material is primarily derived from large landslides and debris flows.

Conversely, much of the material being deposited in Reach 5 appears to be derived locally from more frequent episodes of bank erosion. Past channel incision, resulting from downstream changes in base level and past confinement of the channel has produced steep banks that are prone to failure during moderate and high flow events. Prior to confinement and channel incision there was a delicate balance between supplied sediment from upstream and transport through the reach. The amount of sediment supplied to the reach most likely exceeded the amount of sediment being transported, producing a sinuous channel with large bar forms and a relatively stable low flow channel. Confinement of the channel and development of floodplain areas, combined with the lowering of base level downstream resulted in an increase in the sediment transport rate with the resulting channel incision. Once the new base level was achieved, which appears to have happened through this reach, excess energy associated with a confined and incised channel began the process of bank erosion that overwhelmed the sediment transport capacity of the channel. The deposited sediment has created new bar forms which have resulted in an increase in the sinuosity of the channel, resulting in additional bank erosion as Gales Creek attempts to build new floodplain and achieve a new equilibrium (Schumm, Harvey, and Watson 1984; Simon and Hupp 1986).

This process of bank erosion, leading to additional bank erosion is referred to as a positive feedback loop. It is difficult to predict the expected width of the channel with any accuracy but additional bank erosion and channel widening is expected, especially in the sections of Reach 5 that are currently straight and have not experienced significant erosion. Though this may seem counterintuitive, material recently eroded from localized bank erosion upstream and deposited in point bars will most likely migrate downstream, causing episodes of bank erosion and widening in unaffected areas.

The negatives associated with this current episode of bank erosion through Reach 5 are obvious. Landowners adjacent to the channel must deal with the unpredictable nature of Gales Creek, the potential loss of usable farmland and structures, sedimentation of downstream aquatic habitat associated with the delivery of fine sediment from eroding banks, and loss of the shading benefits that the streamside vegetation provides when the narrow riparian corridor is removed when a bank fails. There are also potential positives. Namely, channel widening is part of a natural process that the channel is responding to because of past confinement and incision. Presumably, when the channel achieves a new equilibrium width, future bank erosion will be more predictable and not as catastrophic. Additionally, when a bank erodes it not only delivers fine sediment that gets flushed downstream, but also provides clean gravel and large woody material to the channel that helps build physical habitat for fish. Gravel creates salmonids spawning habitat and large woody material can create deep pools and cover habitat for refuge and rearing habitat.

5. Salmonid Restoration

5.1 Past Enhancement/Restoration Work

Historically, very little focus has been given to salmonids restoration on lower Gales Creek due to the perception that high summer water temperatures combined with low flow summer conditions have resulted in conditions that limit salmonids recovery. The restoration and/or enhancement work that has been completed through the study reach has focused primarily on reducing sources of fine sediment from bank erosion, implementing best management practices to control runoff of nutrients and sediment from adjacent agricultural lands, planting of riparian vegetation, and removal of non-native vegetation. Much of this work has been initiated by landowners with technical assistance from agencies such as the National Resource Conservation Service.

5.2 Evaluation of Recommended Restoration Sites

A primary objective of this study was to evaluate the feasibility of salmonids enhancement and restoration projects proposed in the Lower Gales Creek Habitat Enhancement Plan (LGCHEP) prepared in March of 2003 in relation to existing channel morphology and geomorphic trends. Though each of these projects would undoubtedly benefit salmonids if they were implemented, questions remained about their compatibility within the geomorphic setting and the likelihood of long-term project success given the dynamic nature and extensive bank instability of several of the reaches.

In the LGCHEP, projects were organized by reach. In most cases the recommended projects focused on riparian plantings and outreach programs with the community and landowners. Other project sites included recommendations to enhance instream habitat conditions such as large woody material installations or retrofitting of existing bank protection structures to include habitat enhancement elements. These projects were general in the sense that an entire reach was called out for treatment rather than specific project locations. Site specific projects were recommended based on discussions with landowners and often included bank protection work that could be integrated with habitat enhancement elements. Our analysis evaluates each of the instream projects and includes a discussion of the appropriateness of each of these projects and recommended modifications to improve their effectiveness. In Section 5.3 we provide a summary of the projects and provide additional project recommendations, where appropriate, to improve salmonid habitat.

Reach GL01 (Geomorphic Reach 2)

The LGCHEP recommended that large woody material be placed in this reach to increase instream complexity and provide refuge areas from high water temperatures. The initial focus of this work would be near the confluence of Clear Creek. The geomorphic analysis for this reach suggests that this area, especially near the confluence with Clear Creek, is depositional. The location of the low flow channel, bar deposits, and pools and riffles, are ephemeral in a strongly depositional environment. The location of these morphological features shifts during high flow events which may limit the success of installing large wood structures that are static. Given the presence of bridges and other infrastructure, large wood structures would need to be secured in order to gain landowner approval, meaning in some cases they could be left high and dry as the bar forms shift. There may be an opportunity to install large wood structures at the lower end of the reach or in areas where channel dynamics have been constrained by bank protection structures such as rock revetments. In that case, large wood structures could be integrated into these existing structures to improve localized scour and provide cover habitat for fish.

Reach GL02 (Geomorphic Reach 3)

Recommendations in GL02 are similar to those proposed for GL01. The focus would be on riparian revegatation and installation of large wood structures. Since this reach has been determined through the geomorphic assessment to be a transitional reach, large wood structures integrated into existing bank protection structures and/or strategically placed to encourage pool scour could be successful. Installation of large wood structures should be avoided in the vicinity of the bridge crossing through this reach given expected high velocities and the presence of easily erodible bedrock on the bed which would make it difficult to secure each element.

Reach GL03 (Geomorphic Reach 4)
No recommended actions.

Reach GL04 (Geomorphic Reach 4)
No recommended actions.

Reach GL05 (Geomorphic Reach 4)
This reach is located just upstream of the Roderick Road Bridge through a highly confined section of channel with extensive resistant bedrock exposures along both the bed and the banks. The LGCHEP recommends installation of large wood structures along this reach to enhance in-stream complexity. Given the confined nature of this reach, the lack of access, and bedrock exposures (implying high velocities), we do not recommend installing structures through this reach. It may be possible to anchor existing large wood that exists through the reach but bringing in new material may be difficult from an access standpoint.

Reach GL06 (Geomorphic Reach 4)
This reach is located downstream of the Roderick Road Bridge and consists of a straight section of channel that is transitional to the depositional reach downstream. The LGCHEP recommends installation of large wood structures through this reach as a way to enhance connectivity between the channel and floodplain. Conceptually, enhancing connectivity would be achieved by adding large wood as roughness, causing the stream to backwater under high flow conditions, thereby raising the water surface, which would increase the frequency at which water accesses the floodplain surface. Though there appears to be some floodplain through this reach, the channel is still fairly confined and much of the floodplain surface consists of low benches or terraces rather than abandoned secondary channels. Improved floodplain access should be one of the salmonid restoration goals but any recommended project should focus on reactivating an existing secondary channel rather than just improving floodplain surface connectivity. Secondary channels would provide the most benefit to salmonids as refuge habitat from high winter flows.

Reach GL07 (Geomorphic Reach 5)
This reach has been affected by recent channel incision and bank erosion. Sediment eroded from the banks has deposited as bars along this reach, exacerbating the channel widening phase. The LGCHEP recommends a combination of large wood structures and activation of a secondary channel in Reach GL07. Given the fact that this reach could provide high quality salmonid rearing habitat if enhancement measures were implemented, we support these proposals. In addition, where opportunities exist, floodplain areas should be created by cutting back vertical banks and creating benches located at the bankfull flood elevation.

The secondary channel identified as an opportunity on the left bank, appears to already have access with the primary channel. This interaction could be enhanced and habitat elements and large wood structures could be placed in the secondary channel to encourage its use as a refuge area for fish. In addition, large wood structures could be integrated into bank protection projects along the right bank. The bank protection projects would consist of toe protection with large wood and bank recontouring to reduce the slope angle. If space is available, a low bench could be built at the toe of the bank to provide additional protection and improve revegetation success.

Reach GL08 (Geomorphic Reach 5)

This reach consists of a relatively short section of channel with extensive bank erosion, primarily along the left bank. The prominent feature through this reach is a tortuous meander that is armored with rock along the outside of the bend. The point bar, which is now a terrace due to recent channel incision, constricts the flow through this meander bend. The result is a backwater condition during high flow conditions that has resulted in the formation of a large gravel bar at the confluence of Roderick Creek. As the gravel bar grows the point bar it forms is inducing severe erosion along the left bank, just upstream of the meander. The LGCHEP recommends enhancing the meander pattern upstream so as to slow the water, lengthen the flowpath and reduce the amount of energy directed at the eroding bank. If opportunities exist to increase the meander pattern upstream they should be pursued, but we feel that this approach will not reduce the amount of energy directed at the downstream bank. The problem lies with the channel constriction at the tortuous meander which has created a large, persistent bar deposit. The best approach to fixing this site would be to remove the constriction by cutting down the terrace to the bankfull elevation so it can act as floodplain. The existing steep bank could be cut back with large wood installed at the toe.

Reach GL09 (Geomorphic Reach 5)

The main recommendation along this reach is to reduce vehicle access and install large wood structures, where appropriate. Given the potential for this reach to support rearing habitat if water temperatures are reduced, we support this recommendation. Site access would be straightforward and the lack of high velocity conditions would allow for anchoring of any installed structures.

Reach GL10 (Geomorphic Reach 6)

The LGCHEP recommends installing large wood structures to increase in-stream channel complexity along this reach. Given the confined nature of this reach and the lack of a riparian corridor, any large wood structures installed along this reach should be integrated with bank recontouring and riparian revegetation.

5.3 Additional Restoration Recommendations

Figure 12 summarizes our review of the LGCHEC project recommendations and adds additional project opportunities based on our field visits. Figure 12 breaks the projects up into four categories and was meant to focus some of the recommendation provided in the LGCHEP. Consequently, some of the project recommendations may overlap:

- *Large wood structures*: These projects consist of stand-alone installations of large wood to improve in-stream complexity, scour pools, and provide cover habitat.
- *Riparian plantings*: These projects consist of riparian plantings to fill gaps in the riparian corridor. Riparian planting should focus on a mix of hardwoods and coniferous species so as to increase the diversity and provide future large wood to the channel.
- *Reactivate secondary channel*: These projects consist of enhancing existing floodplain features to increase the frequency of primary and secondary channel interaction. Enhancements would be directed at both the primary channel and the secondary channel to encourage refuge areas for salmonids.
- *Bank recontouring:* These projects are intended to reduce fine sediment erosion from steep banks. The techniques would vary depending on space available. Ideally the bank would be pulled back to provide a floodplain bench, the toe would be protected wilth large wood, the remaining bank would be angled to a 3:1 slope or less, and the site would be revegetated.

Additional projects, beyond what was reviewed from the LGCHEP and discussed in Section 5.2, include a recommended project in Reach 1 (Project #1) and a recommended project in Reach 4 (Project #6). Table 8 summarizes the objectives of each of the recommended projects.

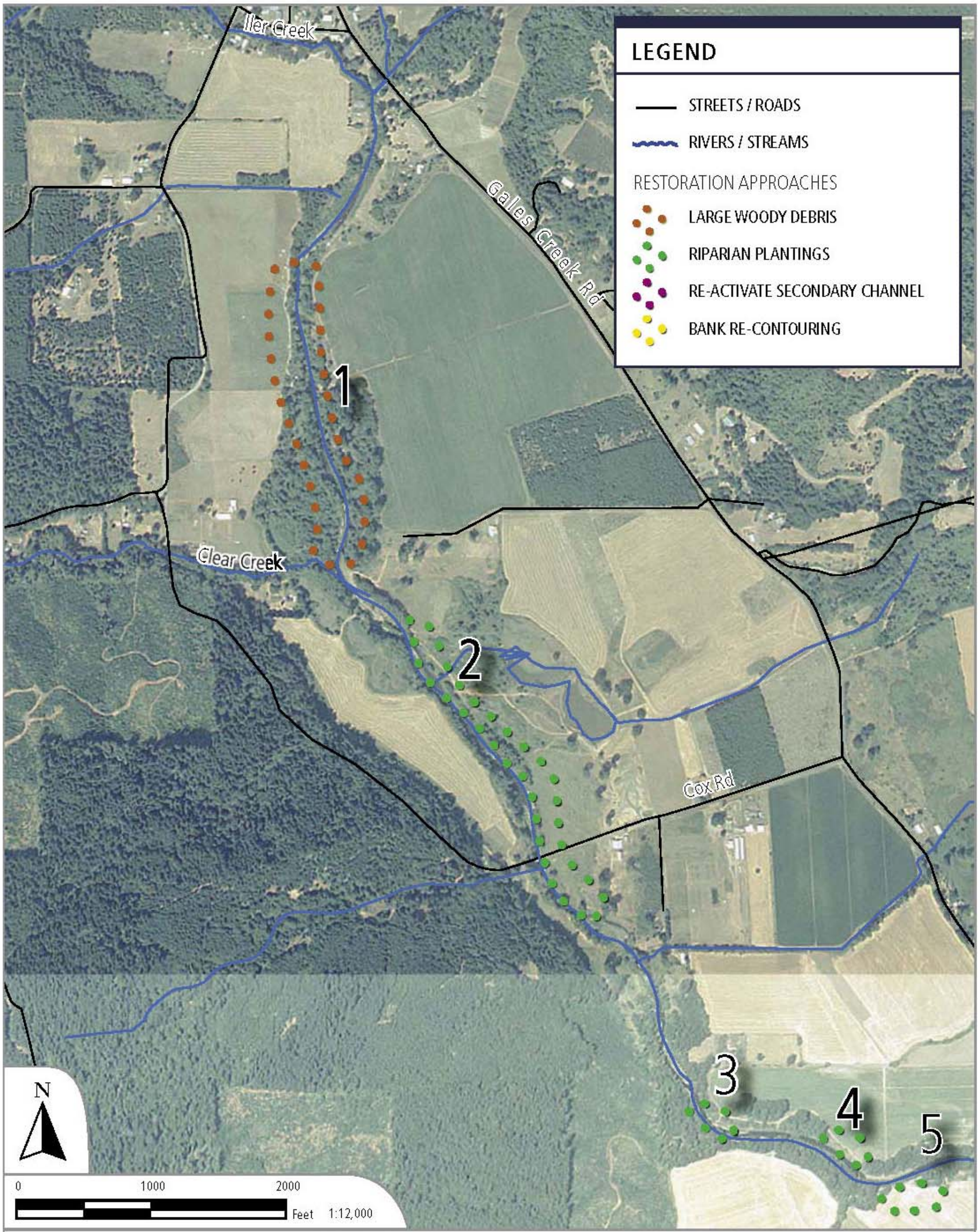

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FIGURE 12a: Recommended restoration approaches for portions of the Gales Creek study area to improve salmonids habitat. Project sites and opportunities were adopted from recommendations provided in the Lower Gales Creek Habitat Enhancement Plan. Project recommendations include bank recontouring, riparian revegetation, development of secondary channels, and large woody debris installations (LWD). Descriptions of proposed project opportunities are provided in Table 8.

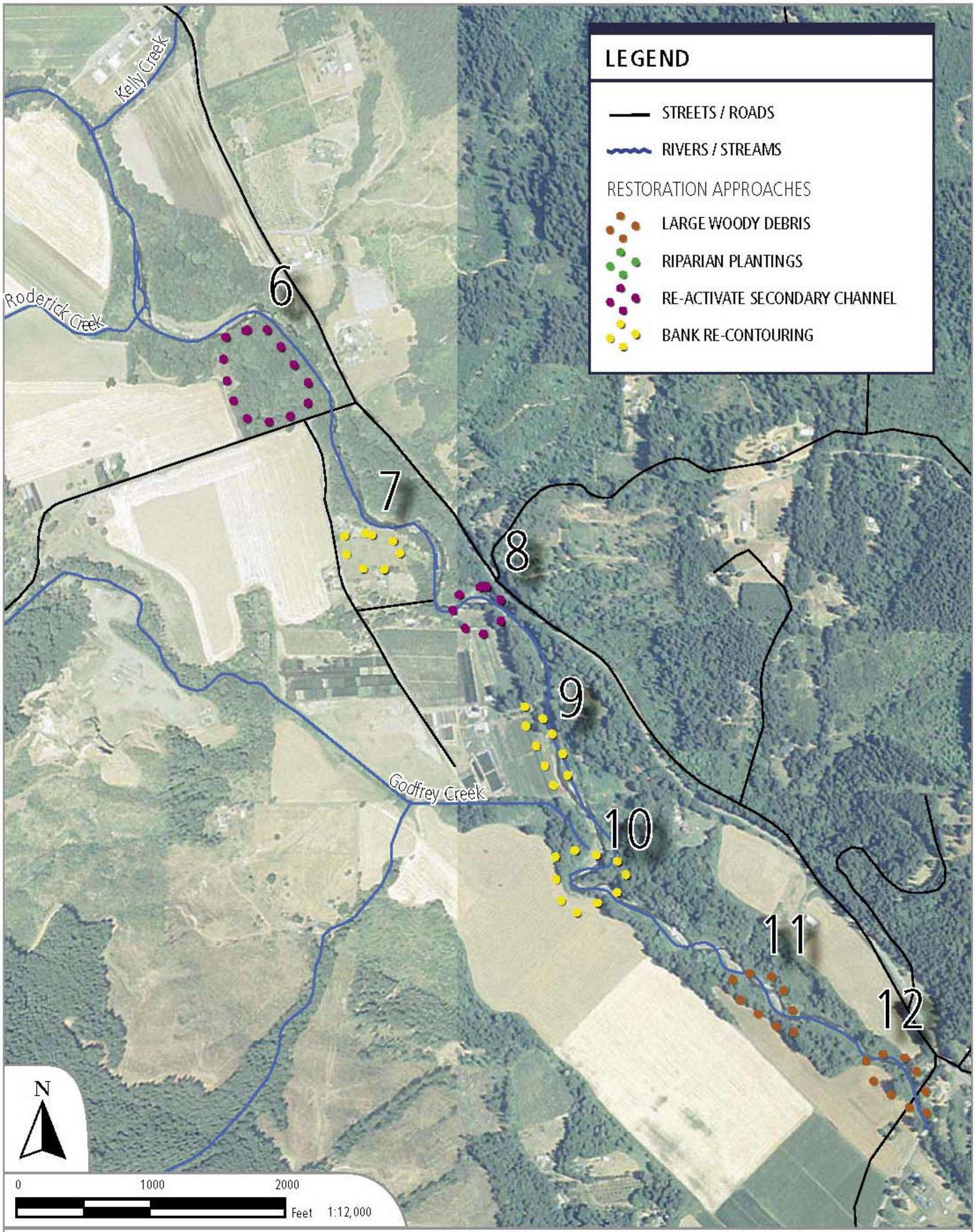

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FIGURE 12b: Recommended restoration approaches for portions of the Gales Creek study area to improve salmonids habitat. Project sites and opportunities were adopted from recommendations provided in the Lower Gales Creek Habitat Enhancement Plan. Project recommendations include bank recontouring, riparian revegetation, development of secondary channels, and large woody debris installations (LWD). Descriptions of proposed project opportunities are provided in Table 8.

Table 8: Potential habitat enhancement project opportunities for the Gales Creek study area. Project recommendations are based on field work, review of projects recommended in the LGCHEP, and a geomorphic evaluation of reach dynamics with regard to planform stability and sediment transport.

Project #	Geomorphic Reach	LGCHEP Reach	Project Type	Description
1	1	NA	Large Wood Structures	Reach 1 provides good opportunities for salmonids juvenile rearing. An existing canopy cover along with a lack of fine sediment filling pools provides an opportunity to enhance instream habitat. Construction access may be an issue through this reach.
2	2	GL01	Riparian Plantings	Some gaps exist in the narrow riparian corridor. Opportunities may exist to widen the riparian corridor through this reach depending on landowner interest. Plantings should include native hardwoods and coniferous species.
3, 4, & 5	3	GL02	Riparian Planting / Large Wood Structures	Gaps exist in the riparian corridor through this reach where past bank protection structures have been installed. Prior to replanting, large wood structures could be integrated into the bank protection to improve instream complexity.
6	4	GL05	Reactivate Secondary Channel	In 1996, Gales Creek apparently altered its course, abandoning the active channel that ran along the right edge of the riparian corridor and reactivated an old secondary channel along the left margin of riparian corridor. This project would aim to improve flood flow access to the abandoned secondary channel and enhancement of the channel for use as a refuge area for salmonids during high flow conditions. Landowner cooperation would be required to move this project forward and access may be an issue.
7, 9, & 10	5	GL07 & GL08	Bank Recontouring	Steep, eroding banks exist in two locations along this reach (not including Project 10). Depending on the level of landowner cooperation, the banks should be pulled back and recontoured. The toe would be protected by installing large wood structures and the site would be revegetated with native riparian species.
8	5	GL07	Reactivate Secondary Channel	Though there already appears to be interactions between the primary and secondary channels located in this area, enhancements could be made to the secondary channel by installing large wood structures and other roughness elements to provide cover habitat.
11	5	GL09	Large Wood Structures	This reach provides rearing habitat potential and access is good given landowner participation. Installing large wood structures to improve rearing habitat would greatly benefit this reach.
12	6	GL10	Large Wood Structures	Installing structures through this reach would require landowner cooperation. Any project should be combined with bank recontouring and revegetation efforts.

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