

Appendix C

Geomorphic Analysis of the East Fork Lewis River



Geomorphic Analysis of the
East Fork Lewis River in the Vicinity
of the Daybreak Mine
Expansion and Habitat Enhancement Project

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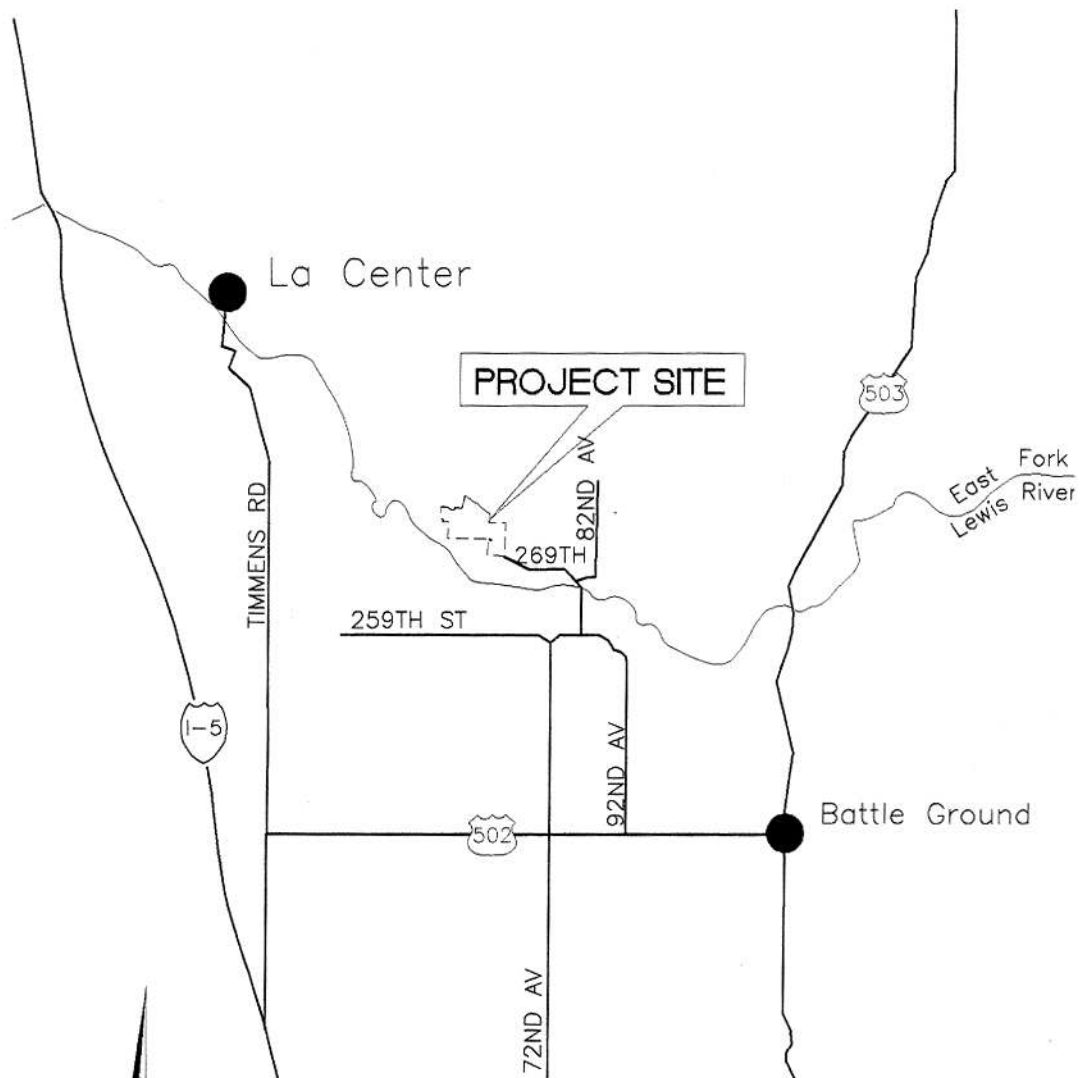
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Appendix 1. Monthly Flow-duration Curves for the East Fork Lewis River at Project Site.

1 Introduction

J. L. Storedahl and Sons, Inc. owns a gravel extraction operation and processing plant, known as the Daybreak Mine, in rural Clark County, Washington, near the confluence of Dean Creek with the East Fork Lewis River. The Daybreak Mine is located approximately 15 miles north of Vancouver, 4 miles southeast of La Center, and approximately 1 mile downstream of Clark County's Daybreak Park (Figure 1-1). The plant is currently operated for processing and distributing sands and gravels that are imported from offsite. The gravel pits located on-site have been mined out, one has been reclaimed and the others are planned for reclamation. Located just north and east of the processing plant is an important source of high quality sand and gravel, which forms a terrace above the 100-year floodplain. This area has been proposed as an expansion to the existing Daybreak Mine and is referred to as the Proposed Project throughout this report. A detailed description of the mining, reclamation, mitigation and conservation activities proposed for the site is given in the Site Plan, Daybreak Mine: Mine Expansion and Habitat Enhancement (EMCON, 1998).

This report was prepared as part of a Habitat Conservation Plan (HCP) and an Environmental Impact Statement (EIS) for the proposed expansion of the Daybreak Mine. In the following sections, the affected environment is described and analyses are presented of hydrology, hydraulics, sediment transport, channel profile, channel planform and channel avulsion. Each section contains its own summary with discussion of impacts to the East Fork Lewis River and Dean Creek from the Proposed Project.



N.T.S.

VICINITY MAP

S.W. 1/4 SECTION 18 AND
N.W. 1/4, N.E. 1/4 SECTION 19
T4N, R2E AND S.E. 1/4 SECTION 13
AND N.E. 1/4 SECTION 24 T4N R1E

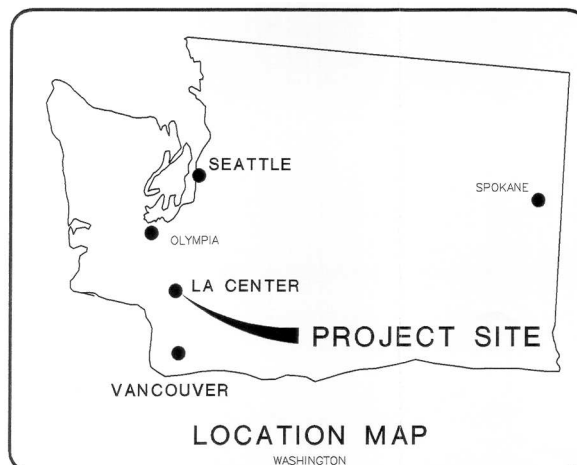


Figure 1-1. Project Location Map

2 Characterization of Affected Environment

2.1 Introduction

In the following sections the location and the physical characteristics of the basin and study area are described.

2.2 Basin Location and Size

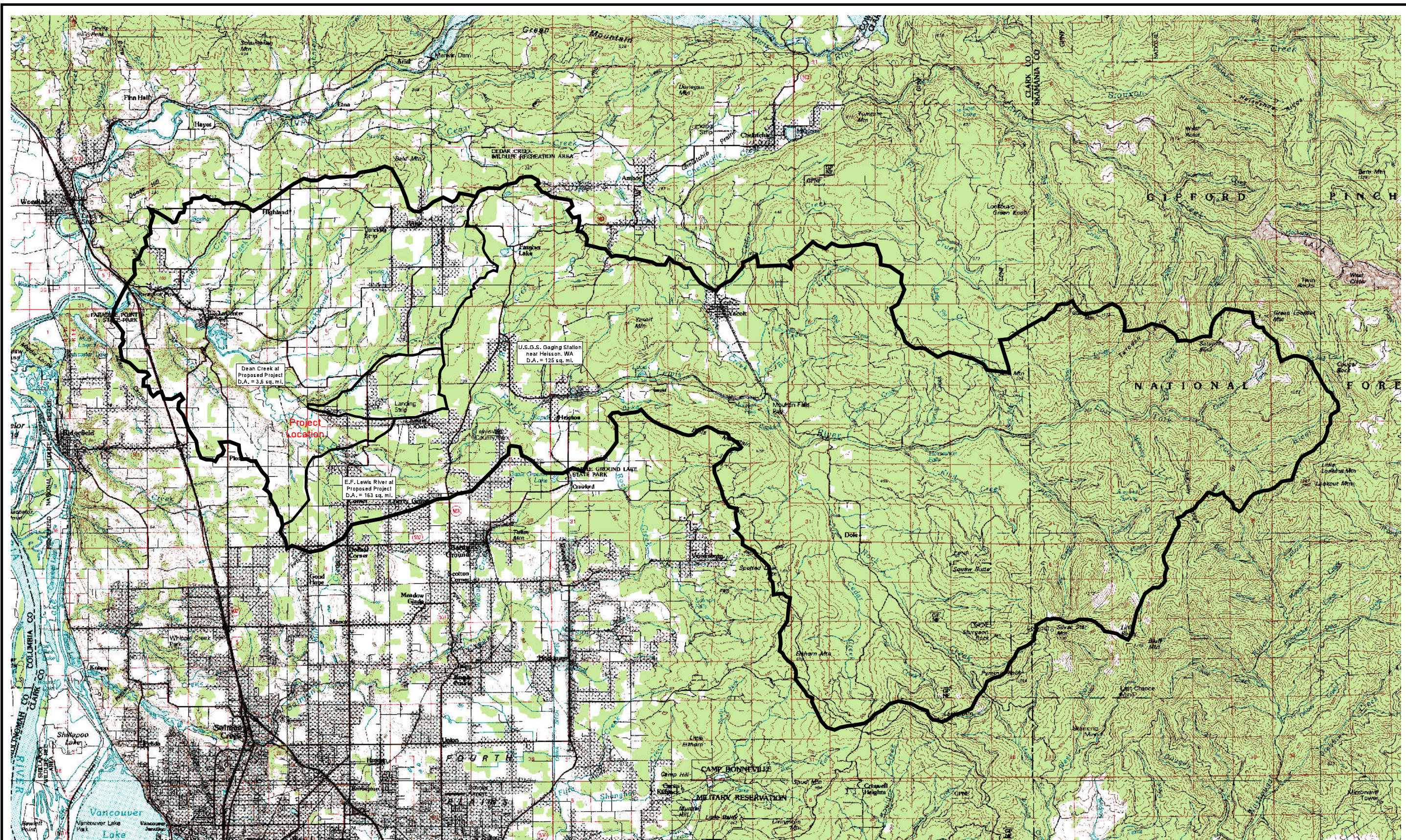
The East Fork Lewis River basin is located in southwestern Washington State (Figure 2-1). Seventy-nine percent of the basin is within Clark County while the remaining twenty-one percent of the upper basin is in Skamania County. The outlet of the basin is approximately fifteen miles north of the Portland, OR – Vancouver, WA metropolitan area. The 212 square mile basin extends from the Western Cascade Mountains to the Willamette-Puget Trough (S.C.S., 1972). The basin is bordered on the east by the Cascade Mountains, the north by the Lewis River basin divide, and to the south by the Washougal River basin divide and Salmon Creek basin divide. The basin is approximately 31 miles long and ranges from 4 miles to 12 miles in width.

The East Fork Lewis River headwaters are in the western foothills of the Cascade Mountains on the west slopes of Cougar Rock and Lookout Mountain in the Gifford Pinchot National Forest. From this location the river flows west to its confluence with the Lewis River near La Center, WA. Basin elevations range from 4,442 feet at Green Lookout Mountain to approximately mean sea level at the confluence with the Lewis River. The main stem of the East Fork flows for approximately 11 miles in Skamania County and the National Forest before entering Clark County. The river continues for another 32 miles to its confluence with the Lewis River. From the confluence, the Lewis River flows southwesterly for approximately 3 miles to its confluence with the Columbia River at river mile 87. A profile plot of the lower and middle portions of the East Fork Lewis River is shown in Figure 2-2.

The basin can be subdivided into three main sections based on similar geomorphic characteristics. The upper or mountainous section is characterized by steep forested terrain with tributary gradients that average 130 feet per mile. The middle section is characterized by a transition from steep to flat gradients with slopes averaging 20 feet per mile. The lower section is characterized by very flat and broad terrain with slopes averaging 2 feet per mile.

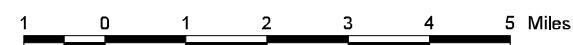
2.3 Floodplain / Channel Characteristics

In the following sections, a general description of the channel and floodplain characteristics associated with the East Fork Lewis River and Dean Creek are described. These characteristics include the channel slope, channel confinement, sinuosity and approximate floodplain width.



East Fork Lewis River Basin

Drainage Area = 212 Square Miles



Map Data Source: U.S.G.S. 1:100,000 Scale Map (Vancouver, WA; 1979)

Figure 2-1. East Fork Lewis River Basin Map

2.3.1 East Fork Lewis River Characteristics

Field reconnaissance observations and examination of a series of USGS 7.5-minute series topographic maps were used to define floodplain and channel characteristics of the East Fork Lewis River. The upper portion of the East Fork (headwater to RM 23.1) has a mean gradient of approximately 2.5 percent. The river is typically confined to a narrow v-shaped valley that includes several falls and rapids. From RM 23.1 to RM 19.0 the river travels through a narrow valley with a discontinuous floodplain. The mean gradient of the river in this reach is approximately 0.74 percent. From RM 19.0 to RM 16.8 the river is confined to a narrow gorge adjacent to a small terrace. The mean gradient in this reach is approximately 0.69 percent. From RM 16.8 to RM 10.2 the river is confined to a narrow meander belt that is approximately one-eighth to one-quarter of a mile in width. The river in this reach is very sinuous and includes island and bar deposits with a mean gradient of approximately 0.42 percent.

From RM 10.2 to RM 7.0 the river transitions to a much lower gradient system. This reach represents a depositional zone that is the focus of this study. The valley bottom in this section of river is approximately one-half to three-quarters of a mile in width. Several alluvial terrace deposits have been mapped (Mundorff, 1964) in the vicinity of the Daybreak site. The terraces are the result of sediment deposition that occurred at different river elevations from the mid-Pleistocene to the present. The Proposed Project will be located on existing ground that is 10 to 15 feet in elevation above the existing channel. However, after mining, the minimum elevation of Proposed Pits will be below the existing thalweg elevation of the channel. The channel is generally located along the southern edge of the valley throughout this reach.

The East Fork Lewis River channel typically ranges from 100 to 350 feet in width and averages approximately 4 to 6 feet in depth at bank full stage. The banks are typically comprised of non-cohesive materials similar to the sediments found in the channel bed (sand, gravel and cobble). The rapid reduction in river gradient through the reach correspondingly reduces the sediment transport capacity of the river. The reduction in sediment transport capacity results in the deposition of sediments transported from upstream sources. The natural trend for sediment deposition along the river in this area results in a relatively high lateral migration rate. Additionally, lateral migration tends to rework materials that have been deposited in the past.

Three tributaries join the East Fork in the vicinity of the Proposed Project. The confluence with Mill Creek is located at about RM 9.2, Dean Creek joins the river at about RM 7.3, and Mason Creek enters at RM 5.9. All three tributaries issue from the steep valley walls surrounding the East Fork Lewis River and have much smaller drainage areas. Of these tributaries, Dean Creek is considered to be an important stream due to its proximity to the Proposed Project and its use by salmonids. A summary of drainage areas for the East Fork Lewis River and its tributaries in the vicinity of the Proposed Project is shown in Table 2-1.

Table 2-1. Drainage area of East Fork Lewis River and major tributaries in vicinity of Proposed Project.

Stream	Location	Drainage Area (mi²)
East Fork Lewis River	At entrance to Ridgefield Pits	163
Mill Creek	At confluence with East Fork Lewis River	3.79
Dean Creek	At confluence with East Fork Lewis River	4.02
Mason Creek	At confluence with East Fork Lewis River	10.8

During a field reconnaissance conducted on January 18, 1999, the East Fork Lewis River was seen to be actively eroding the high banks of the south valley wall in several locations between RM 10.2 and RM 7.0. The eroding banks are approximately 75 to 100 feet in height and are situated in an exposure of the Lower Troutdale geologic formation that consists of sands with some clays and silts. The high banks were observed to be eroding due to a combination of undercutting and overland runoff. In both locations, the river was seen to be impinging on the toe of the slope. At RM 7.0, runoff from upland areas was flowing down and eroding the bank slope. Runoff was also seen to be flowing from the boundaries between different soil horizons in the bank. Large blocks of the high bank had been recently eroded and the river was transporting the eroded materials away from the toe of the slope.

From RM 7.0 to RM 2.4 the river valley broadens further and the river continues its sinuous pattern at an approximate slope of 0.05 percent. Tidal effects from the Columbia are normally present up through this reach to approximately RM 5.9 (Hutton, 1995), but can extend as far as RM 7.3 when flooding coincides with high tide (FEMA, 1991). Field observations indicate that the median sediment size decreases rapidly in a downstream direction. Gravel bars are absent and river banks are comprised of sands and silt. Bank heights are typically 5 to 8 feet above the river surface.

From RM 2.4 to RM 0.8 the river channel widens but is confined by steep hill slopes and the I-5 freeway bridge. The mean gradient in this section is approximately 0.02 percent. From the I-5 bridge at RM 0.8 to its confluence with the Lewis River the gradient is approximately 0.01 percent. Downstream of the I-5 Bridge the river turns to the south and then to the west flowing around a bar that has formed at the confluence of the East Fork Lewis and Lewis Rivers.

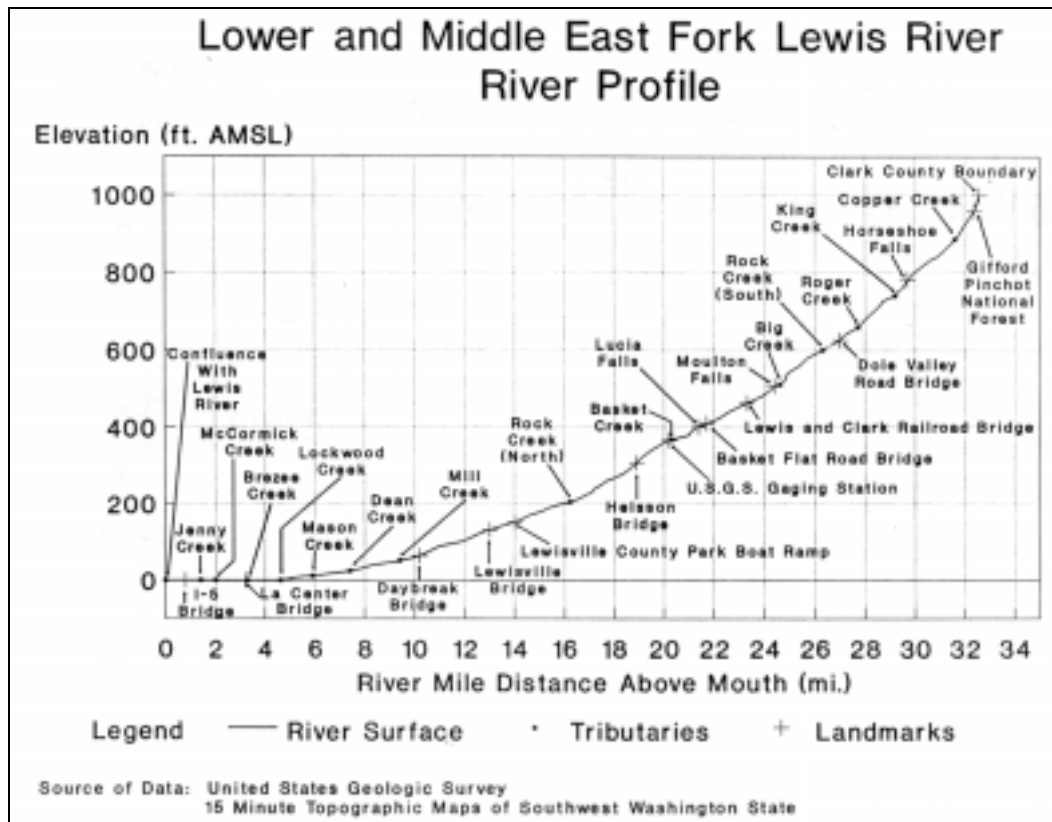


Figure 2-2. Profile of lower and middle East Fork Lewis River (Hutton, 1995).

2.3.2 Dean Creek Characteristics

Field reconnaissance observations and examination of a series of USGS 7.5-minute series topographic maps were used to define channel characteristics of Dean Creek. The headwaters of Dean Creek (headwater to NE 112th Avenue) have a mean gradient that ranges from 5 to 6 percent. The creek is typically confined to a shallow v-shaped valley. Below this section (from NE 112th Avenue to NE 82nd Avenue) Dean Creek has a channel gradient of approximately 1 percent where it flows along the high terrace above the East Fork Lewis River valley. From NE 82nd Avenue the channel gradient increases to approximately 2.5 percent as it descends through a narrow canyon into the East Fork Lewis River valley. Below J. A. Moore Road, the gradient is reduced to approximately 0.5 percent and the creek becomes slightly sinuous as it descends a small alluvial fan down to the East Fork Lewis River. Bed material is typically deposited in the vicinity of the J.A. Moore Road crossing due to the rapid reduction in channel slope at this location. Deposited sediments are periodically removed by county maintenance crews to maintain conveyance through the crossing. Additionally, discontinuous small levees exist on both sides of the creek that help maintain flow in the channel. However, these levees are composed of erodible native soils that would not be expected to prevent channel migration. A plan view of Dean Creek is shown in Figure 2-3.

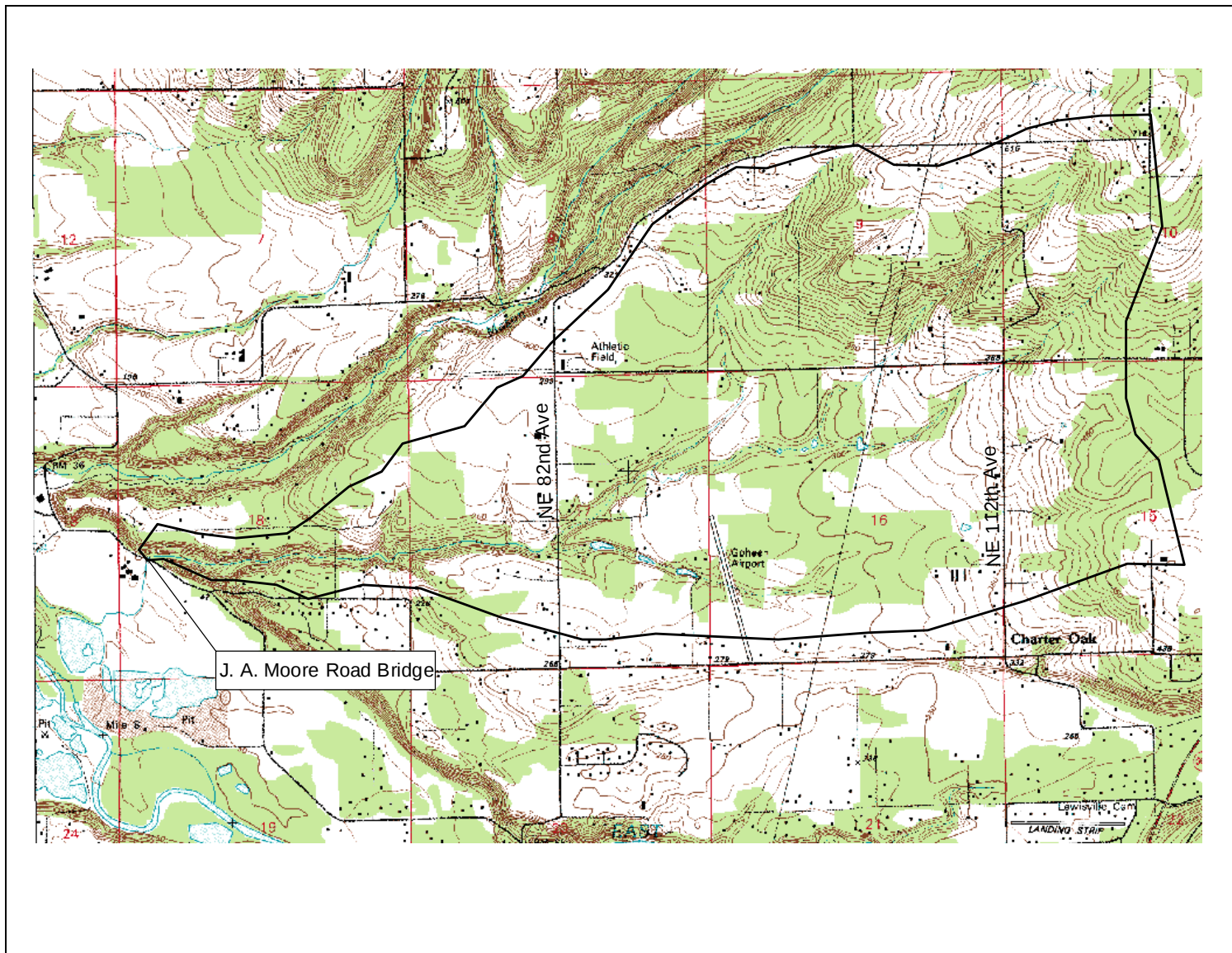


Figure 2-3. Plan view of Dean Creek Basin above J.A. Moore Rd.

2.4 Bed Material Characteristics

The following sections describe the bed material size characteristics for the East Fork Lewis River and Dean Creek in the vicinity of the Proposed Project.

2.4.1 East Fork Lewis River Bed Material Characteristics

Sediments found in appreciable quantities within the bed of the river are called bed material. The size characteristics of bed material along the East Fork Lewis River vary with stream gradient. They range from sand to medium cobbles in size. The portions of the channel bed observed during field reconnaissance activities displayed armoring characteristics typical of gravel-bed rivers. The low gradient sections of the channel were armored with smaller 1- to 2-inch diameter gravel while the steeper sections were armored with 4- to 6-inch diameter cobbles. Abandoned channels, with the lowest gradients, were observed to have significant deposits of medium to coarse sand building on top of gravel and cobble armor developed under former flow conditions. Subsurface sediment sizes were observed to be relatively consistent along the river in the vicinity of the project. The median sediment size (D_{50}) of material underlying the armor layer was estimated to be gravel of approximately 1.5 inches in diameter. The largest sediment size observed was about 8 inches in diameter. Detailed bed material size gradation information is provided in Section 5, "Sediment Transport".

2.4.2 Dean Creek Bed Material Characteristics

Field observations of bed material in Dean Creek near J. A. Moore Road show it to have size characteristics similar to the bed material of the East Fork Lewis River. In the steeper portions of the creek the channel is seen to be armored with large gravel- and cobble-sized material. Subsurface sediments range from sand to gravel in size.

2.5 Geology

The geology of the East Fork Lewis River basin was mapped and described by Phillips (1987). The East Fork Lewis River basin contains 3 major types of geological deposits: volcaniclastic rocks forming the Cascade Mountains, sedimentary deposits of the Troutdale formation, and periglacial deposits from the Lake Missoula Glacial Outburst Floods. Minor inclusions include intrusive granitics of the Silver Star pluton and basalt flows of the Boring lavas. Alluvium dating from the Pleistocene to the present occupies the valley formed by the lower East Fork Lewis River.

Sedimentary deposits of the Troutdale formation dating from the Pliocene are located along the western foothills of the Cascades, trending northwest to southeast across the East Fork Lewis River basin. The older, Lower Troutdale is composed primarily of clay, silt, and fine sand (Mundorff, 1964). The lower Troutdale crops out along the East Fork Lewis River valley and is visible on the north side of the valley above the Daybreak Bridge as well as the south bank across from the Daybreak site and in the mining operation east of Dean Creek. Mundorff (1964) mapped the upper surface of the lower Troutdale formation in Clark County. Information in Mundorff (1964) and from site observations indicate that the top of the lower Troutdale formation is at an elevation of approximately 100 to 115 feet along the south bank of the East Fork Lewis River near the Daybreak site. The fine-grained lower Troutdale is exposed along a steep cut-bank

directly south of the site. The Pliocene-age Upper Troutdale Formation consists of cemented gravel and conglomerates, with lenses of sand and claystone. The formation occurs as a wedge of sediments throughout the Portland Basin.

The Lower Troutdale formation exposed along the south side of the East Fork Lewis River near the Ridgefield Pits is overlain by a Pleistocene alluvial terrace deposit. There is an erosional unconformity between the Lower Troutdale and alluvial deposits which is visible along the riverbank. The alluvial terrace deposit consists of very coarse gravel in a sandy matrix and is known to be unstable. The deposits include quartzite and granitic pebbles, which were reworked from the Upper Troutdale formation and periglacial deposits. Recent observations suggest this to be a significant source of local sediment input to the river.

Periglacial deposits from the Lake Missoula glacial outburst floods were left along the Columbia River between about 12,700 to 15,300 years ago. The material was deposited as a great delta or fan at the mouth of the gorge (Mundorff, 1964). Within the East Fork Lewis River basin, these deposits are predominantly sand-sized. The Columbia River cut down through this formation, leaving a series of wide benches and terraces to the south.

The river valley formed by the lower East Fork Lewis River is filled with alluvium dating from the Pleistocene to the present. The alluvium consists of gravel, cobbles, sand, and silt, and ranges from several feet to 50 feet thick at and near the Proposed Project site. Gravels and cobbles are exposed in cut banks and on the river bottom in the vicinity of the site. Gravel bars are common in the river reaches above and along the Daybreak site but are absent downstream in the tidally influenced reach, where fine sands, silts, and clays predominate.

2.6 Soils

Soils in the upper East Fork Lewis River basin are generally deep, well-drained silt loams (McGee, 1972). Soils formed on periglacial deposits adjacent to the lower river are deep, well to poorly drained silt and sandy loams. Soils formed on alluvium deposited by the East Fork Lewis River are generally excessively drained sandy loams underlain by gravelly sand or loamy sand at a depth of 16 to 40 inches (McGee, 1972).

The soil types identified at the Daybreak site, as mapped by the Soil Conservation Survey (SCS) (McGee, 1972) include the Washougal loam (WaA), Washougal gravelly loam (WgB, WgE), Puyallup fine sandy loam (PuA), and Pilchuck fine sand (PhB). Descriptions of each soil type are as follows:

Washougal Loam and Washougal Gravelly Loam

The Washougal loam and Washougal gravelly loam consist of well-drained soils on top of sands and gravels. The water-holding capacity of the loam is slightly higher than that of the gravelly loam. Permeability in the units is rapid in the substratum and the surface runoff potential is low, making the erosion hazard slight to none. The Daybreak site contains about 50 acres of Washougal loam, 50 acres of Washougal gravelly loam with 0 to 8 percent slopes, and 0.4 acre of Washougal gravelly loam with 8 to 30 percent slopes. The soils are classified as Capability unit IIIe-3 (low fertility).

Puyallup Fine Sandy Loam

Puyallup soils are excessively well drained and overly sands and gravel of moderately rapid permeability. Surface runoff is low, making the erosion hazard slight to none. About 125.5 acres of Puyallup fine sandy loam occur on the Daybreak site. The soil is classified as Capability unit IIIs-1 (moderate fertility).

Pilchuck Fine Sand

Pilchuck fine sand consists mostly of sand, with some cobbles and gravel. The Daybreak site contains about 40 acres of Pilchuck fine sand. The soil is classified as Capability unit VIIIw-1 (not suited for cultivation).

2.7 Human Influences

The East Fork Lewis River basin is subject to a variety of human activities that may influence the morphology of the river. These activities include conversion of land use due to rapidly expanding residential developments, mining, road and bridge construction, and forestry practices. Brief descriptions of these human influences follow.

2.7.1 Population

Population data for the entire East Fork Lewis River basin is not available; however, historic population information for the Clark County portion of the basin can be used as an indicator of population trends. The population within Clark County's portion of the basin has increased from approximately 17,900 in 1981 to 20,500 in 1991, approximately a 15 percent increase (Hutton, 1995). The majority of the population lives in the western two-thirds of Clark County's portion of the basin (Hutton, 1995). Higher population densities are found along the State Route 503 corridor near the three incorporated areas of Battle Ground, La Center, and Yacolt as well as adjacent to the mainstem East Fork Lewis River (Hutton, 1995). In recent years, there has been a substantial increase in the number of homes built and seasonal cottages renovated adjacent to the East Fork (Hutton, 1995).

2.7.2 Land Use

The pattern of land use within the East Fork Lewis River basin changes over the three general topographic subdivisions (lower, middle, upper) of the watershed. Generally, forestland increases and farming and residential land use decreases from west to east. The predominant land uses in the basin are forestland and agriculture. The character of the basin remains mostly rural. In recent years, residential development has increased in the lower section of the basin (Hutton, 1995).

In the vicinity of the Proposed Project, residential developments are significant along NE 269th Street. The roads and residential developments in this area are in close proximity to and may be influenced by flooding along the East Fork Lewis River. Effectively, the developments in this area constrain the potential migration range of the East Fork Lewis River.

From field reconnaissance observations, it is noted that urbanization is rapidly increasing in the watershed areas of tributaries to the East Fork Lewis River including the Dean Creek basin. The increasing urbanization would be expected to increase runoff volumes and flood peaks along the tributary streams. Channel adjustments along the tributaries would be expected to accommodate the altered hydrologic conditions. Channel adjustments may include channel downcutting and bank erosion.

2.7.3 Mining

Copper and gold associated with the Silver Star Pluton were discovered near the headwaters of the East Fork Lewis River in the late 1890's (USFS, 1995). Several hundred mining claims were staked, and small mining communities such as Copper City and Texas Gulch were established (USFS, 1995). The Yacolt Burn forest fire of 1902, and subsequent fires brought an abrupt end to mining activities, destroying mine structures and the timber that provided a source of construction materials (USFS, 1995). There are currently approximately 300 active mining claims within the basin (USFS, 1995).

The aggregate resources of the East Fork Lewis River are valuable due to their high quality and close proximity to the Vancouver - Portland metropolitan area. Aggregate from mines along the East Fork Lewis River has been incorporated into a substantial portion of the asphalt and concrete paving of Clark County as well as many public and private projects in the county. It is not known when gravel mining first began in the lower East Fork Lewis River basin. However, it is known that numerous operators have historically conducted gravel mining along the lower East Fork for many years. Mining at the Daybreak site began sometime prior to 1968. A composite aerial photograph identifying the location of various currently operating and abandoned gravel pits along the lower East Fork is shown in Figure 2-4.



Approximate Scale : 1"=1,340'



Figure 2-3. Composite Aerial Photo of East Fork Lewis River near Daybreak Mine

The gravel mining along the East Fork Lewis River has numerous potential hydrologic, hydraulic, water quality, and geomorphic impacts. Geomorphic impacts include creation of floodplain lakes and their associated potential for channel avulsion. A channel avulsion is a rapid and unexpected shift in channel position that causes a portion of the existing channel to be abandoned. An avulsion of the river into a gravel pit can dramatically alter the location of the watercourse resulting in the abandonment of sections of the existing channel system. The hydraulic and sediment transport characteristics of the river may be affected upstream, within, and downstream of the pit location. A potential for upstream and downstream degradation of the channel bed and other channel adjustments is associated with the avulsion of the river into a gravel pit.

The historic gravel mining activities in the vicinity of the Proposed Project have already influenced the morphology of the river (see Figure 2-4). In 1995, the river avulsed in to an abandoned gravel pit (RM 9 Pit) located near RM 9.0. This event caused the abandonment of a large meander bend. During the February 1996 flood, the river broke into the southeast corner of Ridgefield Pit No. 7, flowing back into the channel at its northwestern most point (Miller, 1996). This caused the abandonment of approximately 1,500 feet of channel located southwest of Daybreak Pit No. 5. In November 1996, the river migrated into the Ridgefield Pit No. 1, flowing back into the channel from Pit No. 7 again relocating a section of the main channel of the river. The avulsions into abandoned gravel pits have altered the hydraulic and sediment transport characteristics of the river. Other abandoned or mined out gravel pits exist along the river in the vicinity of the Proposed Project including the Daybreak Pits, County 1 Pit and County 2 Pit, and the remaining Ridgefield Pit No. 9 (see Figure 2-4) and may influence the river in the future. The most significant of these pits are the Daybreak Pits. Consequently, an evaluation of geomorphic impacts must consider both the effects of the Proposed Project individually and cumulatively with other historic gravel mining operations in the area.

2.7.4 Roads

As seen in Figure 2-4, numerous roads are located in the East Fork Lewis River valley in the vicinity of the project. The roads influence the morphology of the river by confining its potential migration boundaries and restraining its main channel location at bridge crossings. At RM 10.2, the Daybreak Bridge holds the East Fork Lewis River main channel against the north valley wall. However, the piers of the Daybreak Bridge direct downstream flow toward the south valley wall. Between RM 10.2 and 8.9, the river valley is crossed by several roads. These roads, and the developments bordering them, present practical barriers to the potential migration boundaries of the river. Erosion control measures would most likely be employed if migration of the river threatened the roads or surrounding developments, preventing permanent relocation of the channel to this portion of the valley.

Numerous forest roads are also located in the upper watershed of the East Fork Lewis River. Construction of the roads in the upper basin began in the 1940's, primarily to support recreation and timber harvest (USFS, 1995). The construction and operation of forest roads can alter runoff characteristics by increasing drainage density, runoff volumes, and flood peaks. The alteration of hydrologic conditions and slope failures

associated with forest roads can increase sediment supplies to stream channels. It is assumed that hydrologic alterations associated with forest roads in the upper basin are insignificant in the lower basin in the vicinity of the Proposed Project due to the large increase in drainage area. Furthermore, it is assumed that any increase in the sediment supply to the river attributed to forest roads will continue in the future.

2.7.5 Logging

Extensive forest fires in the early 1900's and the late 1920's reduced the amount of mature timber in the East Fork Lewis River watershed. This likely increased the amount of sediment input to the stream system at that time. Vegetation in the upper basin is composed primarily of early- to mid-successional conifer stands, and hardwoods (USFS, 1995). As timber harvesting increases in the upper watershed, sediment input to the streams may potentially increase.

2.8 Summary

The morphology of the East Fork Lewis River is affected by both natural and human influences. The Proposed Project is located in a transition zone between a steep, narrow transport reach and tidally influenced lowlands. It is a natural zone of sediment deposition. As the gradient of the stream reduces, the velocity of flow reduces, and the sediment transport capacity of the river is decreased. The reduction in sediment transport capacity causes the deposition of sediments supplied from upper watershed areas. The deposition of sediments results in relatively large lateral migration rates.

A similar process of sediment deposition occurs along Dean Creek where it transitions from a relatively steep system above J. A. Moore Road to a shallow gradient alluvial fan where it meets the East Fork Lewis River valley bottom. Sediment has been routinely removed from the Dean Creek channel in the vicinity of the J. A. Moore Road Bridge by Clark County to maintain channel conveyance. The removal of sediment may be contributing to the relative long-term stability of the Dean Creek channel in its present location. As described in Section 7, "Planform Analysis", Dean Creek has remained in the same location for at least the last 38 years.

The project area is influenced by a variety of human influences. These include land use changes, urbanization, mining, roads, and forestry practices. Urbanization of the watershed is expected to increase runoff volumes, flood peaks and sediment supply. The altered hydrologic characteristics of the basin may also alter sediment transport characteristics of the East Fork Lewis River. The urban development, roads and bridges along the river and throughout the river valley present practical limits to future river migration.

Gravel mining has been occurring along the East Fork Lewis River in the vicinity of the Daybreak site since at least the 1960's. Several abandoned or mined out gravel pits exist along the East Fork in the vicinity of the Proposed Project. Avulsion of the river into abandoned or unused pits has affected the hydraulics, sediment transport, and morphology of the watercourse. Avulsions of the river into abandoned pits occurred once in 1995 (RM 9.0 pit) and twice in 1996 (Ridgefield Pits). Future avulsions of the river into

existing and proposed gravel pits are possible. Both individual and cumulative impacts of such avulsions into gravel pits are evaluated in Section 8, “Channel Avulsion”.

3 Hydrology

3.1 Introduction

In the following sections, the hydrologic characteristics of the East Fork Lewis River and its tributary Dean Creek are described.

3.2 Climate

Western Washington's regional climate is maritime, influenced by mountainous barriers that inhibit the passage of both the moist marine air masses arriving from the west and the hot, dry continental air masses from the east. This region is characterized by mild temperatures with prolonged fair and cloudy periods, muted extremes, and narrow diurnal fluctuations (Hutton, 1995). Summers are relatively dry and warm, while winters are typically mild, wet, and cool. The majority of the precipitation occurs as rain caused by low-pressure systems that move in off the Pacific Ocean.

In Battleground, WA, located approximately 4 miles southeast of the Proposed Project site, average annual temperatures range from a mean monthly minimum of 31.4 °F in January to a mean monthly maximum of 78.1 °F in July (WRCC, 1998). Local climate varies substantially with elevation and season. Rainfall and snowfall increase and temperatures decrease rapidly with increasing elevation. The East Fork basin's local climate is heavily influenced by elevation increases in the Cascade foothills just east of Battle Ground (Hutton, 1995). As elevation rises over a relatively short distance, precipitation increases significantly and temperature decreases rapidly.

3.3 Precipitation

Average annual precipitation varies from 52.3 inches in Battleground, WA to over 100 inches in the upper East Fork Lewis River basin. Generally, precipitation is the lowest in the southwestern lower elevation areas and the highest in the northeast high elevations areas. Figure 3-1 shows the average monthly precipitation for representative stations in the basin. In general, the highest precipitation occurs during the months of November through February while the lowest precipitation occurs during the months of July and August.

3.4 Gage Records

The East Fork Lewis River contains only one long-term gaging station (East Fork Lewis River near Heisson, WA, USGS Gage No. 14222500). The record from this gage was used to describe the flow statistics along the East Fork Lewis River in the vicinity of the Proposed Project site. This included a flood-frequency analysis, average-flow conditions analysis, flow-duration analysis, and low-flow conditions analysis.

The gage (USGS gage no. 14222500) is located on the right bank, 60 feet downstream from Basket Creek, 1.5 miles northeast of Heisson and 3.4 miles southwest of Yacolt at river mile 20.2. The drainage area at this gage is 125 square miles. The period of record is from September 1929 to present. There is no regulation or diversion of flow upstream

of the gage. The gage datum is 356.8 ft above sea level. Gage data were obtained from the USGS world wide web site (USGS, 1998)

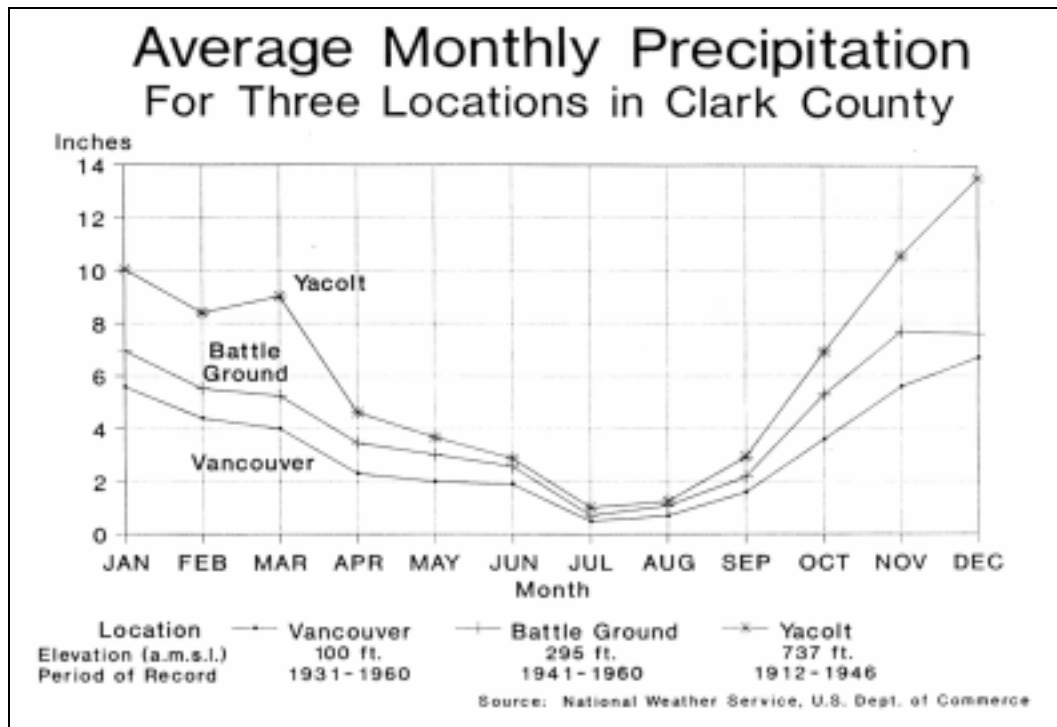


Figure 3-1. Average monthly precipitation (Hutton, 1995)

3.5 Flood History

The maximum discharge for the period of record for the gage near Heisson, WA was estimated to be 28,600 cfs and occurred on February 8, 1996 (Kresch, 1996). The ten largest floods measured at the gage are shown in Table 3-1. The smallest annual peak discharge of 3,390 cfs occurred on March 7, 1977. Figure 3-2 shows the peak flood events by water year for the period of record through 1996.

Table 3-1. Ten highest annual flood peaks for the East Fork Lewis River near Heisson, WA (1930 –1996).

Rank	Date	Discharge (cfs)
1	2/8/96	28,600
2	12/2/78	19,300
3	1/20/72	19,200
4	12/22/33	15,600
5	3/31/31	15,500
6	2/23/86	15,200
7	1/24/82	14,400
8	2/17/49	14,000
9	12/22/64	13,500
10	1/25/64	13,400

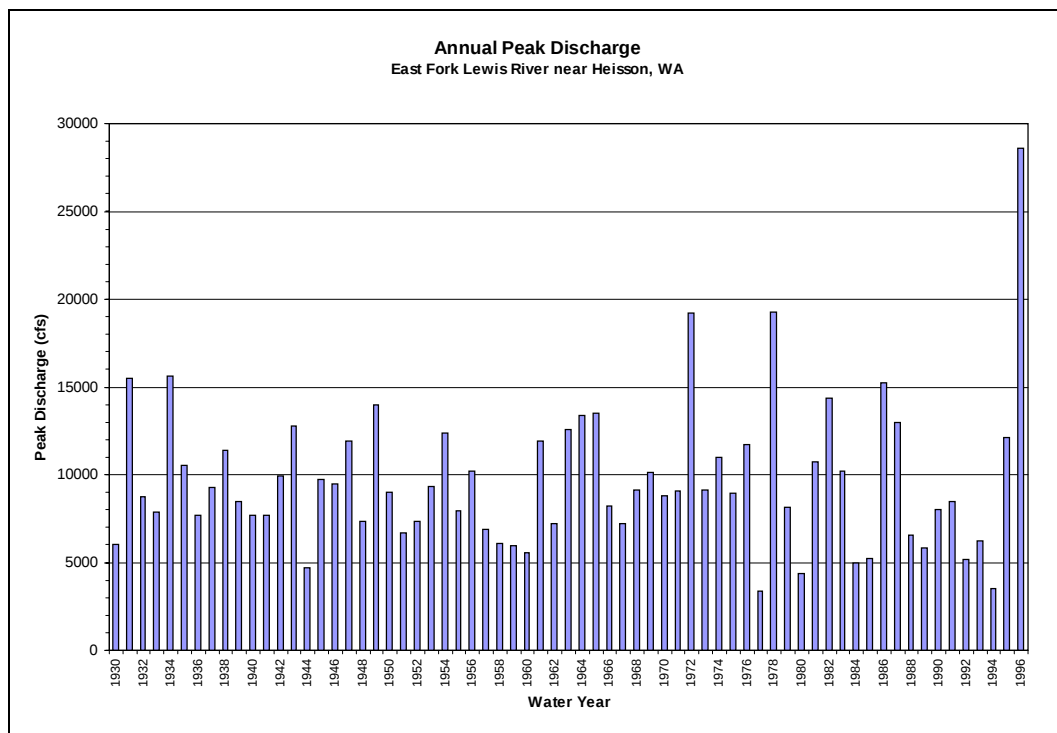


Figure 3-2. Annual peak flows for the East Fork Lewis River near Heisson, WA.

3.6 Flood Frequency Analysis

A flood frequency analysis was prepared for use in hydraulic and sediment transport analyses. The following sections describe the analyses conducted for the East Fork Lewis River and Dean Creek.

3.6.1 East Fork Lewis River Flood Frequency

A flood frequency analysis was prepared based on the East Fork Lewis River near Heisson, WA gage record. A Log-Pearson Type III analysis was performed using the Army Corps of Engineers HEC-FFA flood frequency analysis program (USACE, 1992). The analysis used data for the period from water year 1930 to water year 1996. The flood-frequency values for the USGS gage near Heisson, WA are given in Table 3-2.

Table 3-2. Flood-frequency values for the East Fork Lewis River gage near Heisson, WA.

Probability of Exceedance (%)	Recurrence Interval (yrs)	Discharge (cfs)
50	2	8,930
20	5	12,600
10	10	15,000
4.0	25	18,200
2.0	50	20,700
1.0	100	23,300
0.5	200	25,900
0.2	500	29,600

Based on the results of the flood-frequency analysis, the flood of record that occurred on February 8, 1996 had a recurrence interval of 500 years (USGS, 1997). The flood-frequency curve is shown in Figure 3-3.

In order to estimate the flood-frequency values for the East Fork Lewis River at the Proposed Project site, the values determined for the gaged site were transferred to the ungaged study site by a drainage area ratio transfer procedure. This was done using the following equation:

$$Q_{p \text{ ungaged}} = Q_{p \text{ gage}} * (D.A. \text{ ungaged} / D.A. \text{ gage})^b$$

Where:

$Q_{p \text{ ungaged}}$ is the peak discharge calculated for the location of interest downstream for a given recurrence interval.

$Q_{p \text{ gaged}}$ is the peak discharge for the USGS gage near Heisson, WA for a same recurrence interval.

$D.A. \text{ ungaged}$ is the drainage area of the location of interest.

D.A._{gaged} is the drainage area at the USGS gage (in this case, 125 mi²).

b is the exponent for drainage area parameter from the regional regression equation published by the USGS (USGS, 1974).

- For 2-year frequency, b=0.86
- For 5-year frequency, b=0.86
- For 10-year frequency, b=0.85
- For 25-year frequency, b=0.85
- For 50-year frequency, b=0.86
- For 100-year frequency, b=0.86
- For 500-year frequency, b=0.86 (assumed)

The drainage area for the East Fork Lewis River at the Proposed Project site is 163 square miles. Using the drainage area ratio transfer procedure, the calculated flood recurrence intervals are given in Table 3-3.

Table 3-3. Flood-frequency values determined for E.F. Lewis River at Proposed Project site.

Probability of Exceedance (%)	Recurrence Interval (yrs)	Discharge (cfs)
50	2	11,200
20	5	15,800
10	10	18,800
4	25	22,800
2	50	26,000
1	100	29,300
0.2	500	37,200

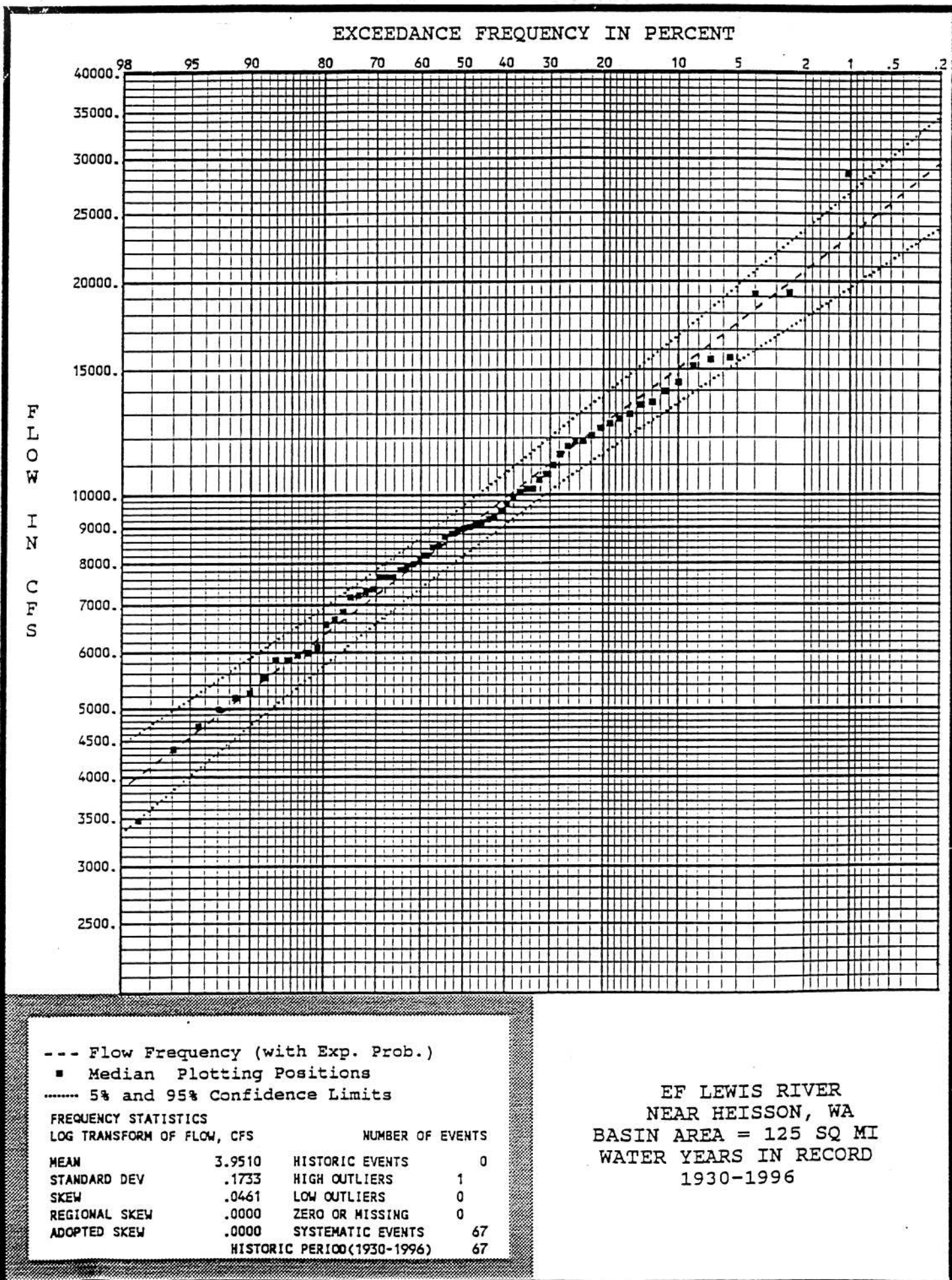


Figure 3-3. Flood-frequency curve for the East Fork Lewis River near Heisson, WA.

3.6.2 Dean Creek Flood Frequency

Dean Creek is an intermittent stream that flows along the northwest border of the project site. In order to determine peak flows for Dean Creek, regional regression equations (USGS, 1998) were used. The regional regression equation for Region 3, which includes Dean Creek, is shown below:

$$Q=aA^bP^c$$

Where:

Q is the flood magnitude in cubic feet per second.

A is the drainage area of the basin in square miles.

P is the mean annual precipitation in inches.

a,b,c are regression coefficients.

Values used for Dean Creek are given in Table 3-4.

Table 3-4. Values used in regional regression equation (USGS,1998).

Probability of Exceedance (%)	Return Period (yrs)	a	b	c
50	2	0.817	0.877	1.02
10	10	0.845	0.875	1.14
4	25	0.912	0.874	1.17
2	50	0.808	0.872	1.23
1	100	0.801	0.871	1.26

The drainage area of Dean Creek at the Proposed Project site is 3.6 square miles. The mean annual precipitation is 60 inches (USGS, 1998). The developed flood peak estimates for Dean Creek are given in Table 3-5. The flood-frequency relation is shown graphically in Figure 3-4.

Dean Creek Flood-frequency Curve

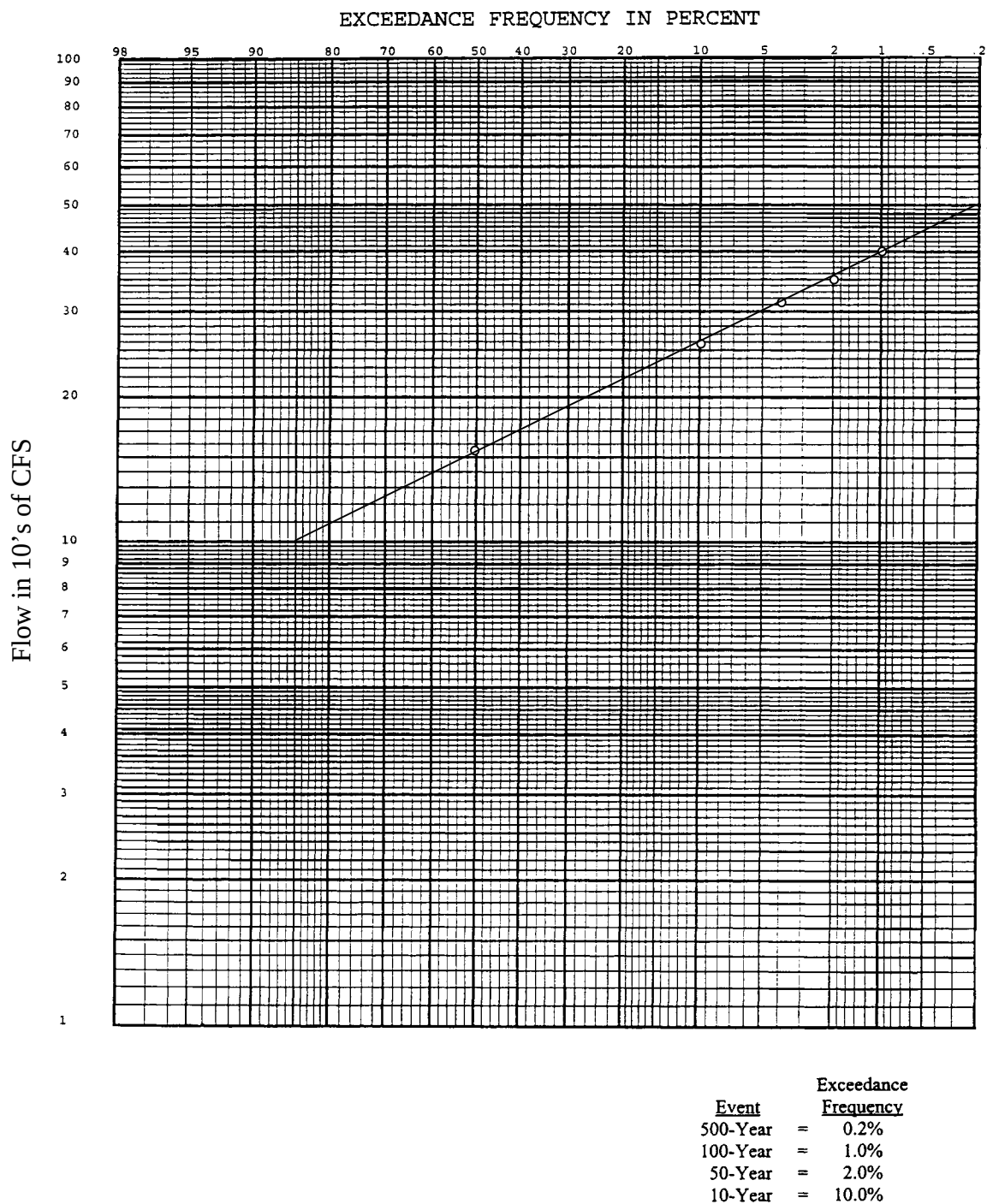


Figure 3-4. Flood-frequency curve for Dean Creek.

Table 3-5. Flood-frequency values determined for Dean Creek at the Proposed Project site.

Probability of Exceedance (%)	Return Period (yrs)	Peak Discharge (cfs)
50	2	164
10	10	276
4	25	336
2	50	380
1	100	425

3.7 Average Flow Characteristics

In the following sections, average flow characteristics for the East Fork Lewis River and Dean Creek are presented.

3.7.1 East Fork Lewis River Average Flow Characteristics

Figure 3-5 shows the mean annual and mean monthly discharge determined for the East Fork Lewis River at the project site for water years 1930 through 1996. The pattern of average monthly stream flows is very similar to the pattern of precipitation shown in Figure 3-1. This is indicative of a rain-dominated system.

The average monthly flow values were determined by direct scaling of measurements at the Heisson gage. Scaling was done based on the ratio of drainage areas. The mean annual discharge of the East Fork Lewis River at the Proposed Project site was estimated to be 967 cfs. Monthly average discharges for the months of November through April exceed the mean annual discharge while the monthly average discharges for the months of May through October are less than the mean annual discharge. December has the highest mean monthly discharge of 1,909 cfs or 198% of the mean annual discharge while August has the lowest mean monthly discharge of 108 cfs or 11% of the mean annual discharge. December had the largest mean monthly discharge of 5,160 cfs, which is 534% of the mean annual discharge. August had the lowest monthly discharge of 48 cfs, which is 5% of the mean annual discharge.

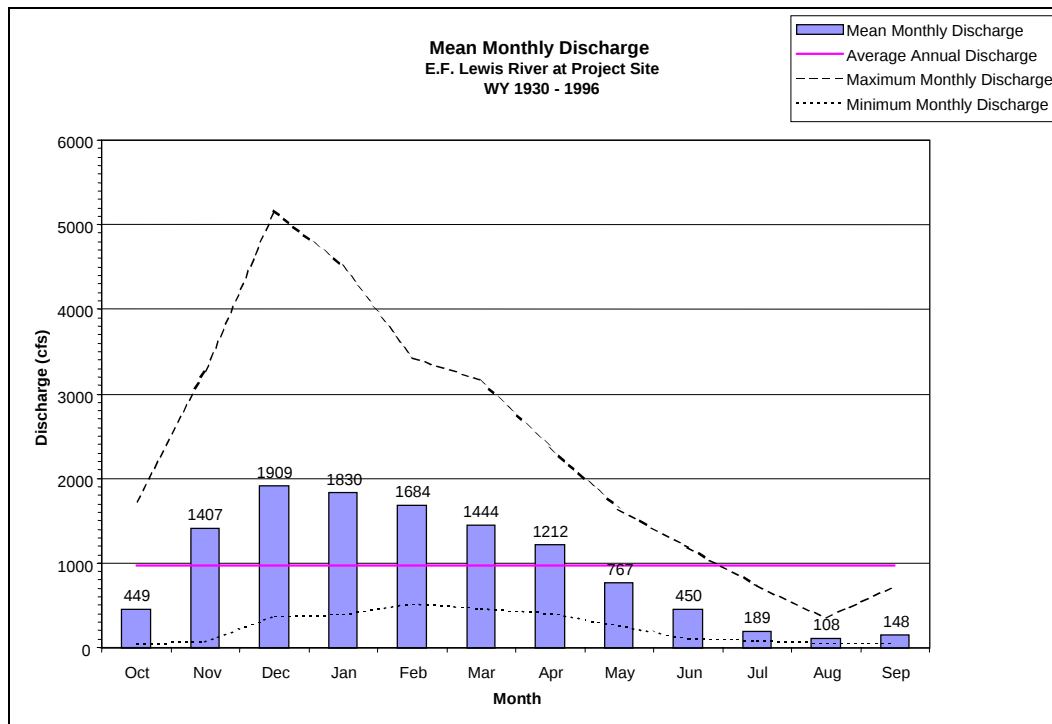


Figure 3-5. Estimated annual and monthly flow characteristics – E. F. Lewis River at the Proposed Project site.

3.7.2 Dean Creek Average Flow Characteristics

There is no continuous flow data available for Dean Creek. Additionally, there are no gaged streams of similar hydrologic characteristics within the basin on which to base a similar gage analysis. Thus, only a qualitative description of the flow characteristics can be given.

Dean Creek is an intermittent stream with an average monthly streamflow pattern that is assumed to be similar to that of the East Fork Lewis River. High flows occur during the winter months of November through February while low flows are fed by groundwater during the late summer months of July through September.

The flow characteristics of Dean Creek may change over time as urbanization of its watershed increases. Peak flows during winter runoff events will likely increase as urbanization increases impermeable areas and reduces the amount of vegetative cover. Urbanization will likely increase the magnitude of peak flows, increase winter runoff and increase the amount of sediment input to Dean Creek. Summer low flows may also be reduced as water that would otherwise infiltrate into soils becomes surface runoff. Reduced infiltration can lower the amount of water stored in the soils that supply water for late summer base flows.

3.8 Average Daily Discharge – East Fork Lewis River

Mean daily discharge for the East Fork Lewis River near Heisson, WA during water years 1995 and 1996 are shown in Figure 3-6. The individual high flow events are easily distinguished from one another. Both the rising and falling limbs of individual storm events are very steep. The stream system responds rapidly to rainfall events with increased discharge and drops off rapidly when the rains cease. High-flow events typically last less than two weeks. Extreme high flows, such as the February 1996 event, typically last a few days. Given sufficient time between storm events, the river discharge can drop off dramatically to well below the mean annual discharge. This is likely due to the shallow well-drained soils and steep slopes in the middle and upper portions of the basin. Such soils rapidly transmit water as subsurface flow to the stream channel (Whipkey, 1965). The rapid response of the river from the storm event is reflected in the steep rising and falling limbs of the runoff hydrograph.

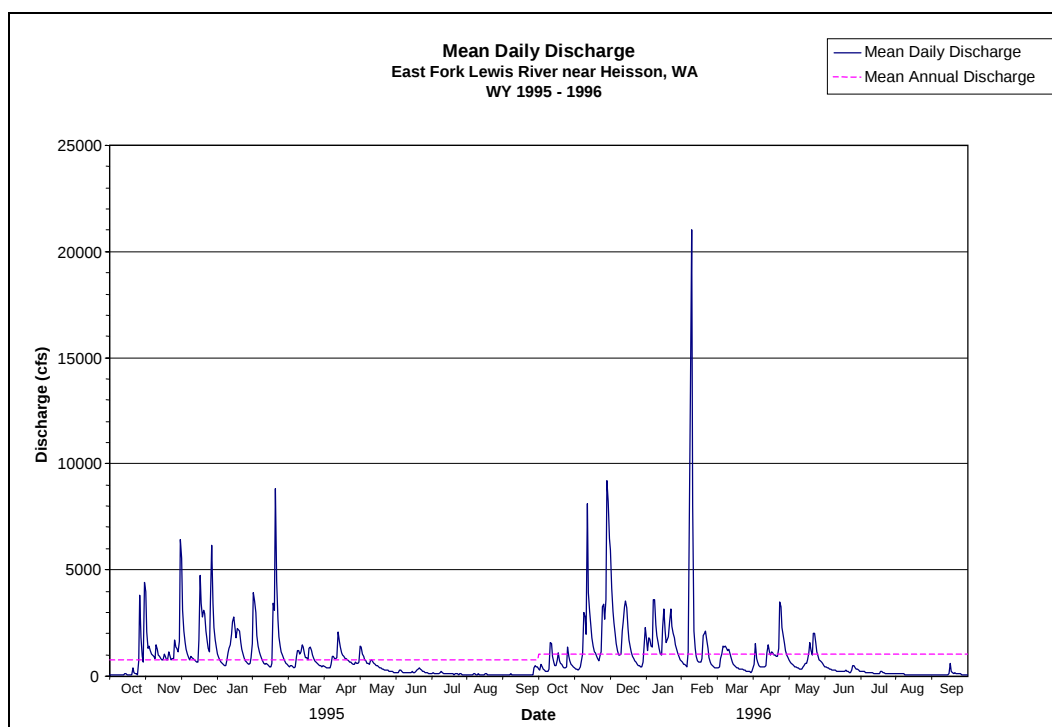


Figure 3-6. Mean daily discharge for the East Fork Lewis River near Heisson, WA (water years 1995 and 1996).

3.9 Flow-Duration Analysis – East Fork Lewis River at the Proposed Project Site

Figure 3-7 shows a flow-duration curve developed for the East Fork Lewis River at the Proposed Project site based on average daily flows. Values for this curve were obtained by scaling the flow duration curve for the USGS gage near Heisson, WA. The mean annual discharge is equaled or exceeded approximately 33 percent of the time. Table 3-6 summarizes the values for the flow-duration curve. Appendix 1 shows monthly flow-duration curves, based on average daily values, for the East Fork Lewis River at the Proposed Project site.

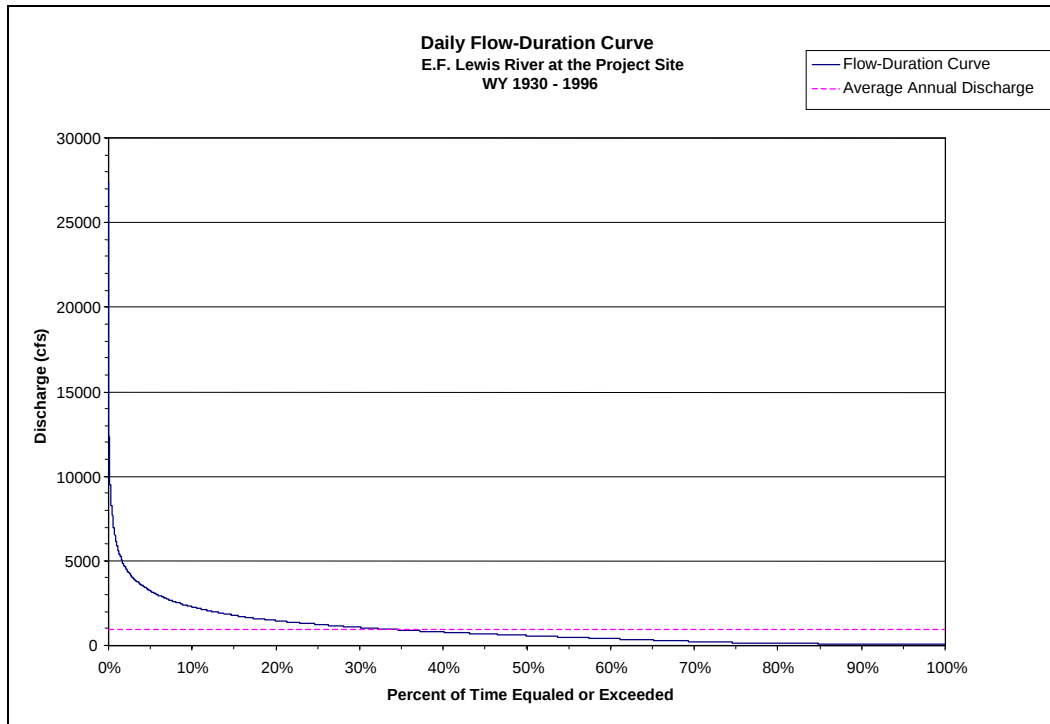


Figure 3-7. Estimated flow-duration curve for the East Fork Lewis River at the Proposed Project site.

Table 3-6. Estimated flow-duration values for East Fork Lewis River at the Proposed Project site.

Percent of Time Equaled or Exceeded	Discharge (cfs)
5	3,221
10	2,282
15	1,786
20	1,460
25	1,249
30	1,063
35	913
40	789
45	678
50	579
55	488
60	398
65	310
70	230
75	166
80	126
85	102
90	83
95	68

3.10 Low-Flow Characteristics

Low-flow characteristics are important for understanding the ability of the basin to deliver groundwater to the stream system. This can have a direct impact on the aquatic ecology of a stream. In the following sections, the low-flow characteristics of the East Fork Lewis River and Dean Creek are presented.

3.10.1 East Fork Lewis River Low-Flow Characteristics

Figure 3-8 shows the low-flow frequency distribution determined for the East Fork Lewis River at the Proposed Project site. The distribution is based on average daily flows obtained from the USGS gage near Heisson, WA. The flows at the project site were estimated based on drainage area ratios. Average 1-day, 3-day, 7-day, 14-day, 30-day, 60-day and 90-day flows were determined for each water year from 1930 to 1996. The lowest average daily flows from each category were then used for each water year. The flows were then ranked from smallest to largest with the smallest flow ranked number one. The Weibull plotting position formula was used to determine the recurrence interval for each annual low-flow event. Low flow frequency curves were visually fitted to the data plotted on the graph (Figure 3-8).

The lowest estimated average 1-day discharge of 37 cfs has a recurrence interval of 68 years. A summary of low-flow frequency distribution values determined for the East Fork Lewis River at the Proposed Project site is given in Table 3-7.

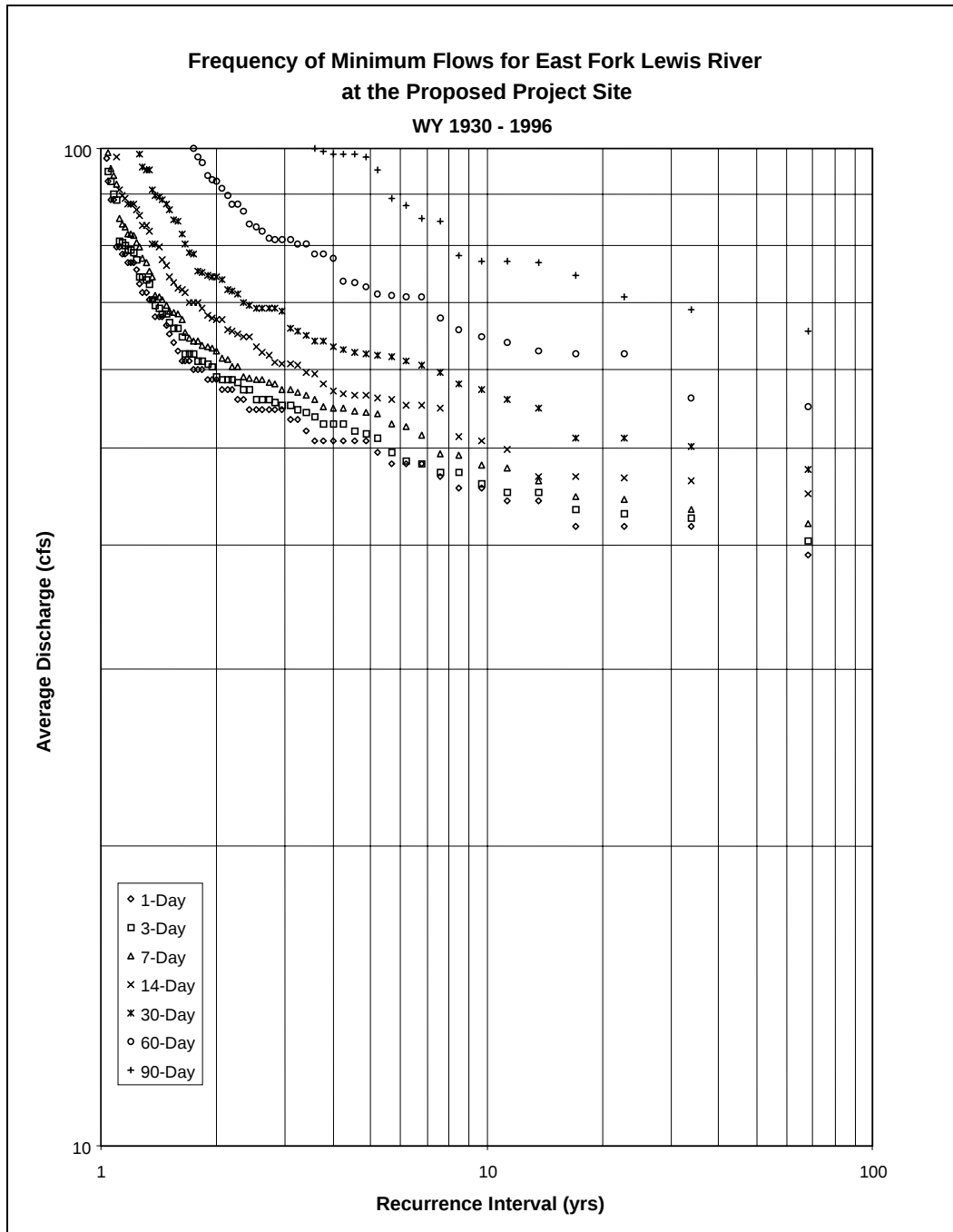


Figure 3-8. Low-flow frequency distribution for the East Fork Lewis River at the Proposed Project site.

Table 3-7. Summary of low-flow frequency distribution – East Fork Lewis River at the Proposed Project site.

Time Period (days)	2-Year (cfs)	5-Year (cfs)	10-Year (cfs)	50-Year (cfs)	100-Year (cfs)
1	58	48	45	40	37
3	60	51	46	41	40
7	61	54	47	42	41
14	66	56	51	46	45
30	75	61	56	48	46
60	91	71	66	52	51
90	130	81	79	64	61

3.10.2 Dean Creek Low-Flow Characteristics

Two separate streamflow measurements on Dean Creek made by McFarland and Morgan (1996) in October 1987 and October 1988 measured 0.10 and 0.15 cfs, respectively. These flows were approximately 0.25 percent of the flows measured in the East Fork Lewis River above Mason Creek. October is at the end of the dry season and likely represents the magnitude of typical low flows in Dean Creek. However, Dean Creek is known to go dry or become subterranean flow in the summer in some locations near J.A. Moore Road bridge (EMCON, 1998). The gradient of the stream changes rapidly at this location as the stream enters the relatively flat East Fork Lewis River valley bottom. Coarse gravel and cobble are deposited in this location providing a highly porous and permeable medium for water to flow through.

Groundwater-surface waters interactions of Dean Creek and the Proposed Pits are presented in the Project HCP. As discussed in the HCP, there does not appear to be a direct connection between the groundwater and surface flows in Dean Creek. Nearer the confluence with the East Fork Lewis River, beaver dams are known to exist that help maintain water levels in the lower portion of the stream during the summer months.

3.11 Evaporation

Evaporation from gravel pit ponds could cause a decrease in water resources available to the East Fork Lewis River. The net evaporation is the difference between the evaporation due to the ponds and the evapotranspiration that would normally exist due to native vegetation. A detailed analysis of the net evaporation is presented in the project HCP. As described in the HCP, the net evaporation loss from the Proposed Project is less than the existing irrigation water right.

3.12 Flood Storage

Gravel mining has occurred along the East Fork Lewis River in the vicinity of the Daybreak site since at least the 1960's. Previous mining has resulted in several abandoned or unused gravel pits in the valley floor surrounding the East Fork Lewis River. The Proposed Project will construct additional pits. The volume of material removed from these pits will create additional volume that could be utilized for flood storage if the pits became connected with the river.

The Ridgefield Pits are estimated to have a total volume of 2 million yd³ (Norman et al., 1998). The Daybreak pits have an approximate volume of 1.6 million yd³ (EMCON, 1999). The

Proposed Pits will have an approximate final volume of 5 million yd³ (EMCON, 1999). The total volume of the existing and proposed pits is about 8.6 million yd³ (5,330 acre-ft). The volume of other pits (County 1 and County 2) are unknown but estimated to be minor compared to the Ridgefield, Daybreak, and Proposed Pits volumes. Increased flood storage could reduce flood levels adjacent to and downstream of the project site.

The actual volume of storage available for flood storage depends upon the interconnectivity of the pits with the river and the pre-flood water surface in the pits. If the pits are completely disconnected from the low-flow channel, flood storage does not become available until overtopping of the high ground between the channel and the pit occurs. Available flood storage would be calculated as the total volume of the pit above the pit water surface. In the case of low magnitude events, that are unable to overtop the high ground, the additional flood storage provided by the pit would not be utilized by the river. However, the pit may capture localized runoff. If the pits were completely connected to the river, such as the Ridgefield Pits, the entire volume of the pits above the pre-flood water surface would be available for flood storage.

It is not possible to determine the future connectivity of the Existing and Proposed Daybreak Pits with the East Fork Lewis River, the pre-flood water surface elevations in the pits, or the exact amount of storage that would be utilized. Thus, a simplified approach was used to estimate the potential reduction in flood peaks related to the additional storage provided by the pits. The simplified approach estimates the maximum flood peak reduction assuming complete interconnectivity of the pits with the river. The available flood storage volume was estimated by determining the difference between the average annual discharge water surface elevation and the peak flood elevations determined from hydraulic modeling and multiplying it by the surface area of the ponds. It is recognized that connection between the existing and proposed ponds and the main channel of the East Fork Lewis River would change the geometry of the channel and therefore could change the hydraulics for both the average flow and flood flow conditions.

To provide a quantitative measure of flood storage created by the Ridgefield, Existing Daybreak and Proposed Daybreak Pits, the volume of flood storage was estimated for the 10-, 50-, 100-, and 500-year floods. The analysis was performed assuming different cases of interconnectivity between the pits with the river. Results of the analysis are summarized in Table 3-8. Synthetic flood hydrographs with a flood-duration of 4 days were used in the analysis.

The estimated reduction of the peak discharge for the 500-year event was found to range from 0.2 to 1.0 percent depending upon the interconnectivity between the different pits with the river. This would likely cause only a minor reduction in the peak stage of the river for an event of this magnitude. However, for more frequent events, the additional flood storage may play a slightly more significant role in reducing the magnitude of the peak discharge. As seen in Table 3-8, the peak discharge of the 10-year event is estimated to be reduced by 1.6 percent.

Table 3-8. Maximum flood peak reduction due to flood storage provided by pits.

Flood Event Return Period (yrs)	Pit Name	Flood Storage Volume (acre-ft)	Percent Reduction of Flood Peak
10	Ridgefield	349	0.5
	Daybreak	289	0.4
	Proposed	559	0.8
	Ridgefield + Daybreak	638	0.7
	Daybreak + Proposed	848	1.1
	Ridgefield + Daybreak + Proposed	1,197	1.6
50	Ridgefield	395	0.4
	Daybreak	327	0.3
	Proposed	632	0.6
	Ridgefield + Daybreak	722	0.7
	Daybreak + Proposed	959	0.9
	Ridgefield + Daybreak + Proposed	1,354	1.3
100	Ridgefield	400	0.3
	Daybreak	331	0.3
	Proposed	640	0.6
	Ridgefield + Daybreak	731	0.6
	Daybreak + Proposed	971	0.8
	Ridgefield + Daybreak + Proposed	1,371	1.2
500	Ridgefield	434	0.3
	Daybreak	360	0.2
	Proposed	694	0.5
	Ridgefield + Daybreak	794	0.5
	Daybreak + Proposed	1,054	0.7
	Ridgefield + Daybreak + Proposed	1,488	1.0

3.13 Summary

The hydrology of the East Fork Lewis River basin is typical of the rain-dominated systems of the Western Cascade Mountains. During the winter months, moist marine air masses move over the higher elevation Cascade Mountains producing rainfall in excess of 100 inches per year at the higher elevations. Winter runoff consists of a series of isolated high water events with periods of lower flow that often is less than the average annual discharge. Flood events are typically caused by large rainstorm events while extremely large flood events are typically caused by rain-on-snow events. Summers are relatively dry and warm with occasional precipitation events producing a short duration and relatively small increase in runoff.

The flood of record occurred on February 8, 1996, when a combination of heavy rainfall and snowmelt produced record setting discharges at many stations in the Pacific Northwest. At the USGS gage near Heisson, WA, this event was estimated to have a maximum discharge of 28,600 cfs and a recurrence interval of 500 years (USGS, 1996).

Summer low flows in the East Fork Lewis River and Dean Creek are fed by groundwater. At the Proposed Project site, estimated flows for the East Fork Lewis River ranged from a low of 37 cfs for a one-day period and a 100-year return interval to a high of 58 cfs for a one-day period and a 2-year return interval. August generally has the lowest flows, typically ranging between 60 cfs and 360 cfs with a 66-year average of approximately 110 cfs at the Proposed Project site. Two separate flow measurements on Dean Creek made by McFarland and Morgan (1996) in October 1987 and October 1988 measured 0.10 and 0.15 cfs, respectively. These flows were approximately 0.25 percent of the flows measured in the East Fork.

The surface area of water exposed by the existing and proposed pits influences the amount of evaporation of East Fork Lewis River water resources. A detailed analysis of the net evaporation associated with the Proposed Pits is presented in the Project EIS. In total, the net evaporation is less than the water volume consumed under the irrigation water right for the property. Accordingly, net evaporation will have no impact to average flow characteristics along the East Fork Lewis River. However, the proximity of the Proposed Project excavations to Dean Creek may impact groundwater inflows and outflows to and from the creek. An analysis of groundwater interconnectivity with Dean Creek is presented in the Project EIS.

The combination of the Existing and Proposed Daybreak Pits and the Ridgefield Pits with combined volumes of approximately 8.6 million cubic yards (5,330 acre-ft) would create an additional volume for flood storage assuming a direct connection with the river. It was demonstrated that the combined flood storage potential of the pits would cause only slight reductions in the magnitudes of the flood peaks in the vicinity and downstream of the Daybreak Site. The flood storage created by the gravel pits would have the least influence on the larger less frequent flood events, such as the 500-year event, while having a progressively greater influence as the magnitude of the flood event decreases.

4 Hydraulics

4.1 Introduction

Hydraulic conditions along watercourses potentially influenced by the proposed project were evaluated. This included the East Fork Lewis River and Dean Creek in the vicinity of the proposed project.

4.2 East Fork Lewis River Hydraulics

A hydraulic analysis of the East Fork Lewis River was conducted using the Army Corps of Engineers River Analysis System (HEC-RAS) standard-step backwater computer program (U.S. Army Corps of Engineers, 1998). The analysis included flows ranging from the 50 percent equaled or exceeded discharge to the 100-year return period event. The analysis extended from river mile 6.78 upstream to river mile 10.01, near the Daybreak Bridge. As described in Section 5, “Sediment Transport”, the results from the hydraulic analysis were used to conduct a quantitative geomorphic assessment of sediment transport and channel stability of the East Fork Lewis River in the vicinity of the Proposed Project.

4.2.1 FEMA Regulated 100-year Floodplain

Flooding in the vicinity of the Daybreak site, caused by the 500-year event that occurred in February 1996, was less extensive than depicted by the 100-year FEMA floodplain. The FEMA regulated 100-year floodplain in the vicinity of the Proposed Project was revised by WEST Consultants (1997) and presented as a letter of map revision (LOMR). The revised map has been accepted by FEMA and adopted by Clark County. The revised map is presented in the Project EIS.

4.2.2 Hydraulic Analysis Methods

The analysis utilized an existing HEC-RAS hydraulic model developed previously for delineation of the East Fork Lewis River floodplain (WEST Consultants, 1997). Topography for the study was based on topographic maps developed from aerial photography dated December 1996 and field surveys. The topographic elevations are based on the National Geodetic Vertical Datum (NGVD) of 1929.

The conditions modeled assume that existing high ground that separates the pits from the river remains in place. This would presumably yield the greatest flow depths and velocities and therefore the most conservative results.

The system was divided into a number of reaches as shown in Figure 4-1. The division of flow at the junction of any two reaches was determined by balancing energy between the upstream most cross-sections of each respective reach. Four locations were identified where flow splits away from the mainstem “EF Lewis” flow path and two locations where flow escapes from the “EF Split” and then returns to the main channel. Initially, water splits from the main channel (flow path “EF Lewis”) along flow path “EF Split”.



Approximate Scale : 1"=1,340'



Figure 4-1. Flow Paths of Hydraulic Model.

Water escapes from the “EF Split” flow path and returns to the main channel through flow paths “Spill 1” and “Spill 2.” A second flow split from the main channel to the “EF Split” occurs along flow path “South Split.” The third and fourth split from the main channel occurs along flow paths “Path 1” and “Path 3.” Both of these splits return to the main channel. The split of flow between the various flow paths was determined by balancing the energy grade line at cross-sections located at the upstream limit of the two diverging flow paths.

4.2.3 Hydraulic Roughness

Hydraulic roughness (Manning’s n) values utilized in the hydraulic model were chosen based on field reconnaissance observations, review of recent color aerial photographs of the study area, published descriptions of Manning’s n values (Barnes, 1987 and Chow, 1959), and professional judgement.

4.2.4 Starting Water Surface Elevations

The boundary condition at the downstream end of the hydraulic model was determined from a normal depth calculation. The downstream most cross-section in the model corresponds with a cross-section from the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FEMA, 1991). The water surface slope at this FEMA cross-section was used as the downstream boundary condition in the hydraulic analysis. The FEMA study had water surface slopes for the 10-, 50-, 100-, 500-year events. For the 100-year and 50-year flows in the hydraulic analysis an estimated FEMA water surface slope of 0.00018 and 0.0004, respectively, was used. For the 20-year flow and all smaller volume flows, the 10-year estimated FEMA water surface slope of 0.0007 was used for the downstream boundary condition. The 500-year event was not evaluated as part of this study. The flow data as discussed in Section 3, “Hydrology”, were used in the analysis. Table 4-1 summarizes the nine flows used in the hydraulic model.

Table 4-1. Discharges used in hydraulic model.

Event	Exceedance Frequency	Flow (cfs)
50% Equaled or Exceeded Daily	N/A	579
Average Annual Flow	N/A	967
2-Year	0.50	11,200
5-Year	0.20	15,800
10-Year	0.10	18,800
20-Year	0.05	22,800
50-Year	0.02	26,000
100-Year	0.01	29,300

4.2.5 HEC-RAS Analysis

Figure 4-2 and Figure 4-3 are profile plots of water surface elevation and average channel velocity for the East Fork Lewis River mainstem for selected flows. A large spike in the average cross section velocity is seen near RM 8 in Figure 4-3. This spike is due to a constriction of the channel in the Ridgefield Pit complex. It would be expected that this constriction would be rapidly eroded by the high velocities caused by the channel geometry. Figure 4-4 shows the flow volume in each for the various events. The river is contained within the mainstem for both the 50% equaled or exceeded flow and the average annual flow. For the 2- and 5-year events overtopping occurs into “Path 1” and “Path 2.” For the 10-year event and greater flows there is some portion of the river flow in nearly all of the flow paths.

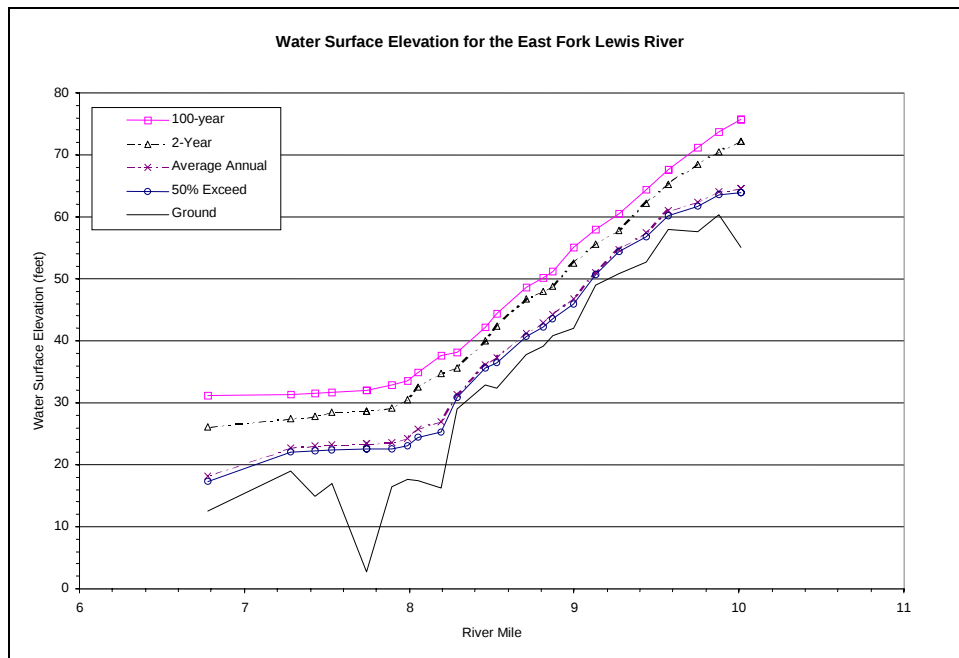


Figure 4-2. Estimated water surface elevations of the East Fork Lewis River for selected flows.

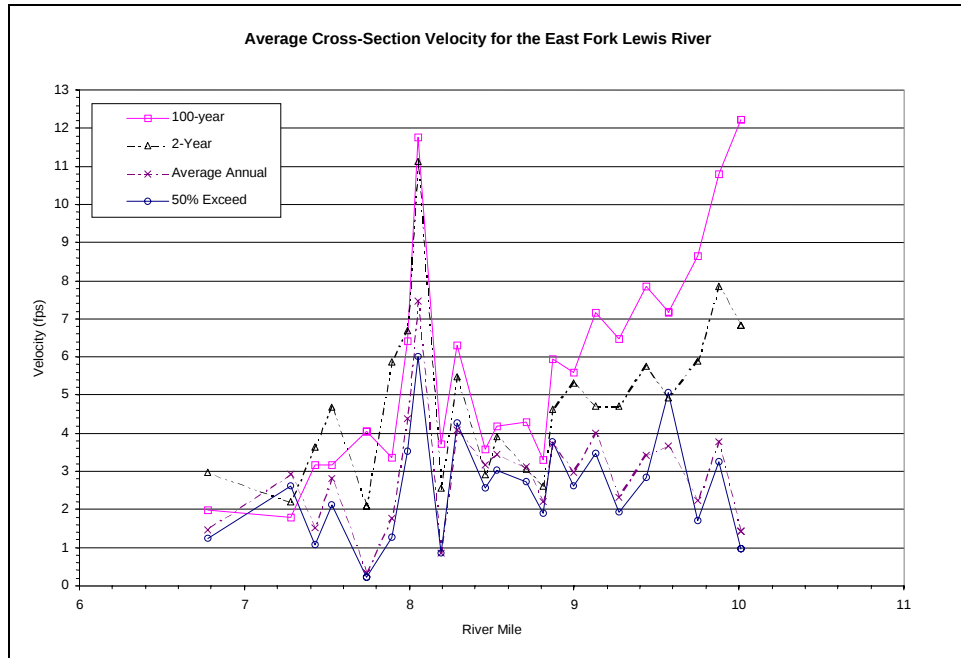


Figure 4-3. Estimated average velocities of the East Fork Lewis River for selected flows.

4.2.6 Hydraulic Analysis Results

Table 4-2 summarizes selected hydraulic values estimated for the 2- and 100-year recurrence interval flood. Average channel velocities range from 2.2 to 7.8 and 1.8 to 12.2 feet per second for the 2- and 100-year recurrence interval events, respectively. Average depths ranged from 1.5 to 10.3 and 3.5 to 14.7 feet for the 2- and 100-year recurrence interval events, respectively. Locations within the Ridgefield Pits were excluded from the table, as hydraulic conditions were not considered typical of the main channel of the East Fork Lewis River for the purpose of developing sediment transport estimates.

Table 4-3 summarizes maximum channel velocities and channel bank velocities for the average annual discharge and 2- and 100-year return period flood events at selected cross sections. Maximum channel velocities ranged from 1.1 to 14.6 feet per second for the average annual discharge and 100-year return period flood event, respectively. Main channel bank velocities ranged from near 0 in the Ridgefield Pits to 6.7 feet per second at RM 8.53 for the 2-year return period event. This suggests that velocities in the river are sufficient to erode the bank material during a 2-year (bank-full) flood event.

Table 4-2. Hydraulic values for the for 2- and 100-year flood events for selected main channel locations.

River Mile	2-year event	2-year event	2-year event	2-year event	100-year event	100-year event	100-year event	100-year event
	Top Width (ft)	Avg. Depth (ft)	Energy Gradient	Avg. Velocity (ft/sec)	Top Width (ft)	Avg. Depth (ft)	Energy Gradient	Avg. Velocity (ft/sec)
10.01	159.5	10.28	0.0016	6.8	628.3	13.1	0.0038	12.2
9.88	515.3	7.29	0.0032	7.8	888.4	10.5	0.0038	10.8
9.75	459.6	4.48	0.0035	5.9	770.3	6.8	0.0042	8.6
9.57	1006.6	3.45	0.0034	4.9	1103.1	5.8	0.0036	7.2
9.44	690.2	2.82	0.0061	5.8	832.5	4.4	0.0061	7.9
9.27	774.8	3.08	0.0036	4.7	1329.9	5.6	0.0031	6.5
9.13	660.4	3.61	0.0029	4.7	889.3	6.0	0.0034	7.2
9.00	1135.6	1.94	0.0067	5.3	1377.1	4.2	0.0062	5.6
8.87	950.2	3.02	0.0045	4.6	1382.6	3.5	0.0052	6.0
8.81	1439.4	2.99	0.0017	2.6	2152.8	4.3	0.0021	3.3
8.71	1546.9	2.49	0.0034	3.1	1869.7	4.3	0.0035	4.3
8.53	1928.5	1.49	0.0067	3.9	1938.5	3.5	0.0067	4.2
8.46	1996.7	1.93	0.0056	2.9	2013.2	4.0	0.0054	3.6
7.53	3873.6	5.72	0.0016	4.7	4145.9	8.6	0.0004	3.2
7.43	3865.2	7.97	0.0006	3.6	4126.9	11.7	0.0003	3.2
7.28	3943.2	4.05	0.0007	2.2	4880.1	8.0	0.0002	1.8
6.78	2814.3	9.7	0.0007	3.0	4499.9	14.7	0.0002	2.0

Table 4-3. Hydraulic values for the average annual discharge, 2- and 100-year return period events for selected cross sections.

River Mile	Average Annual Discharge			2-year flood			100-year flood		
	Left Bank Velocity	Right Bank Velocity	Max Velocity	Left Bank Velocity	Right Bank Velocity	Max Velocity	Left Bank Velocity	Right Bank Velocity	Max Velocity
10.01	0.5	0.3	1.7	1	1	8.2	4.1	4.4	14.6
9.00	0.2	2.5	3.7	0.5	5	9.3	2.7	5.9	12.0
8.53	1.1	1.8	4.1	6.7	2.6	9.2	9.5	3.0	11.9
8.19	0	0	1.1	0	0	2.9	0	0	4.1
7.43	0.2	0.4	1.8	1.4	1.4	4.4	2.0	2.3	3.7

4.2.7 Summary of East Fork Lewis River Hydraulic Analysis

In the previous sections, a hydraulic analysis of the East Fork Lewis River was presented. The values of velocity and depth were estimated for a variety of flow conditions ranging from the 50 percent equaled or exceeded flow to the 100-year return period flood. As seen in Table 4-2 average velocities ranged from 2.2 to 7.8 feet per second for the 2-year return period event and 1.8 to 12.2 feet per second for the 100-year return period event. In general, velocities decrease in the downstream direction as the slope decreases, although deviation occurs due to changes in local channel geometry and slope.

As seen in Table 4-3, maximum velocities ranged from 2.9 to 14.6 feet per second for the 2- and 100-year return period events, respectively. Velocities along the channel banks ranged from 0 in the Ridgefield Pits to 6.7 feet per second at RM 8.53 (0.23 miles upstream of entrance to the Ridgefield Pits) for the 2-year return period event. The largest flow velocity along the bank was 9.5 feet per second, also at RM 8.53, for the 100-year return period event.

4.3 Dean Creek Hydraulics

A hydraulic analysis of Dean Creek was conducted using the Army Corps of Engineers River Analysis System (HEC-RAS) standard-step backwater computer program (U.S. Army Corps of Engineers, 1998). The analysis included flow from the 2-year and 100-year return period events. The analysis extended from the J. A. Moore Road Bridge downstream to Daybreak Pond 5.

The analysis was conducted to characterize the hydraulic conditions along Dean Creek in the vicinity of the project. Proposed modifications to Dean Creek are described in the Habitat Conservation Plan. These include removal of the existing discontinuous levees along the channel, grading of the floodplain in the vicinity of the existing levees, and restoration of riparian forest within a 200-foot wide buffer.

4.3.1 Hydraulic Analysis Methods

An existing conditions hydraulic model of Dean Creek was based on 9 cross sections of the Dean Creek channel (labeled 2 –10) (Spurlock & Associates, 1999). The hydraulic model encompasses an approximate 2,100-foot reach of Dean Creek between J. A. Moore Road Bridge and Daybreak Pond 5 (see Figure 4-4). Additional cross sections, delineated from available topographic mapping (WEST, 1996), were used to model the existing overflow channel that parallels Dean Creek to the west (located on the Woodside Property). Geometry in the overbank areas was supplemented with data from a 2-foot contour interval topographic map (WEST, 1996).

4.3.2 Hydraulic Roughness

Hydraulic roughness (Manning's n) values utilized in the hydraulic model were chosen based on field reconnaissance observations, review of recent color aerial photographs of the study area, published descriptions of Manning's n values (Barnes, 1987 and Chow, 1959), and professional judgement. A Manning's n value of 0.035 was used for the main channel. This is a typical value used for gravel and cobble streams (Chow, 1959). A Manning's n value of 0.040 was used for the existing overbank areas. This is typical of values used for pastureland (Chow, 1959).

4.3.3 HEC-RAS Analysis Results

The 2-year and 100-year return period flood events (164 and 425 cfs, respectively) were evaluated in the hydraulic model. The 2-year return period event was evaluated to define geomorphic implications of the project. A 2-year return period discharge is considered to approximate the dominant discharge. The 100-year return period event was evaluated to define the flooding characteristics of Dean Creek. The discharge values for these events were estimated from USGS regional regression equations (USGS, 1998) as discussed in Section 3, "Hydrology".

During high flow events, water is seen to split from the main channel of Dean Creek just below the J. A. Moore Road Bridge and flow to the west through an overflow channel that parallels the Creek (see Figure 4-4). The overflow channel transitions into a series of shallow swales within the farm fields to the west. These swales are seen to connect to the lower portion of Dean Creek and Mason Creek, further to the west. The flow split between Dean Creek and the overflow channel was modeled by balancing the energy at the upstream confluence of the two channels. In addition to the split at J. A. Moore Road Bridge, water is seen to overflow from the main Dean Creek channel to the west at approximately cross section 6. As seen in Table 4-4, the discharge in the main channel at and below cross section 6 is reduced to account for this overflow. The excess discharge was added to the overflow channel to maintain continuity.

Average cross sectional velocities associated with the 100-year recurrence interval flood range from 2.3 to 6.5 feet per second under existing conditions. Velocities along the left bank levee are typically 3 to 5 feet per second under existing conditions for the 100-year return period event. No change to the channel geometry or hydraulic roughness is planned for locations below the 2-year water surface (OHWM) elevation. Accordingly, no significant impacts to the sediment transport characteristics of Dean Creek are expected as a result of the overbank modifications.

4.3.4 Summary of Dean Creek Hydraulic Analysis

The Dean Creek channel is situated on a small alluvial fan. The apex of the fan is located approximately where J.A. Moore Road crosses the creek. Generally, the topography of the fan is steeper in a westerly direction from the apex. Accordingly, overflows of the channel in the vicinity of the apex would be expected to flow to the west, away from the Proposed Project. In fact, a secondary channel is located to the west of the existing Dean Creek channel. The secondary channel provides flood protection from overflows of the Dean Creek channel. From the apex of the fan downstream to the approximate location of Cross Section 5, high ground and a discontinuous levee exists along the left bank of the stream. The levee prevents overflows to the west along this portion of the channel.

No significant change in the velocities and water surface elevation will occur for the 2-year flood. This is because no modifications are planned for the channel below the OHWM (2-year discharge water surface elevation). Accordingly, no significant impacts to the sediment transport characteristics of Dean Creek are expected. However, it is noted that the significant reduction in gradient naturally occurring along Dean Creek in the vicinity of J.A. Moore Road and further downstream create a depositional environment for sediments transported from upstream areas.

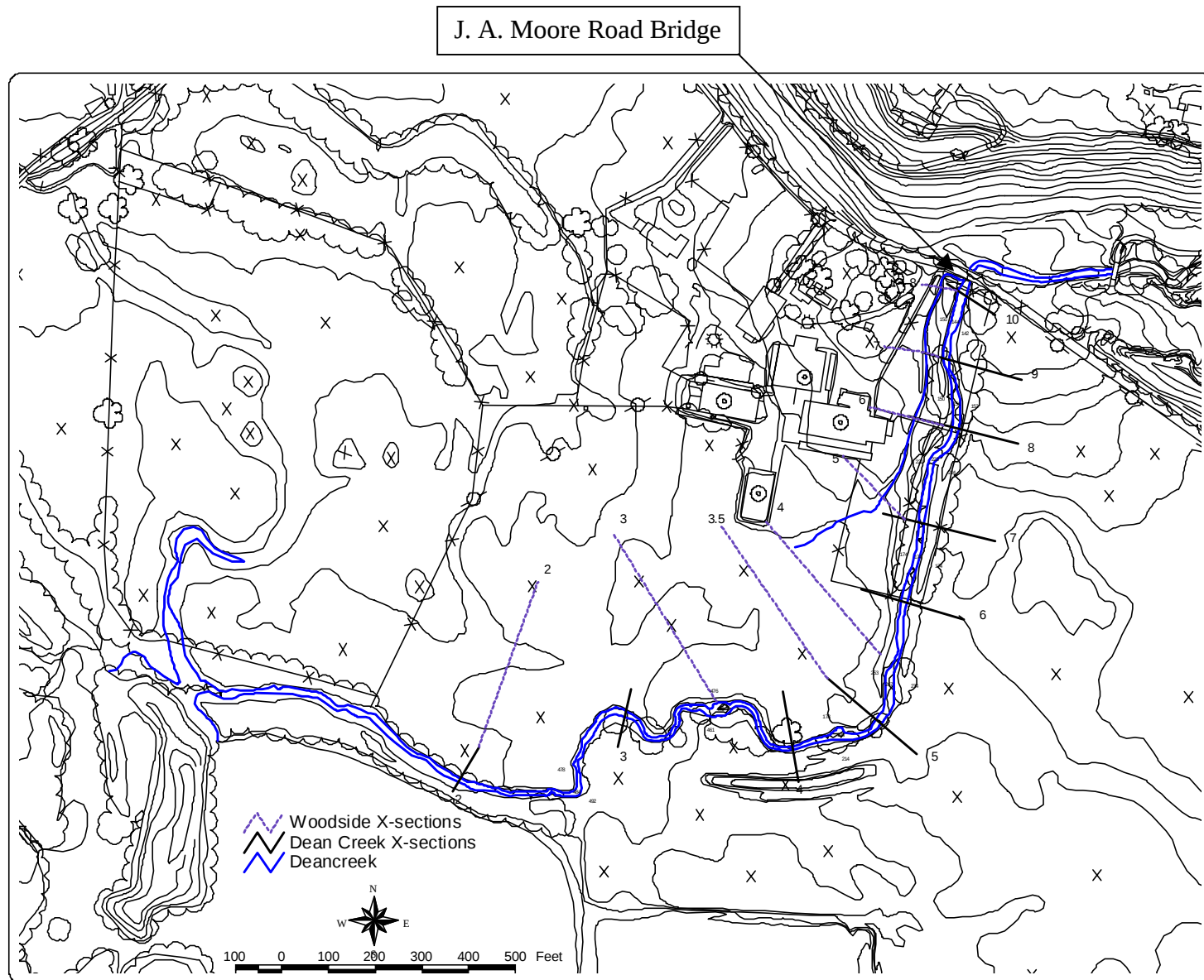


Figure 4-4. Plan view of Dean Creek showing cross section locations.

Table 4-4. Hydraulic analysis results for Dean Creek existing conditions with flow split.

Total 2-year Discharge = 164 cfs			
Cross Section	Channel Discharge (cfs)	WS El. (ft)	Average Velocity (ft/sec)
10	137	46.41	4.54
9	137	45.05	3.51
8	137	43.50	4.96
7	137	40.17	4.71
6	137	38.19	4.29
5	137	35.54	4.28
4	137	34.18	3.57
3	137	32.63	2.81
2	137	31.88	2.48

Total 100-year Discharge = 425 cfs			
Cross Section	Channel Discharge (cfs)	WS El. (ft)	Average Velocity (ft/sec)
10	345	47.16	5.78
9	345	45.87	4.96
8	345	44.22	6.24
7	345	40.87	6.51
6	290	38.84	5.08
5	290	36.30	4.90
4	290	34.94	4.70
3	290	33.56	2.31
2	290	32.51	3.38

5 Sediment Transport

5.1 Introduction

The following sections describe the analysis methods used to evaluate sediment transport conditions along the East Fork Lewis River and Dean Creek near the Proposed Project site. The objective of the sediment transport analysis for the East Fork Lewis River was to estimate its average annual sediment transport capacity. The sediment transport rate was used to estimate the expected rate of morphologic change in the Ridgefield Pits as well as Existing and Proposed Daybreak Pits in the event of an avulsion of the East Fork Lewis River. A qualitative evaluation of the sediment transport characteristics of Dean Creek was made to characterize potential impacts of the Proposed Project.

5.2 Definitions

To facilitate the discussion of sediment transport characteristics of the East Fork Lewis River, concise definitions of the terminology used are warranted. The total sediment load of a river consists of two components, the suspended load and bed load. Within the suspended load is another component called the wash load. Figure 5-1 shows a comparative classification of sediment transport, showing various modes of transport of the total load.

Total Sediment Load	Suspended Load	Wash Load	Suspension Load
		Bed Material Load	Saltation Load
	Bed Load		Contact Load
Classification	by mechanism of movement	by bed composition, source area, or method of calculation	by manner of movement

Figure 5-1. Comparative classification of sediment transport.

The definitions of the various components of the total sediment load can be classified based on the mechanism of movement, composition, or on the manner of movement. In general, the suspended load is comprised of fine-grained material that moves in suspension while the bed load consists of coarse-grained material moving on or near the bed. The wash load is part of the suspended sediment load and has particle sizes smaller than those found in appreciable quantities in the stream bed. Typically, the wash load is comprised of silt and clay sized sediment (< 0.0625 mm) while the bed-material load is that part of the total sediment load that is composed of particle sizes found in appreciable quantities in the stream bed. The bed material transport capacity is relevant to the form and stability of the channel.

For this study, we are concerned with that portion of the sediment load that is conveyed into and out of the vicinity of the Proposed Project and that composes the bed of the river (bed material load). However, it must be remembered that the sediment sizes found in the bed at one location within the stream are not necessarily the same as the sizes found in a different location. Thus, the bed material load will differ from one location to another. The transport and deposition of sediment is generally controlled by the channel hydraulics and the size characteristics of the sediment.

5.3 Sediment Transport Characteristics

A qualitative evaluation of the sediment transport characteristics for streams is important for understanding the overall processes that control the morphology of a stream system. In the following sections, the sediment transport characteristics for the East Fork Lewis River and Dean Creek are presented.

5.3.1 East Fork Lewis River

The profile of the East Fork Lewis River, in the vicinity of the Proposed Project, transitions from a steep slope to a flat slope. In this transition zone the transport capacity of the river is reduced causing deposition of the sediment carried into the reach. The size of the deposited bed material transitions from larger material in the upstream reaches to finer material in the flatter downstream section of the river. This is due to the energy required to transport the different sizes of sediment. As the slope of the river decreases, so does the energy of the river and its ability to transport large sediment. In other words, as the slope decreases the size of the sediment being transported also decreases. Downstream of the Proposed Project site the channel is relatively flat and it is influenced by backwater from the Lewis and Columbia Rivers. This causes even finer sediments (sands and silts) to deposit. The wash load (silts and clays) is typically transported through the system or may be deposited in over bank areas during high flows.

It is typical for gravel bed rivers such as the East Fork Lewis River and to form an armor layer of coarse material (gravels and cobbles) that acts to protect the underlying mixture of fine and coarse sediment. When a channel's sediment transport capacity exceeds the rate of sediment supply to the channel, the excess sediment transport capacity will be satisfied by erosion of the channel bed and/or banks. When sediment is eroded from the bed the channel will degrade. The different sizes of sediment that compose the bed of the river will be transported at different rates depending on their size. The finer material will be removed at a faster rate, leaving the coarser material behind. This coarsening process will stop once a layer of coarse material effectively covers the streambed protecting the finer material beneath from being transported downstream. After the process is complete, the streambed is armored. The coarse layer of sediments is referred to as the armor layer.

The armor layer will develop based on the size of bed material that is available, the discharge, and the related local hydraulic conditions. If the discharge and hydraulic conditions change sufficiently to transport the material that forms the existing armor layer, then the underlying bed material will be transported. If sufficient coarse material exists to resist the forces created by the altered hydraulic conditions, then a new armor layer will develop and erosion of the bed will be

limited. If sufficient material does not exist to form a new armor layer, the bed material will be transported until the discharge and related hydraulic conditions have moderated sufficiently to form an armor layer.

5.3.2 Dean Creek

The profile of Dean Creek, in the vicinity of the Proposed Project, transitions from a steep slope to a mild slope where it meets the valley floor of the East Fork Lewis River. Over geologic time, this deposition zone has formed an alluvial fan. The apex of the fan is fixed at J. A. Moore Road Bridge, which is located at a break in slope. Bed material in Dean Creek ranges from sands to cobbles in size and are similar to those described for the East Fork Lewis River. Bed material has been removed from the channel in the vicinity of the J.A. Moore Road Bridge on a regular basis by Clark County to maintain conveyance through the structure. The removal of deposited sediments has likely helped Dean Creek to remain relatively stable over the recent past. If sediment removal activities cease, significant aggradation of the Dean Creek channel is expected, resulting in loss of hydraulic conveyance and sediment transport capacity.

5.4 East Fork Lewis River Bed Material Size Characteristics

The average size of the sediments composing the armor layer will transition from large to small as the channel slope decreases. The D_{90} of the armor transitions from approximately 8 inches (200 mm) just upstream of the site near RM 9 to approximately 2.5 inches (60 mm) in the vicinity of the Proposed Project site near RM 8. The armor size will vary locally, depending on the local hydraulics in the channel.

The size distribution of the channel bed material was determined from sieve analysis of floodplain substrate and channel materials sampled in the vicinity of the Proposed Project. The resultant size distribution is shown graphically in Figure 5-2. As seen from the Figure, the bed material sediments are comprised primarily of gravels and cobbles with some sands. The D_{50} values of the samples range from coarse gravel (25 mm) to very coarse gravel (40 to 60 mm). These data were used for estimating sediment transport capacity.

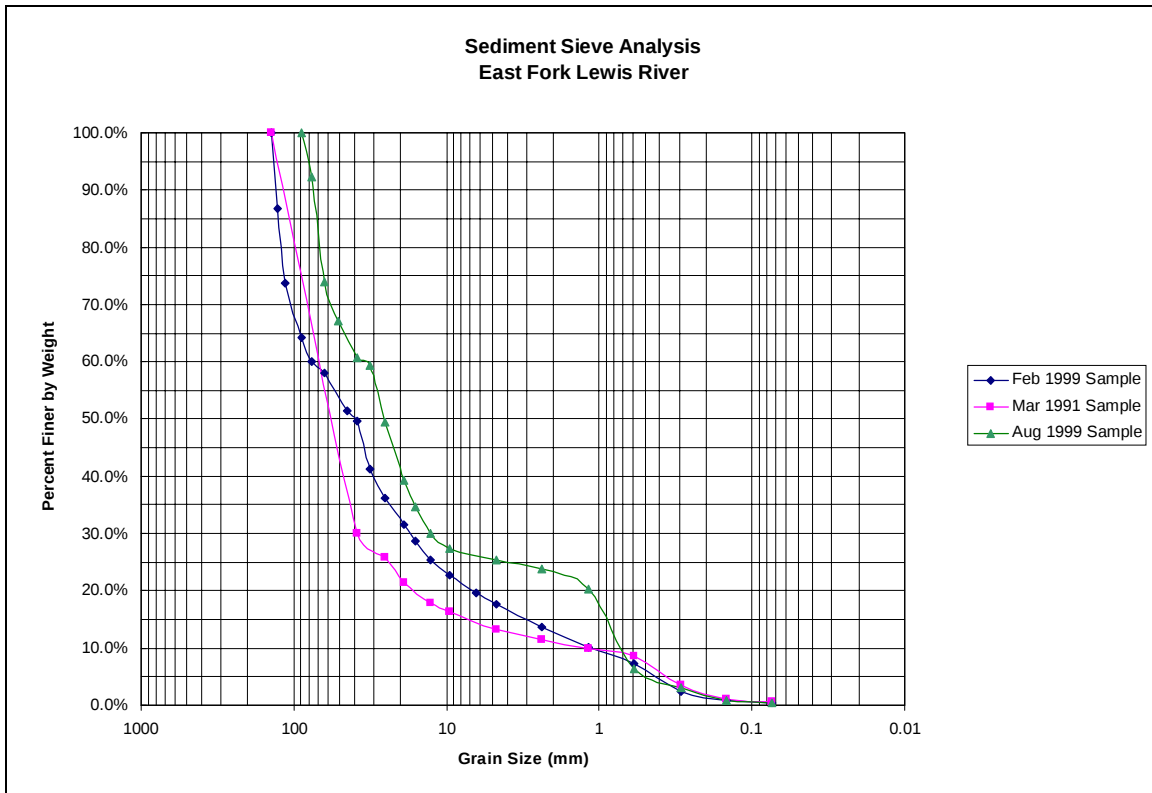


Figure 5-2. Bed material size distributions, East Fork Lewis River near Daybreak.

The avulsion of the East Fork Lewis River into the Ridgefield Pits in 1996 significantly reduced the supply of bed material sediment to reaches downstream of the pits. The flattened slope and modified channel geometry in the abandoned gravel pits has reduced the capacity of the river to transport coarse sediment to reaches downstream of the pits. To satisfy its sediment transport capacity along downstream reaches, the river may recruit material from the bed and/or banks. This may cause the channel bed to erode or coarsen, and cause the channel banks to erode.

5.5 East Fork Lewis River Armoring Characteristics

Armoring sizes were calculated using incipient motion equations from Meyer-Peter and Muller (1948), Mavis and Laushey (1948), Lane (1952), Shields (1936), and Yang (1973) for two locations along the East Fork Lewis River. The analysis was conducted to illustrate differences in sediment transport and armoring characteristics along the river. The differences in the armoring potential are related to the slope of the river, hydraulics of the flow, and the sediment size characteristics. The armoring conditions upstream at RM 10.01 are considered to be characteristic of the steeper river reaches supplying sediment to the Proposed Project area. The armoring conditions at the downstream section RM 7.43 are representative of the flatter channel gradient downstream of the Proposed Project area. Armoring calculations were performed for the estimated 50 percent equaled or exceeded discharge, average annual discharge, and the 2-, 5-, 10-, 20-, 50- and 100-year return period flood events. Table 5-1 summarizes these calculations for RM 10.01 near the Daybreak Bridge and RM 7.43 located just downstream of the Ridgefield Pits. This information helps to characterize the ability of the river to transport bed material along the reach near the Proposed Project site.

Table 5-1. Estimated armor size characteristics for RM 10.01 and 7.43, East Fork Lewis River.

Discharge Event	Average Armor Size (mm)	Armor Thickness (ft)	Percent Coarser by Weight	Depth of Degradation Required to form Armor Layer (ft)
RM 10.01				
50%	2	0.02	89	0.002
AAQ	3	0.03	85	0.006
2-yr	68	0.7	41	1
5-yr	103	1	31	2.3
10-yr	134	1.3	7	-
20-yr	165	1.6	0	-
50-yr	192	1.9	0	-
100-yr	214	2.1	0	-
RM 7.43				
50%	2	0.02	88	0.002
AAQ	4	0.04	84	0.007
2-yr	20	0.19	68	0.09
5-yr	21	0.2	68	0.1
10-yr	21	0.2	68	0.1
20-yr	25	0.2	65	0.1
50-yr	19	0.2	69	0.08
100-yr	14	0.1	74	0.05

* Not computed

The armoring calculations for the cross section at RM 10.01 show that the bed of the East Fork Lewis River can develop an armor layer for flows up to the 5-year return period event. When discharges exceed this amount, bed material of sufficient size is not available to form an armor layer. For discharges greater than the 5-year flood, the entire bed is mobilized.

At RM 7.43 the slope is much flatter and a larger portion of the discharge is conveyed in the overbank areas, reducing the ability of the river to transport coarse material. At high discharges, downstream backwater effects also reduce the sediment transport capacity. The armoring calculations indicate that the channel bed can armor itself over the entire range of flows evaluated. Compared to the upstream section, only much finer-grained sediment can be transported beyond this section of the East Fork Lewis River. At RM 7.43, it was estimated that the river is unable to transport material greater than about 1 inch (25 mm) in diameter. Thus, sediment sizes used for spawning are generally not transportable beyond this location.

5.6 East Fork Lewis River Sediment Transport Estimates

There are two commonly used methods for estimating sediment transport capacity when actual measurements are not available. These methods include 1) extrapolation from historic suspended sediment measurement data and 2) empirical/physical predictive equations. Published measurements of sediment transport are unavailable for the East Fork Lewis River.

Consequently, sediment transport equations were used to estimate bed material load transport rates.

The Pacific Northwest River Basin Commission Study (PNRBC, 1970) evaluated sediment data from various sources and published a generalized annual sediment yield map for the Lower Columbia River region, which includes the East Fork Lewis River Basin. This map was developed from a limited number of unpublished suspended sediment measurements for the East Fork Lewis River. The PNRBC sediment yield estimates were used as a comparison to the estimates of sediment transport capacity for the East Fork Lewis River determined using sediment transport equations.

The Corps of Engineers Hydraulic Design Package for Channels (SAM) (USACE, 1998) was used to estimate the sediment transport capacity of the East Fork Lewis River in the vicinity of the Proposed Project. Transport formula by Toffaleti (1966) and Meyer-Peter and Muller (1948) were used. The bed material size distributions in Figure 5-2 were used in the evaluation.

5.7 East Fork Lewis River Sediment Transport Capacity

A typical channel cross section, located near the Daybreak Bridge (RM 10.01), was used to estimate sediment transport capacity in the vicinity of the Proposed Project. This location was chosen as it was judged to best represent a transport reach rather than a depositional reach. A sediment transport rating curve was developed for the cross section. The rating curve was then integrated with flow-duration information to provide an estimate of the average annual sediment transport capacity of the river at this cross section. The sediment transport capacity was estimated to be 145,000 tons per year. In low-gradient gravel- and cobble-bed rivers, bed load is typically 2 to 16 percent of the suspended load, with lower-gradient channels typically having lower values, and steeper rivers having higher values (Collins, 1997). Thus, bed load transport capacity would range from 3,000 to 20,000 tons per year. Using a value of 5 percent to represent the low gradient portion of the East Fork Lewis River, bed load transport would be approximately 7,000 tons/year.

The sediment transport volumes associated with specific flood events were also estimated. Synthetic flood-hydrographs with a base of 4-days were estimated for the 2-, 5-, 10-, 25-, 50-, and 100-year floods and were input into the SAM Model to compute the sediment transported by each of these events. Table 5-2 summarizes these values. As seen from the table, the 100-year flood event has the capacity to transport approximately 2 times the average annual sediment load.

Table 5-2. Sediment transport capacity for floods of various return periods.

Sediment Load	2-Year Flood (tons)	5-Year Flood (tons)	10-Year Flood (tons)	25-Year Flood (tons)	50-Year Flood (tons)	100-Year Flood (tons)
Total Load	24,000	57,000	88,000	140,000	192,000	249,000

Sediment transport capacity results were compared to annual sediment yield estimates for the basin published as part of the PNRBC (1970) study. The PNRBC study estimated the annual

sediment yield for the East Fork Lewis River Basin to range from 0.1 to 0.2 acre-ft of sediment per square mile of basin. As seen in Table 5-3, the total transport capacity estimated by the current study is approximately 2 to 4.5 times higher than the values published. This suggests that the East Fork Lewis River may be supply limited. In other words, the capacity of the river to transport sediment exceeds the supply of sediment to the river. This is typically due to the natural tendency of the river to armor itself whereby a coarser sediment layer protects underlying finer sediment. Only during flows high enough to disrupt the armor layer are the finer underlying sediments transported.

Table 5-3. Sediment yield values for the East Fork Lewis River at Daybreak Bridge.

PNRBC Study Values	Total Yield (0.2 acre-ft/mi ²)	Total Yield (0.1 acre-ft/mi ²)
Total Volume (acre-ft/year)	32.6	16.3
Total Yield* (tons/year)	64,000	32,000

* Unit weight of 90 lb/ft³

Conditions can exist where there is insufficient sediment available to satisfy the transport capacity of the river, causing the actual sediment transport to be less than the equilibrium transport (supply limited). This can occur due to armoring of the bed and bank materials as described in the previous paragraph. As described in Section 5.5, the armoring characteristics along the East Fork Lewis River vary with location. At RM 10.01 the armoring conditions were shown to protect the bed for events with a recurrence interval equal to or less than 5-years while at RM 7.43 the armoring conditions protect the bed for the entire range of flows evaluated. It is noted that the developed sediment transport estimates assume that equilibrium transport conditions exist. Equilibrium transport conditions exist when there is enough transportable sediment to satisfy the transport capacity. In such cases, the long-term average sediment transport rates may be overestimated.

5.8 Estimated Time for Geomorphic Recovery of the Ridgefield Pits

The East Fork Lewis River avulsed into the abandoned Ridgefield Pits in 1996. Because the river has the potential to avulse into other nearby off-channel gravel pits such as the Existing or Proposed Daybreak Pits, it is necessary to estimate the amount of time that is required for its geomorphic recovery. Geomorphic recovery of the East Fork Lewis River channel within the Ridgefield Pits will occur when the geometry and hydraulics of the channel return to conditions similar to those that existed prior to the avulsion in 1996. This is assumed to occur when the channel has returned to an elevation similar to the pre-1996 avulsion channel. The avulsion into the Ridgefield Pits that occurred in 1996 provides an opportunity to estimate this recovery time. The geomorphic recovery of the Ridgefield Pits is also important in the discussion of the potential for avulsion into the Existing and Proposed Daybreak Pits. It was determined that the potential for the river to avulse into the downstream end of the existing Daybreak Pits is greatly reduced due to the river's current location within the Ridgefield Pits (see Section 8 "Channel Aulsion"). Once geomorphic recovery occurs within the reach of the Ridgefield Pits, the river may have an increased potential for migration in the lateral direction. Lateral migration could allow the channel to move back to a location near the Existing Daybreak Pits.

Fill elevations for geomorphic recovery for the Ridgefield Pits were determined from pre-avulsion channel elevation data. These data show a channel elevation of approximately 35 ft at the upstream end (above Pit 1) and an elevation of approximately 24 ft at the downstream end (below Pit 7) of the Ridgefield Pits reach. Average pit elevations required for geomorphic recovery ranged from 33 ft in Pit 1 to 24 ft in Pit 7. Because the active channel of the East Fork Lewis River currently occupies Ridgefield Pits 1 through 7, Pits 8 and 9 were not evaluated as part of this analysis.

The average depths of pre-avulsion pits, below average water levels in the pits, were estimated by a former gravel mine operator at the Ridgefield Pits (Personal Communication with Kimball Storedahl, 1999). The average excavation depths below the water surface of the pre-avulsion pits were estimated to be 12 ft in Pits 1 and 2, 20 ft in Pits 3 through 5, and 30 feet in Pits 6 and 7. It is noted that the depth of Pit 7 was influenced by an avulsion into that pit which occurred prior to the 1996 avulsion. It was estimated that approximately 10 ft of fill occurred, reducing the pre- 1996 avulsion depth to 20 ft.

Average water surface elevations in the Ridgefield pits were estimated based on groundwater contours defined for the Daybreak site and extrapolating them across the valley. Average water surface elevations in the Ridgefield Pits were estimated to range from 35 ft in Pit 1 to 30 ft in Pit 7. This resulted in pre- 1996 avulsion fill requirements ranging from 10 ft in Pit 1 to 24 ft in Pit 7. The total fill volume for geomorphic recovery prior to the 1996 avulsion was estimated to be approximately 1.1 million cubic yards for Pits 1 through 7. Compared to pre-1996 avulsion conditions, recent surveys (Chase Jones, 1999) indicate the Ridgefield Pits have filled significantly. As seen in Table 5-4, average pit elevations have increased between 1 to 13 ft reducing the geomorphic recovery volume to approximately 0.7 million cubic yards. The total volume of Ridgefield Pits 1 through 7 including material removed above the geomorphic recovery elevation, was estimated to be approximately 1.8 million cubic yards. When the volumes of Pits 8 and 9 are included, the total volume of the Ridgefield Pits is similar to the 2 million cubic yards estimated by Norman (1998).

Table 5-4. Estimated changes in geometry of the Ridgefield Pits since the 1996 avulsion.

Pit	Estimated Pre-1996 Avulsion Pit Depth (ft)	Estimated Pre-1996 Avulsion Pit Elevation (ft)	Estimated Pre-1996 Avulsion Pit Volume (yd ³)	Estimated 1999 Pit Depth (ft)	Estimated 1999 Pit Elevation (ft)	Estimated 1999 Pit Volume (yd ³)	Estimated Change in Pit Elevations (ft)	Volume Change (Percent)
1	12	23	157,700	9	26	110,400	+3	-30.0
2	12	22	102,900	11	23	92,600	+1	-10.0
3	20	13	108,500	16	17	82,900	+4	-23.6
4	20	12	143,500	13	19	84,400	+7	-41.2
5	20	11	164,800	15	16	113,300	+5	-31.3
6	30	1	204,900	17	14	93,900	+13	-54.2
7	20	10	186,900	14	16	106,800	+6	-42.9
Total			1,069,200			684,300		-36.0

The volume of sediment deposited in the Ridgefield Pits since the 1996 avulsion is estimated to be approximately 385,000 cubic yards. Sediment samples taken from the Ridgefield Pits were tested to determine the unit weight of the deposited sediments. Sand sized material deposited in portions of Pits 1 and 2 were found to have a unit weight of 90 lbs/ft³ while fine sand and silt material in Pit 4 had a unit weight of 55 lbs/ft³. To estimate the weight of sediment deposited within the Ridgefield Pits, a unit weight of 90 lbs/ft³ was used for Pits 1 and 2 and a unit weight of 55 lbs/ft³ was used for Pits 3 through 7. Accordingly, an estimated 300,000 tons of sediment have accumulated in the Ridgefield Pits since the 1996 avulsion. This is equivalent to an average rate of 100,000 tons/year. However, it is noted that this rate was high initially and has likely reduced since the avulsion occurred.

Sediment supplies to the Ridgefield Pits since the 1996 avulsion have included long-term average supplies from upstream watershed areas and short-term locally increased supplies caused by avulsion related erosion. Locally increased short-term sediment supplies would include material from the breached levees, erosion of the upstream channel bed, and locations of upstream bank erosion. The contribution to the pits from short-term locally increased sediment supplies was estimated to be 85,000 tons over the last three years, of which approximately 60,000 tons was likely deposited during and immediately following the avulsion in 1996. These estimates are based on field observations, aerial photography, and survey data. Compared to the volume of sediment accumulated in the pits since the 1996 avulsion, the supply of sediment from upstream watershed areas is approximately 215,000 tons or an average of 72,000 tons per year. The sediment transport capacity of the East Fork Lewis River upstream of the Ridgefield Pits was estimated to be 145,000 tons per year based on the application of the Toffaleti (1966) and Meyer-Peter and Muller (1948) sediment transport functions. Assuming that the stream is not sediment supply limited, the trap efficiency of the pits can be estimated to be about 50 percent since the avulsion in 1996.

If the Ridgefield Pits continue to fill at a rate equivalent to the upstream supply of 72,000 tons per year and the trap efficiency remains at 50 percent, it will take approximately 10 years (average unit weight of 70 lbs/ft³) to complete the filling of the pits to an elevation similar to the river channel prior to the 1996 avulsion. However, it is recognized that the trap efficiency of the pits will diminish over time and the unit weight of the deposited sediments will increase. As the channel through the pits becomes more defined it will be more capable of transporting material through the pits and the trap efficiency will be reduced. Similarly, the unit weight of the deposited material will increase over time as coarse delta deposits migrate downstream and consolidation of deposited sediments occurs. Assuming an average trap efficiency of 20 percent, and an average unit weight of 80 lbs/ft³, the time required to fill the pits would be approximately 25 years. If the geomorphic recovery of the Ridgefield Pits were to be judged against deposition of the approximate 2 million cubic yard volume estimated by Norman (1998), the time required to fill the pits would be approximately 75 years.

To further evaluate the rate of filling in the pits, an analysis of the growth rate of the gravel and cobble delta forming in Pits 1 and 2 was conducted. The purpose of this analysis was to characterize the rate and manner in which these pits are filling. As observed in the field, the delta forming in Pits 1 and 2 is composed of coarse gravel and cobble, while finer material (sands and silts) was observed in the backwater portions of the downstream pits. Using the

downstream growth rate (approximately 100 ft/year) of the gravel delta formed since 1996, it is estimated that it will take approximately 30 years for it to reach the downstream end of the Ridgefield Pits. This time frame is consistent with the estimates described above for geomorphic recovery of the Ridgefield Pits. It is noted that the growth rate of the delta was high initially and has likely reduced since the avulsion occurred.

5.9 Estimated Time Required for Geomorphic Recovery of the Existing and Proposed Daybreak Pits

To evaluate the impacts of a potential avulsion of the river into the Existing and Proposed Daybreak Pits, an analysis of the time required for geomorphic recovery of the pits was conducted. This analysis assumes that the river is flowing through the entire series of pits, and that the entire pit volume below the pre-1996 avulsion channel elevation must be filled for geomorphic recovery to occur. It is also assumed that the regional hydrologic and sediment transport characteristics will remain the same during the filling process. Because the exact nature of a potential avulsion can not be predicted, the amount of sediment supplied to the pits by local sources such as levee, bank, and bed erosion can not be predicted. Therefore, the total pit volumes may be overestimated. Table 5-5 summarizes the estimated time required for geomorphic recovery of the Existing and Proposed Daybreak Pits.

Table 5-5. Estimated time for geomorphic recovery of the Existing and Proposed Daybreak Pits.

Daybreak Gravel Pits	Estimated Geomorphic Recovery Volume (yd ³)	100% of Total Load 70 lb/ft ³ (years)	50% of Total Load 70 lb/ft ³ (years)	20% of Total Load 80 lb/ft ³ (years)	100% of Bed load* 80 lb/ft ³ (years)	PNRBC 100% of Total Load 80 lb/ft ³ (years)
Existing	720,000	5	10	30	40-260	10-20
Proposed	4,200,000	30	55	160	230-1500	70-140
Total	4,920,000	35	65	190	270-1760	80-160

*Bed load ranges from 2 to 16 percent of the suspended load.

As seen from the table, the expected time required to fill the pits varies widely with the volume of the pits and the proportion of the total bed material sediment load that is assumed will deposit in the pits. Assuming an average trap efficiency of 20 percent and unit weight of 80 lb/ft³, it is expected to take approximately 30 and 160 years for geomorphic recovery of the Existing and Proposed Daybreak Pits, respectively. It must be noted that projections that exceed approximately 50 years require qualification. The sediment transport calculation methods employed are based on hydrologic data collected since 1930 (66-years). Extrapolation for periods outside of the observed record is less reliable. For predictions that are several times longer than the observed record, significant deviations from the presented estimates could be expected.

Furthermore, the time required for geomorphic recovery is directly related to the specific hydrologic conditions experienced. If low flows occur, the rate of filling would be less than that estimated for average conditions. If larger flows occur, the rate of filling would be greater than average. As seen from Table 5-2, the estimated amount of sediment transported in a 100-year return period flood would fill about 30 percent of the Ridgefield Pits during a single event.

5.10 Summary

Bed material of the East Fork Lewis River is composed of coarse sands, gravels, and cobbles. Fine sands, silts, and clays are carried as wash load and are typically transported downstream of the area of the Proposed Project to flatter gradient, low energy reaches. As described previously in Section 2, “Characterization of Affected Environment”, the bed and banks downstream at RM 6 are typically composed of sands and silts. The changes in channel geometry and hydraulics associated with the avulsion of the Ridgefield Pits have reduced the transport capacity of the river in the pits. The Ridgefield Pits effectively capture the bed load and a portion of the suspended load that might otherwise be transported downstream. However, it is recognized that due to the natural reduction in channel gradient in this reach, a large portion of the bed material load from upstream areas would be expected to deposit in this section of river even if the avulsion into the Ridgefield Pits had not occurred.

Dean Creek, in the vicinity of the Proposed Project, transitions from a steep slope to a mild slope where it meets the valley floor of the East Fork Lewis River. Over geologic time, this natural deposition zone has formed an alluvial fan. The apex of the fan is fixed at J. A. Moore Road Bridge, which is located at a break in slope. Historically, bed material has been removed from the channel in the vicinity of the bridge on a regular basis by Clark County to maintain conveyance. This action has likely helped maintain the stability of Dean Creek over the recent past. If deposited sediments are not periodically removed from the channel in the vicinity of the bridge, the hydraulic conveyance and sediment transport capacity of the channel will diminish. This will cause an increase in overflows from the channel that may cross J.A. Moore Road. This will generally increase the potential for channel instability. The Proposed Project will reduce any potential for migration of the channel to the east. The proposed channel improvements and removal of the existing discontinuous levee will enlarge the floodplain area available to the watercourse, dissipate flow in the left overbank, and reduce sediment transport capacity.

The gravels and cobbles that form the bed of the East Fork Lewis River in the vicinity of the Proposed Project can form an armor layer that protects the underlying mixture of bed sediment from erosion. The armor layer is disrupted by hydraulic conditions that exceed the incipient motion conditions for the armor material. The presence of the armor layer and the size of the particles vary with location, but usually will decrease in size in the downstream direction.

The average annual sediment transport capacity of the East Fork Lewis River was estimated by application of the Toffaleti (1966) and Meyer-Peter and Muller (1948) sediment transport formulas. Average transport capacity was estimated to be 145,000 tons per year. Measurements of the bed load transport in other gravel bed rivers indicated the bed load to suspended load ratio is 2 to 16 percent (Collins, 1997). Thus, for the East Fork Lewis River, bed load transport capacity would range from 3,000 to 20,000 tons per year. In the vicinity of the Proposed Project, it is estimated that the bed load transport capacity is approximately 7,000 tons/year or 5 percent of the total transport capacity.

The time required for existing and proposed gravel pits to fill was estimated based on various sediment deposition scenarios. It is most likely that the amount of sediment trapped by pits will reduce over time. As the channel through the pits becomes more defined it will be more capable

of transporting material through the pits and the trap efficiency will be reduced. Similarly, the unit weight of the deposited material will increase over time as coarse delta deposits migrate downstream and consolidation of deposited sediments occurs. If we assume an average trap efficiency of 20 percent, and an average unit weight of 80 lbs/ft³, the time required for geomorphic recovery of the Ridgefield Pits would be approximately 25 years. Similarly, the time required for geomorphic recovery of the Existing and Proposed Daybreak Pits would be 30 and 160 years, respectively. Combined geomorphic recovery of these pits will take approximately 200 years under current hydrologic and sediment transport conditions. It should be noted that sediment transport calculation methods are based on existing conditions and only 66 years of hydrologic data. Significant deviation in the hydrologic, hydraulic, and sediment transport conditions in the East Fork Lewis River watershed could occur over time periods in excess of the period of record.

6 Channel Profile

6.1 Introduction

An analysis of historic East Fork Lewis River profile data was conducted to understand the physical characteristics of the river channel. An evaluation of available cross section data was made to characterize slopes along the river and understand the sediment transport characteristics along the channel. The influence of historic river avulsions into abandoned gravel pits on the profile of the channel was investigated. The potential impacts of the Proposed Project on the channel profile were characterized. No historic data was available for the profile of Dean Creek, however a discussion of the current profile is presented.

6.2 Channel Profile

In the following sections, a general description of the channel profiles for the East Fork Lewis River and Dean Creek are given.

6.2.1 East Fork Lewis River Profile

As seen in Figure 6-1, the profile of the East Fork Lewis River channel in the vicinity of the Proposed Project can be divided into three reaches. Reach 1 is from the confluence with the Lewis River at RM 0 to RM 4. This reach has a channel slope of less than 1 foot per mile and is influenced by backwater from the Columbia and Lewis Rivers. Reach 2 is from RM 4 to RM 7.5 and has a slightly steeper channel slope of approximately 7 feet per mile. Tidal influences occur within the lower portion of this reach. Reach 3 is from RM 7.5 to RM 12.7 and has an even steeper channel slope of approximately 18 feet per mile. The transition zone between the steeper slope of Reach 3 and the shallower slope of Reach 2 is the location where coarse sediments (sands, gravels, and cobbles) carried downstream by the East Fork Lewis River are deposited. This is also the location of Existing and Proposed Daybreak Pits. Finer sediments (fine sands, silts and clays) are generally transported further downstream, depositing in Reach 1.

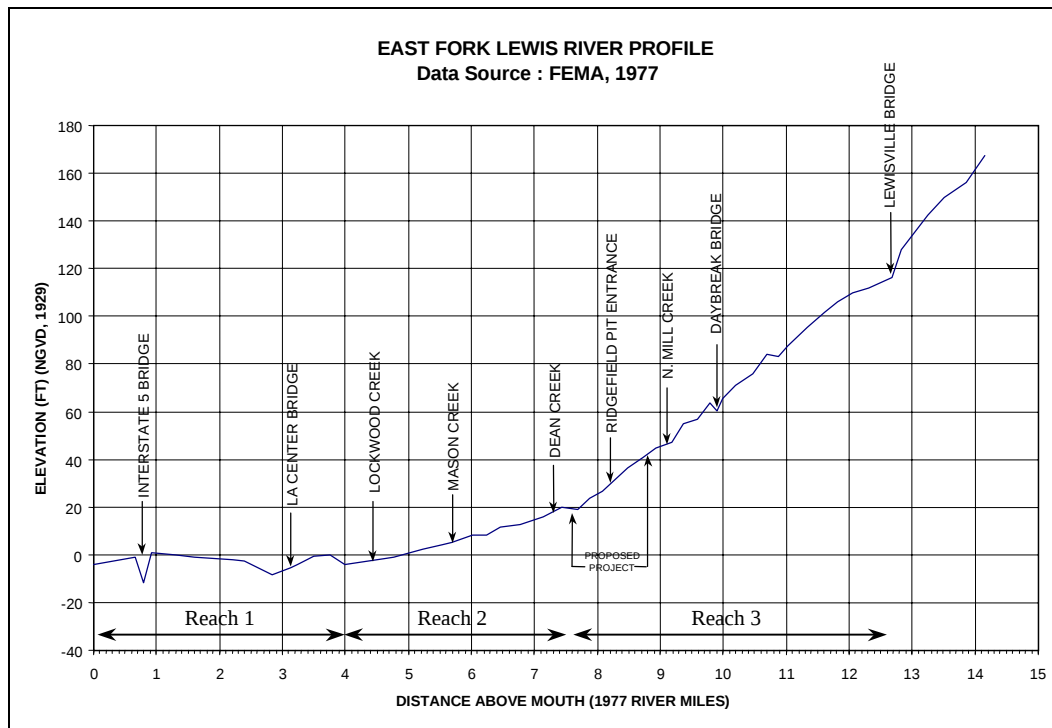


Figure 6-1. Profile of lower East Fork Lewis River.

6.2.2 Dean Creek Channel Profile

As seen in Figure 6-2, the profile of Dean Creek can be divided into four reaches. Reach 1 is from the confluence with the East Fork Lewis River to J. A. Moore Road. This reach has an average channel slope of approximately 25 feet per mile and is partially influenced by backwater during high flows in the East Fork Lewis River. Reach 2 is from J. A. Moore Road Bridge to NE 82nd Avenue. This reach has an average channel slope of 130 feet per mile as it descends the relatively steep wall of the East Fork Lewis River valley. Reach 3 is from NE 82nd Avenue to NE 112th Avenue. This reach has an average slope of approximately 50 feet per mile as it descends through a relatively flat section of land overlooking the East Fork Lewis River valley. This area is occupied by a large number of rural homes and a small airport, which have likely caused increased runoff and sediment supply to Dean Creek. Reach 4 is from NE 112th Avenue to the headwaters and has an average slope of approximately 300 feet per mile.

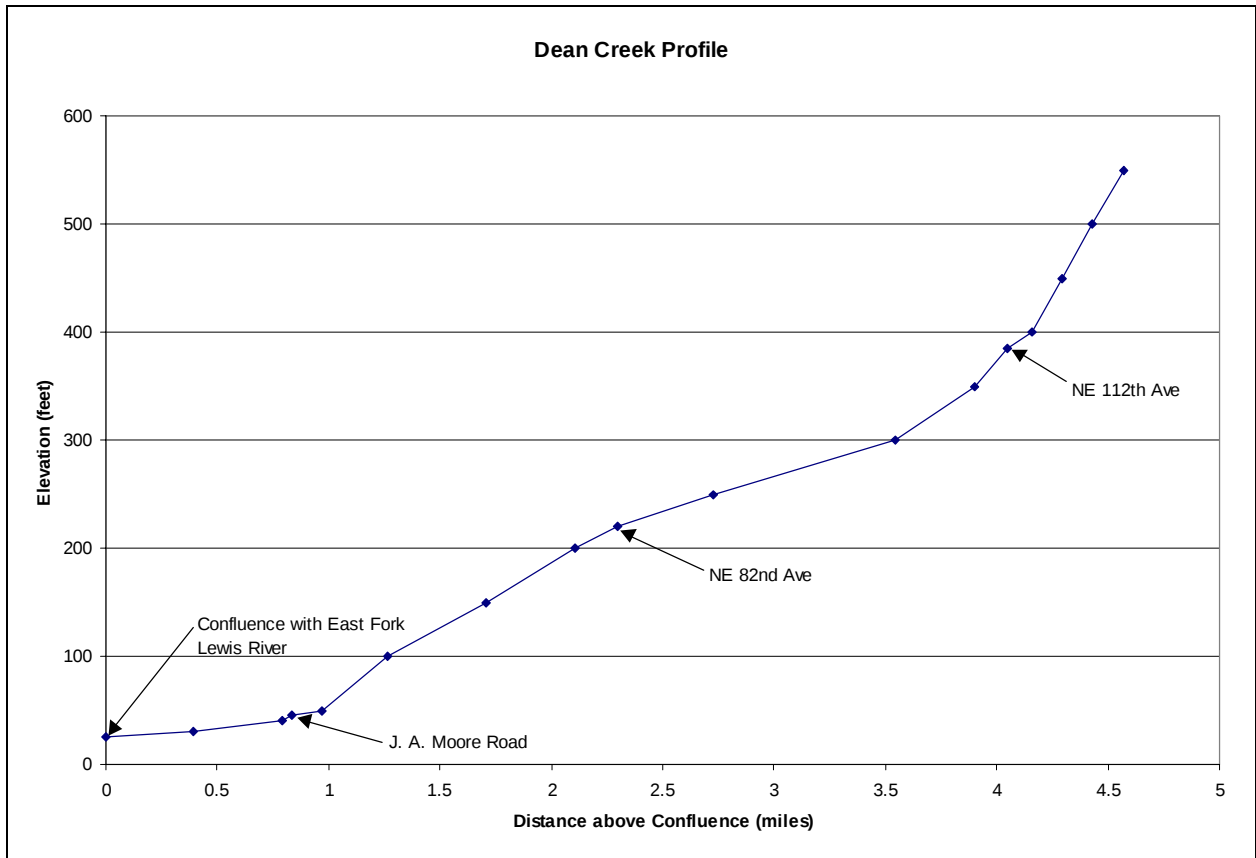


Figure 6-2. Profile of Dean Creek.

6.3 Evaluation of Historic Cross Section Data for the East Fork Lewis River

Two sets of historic cross section data are available for the East Fork Lewis River pertinent to the Proposed Project area. Cross section data for the East Fork Lewis River was collected as part of the FEMA Flood Insurance Study in 1977 (FEMA, 1991). The second data set was collected in December 1996 as part of a reevaluation of the East Fork Lewis River floodplain (WEST Consultants, 1997). The thalweg elevation data of each cross section was plotted against its distance in the upstream direction from the river mouth (Figure 6-3). The slopes of the river were determined from these plots. The section of river covered by this analysis is between RM 7.2 and the Daybreak Bridge (approximately RM 10.2). The average channel thalweg slope in 1977 was 0.327% while the slope in 1996 was 0.398%, a difference of +0.071%. The average slope in 1996 is steeper due to the avulsion of the East Fork Lewis River into the Mile 9 Pit in 1995 and the abandoned Ridgfield Pits in 1996. As seen in the profile (Figure 6-3), the thalweg of the channel in 1996 is at a lower elevation than the thalweg of the channel prior to the avulsions.

One must be careful in evaluating the type of plot shown in Figure 6-3 due to the dynamic nature of the river channel. The channel length is continuously changing as the river meanders and avulses over time. Accordingly, the channel distance measured along the center of the channel upstream from its confluence with the Lewis River also

changes. In 1977, the distance from the mouth to the Daybreak Bridge was 9.89 river miles, while the 1990 USGS quad map indicates 10.19 river miles, and 1996 topographic mapping shows 10.04 river miles. From 1977 to 1990 the river channel increased its length by approximately 1,600 feet. From 1990 to 1996 the channel decreased its length by approximately 800 feet. For this reason, the deposition or erosion of sediment at any given location cannot be simply evaluated by comparing the profile plots for different time frames. The physical locations of intermediate points along the two profiles shown in Figure 6-3 are not the same.

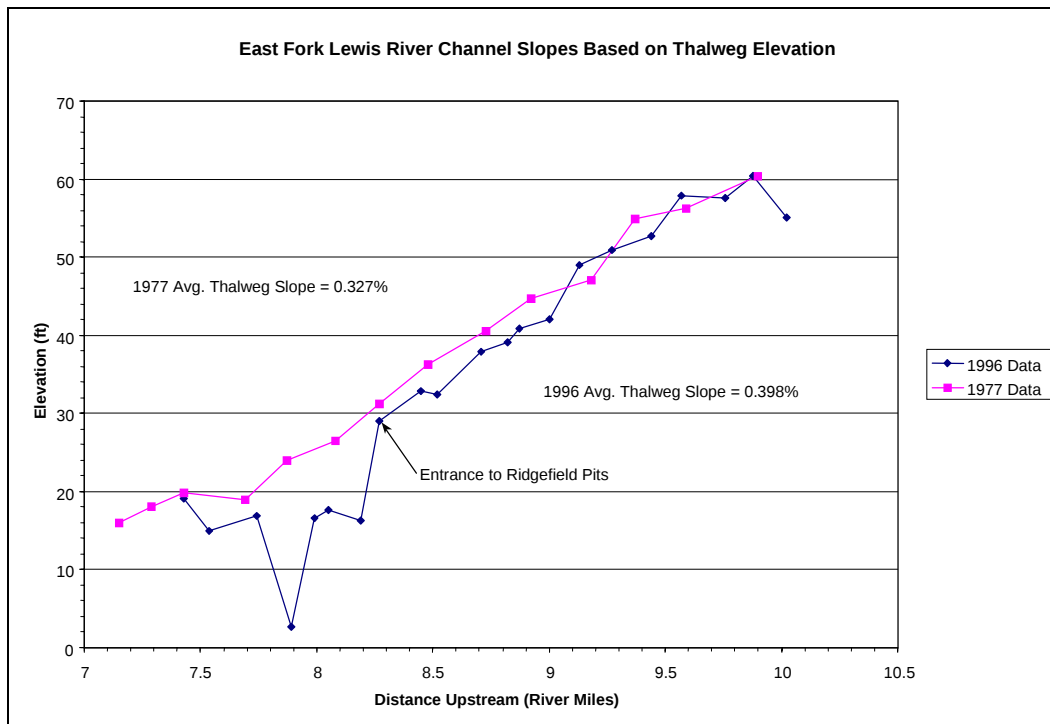


Figure 6-3. Channel slopes from 1977 and 1996.

From examination of the 1996 topographic maps (WEST Consultants, 1996), it is noted that only one month had passed between the time of the breach into the Ridgefield Pits and the collection of the 1996 cross section data. It is also noted that the flood of record had occurred 10 months earlier. Although some head cutting appears to have occurred upstream of the Ridgefield Pit avulsion (from field observations), the exact upstream extent is unknown. From examination of the 1996 topographic maps (WEST Consultants, 1996), the channel was judged to have lowered its base by approximately 5 feet immediately upstream of the pit entrance. Later estimates made by Norman et al. (1998) had estimated degradation of approximately 10 feet at this same location. Channel changes will continue as the river adjusts to the impacts of the 1996 flood and avulsion.

Figure 6-4 shows an evaluation of the historic river slopes in reaches upstream and downstream of the entrance to the Ridgefield Pits. This comparison was made to determine the impacts of the breach on the slope of the river channel upstream of the pits and through the pits. However, it is important to understand that the 1996 data reflects

river conditions only one month after the avulsion of the river into the Ridgefield Pits. The 1996 thalweg profile data are compared to the river conditions from nineteen years earlier. No data were available to compare with the channel conditions just prior to the avulsion.

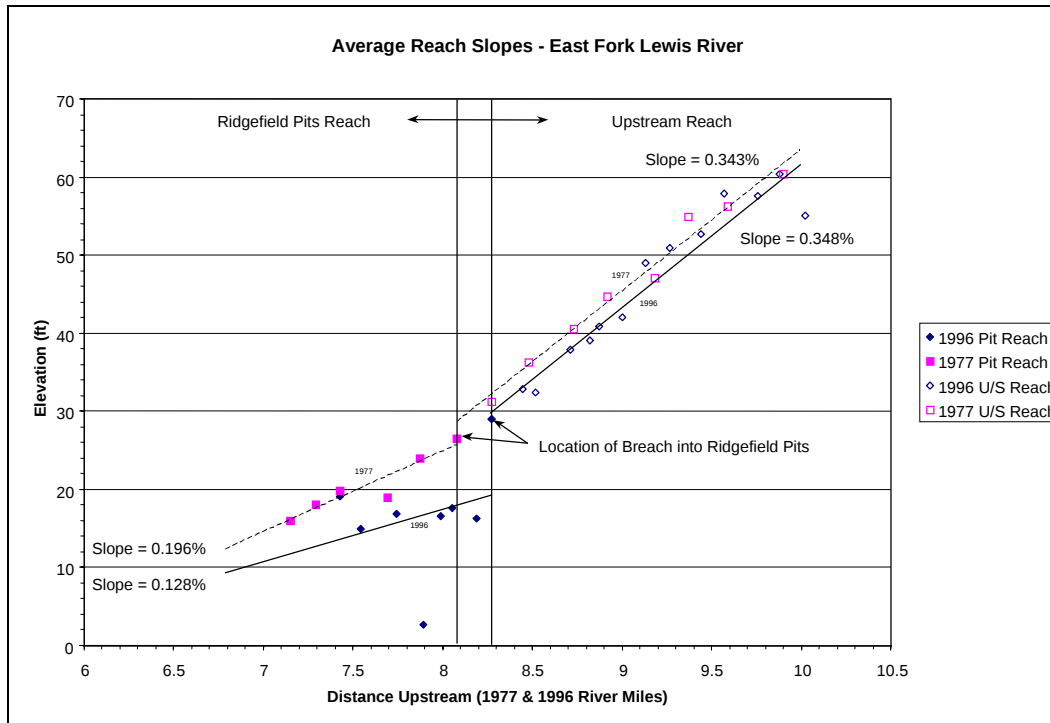


Figure 6-4. Average channel slope by reach.

Average slopes in the reach between the Ridgefield Pits and the Daybreak Bridge (labeled “Upstream Reach” in Figure 6-4) are very similar for 1977 and 1996, 0.343% and 0.348%, respectively. The location of the break point from the steeper slope upstream to the flatter slope downstream is shown in two locations on Figure 6-4. This is due to changes in the river length caused by avulsion and meandering of the river. As measured from the 1977 and 1996 data, the average slope in the reach along the Ridgefield Pits has changed from a slope of 0.196% to a flatter slope of 0.128%. It is noted that tidal backwater influence from the Columbia River occurs at approximately RM 5.9 of the East Fork Lewis River (Hutton, 1995). The tidal influence serves as a downstream hydraulic control that regulates the deposition of material transported out of the steeper portions of the watershed. This tidal influence creates backwater conditions that are similar to that of a river flowing into a reservoir.

In a reservoir, a delta will form as sediment is deposited at the transition from the flowing river to the slack water of the reservoir. Larger sediments deposit further upstream while the finer sediments are transported further downstream, settling out in more quiescent water conditions. Given sufficient time, the delta deposits can become significant, raising the local bed elevation and causing a slow migration of the delta. When the reservoir level drops, the river head cuts through the delta deposits, lowering its bed

elevation and abandoning its floodplain. Sediment is transported further downstream and deposits at the new transition location. The zone of accumulation will migrate upstream and downstream as the reservoir level rises and falls. Similarly, backwater influences from the Columbia River act like a reservoir at the lower end of the East Fork Lewis River. Using this analogy one can understand the sequence of deposition and erosion that has taken place within the East Fork Lewis River study area over geologic time.

In order to evaluate historic deposition and erosion patterns, a comparison of elevations at similar locations was made. Figure 6-5 shows a plot of thalweg elevations from 1977 and 1996. The 1977 elevation data were referenced to the 1996 channel profile to allow comparison.

Comparison of the historic thalweg data indicates several significant changes. A large change in bed elevation is noted in the vicinity of the Daybreak Bridge between the two time periods. The 1996 thalweg elevation downstream of the bridge is lower than the 1977 thalweg. The degradation at the bridge may be explained as a localized scour phenomenon caused by the bridge. It is noted that the 1977 cross section is located just upstream of the bridge while the 1996 cross section is located just downstream. The scoured area downstream of the bridge may have been present in 1977 but was not surveyed. Contraction scour and local scour caused by the constriction of the river through the bridge may account for the lower bed elevation downstream of the bridge as seen in the 1996 data.

Between RM 9.9 and RM 9.5 an increase in the channel thalweg elevation is observed between 1977 and 1996. The amount of pre-avulsion aggradation in this reach is unknown. Head cutting caused by the avulsions of the Mile 9 Pit in 1995 and the Ridgefield Pits in 1996 may have lowered the elevation at this location. However, the 1996 channel thalweg elevation is still above the elevations measured in 1977. It appears that head cutting at this location was not as significant as it was further downstream.

In the vicinity of the confluence of North Mill Creek (RM 9.5 – RM 9.1), the river tends to flatten and widen. This suggests an influx of sediment from the tributary or other localized source such as the high bank of the south valley wall has helped to maintain a lower channel gradient. The thalweg elevation has risen approximately 4 feet at this location between 1977 and 1996. As described above, effects of head cutting due to the breach of the Mile 9 Pit or the breach of the Ridgefield Pits are unknown. The 1996 data suggest that head cutting has occurred downstream between RM 9.1 and the Ridgefield Pits. The exact extent of head cutting upstream of RM 9.1 is unknown.

It can be seen from the plot of thalweg elevations that the East Fork Lewis River between RM 9 and the Ridgefield Pits has lowered its base elevation to approximately the same as that which existed in 1977. In other words, the breach into the Ridgefield Pits, and its subsequent head cutting, has eroded approximately nineteen years worth of accumulated channel-sediments. The eroded sediments were likely deposited into the Ridgefield Pits.

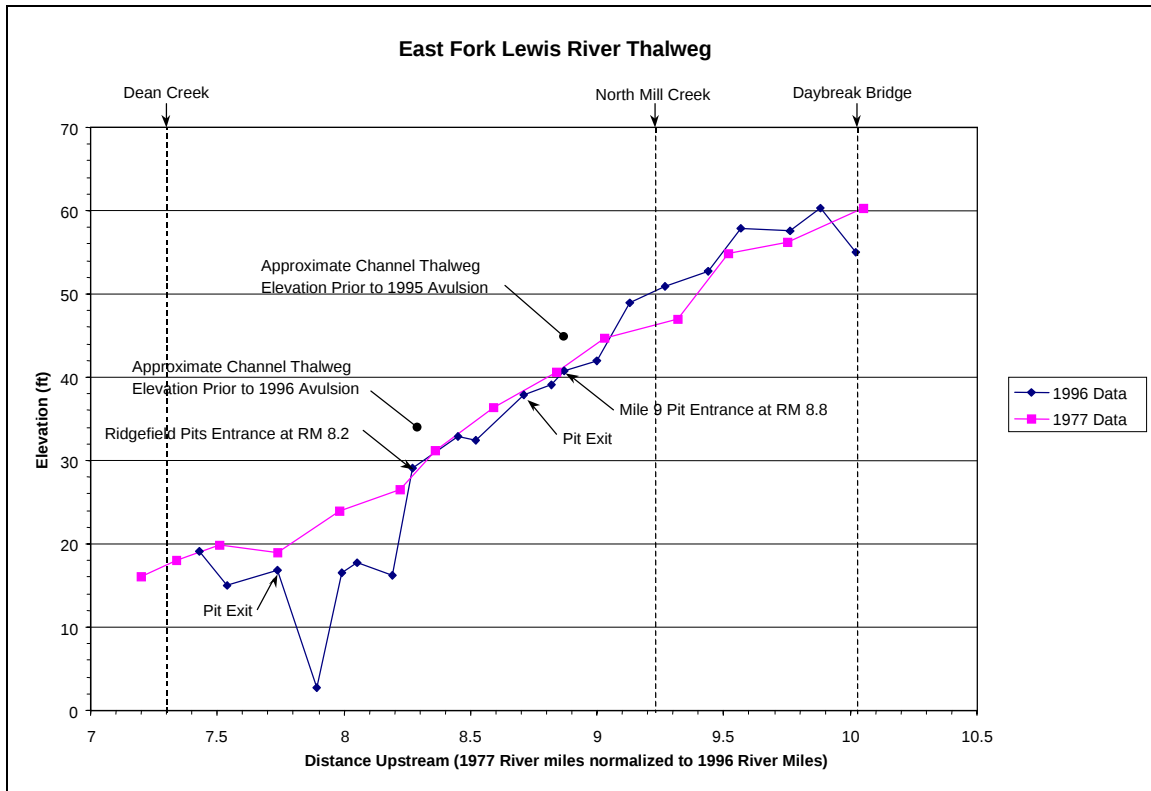


Figure 6-5. Channel thalweg elevations along valley floor.

6.4 Impacts of the Proposed Project on the Channel Profile

The Proposed Project should have no impact on the channel profile of the East Fork Lewis River as long as the river remains separated from the Existing and Proposed Daybreak Pits. The Proposed Project would impact the channel profile only if an avulsion into the pits were to occur. The probability of channel migration and avulsion into these pits is presented in Section 8, “Channel Avulsion”. The potential impacts from an avulsion on the channel profile would be similar to the impacts caused by the breach into the Ridgefield Pits in 1996. The observed impacts to the river profile included a local steepening of the slope and incision of the channel upstream of the pits due to head cutting and a flattened slope through the pits.

Specific impacts downstream of the Ridgefield Pits are not quantifiable, although some generalizations can be made. Gravel pits tend to trap sediment similar to a reservoir. The bed material load of the river below the pits will be significantly reduced relative to its transport capacity. The river will attempt to recruit material from the bed and/or banks by erosion to satisfy its sediment transport capacity unless prevented by armoring of the bed or bank sediments. Such erosion could cause deepening of the downstream channel, increased bank heights and erosion, and coarsening of the channel substrate. However, it must be noted that the length of river below the Ridgefield Pits directly impacted by the avulsion and not affected by tidal backwater is relatively short (approximately 1.5 miles).

The specific impacts to be expected will depend on the magnitude of the unsatisfied sediment transport capacity and the size characteristics of the bed and bank materials. It is also noted that the gradient of the East Fork Lewis River reduces rapidly downstream of the Proposed Project location. Furthermore, tidal influences substantially reduce the sediment transport capacity of the river in this area. An evaluation of the relative sediment transport characteristics of the various reaches of the East Fork Lewis River is discussed in Section 5, “Sediment Transport”.

6.5 Summary

The profile of the East Fork Lewis River in the vicinity of the Proposed Project can be characterized as a transition zone from a steep slope to a flatter slope. This break in slope creates a transition zone where river sediments tend to deposit. A comparison of the 1977 and 1996 bed elevation data show that changes in the profile are directly related to the avulsions into the Mile 9 Pit in 1995 and the Ridgefield Pits in 1996. As seen in Figure 6-5, the avulsions reduced the thalweg bed elevations between RM 9 and the Ridgefield Pits to a level similar to that in 1977 while causing a significant lowering of the bed elevation in the channel section that occupies the pits.

Impacts from the Proposed Project on the profile of the river will only occur if the river avulses into the existing Daybreak and/or subsequently into the Proposed Pits. If this were to occur in the future, the impacts would likely be similar to those created by the avulsion into the Ridgefield Pits. However, it must be remembered that the impacts on the river profile are cumulative and would be inversely proportional to the time between subsequent avulsions. In other words, the longer the time between pit avulsions the smaller the impact on the channel profile. However, the risk of avulsion would be directly proportional to the time between avulsions. In other words, as the time between subsequent avulsions increases, the risk of avulsion into abandoned channels or other nearby gravel pits within the channel migration zone (CMZ) increases. The CMZ for the East Fork Lewis River is described in Section 8, “Channel Avulsion”.

It is further emphasized that the 1996 profile data used in the comparison of historic profiles was surveyed only about one month after the river avulsed into the Ridgefield Pits. The full impact of the head cutting caused by the avulsion may not be evident in the data available for comparison. The specific impacts of the head cutting due to the avulsion into the Mile 9 Pit and the Ridgefield Pits on the Daybreak Bridge are also not quantified. However, the thalweg plots in Figure 6-5 suggest a net deposition of sediment has occurred between RM 9.1 and 9.9 from 1977 to 1996. The data suggests that head cutting has not adversely affected this section of river or the Daybreak Bridge.

The profile of Dean Creek in the vicinity of the Proposed Project is a transition zone from a steep slope to a flatter slope that is naturally depositional. This area shows typical characteristics of an alluvial fan that forms at the intersection of a small tributary with a larger river valley. The apex of the fan is fixed at J. A. Moore Road Bridge, which is located at a break in slope. Examination of the topography surrounding the Dean Creek channel in the vicinity of the apex shows that the west side of the fan is steeper. Historically, bed material has been removed from the channel in the vicinity of the bridge

on a regular basis by Clark County to maintain hydraulic conveyance. This has likely helped the profile of Dean Creek to remain relatively stable over the recent past. It is also noted that an overflow channel parallels Dean Creek to the west. Because the west side of the fan is steeper, overflows from the Dean Creek main channel flow to the west into the existing overflow channel.

7 Channel Planform

7.1 Introduction

Planform analyses of the East Fork Lewis River and Dean Creek near the project site was conducted to understand the historic movements, or migration of the stream channels, with respect to the surrounding landscape as well as the Proposed Project location. The analysis was used to determine the types of channel movement and the average rates of movement in the lateral and longitudinal directions along the river. The historic trends identified from the analysis can be used to predict expected future locations of the river and is important for evaluating the potential impacts of the Proposed Project on the morphology of the channels.

7.2 Prior Studies

Several prior studies have been conducted on the geomorphology of the East Fork Lewis River. The reports from those prior studies were reviewed to identify available data and information. In the following paragraphs, the general conclusions of the prior studies are described. No prior studies are known to exist for Dean Creek.

Bradley (1996) reviewed historic aerial photography covering a period of 61 years. He showed that the channel position has remained relatively constant along the south valley wall from the Daybreak Bridge site down to the confluence of North Mill Creek at RM 9.5 (Figure 7-1). Bradley contends the Daybreak Bridge fixes the location of the river and helps direct downstream flow from the bridge toward the southern valley wall. He also documented the migration of the large meander bend just upstream of the abandoned Ridgefield Pits. He noted a recent trend for the meander to migrate toward the south valley wall away and from the existing Daybreak Pits. Bradley recognized and warned of the possibility of the channel avulsing into the Ridgefield Pits.

Collins (1997) described a widespread historic transformation in the morphology of the East Fork Lewis River he identified from the mapping and photographic record. Collins presented figures created from survey data, maps, and/or aerial photos depicting channel locations in 1854/1858, 1937, 1951, and 1990 (Figure 7-2). The 1854-era map shows nearly the entire valley bottom as wetlands “subject to inundation”. It is important to note that the location of the Proposed Project was not mapped as wetlands in the 1854-era map. The river planform in the vicinity of the abandoned Ridgefield Pits and Daybreak Pits is shown to be braided (RM 9 to 7). By 1937, a single thread channel, bordered by a system of ephemeral floodplain sloughs had replaced the braided planform. The 1951 and 1990 planform views indicate further concentration of the flow in a single thread channel and successive loss of floodplain sloughs. Collins suggests that river engineering, floodplain land uses, and gravel mining is responsible for the changes in river morphology.

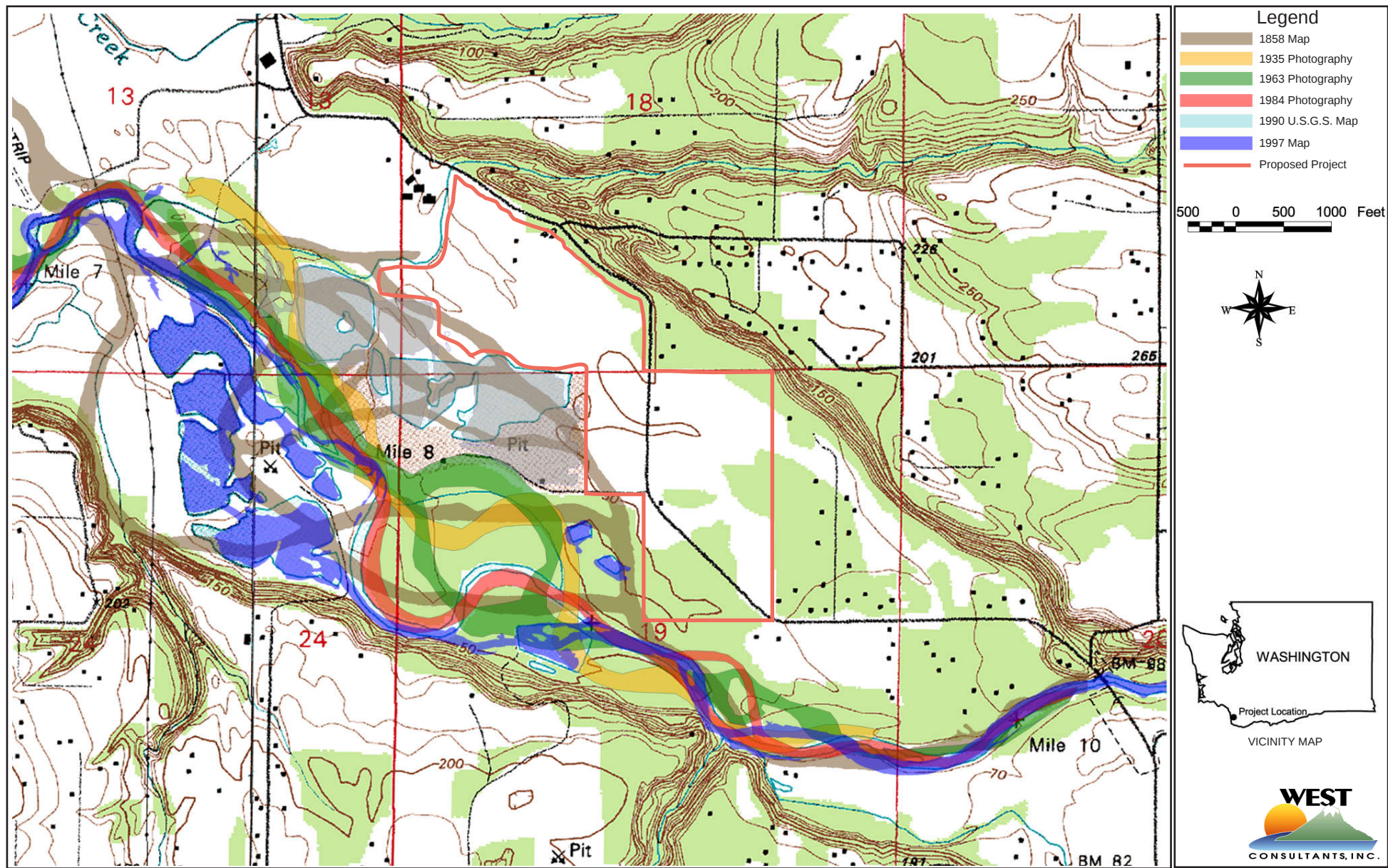


Figure 7-1. East Fork Lewis River - Approximate Historic Channel Locations

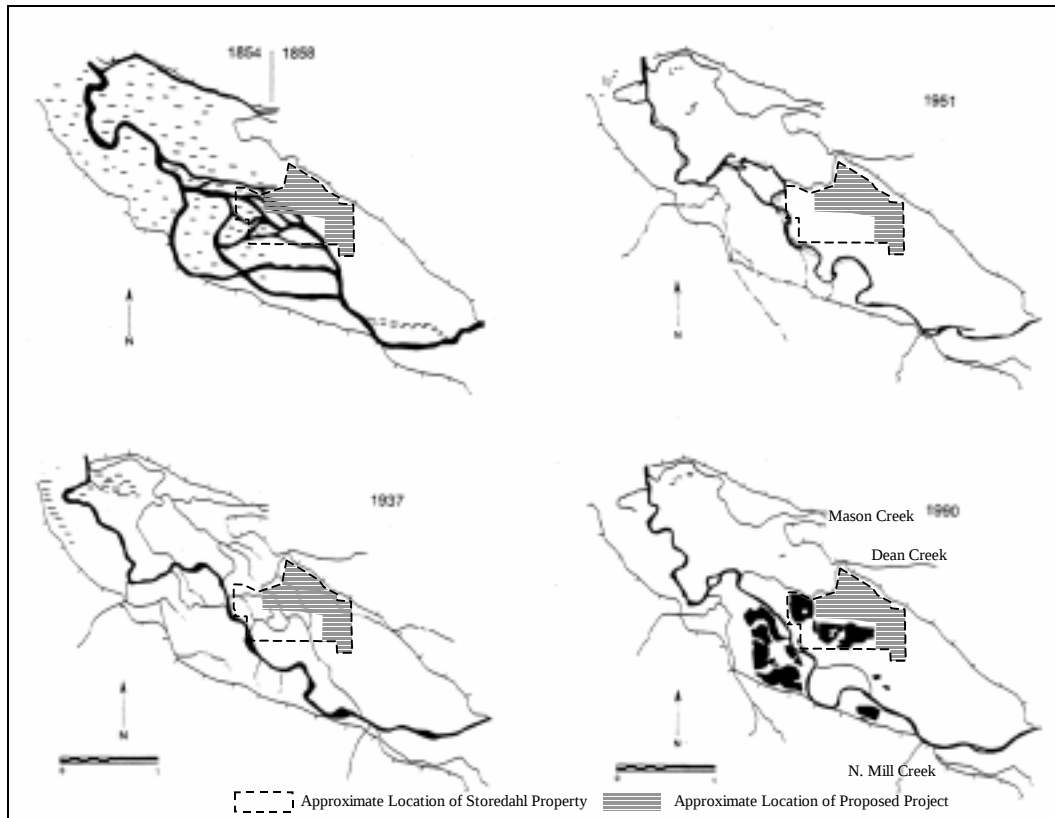


Figure 7-2. Historic Channel Locations (modified from Collins, 1997).

Norman et al. (1998) discusses the impacts of channel avulsions into abandoned gravel pits that occurred in 1995 and 1996. During the November 1995 event, the river avulsed through a gravel pit pond located approximately at RM 9 (Mile 9 Pit) and abandoned approximately 1,700 feet of channel. Observations made subsequent to the avulsions in the Mile 9 Pit showed erosion at the toe of the Pleistocene Terrace/Slide Mass on the south side of the river valley. During the November 1996 event the river avulsed into the Ridgefield Pits. This avulsion abandoned approximately 3,200 feet of channel bordering the southern boundary of the Daybreak Site. According to Norman et al., (1998) the results of the avulsions include approximately 10 feet of channel bed down cutting caused by the upstream migration of a nickpoint, increased erosion along the south bank upstream of the pits, and sluggish flow through the pits. Norman et al., (1998) estimated that it would require more than 2 million cubic yards of sand and gravel to refill the 70-acre pits through which the river now flows. Figure 7-3 is a modified figure from Norman et al. (1998) that shows the historic pattern of the East Fork Lewis River in the vicinity of the Proposed Project along with the avulsion path through the Ridgefield Pits.

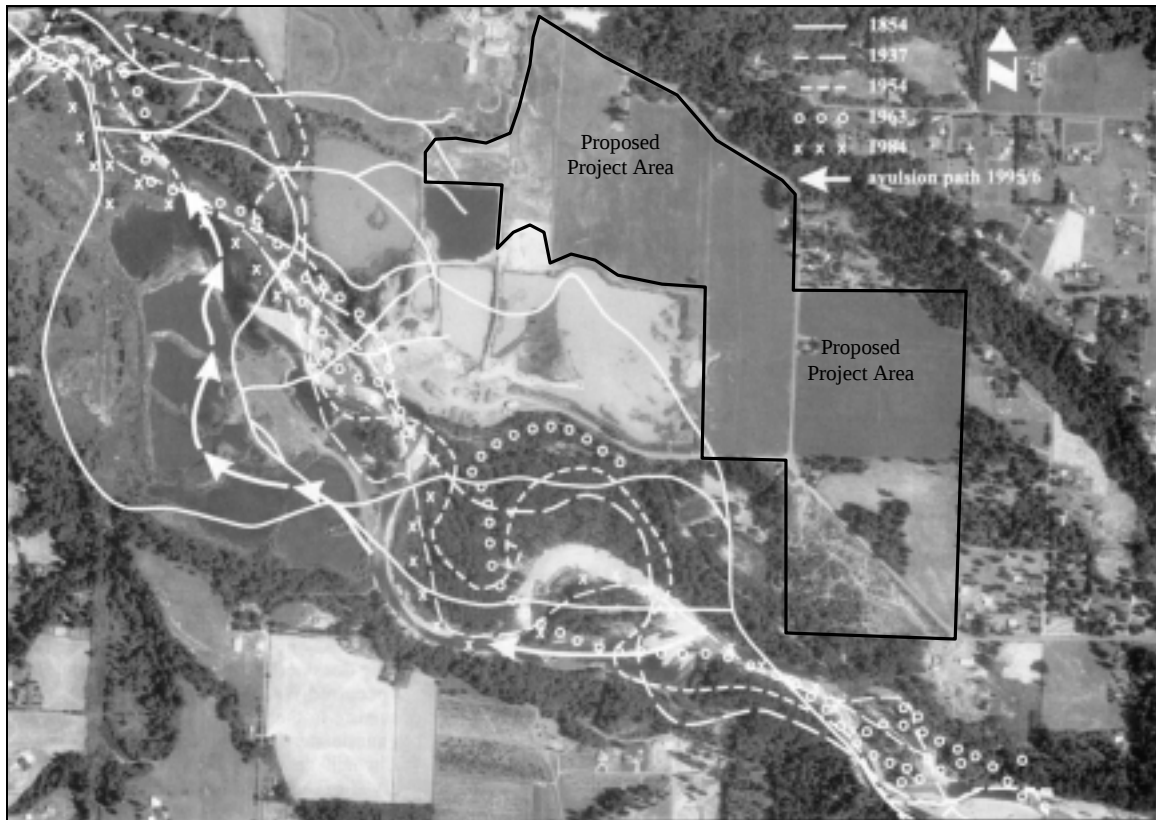


Figure 7-3. Historic channel locations (modified from Norman et al., 1998).

7.3 Historic Channel Locations

In the following sections, a discussion of the historic channel locations for the East Fork Lewis River and Dean Creek are presented.

7.3.1 East Fork Lewis River Historic Channel Locations

Figure 7-1 shows historic channel locations of the East Fork Lewis River near the Proposed Project site. In all time frames evaluated, the course of the river remains relatively constant from the Daybreak Bridge at RM 10.2 to the confluence of North Mill Creek along the south valley wall at RM 9.5. Along this reach, the river has very low sinuosity and shows only minor migration of meanders in the downstream direction. Very little lateral migration of the river has occurred in this reach. The low sinuosity of this reach would suggest that the gradient is steep enough to transport the majority of the bed material load through this reach.

From RM 9.5 to approximately RM 9 the river has shifted laterally back and forth over time in a zone that ranges from 500 to 1,000 feet in width. This zone borders the upper gravel pit (Mile 9 Pit) that was breached in November 1995. The location of the Mile 9 Pit was previously occupied by the main channel in the 1930's and again in the 1960's. The location of the Mile 9 Pit coincides with a break in the channel gradient to a shallower slope. The break in slope causes the river to deposit sediment and migrate laterally. Consequently, the East Fork Lewis River becomes more sinuous in this area.

Maps from the 1850's show that this location was the transition zone from a single thread channel upstream to a braided network of channels downstream.

Between RM 9 and RM 8 the channel has historically formed a large meander bend. The meander has migrated laterally and been cut off several times since the 1930's. The lateral migration zone of the large meander bend is approximately 2,000 feet in width. The wavelength measured from the 1990 map is approximately 2,000 feet with an amplitude of approximately 1,200 feet and an average radius of approximately 800 feet. The 1854-era map depicts this area as having a braided channel pattern rather than the single thread sinuous channel as seen in later time periods.

The transition between the braided pattern shown in the 1854-era map developed by Collins (1997) to the current single thread channel may be attributed to either limitations of the historic data or changes in the geomorphic processes controlling the river morphology. Assuming the historic data are accurate, the change in geomorphic processes may be caused by either natural or human influences. According to Lane (1957), a primary cause for a braided planform is sediment overloading. Sediment overloading can be caused by increased sediment supplies or reduced sediment transport capacity. Changes in the historic woody debris located along the East Fork Lewis River may have also influenced the channel planform. Sedell (1984) has shown that large woody debris within the channel can significantly influence channel patterns. Abbe and Montgomery (1996) discuss the significance of woody debris jams on the geomorphology of rivers in Washington State and how they may influence future channel locations.

The historic braided channel planform was probably produced by the significant reduction in river slope that occurs between RM 9 and 7 and backwater influences of the downstream Lewis and Columbia Rivers. The reduction in slope reduces the sediment transport capacity of the stream, inducing deposition of sediment (sediment overloading). The numerous dams and reservoirs, dredging for navigation, and levees for flood control along the downstream Lewis and Columbia Rivers have altered the influence of their annual flood peaks and hydraulics on the East Fork Lewis River. Effectively, the hydraulic base level of the East Fork Lewis River may have been lowered. These effects could have influenced the location and magnitude of sediment deposition along the East Fork Lewis River. Historic land use changes have also resulted in the draining and filling of sloughs and wetlands.

Remnant alluvial terrace deposits along the stretch of the river in the Daybreak vicinity suggest that the river was at a higher elevation than it is currently. These terrace deposits represent several different higher river elevations from the mid-Pleistocene (0.5 – 1.0 million years ago) to present. The terrace ranges from approximately 4 to 15 feet above the bed of the main channel in a west to east direction. Mine excavations for the Proposed Project will be located on this elevated river terrace and will be limited to areas above the 100-year floodplain.

Below RM 7 the river continues its meandering pattern at a much flatter slope. A similar meander pattern is also seen in the 1854-era map, suggesting the hydraulic and sediment transport characteristics have changed very little in this section since that time. Below RM 5.9 the river is subject to backwater tidal effects from the Columbia River (Hutton, 1995). The East Fork Lewis River has been known to flow in a reverse direction in some sections when low flow in the East Fork coincides with high tide (Hutton, 1995).

7.3.2 Historic Channel Locations for Dean Creek

Dean Creek is situated on a small alluvial fan at the edge of the East Fork Lewis River valley. Over geologic time, Dean Creek has migrated over the extent of the fan. However, analysis of historic aerial photographs suggests that Dean Creek has remained relatively stable for the last 38 years. Figure 7-4 shows a sequence of aerial photographs of Dean Creek dating back to 1962. Dean Creek is a single thread channel that has remained essentially unchanged in position throughout the available period of record. The relative stability of the channel is likely due to the periodic removal of gravel from the channel in the vicinity of the J. A. Moore Road Bridge by Clark County and by past landowner activities within and along the channel.

If sediment removal activities in the vicinity of the J.A. Moore Road crossing cease, the hydraulic capacity of the channel and bridge crossing will decrease, overflows of the channel and road will increase, and instability of the channel may be expected. Ultimately, the sediment deposition would be expected to reduce the hydraulic capacity of the road crossing to low flows. Moderate to high flows will overflow the road and will increase the potential for flooding on all parts of the fan. However, since J.A. Moore Road in the vicinity of the apex slopes to the west, and the topography of the fan is steepest on the western side of the fan, the potential for increased flood impacts would be greatest on the west side of the fan. The potential for migration of the existing channel to the east will be reduced by the proposed removal of the existing levee along the stream and restoration of the riparian forest. The removal of the levee will dissipate flow in the left (east) overbank and the restoration of riparian forest will increase resistance to flow and erosion in the left overbank.

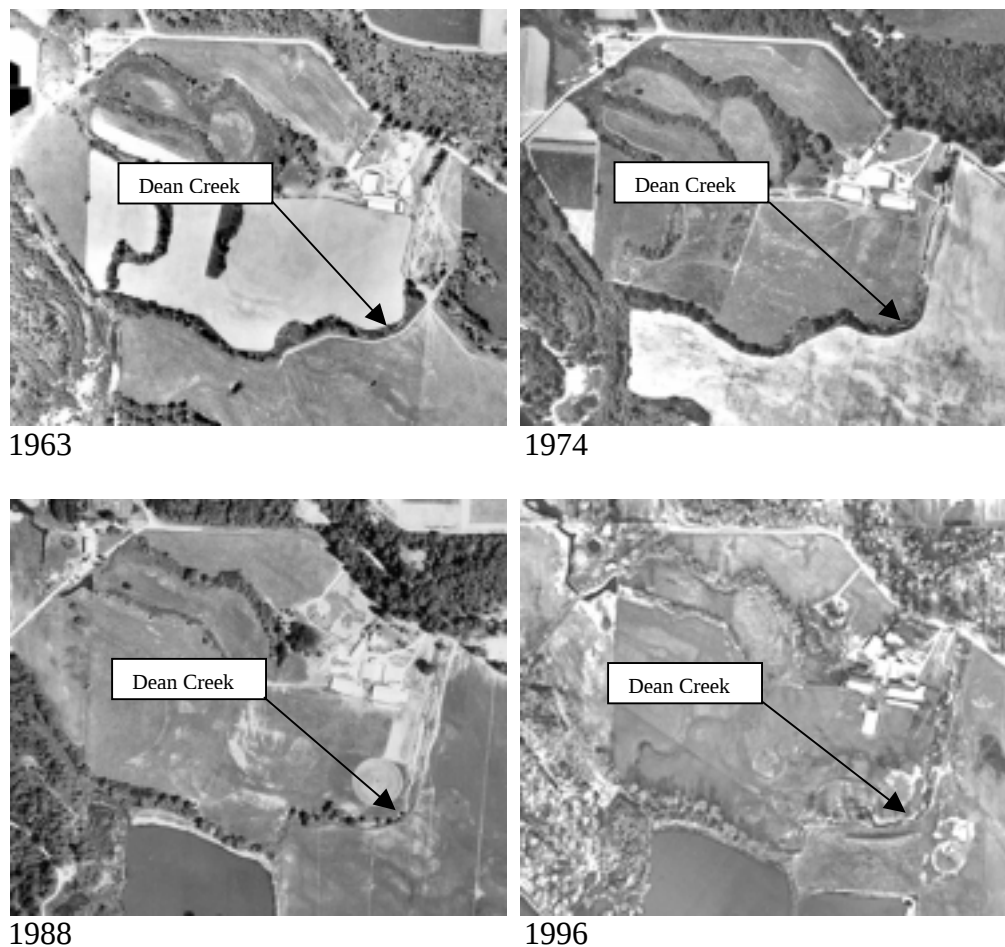


Figure 7-4. Dean Creek historic channel locations.

7.4 Historic Channel Migration Rates

The East Fork Lewis River between RM 10 and RM 9.3 shows evidence of longitudinal migration of meanders in the downstream direction. Between 1984 and 1997 the meander migrated downstream approximately 500 feet. This is an average migration rate of approximately 36 feet per year. Lateral migration was approximately 125 feet between 1963 and 1984, averaging approximately 6 feet per year.

Between RM 9.3 and RM 9.0 the river channel has tended to position itself along the south valley wall at the confluence of North Mill Creek. The 1963 and 1984 data both show a mid channel bar or island formation with the main channel split to the north and south. Lateral migration of the south channel between 1963 and 1984 was approximately 130 feet, averaging approximately 6 feet per year. Longitudinal migration of the north channel averaged approximately 9 feet per year.

Recent field observations at RM 9.0 showed the river to have migrated laterally approximately 200 feet to the north at a site just downstream of North Mill Creek between December 1996 and January 1999. This equates to a 2-year average migration

rate of 100 feet per year. Prior to 1996, the river migration averaged 5 feet per year at this location. Figure 7-5 shows the bank erosion associated with the recent northward migration of the channel.

Between RM 9.0 and RM 8 the river changed direction from a north flowing meander to a south flowing meander as a result of a meander cutoff that occurred sometime between 1935 and 1963. The 1963 channel path shows a split around a large island with the northern channel later becoming abandoned by 1984. The large meander at this location had migrated downstream at an average rate of approximately 27 feet per year when it was flowing to the north between 1935 and 1963. Lateral migration averaged 30 feet per year and longitudinal migration averaged 27 feet per year while the meander was flowing to the south between 1963 and 1984. However, this meander has not migrated downstream past RM 8.

Between RM 8 and RM 7.5 the river migrated approximately 250 feet to the southwest between 1984 and 1990. This equates to an average rate of 42 feet per year. As a result of this migration, the river broke into the abandoned Ridgefield Pit No. 8 along the eastern edge of the site.

Between RM 7.5 and RM 7 the main channel was directed to the north through a meander bend from sometime prior to 1935 to sometime after 1954 where it bordered Daybreak Pit No. 5. During the time period between 1935 and 1954 the channel migrated laterally approximately 500 feet. This is an average migration rate of 25 feet per year. A similar rate was noted for downstream migration. Sometime after 1954 the meander was cut off and river flow was directed more in a northwesterly direction closer to Ridgefield Pit No. 6.

Average channel migration rates for various reaches in the vicinity of the Proposed Project site are summarized in Table 7-1. A long-term average lateral channel migration rate in the vicinity of the Proposed Project was estimated to be about 40 feet per year.

Table 7-1. Channel migration rates in the vicinity of the Proposed Project.

Location	Type of Migration	Average Migration (ft/year)
RM 10 - 9.3	Lateral (side to side)	6
	Longitudinal (up/down valley)	36
RM 9.3 – RM 9	Lateral (side to side)	6
	Longitudinal (up/down valley)	9
RM 9	Lateral (side to side)	5 and 100*
	Longitudinal (up/down valley)	-
RM 9 – RM 8	Lateral (side to side)	30
	Longitudinal (up/down valley)	27
RM 8 – RM 7.5	Lateral (side to side)	-
	Longitudinal (up/down valley)	42
RM 7.5 – RM 7.0	Lateral (side to side)	25
	Longitudinal (up/down valley)	25

* Short-term channel migration between 1996 and 1998.



Figure 7-5. Photo of erosion of north bank just downstream of North Mill Creek at RM 9.

7.5 Expected Future Conditions Based on Historic Trends

Aerial photography and maps of the river through the Daybreak reach show that the river has not been within the Proposed Project area within the recent past with one exception. As shown on Figure 7-1, the 1854-era map shows one channel of the braided channel system within the southwestern portion of the Proposed Project area. Since 1935 the river has displayed a meandering planform and has not influenced the location of the Existing or Proposed Daybreak Pits.

In 1854 the planform of the river in the vicinity of the Proposed Project was braided and the riverbed was likely at a higher elevation compared to the present. It is unlikely that the river would revert back to a planform similar to the 1854 channel unless significant changes occurred in the hydrologic and sediment transport characteristics of the river that would cause significant aggradation. The recent capture of the Ridgefield Pits by the river has reduced the chances of significant aggradation of the channel near the Proposed Project. The Ridgefield Pits would have to substantially fill with sediment in order to rebuild the channel bed elevation up to a level that would allow the channel to migrate north toward the abandoned channel that borders the Daybreak site. Sediment infilling is predicted to take approximately 25 to 30 years. If the river were to migrate toward the Proposed Pits at this location, it would have to breach the existing Daybreak Pits before reaching the location of the Proposed Pits. Significant bank erosion and a breach of the Storedahl Pit Road would have to occur to allow the river to breach the Daybreak Pits at this location.

The East Fork Lewis River between RM 10.2 and RM 9.3 was seen to flow in a southwesterly direction along the southern valley wall throughout the period of mapping and photography. For several reasons it is unlikely that the river will substantially migrate from this path in the future. First, the Daybreak Bridge will continue to direct flow through it toward the south valley wall. Second, substantial development has occurred along NE 269th Street. If the channel began migrating to the north toward NE 269th street, it would be expected that measures would be taken to prevent loss of property (i.e. revetments or similar erosion control structures). The development conditions effectively limit the migration of the main channel and preclude the possibility of the Proposed Pits being breached by a split flow channel developing along the east edge of the Proposed Pit locations.

It is recognized that minor flow splits from the main channel have and will occur to the north of the river between RM 10.2 and RM 9.7 during major floods such as the 1996 event. The flow splits would likely enter the Proposed Pits and cause head cutting similar to that which occurred in Daybreak Pit No. 1 during the 1996 flood. However, it is noted that the 1996 flood has been determined to be a 500-year return period flood (USGS, 1997). The head cuts associated with the 1996 flood event were limited in extent. Practically, head cutting caused by flow splits is limited by the magnitude of flow in the overbank and the duration of flooding.

The sharp northward bend at the confluence of North Mill Creek (RM 9.2) has effected the local hydraulics of the channel, causing a portion of the rivers sediment load to deposit on the downstream point bar. Just downstream at RM 9, the channel has shown a tendency to stay to the north of the south valley wall. Recent field investigations have shown that the channel continues to deposit material on the point bar located on the south side of the channel while eroding the north bank (Figure 7-5). The recent acceleration of erosion on the south bank located immediately upstream may have been induced by the Mile 9 Pit capture in 1995 and possibly the Ridgefield Pit capture in 1996. This material may be contributing to the increased rate of deposition on the point bar at RM 9 and thus causing the channel to migrate to the north. Northward migration of the river at this

location may continue, although likely not at the same high rate. Historic records indicate that high lateral erosion rates are not typical at this location.

The 1854-era map shows a former channel path that splits to the west and northwest at approximately RM 9. The northwest path is directed toward the abandoned county gravel pits (County 1 and County 2). Near the County Pits the former channel splits again to the west and northwest. The westerly path is directed back toward the former meander bend shown in the 1935 and 1963 photography. The northwesterly path is directed toward Daybreak Pit No. 1. A path similar to this former channel path could develop and cause an avulsion into the abandoned county pits as well as the existing Daybreak Pits. However, it should be noted that grading, levees, and road development now occupy portions of this channel and no topographic features of the 1854-era channels exist in the current topography of the floodplain at this location.

Between the Mile 9 Pit and the Ridgefield Pits, the channel has tended to migrate laterally at a relatively high rate. The meander bend located along this reach switched flow direction from north to the south in the early 1960's. Further sediment deposition in this reach of the river would have a tendency to cause the channel to shift back to the north. However, the recent capture of the Ridgefield Pits has increased the slope of the channel in this reach. Sediment that would formerly have deposited in this section of channel is now transported further downstream and deposited in the pits. The potential for northward migration of the channel in this reach of the East Fork Lewis River has been significantly reduced by the capture of the Ridgefield Pits. The potential for deposition of sediment in the channel immediately upstream of the Ridgefield Pits will be reduced until geomorphic recovery of the pits occurs. This is estimated to take approximately 25 to 30 years.

7.6 Impacts of the Proposed Project on the Planform of River

In the following sections, impacts to the planform of the East Fork Lewis River and Dean Creek from the Proposed Project are presented.

7.6.1 Impacts to East Fork Lewis River Planform

The proposed expansion and reclamation of the Daybreak Mining Site should have no impact on the planform of the East Fork Lewis River if an avulsion of the river into the existing Daybreak pits does not occur. The existing Daybreak Pits occupy portions of the 100-year floodplain next to the former main channel of the river. Any migration of the river to the north, away from the Ridgefield Pits, would need to breach the Existing Daybreak Pits before reaching the Proposed Pits. The location of the Proposed Project (further to the north of the channel and Existing Daybreak Pits and outside the 100-year floodplain) is such that any future channel migration would intercept the Existing Daybreak Pits prior to the Proposed Pits. If the river breached the Existing Daybreak Pits, the hydraulics of flow and conditions of sediment transport along the river would be affected. The effects of breaching the Existing Daybreak Pits would likely be similar to those associated with breaching the Ridgefield Pits. The pits would locally steepen the slope of the river channel and store sediments transported into them. Filling of the pits with sediments would occur over several decades. The exact route the river would take

through the Existing Daybreak Pits is unknown. The potential for the river to breach into the Proposed Pits during the same event that breaches the Existing Daybreak Pits would be influenced by the physical characteristics of the breach into the Existing Daybreak Pits and the hydrologic and hydraulic conditions experienced. Breaching of the Proposed Pits during subsequent events would be influenced by the rate at which the Existing Daybreak Pits fill with sediment, the physical characteristics of the delta formed in the Existing Daybreak Pits and the hydrologic conditions experienced. The probability of the Proposed Pits being breached in the future would increase if the river avulsed into the Existing Daybreak Pits.

If the river avulsed into the Proposed Pits, potential impacts on the planform of the river would be similar to the impacts observed to be associated with the recent (1996) avulsion into the Ridgefield Pits. The channel would widen and deepen within the pits. Significant deposition of material would occur at the entrance to the pits causing a sand, gravel, and cobble delta to form. Over time, the delta of sediment would extend downstream within the pits. Ultimately, the delta would extend through all of the pits. Backwater areas in the pits may become isolated from the main flow path through the pits. Some of the shallow backwaters could evolve into wetland areas, filling with fine sized sediments carried to them in suspension during floods. Deeper backwater areas may evolve into pools or floodplain sloughs. The growth of vegetation and collection of woody debris will influence the deposition of sediment and path of the main flow channel within the pits. The capture of the pits will locally lower the elevation and gradient of the main channel, create a preferential location for sediment deposition, and locally steepen the gradient of the channel into the pits.

7.6.2 Impacts to Dean Creek Planform

Impacts to the planform of Dean Creek from the Proposed Project would be directly related to the proposed removal of the existing discontinuous levee, revegetation of the riparian area and the potential for future avulsions. Assuming that the sediment supply to Dean Creek remains the same and the periodic removal of sediment deposits continues, the planform of the channel will not be impacted by the Proposed Project. The sediment transport characteristics of the bankfull channel of Dean Creek will not be altered by the project. The removal of the existing levee will allow high flows to occupy the newly created floodplain and dissipate flow in the left overbank. The restoration of riparian forest will create woody vegetation and debris that will increase hydraulic resistance to flow in overbank areas. Generally, the woody vegetation or debris on the floodplain would be expected to be resistant to any migration of the main channel.

A naturally occurring depositional environment exists in the vicinity of the J.A. Moore Road crossing. Historically, sediment deposits in the channel have been removed by the County to maintain flow conveyance through the bridge. If those sediment removal activities cease, the hydraulic capacity of the bridge and the channel in the vicinity of the bridge will diminish. Moderate to high flows would be expected to bypass the bridge and overflow J.A. Moore Road. This will increase the potential for flooding everywhere on the fan. However, the flooding potential is expected to increase the greatest on the west

side of the fan since J.A. Moore Road slopes to the west in the vicinity of the fan apex. Also, the fan has a steeper gradient on its west side near the apex.

If sediment deposition is unmanaged along Dean Creek in the vicinity of the J.A. Moore Road crossing, a possibility exists for Dean Creek to overflow the road into the Proposed Pits. However, J.A. Moore Road is a rural collector road and a primary transportation route in the area. The possibility of Dean Creek avulsing into one of the Proposed Project Pits is discussed in see Section 8 “Channel Avulsion”.

7.7 Summary

A review of the historic data has shown the East Fork Lewis River to be a dynamic river in the vicinity of the Proposed Project. Measurements of historic lateral migration rates range from 5 to 30 feet per year, while recent rates at one location (RM 9) were estimated at 100 feet/year. A conservative estimate of the average long-term lateral migration rate of the channel in the vicinity of the Proposed Project was determined to be about 40 feet per year.

Available planform data for 1854 indicates that one channel of a braided planform intersected the Proposed Project site at that time. In contrast to the 1854 data, aerial photography data since the 1930's has shown the East Fork Lewis River channel to have a meandering single thread channel that has not intersected the Proposed Project location. Over the last 65 years, the river has flowed along the south valley wall within a fairly well defined zone of migration ranging from 400 to 2,250 feet in width.

It is recognized that during high flow events, minor overflows splits from the main channel have and will occur to the north of the river between RM 10.2 and RM 9.7. The flow splits would likely enter the Proposed Pits and, if the discharge was large enough and for a significant duration, cause minor head cutting similar to what occurred in Daybreak Pit No. 1 during the 1996 flood. However, it is unlikely the river would change course and flow along these overflow paths. Rural collector road, several local streets, improved private roads, utility corridors, the Clark County Road Operations and Maintenance Shops, and residential development occupy this area. It is expected that measures would be taken to prevent loss of property. The development conditions are assumed to effectively limit the migration of the channel and preclude the possibility of the Proposed Pits being breached by a split flow channel developing along the east edge of the Proposed Pit locations.

Just upstream of the Proposed Project site, between the Mile 9 Pit and the Ridgefield Pits, the large meander bend has actively migrated in both the lateral and longitudinal directions. In 1996, the meander captured the Ridgefield Pits. The subsequent head cutting caused by the pit capture has increased the channel slope and decreased the potential for sediment deposition within this section of river. The capture of the Ridgefield Pits has created a well-defined sink for sediments transported along the river. Until the pits are substantially filled, the likelihood of significant lateral main channel migration in the vicinity of the Proposed Project is limited. Estimates of sediment

transport suggest that the Ridgefield Pits could take approximately 25 to 30 years to effectively fill.

Accordingly, the Proposed Project should have no impact on the planform of the river in the short-term. In the long-term, the Ridgefield Pits will continue to fill with sediments. Subsequent to that filling the river channel will again freely migrate. This future migration may put a larger area of developed property, roads, utilities, and buildings at risk from erosion. Before breaching the Proposed Pits, the river must first breach the existing roads and the Existing Daybreak Pits. Based on sediment transport estimates, it would take approximately 30 years to effectively fill the Existing Daybreak Pits. However, due to their proximity, the river could enter the Proposed Pits prior to the complete filling of the Daybreak Pits. The hydraulic and sediment transport characteristics of the river would be significantly affected by breaching the Daybreak Pits. Impacts on the planform of the river from breaching the Daybreak Pits would most likely be similar to those observed to be associated with the recent breaching of the Ridgefield Pits. These impacts would include abandonment of former main channel reaches, significant widening of the flow area within the pits, deposition of sediments in the pits, and local incision of the main channel upstream of the pits.

Dean Creek has shown no evidence of channel migration in the recent past (38 years). The relative stability of the channel during this period may be due to the periodic removal of sediment deposits from the Dean Creek channel in the vicinity of the crossing by the County. If sediment removal activities by the County were to cease, the hydraulic capacity of the channel in the vicinity of the crossing would diminish and overflows from the channel would increase. Ultimately, the hydraulic conveyance capacity of the crossing would be reduced to only low flows and moderate to high flows would overflow J.A. Moore Road. This would create a potential for overflows into the Proposed Pits. However, since the J.A. Moore Road slopes to the west at the crossing, the overflows on the west side of the Dean Creek alluvial fan are more likely. Furthermore, the west side of the alluvial fan has an overall steeper gradient, which should concentrate flows on the west side of the fan. If the overflows enter the Proposed Pits and the discharge is large enough for a significant duration, minor head cutting could occur. However, J.A. Moore Road would be expected to control the upstream limit of potential headcutting.

Deposition of sediment along the existing Dean Creek channel adjacent to the project would reduce its hydraulic conveyance capacity, increase overflows from the channel, and increase the potential for channel migration. The proposed removal of the existing discontinuous levee and restoration of riparian forest along Dean Creek will reduce the potential for migration of the existing channel toward the east. The levee removal will help to dissipate flow while the restoration of woody vegetation and debris will help to resist bank erosion, reduce overbank velocities, promote suspended sediment deposition in overbank areas, and concentrate flow in the main channel.

8 Channel Avulsion

8.1 Introduction

A channel avulsion is a rapid and unexpected shift in channel position that causes a portion of the existing channel to be abandoned. Avulsions are typically caused by an obstruction to the flow such as a log or debris jam or by the breaching of a levee or high ground separating the river channel from a topographic low such as a former channel or gravel pit. The following sections describe the analysis used to characterize the potential for the East Fork Lewis River to avulse into gravel pits within the Proposed Project site.

8.2 Historic Avulsions

In the following sections, a discussion of historic channel avulsions for the East Fork Lewis River and Dean Creek are presented.

8.2.1 Historic Avulsions of the East Fork Lewis River

Historically, the East Fork Lewis River has been an actively migrating channel. Over geologic time the channel is believed to have migrated from valley wall to valley wall in the reach encompassing the Ridgefield Pits, Existing Daybreak Pits, and Proposed Project site. In the recent past, the channel has tended to stay along the south valley wall. Historic maps and photographs show that the channel has migrated and shifted position several times along this reach. Due to the limitations of historic data, for most of the period of record, it is not known where avulsions, if any, took place. However, it is certain that significant channel shifting and abandonment have occurred. These occurrences were probably due to debris jams or meander cutoffs.

In the 1854-era maps, the channel is documented to have had a braided channel pattern. Braided channels are known to be unstable and change alignment rapidly (Simons and Senturk, 1976). This would suggest that natural avulsions in the East Fork Lewis River might have been common during this time period. However, a braided channel pattern has not been observed since the 1854-era maps and is not expected to return under the current hydrologic, sediment transport, and human-influenced conditions. In recent years, three instances of avulsion have been documented. Each of the documented avulsions were associated with the migration of a river meander into abandoned gravel pits that were located in close proximity to the main river channel.

The first documented avulsion involved the Mile 9 Pit in November 1995. The Mile 9 Pit is located approximately one-half mile upstream of the Ridgefield Pits. This event caused the channel to shift to the south, abandoning approximately 1,700 feet of channel (Norman et al., 1998). The second documented avulsion occurred during the February 1996 flood (Miller, 1996). At that time, the river broke into the southeast corner of Ridgefield Pit No. 7, flowing back into the channel at its northwestern most point. This caused the abandonment of approximately 1,500 feet of channel located southwest of Daybreak Pit No. 5. However, the majority of the abandoned channel remained submerged and connected to the main channel. The third documented avulsion again involved the Ridgefield Pits in November 1996. The channel avulsed into the southeastern corner of Ridgefield Pit No. 1. This changed the course of the river, which

was formerly flowing to the north along the southern boundary of the Daybreak Site. The channel currently flows through a complex of six gravel pit lakes. Approximately 3,200 feet of channel was abandoned (Norman et al., 1998).

Other minor avulsions or pit breaches were documented from examination of historic maps and aerial photos. Sometime just prior to 1990 the river had migrated into Ridgefield Pits No. 8. This did not cause the channel to change course. However, a connection was created between the pit and the main channel.

By strict definition, neither the avulsion into the Mile 9 Pit or the Ridgefield Pits, was an “unexpected” shift in channel position. In both cases, a meander of the river migrated toward the pits over a period of time. In fact, the river’s migration into the Ridgefield Pits was predicted several years in advance. The historic migration path of the river had been documented to be in the direction of the Ridgefield Pits for a period of over 60 years (Bradley, 1996).

8.2.2 Historic Avulsions of Dean Creek

The formation of an alluvial fan relies on the movement of the channel over geologic time. Movement of the channel occurs due to the deposition of sediment along the channel. As sediments are deposited, the channel may shift or avulse to a new location on the fan. Dean Creek has likely avulsed many times through geologic time as it formed the fan it now occupies. However, the planform analysis suggests that the creek has remained relatively stable over the recent past (38 years). The lateral stability of the stream is likely due to the continued removal of bed material from the Dean Creek channel near J. A. Moore Road Bridge by Clark County and the presence of a discontinuous levee system along the margins of the channel.

8.3 Hydrologic Floodplain and Channel Migration Zone

The extent of the Hydrologic Floodplain and Channel Migration Zone (CMZ) are important for determining the relative risk of channel migration/avulsion into existing side channels or gravel pits adjacent to the East Fork Lewis River. The boundaries of the CMZ are also important as the environment contained within the CMZ is at greater risk of potentially negative impacts caused by human activities.

The Hydrologic Floodplain is defined as the land adjacent to the baseflow channel residing below bankfull elevation. The hydrologic floodplain is the portion of the floodplain that the river is frequently acting upon. Potential channel migration or avulsion is considered to be most probable within the boundary of the hydrologic floodplain. It is inundated approximately two years out of three (USDA, 1998).

While at some point in time, rivers have occupied each part of the valley floor, the current channel pattern and migration potential are more closely related to recent climatic and erosional patterns (WFPB, 1999). Thus, on the time scale of decades, rivers typically influence only a portion of the valley floor (WFPB, 1999). In short, the purpose of delineating the CMZ along the East Fork Lewis River is to define land areas that have a significant probability of being affected by the river. That portion of the valley floor

influenced by the river is known as the Channel Migration Zone. Several definitions for a CMZ exist in the literature. The following definitions are taken from several Washington Forest Practices Board (WFPB) documents and a Timber Fish Wildlife (TFW) (USFWS et. al, 1999) document.

The Emergency Forest Practice Rules (WFPB, 1999) define the CMZ as “the area where the active channel of a stream is prone to move and this results in a potential near-term loss of riparian habitat adjacent to the stream” and refers to the Forest Practices Board Manual for descriptions and illustration of CMZ’s, and delineation guidelines, including modifications to CMZ’s by a permanent levee or dike. The Board Manual (WFPB, 1999) defines the CMZ as the lateral extent of likely movement along a stream reach with evidence of active stream channel movement over the past 100 years.

According to the Forests and Fish Report (USFWS et. al, 1999) a channel migration zone means, for each of the types of streams described below, the area where the active channel of such stream is prone to move and where such movement would result in a potential near-term loss of riparian forest adjacent to the stream. As described in the report, stream types associated with channel migration zones include moderately confined streams, unconfined streams, unconfined meandering streams, unconfined braided streams, and unconfined avulsing streams. The methods described for delineating the CMZ differ for each stream type. The East Fork Lewis River in the vicinity of the Daybreak Mine currently has or in the past has had characteristics of the last three stream types, while Dean Creek is considered an unconfined stream. Definitions for these four stream types provided in the Forests and Fish Report (USFWS et. al, 1999) are as follows:

Unconfined stream

As used in this definition, “unconfined streams” are 2nd to 4th order type F¹ or S² waters with bankfull widths of less than 50 feet, which usually have gradients less than 4% (but occasionally have a gradient up to 8%). These streams are often located in broader headwater or tributary valleys or are flowing across the terraces of larger river valleys. They may also occur in areas where a significant change in channel slope or confinement causes high amounts of sediment deposition such as at alluvial fans or the mouth of confined tributary valleys. Channel movement typically occurs during floods when woody debris or large sediment accumulations can cause the stream or portions of the stream to jump or avulse into side channels. These side channels are considered part of the active channel. Localized reaches of meandering or braided streams may also be present.

¹ Type S waters include “all waters within their ordinary high-water marks, inventoried as shorelines of the state...”

² Type F waters include “all segments of natural waters (other than Type S waters) (a) are within the bankfull widths of defined channels or (b) with lakes, ponds, or impoundments have a surface area of 0.5 acres or greater at seasonal low water which, in either case, contain fish habitat...”

Unconfined meandering stream definition

As used in this definition, "unconfined meandering streams" are 5th order and larger Type S waters (Type S waters include all waters within their ordinary high-water marks, inventoried as "shorelines of the state") with bankfull widths greater than 50 feet and gradients of less than 2% with the following additional characteristics: The waters are sinuous, primarily single-thread channels that have a distinct meandering pattern readily observable on aerial photographs. Remnant side-channels and oxbow lakes often create wetland complexes within the associated channel migration zone. A diverse set of vegetation can grow within the associated channel migration zone including cedar, spruce, hardwoods, and wetland vegetation on wetter sites and Douglas-fir, spruce, hemlock and true firs on drier terraces. "Unconfined meandering streams" do not include any waters that are unconfined braided streams or unconfined avulsing streams.

Unconfined braided stream definition

As used in this definition, "unconfined braided streams" are 5th order or larger Type S waters with bankfull widths greater than 50 feet and gradients of less than 2% with the following additional characteristics: These waters have a high sediment supply and form numerous channels (multi-threaded) that are likely to move within the bankfull width of the stream in even small storm events. The frequent rate of channel movement means that the associated channel migration zone is typically sparsely vegetated with young hardwoods along the channel margins. Glacially fed streams often have large sections of braided channel. "Unconfined braided streams" do not include any waters that are unconfined meandering streams or unconfined avulsing streams.

Unconfined avulsing stream definition

As used in this definition, "unconfined avulsing streams" are 5th order or larger Type S waters with bankfull widths greater than 50 feet and gradients of less than 2% with the following additional characteristics: These waters are usually large dynamic river systems that in some cases have had dikes and levees constructed that may restrict channel movement. Numerous side channels, wall-based channels, oxbow lakes, and wetland complexes may exist within the associated channel migration zone. Sizeable islands with productive forest land may also exist within the zone. Woody debris jams with larger diameter pieces of large woody debris are an important element for creating pools within these waters, as well as redirecting flow to create side channels and islands. Vegetation within the associated channel migration zone can include cedar, spruce, hardwoods, and wetland vegetation on wetter sites and Douglas-fir, spruce, hemlock and true firs on drier terraces or islands. "Unconfined avulsing streams" do not include any waters that are unconfined meandering streams or unconfined braided streams.

8.3.1 East Fork Lewis Hydrologic Floodplain and Channel Migration Zone

For the purposes of this report, the Hydrologic Floodplain is mapped as the area inundated by the 2-year recurrence interval flood (Figure 8-1) or within 80 feet (2 times the average lateral migration rate of approximately 40 feet per year derived from evaluation of historic aerial photography (See Chapter 7) of the existing low-flow channel, which ever is less. The employed definition of the hydrologic floodplain was selected to provide a conservatively large definition of its limits.

The East Fork Lewis River near the Proposed Project makes a transition from a steeper more confined valley to a flatter less confined valley. At this location much of the river's bed load is deposited causing the stream to become more sinuous. According to maps from 1858, the channel at this location showed evidence of braiding and would fit into the unconfined braided stream category. However, evidence of a braided channel planform has not been seen in any subsequent mapping or photography. Since the 1930's, the planform has been that of a mostly single thread meandering channel. Thus, under the current hydrologic and sediment transport regime, the East Fork Lewis River in the vicinity of the Daybreak Mine would be considered either an unconfined meandering stream or an unconfined avulsing stream.

Historic evidence suggests that at least one natural avulsion has taken place sometime prior to the 1960's that caused a large meander to be cut off, temporarily forming an island. The remnant channel from this former meander bend is located along the south side of Storedahl Pit Road. Also, a smaller island located just upstream, at the confluence with North Mill Creek, had existed for many years between the 1960's and the 1980's. For this reason it is concluded that the East Fork Lewis River in the vicinity of the Daybreak Mine more closely fits the definition of an unconfined avulsing stream.

As defined in the Forests and Fish Report (USFWS et. al, 1999), the CMZ for unconfined avulsing channels can include much of the valley bottom and is typically hundreds of feet, but can easily be a few thousand feet, in width. Delineation of the boundaries is often determined based upon a review of the associated vegetation and history of past migration.

Based on the history of past migration (Figure 7-1), the CMZ for the East Fork Lewis River does not include the entire valley bottom. In fact, since the 1858 (approximately 140 years of record) the river has remained almost entirely within the southern portion of the valley. Because no specific method for determining the CMZ of unconfined avulsing channels is given, the methods described for an unconfined braided and unconfined meandering stream were used. The CMZ for an unconfined braided stream is considered to be the bankfull width. However, it is noted that the East Fork Lewis River in the vicinity of the Proposed Project has not had a braided pattern since at least the 1930's. Accordingly, a CMZ associated with an unconfined braided stream type is not representative of the current channel form. The CMZ for an unconfined meandering stream is defined as (1) the area within the amplitude of the meander bends or (2) the area subject to bank erosion over the time required for growing functional large woody debris. A conservative estimate of the time required to grow functional large woody debris is 200

years (200 ft tall, 2-3 ft diameter Douglas Fir). At an average erosion rate of 40 feet per year, the limits of the CMZ would be 8,000 feet. This distance is greater than the boundaries of all documented historic channel locations and the width of the valley floor, which is approximately 3,000 feet wide in the vicinity of the Daybreak Mine.

Accordingly, this method was not considered appropriate for determining the CMZ for the East Fork Lewis River. Analysis of historic planform data suggests that the CMZ for the unconfined meandering stream type based on method 1 more closely represents the unconfined limits of channel migration under the current hydrologic regime (Figure 8-2).

Both of the methods previously described were not seen to adequately describe the true limits of the CMZ. Several areas with topographic evidence of past channel movement fell outside of the CMZ as they were not represented in the historic photography and mapping. These areas were seen to be located within the active floodplain below the upper terrace elevation. For this reason, another method (method 3) was used to define the edges of the upper terrace deposits as the limits of the CMZ. Method 3 defines the CMZ as the area inundated by the 20-year recurrence interval flood (Figure 8-1), or within 800 feet (20 times the average lateral migration rate of 40 feet per year) of the existing low-flow channel, whichever is less. A period of 20 years was selected since it represents a period of several decades, consistent with the Forest Practice Board Manual definitions (WFPB, 1999). This method of defining the CMZ was combined with the historic planform analysis (method 1) to determine the most conservative representation of the CMZ.

It is noted that overflow paths of the East Fork Lewis River do exist in the vicinity of the Daybreak Mine in the northern portion of the valley. These overflow paths are excluded from the CMZ because they cross several county roads, are above bankfull elevation and show no evidence typically associated with side channels. Side channels are typically characterized by gravel bottoms (often covered with leaf litter), sparse to no vegetation, or a rectangular cross section (WFPB, 1999). The Board Manual (WFPB, 1999) describes secondary channels with beds above the bankfull elevation that are disconnected from the main channel as overflow channels. Overflow channels (such as the overflow paths of the East Fork Lewis River) do not constitute evidence for a CMZ (WFPB, 1999).

It should be further noted that the portion of the East Fork Lewis River for which a CMZ is being delineated is not a forest practice unit. Historically, land use in the vicinity of the Proposed Project has been for agriculture. However, the valley bottom associated with the East Fork Lewis River can be described as a disturbed/alterd floodplain environment as is described in the Board Manual (WFPB, 1999). A disturbed/alterd floodplain environment commonly includes human-caused restrictions on streams from roads, railroads, riprap, dikes and levees (WFPB, 1999). According to the Board Manual, the CMZ does not extend beyond the limits of a structure such as a dike or levee if “the structure supports a public right-of-way or conveyance route and receives regular maintenance to maintain structural integrity” and “the structure was constructed pursuant to appropriate federal, state and local requirements”.

According to this definition, all county roads and Storedahl Pit Road would be considered to limit the extent of the CMZ. This definition is similar to King County's description of Mitigated Hazard Zones for channel migration. A Mitigated Hazard Zone is described as the unconstrained natural limits of channel migration scaled back to the boundaries of major roads, developed areas, revetments and levees (Perkins, 1993). Using the definition of CMZ for disturbed/altered floodplains defined by the Board Manual (WFPB, 1999) and King County (Perkins, 1993), the Channel Migration Zone (CMZ) for the East Fork Lewis River in the vicinity of the Daybreak Mine is shown in Figure 8-3.

8.3.2 Dean Creek Hydrologic Floodplain and Channel Migration Zone

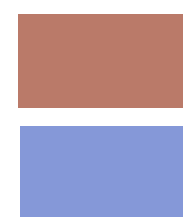
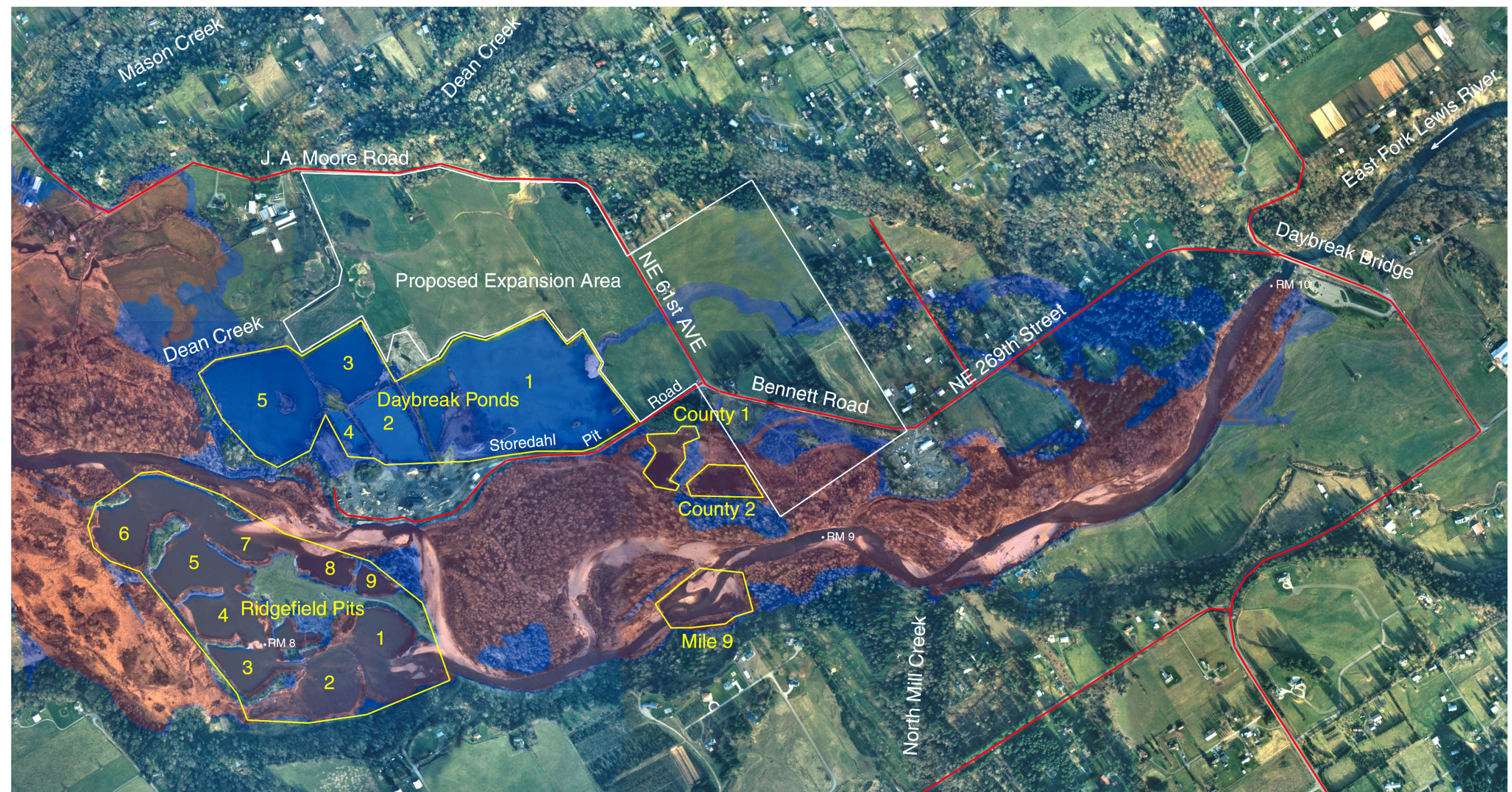
Similar to the East Fork Lewis River, the hydrologic floodplain for Dean Creek was chosen as the 2-year floodplain. Except for a small overflow channel to the west, the existing channel contains the 2-year recurrence interval flood. The existing channel banks along the channel were chosen to define the limits of the hydrologic floodplain.

As defined in the Forests and Fish Report (USFWS et. al, 1999), the CMZ for an unconfined stream is determined by reference to the surrounding topography and vegetation. Delineating the boundaries of these zones can be more difficult because of the subtle changes in these features. The extent of the channel migration zone often coincides with the furthest extent of side channels. The entire channel migration zone width is typically on the order of 10's of feet for small streams, but can be a few hundred feet on moderate sized streams. The lack of side channels and the historic photographic evidence suggest that the CMZ for Dean Creek coincides with the bankfull channel edge.

Dean Creek in the vicinity of the Proposed Project flows over an alluvial fan. For modern alluvial fans, channel migration is common and often difficult to predict (WFBP, 1999). Alluvial fans at the confluence of streams (such as Dean Creek) are typically considered modern alluvial fans (WFBP, 1999). The CMZ will typically encompass the entire fan surface because of the difficulty in predicting future channel locations (WFBP, 1999). However, historic evidence suggests that Dean Creek has remained relatively stable for the last 38 years. The lack of side channels, presence of a discontinuous levee system, and general fan topography indicate the potential for future channel movement is low. Additionally, the extraction of bed material by Clark County in the vicinity of the bridge will continue to reduce the likelihood of channel migration. The available evidence suggests that the current CMZ for Dean Creek should be defined as the bankfull channel edge.

If the removal of sediment deposits along Dean Creek by Clark County is not continued, an increased potential for channel migration would exist. The CMZ for Dean Creek could potentially encompass the entire alluvial fan. However, the steeper gradient on the west side of the fan would likely promote channel migration on that side of the fan. The proposed removal of the existing discontinuous levee would define the east boundary of the CMZ. If sediments are not removed periodically, the hydraulic capacity of the J.A. Moore Road Bridge will diminish and overflows of the road would be expected for moderate to high flows. Overflows of the road to the east may occur that may enter the Proposed Pits. A headcut may develop where the overflow enters a pit. The upstream

extent of the head cut is expected to be limited by J.A. Moore Road. Such an overflow is not an avulsion path since the location of the Dean Creek channel is fixed at the bridge and the road will prevent formation of a channel in any other direction. The proposed removal of the existing discontinuous levee will define a mitigated boundary for migration of the channel. The restored riparian forest in the left overbank would increase hydraulic roughness, reduce overbank flow velocity, and promote deposition of suspended sediments. This will reduce the potential for channel migration to the east, toward the project.



2-year Floodplain

20-year Floodplain



Public Right-of-Way or Conveyance Route



Approximate Scale: 1" = 940'



Figure 8-1. 2- and 20-year floodplain used to define the Hydrologic Floodplain and Channel Migration Zone.

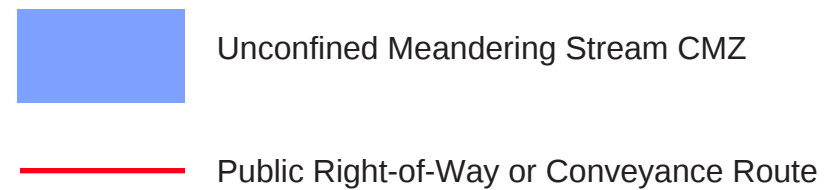
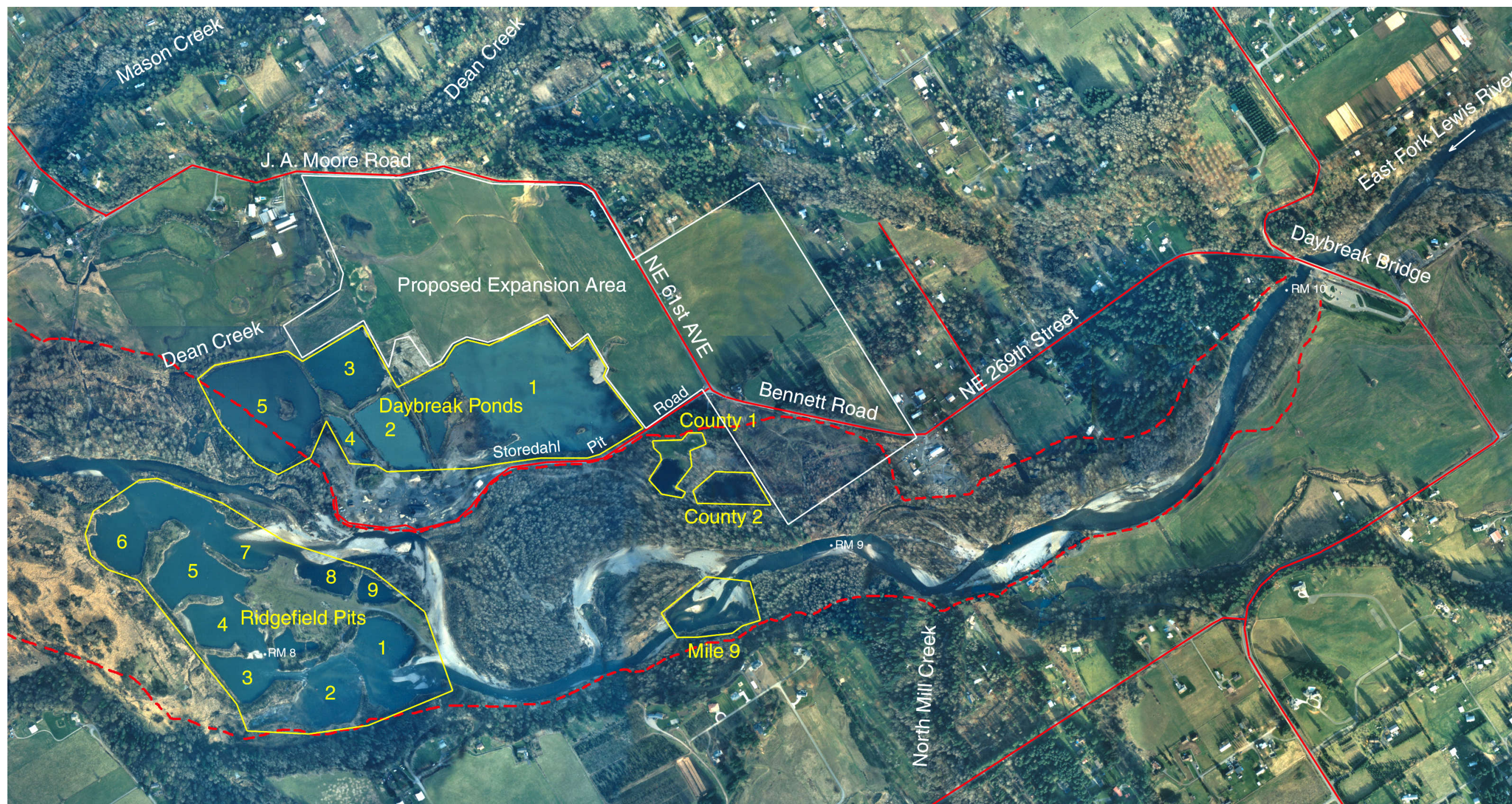


Figure 8-2. Unconfined Meandering Stream (method 1) Channel Migration Zone.



- Limits of Channel Migration Zone
- Public Right-of-Way or Conveyance Route



Approximate Scale: 1" = 940'

Figure 8-3. East Fork Lewis River Channel Migration Zone.

8.4 Potential for Channel Migration / Avulsion

Avulsions are triggered by unpredictable, random events such as large woody debris jams, landslides, large floods, or upstream changes in river position, therefore it is not possible to predict when or if an avulsion will definitely occur. However, the relative risk of one location along the river versus another can be qualitatively evaluated to determine the potential locations of future avulsions. Accordingly, such an evaluation was made based on available information and historic trends. The analysis does not imply that an avulsion will definitely take place at the indicated locations in the future, rather that if an avulsion were to occur, the identified locations have a greater potential for avulsion than other locations. The following sections describe the potential paths for channel migration/avulsion by reach. The analysis incorporates results described in previous sections of this report.

8.4.1 East Fork Lewis River Avulsion Potential

To help define the potential for channel migration/avulsion into the Proposed Project, each potential migration/avulsion path identified is described as within the Hydrologic Floodplain, within the Channel Migration Zone (CMZ) or outside of the CMZ. Migration/avulsion paths that are located within the Hydrologic Floodplain indicate they have a potential to be occupied within about two years. Migration/avulsion paths located within the CMZ are believed to have a potential to be occupied within about 20 years. Observations of current conditions and historic trends were also used to judge the potential for migration/avulsion. In the following paragraphs, refer to Figure 8-4 to define the locations of potential migration/avulsions paths.

Daybreak Bridge (RM 10) to North Mill Creek (RM 9.2).

The planform analysis demonstrated that the river channel within this reach has moved very little in the 145 years since the survey of 1854/1858. The channel profile is relatively steep and shows only minor changes in bed elevation over the period from 1977 to 1996 except at the confluence with North Mill Creek. Aggradation has occurred at this location that may cause increased lateral migration. However, no obvious alternative flow paths exist that would allow the river channel to make a direct connection to the Proposed Project from this location.



- Limits of Channel Migration Zone
- Public Right-of-Way or Conveyance Route
- - - Overflow Path
- Potential Migration/Avulsion Path (within Hydrologic Floodplain)
- Potential Migration/Avulsion Path (within Channel Migration Zone)
- Potential Migration/Avulsion Path (above 100-year Floodplain)



Approximate Scale: 1" = 940'

Figure 8-4. Overflow path and potential paths of channel migration and/or avulsion.

It is recognized that minor overflows split from the main channel between Sites A and B have and will occur along this reach during large floods. The flow splits along this route would possibly enter the Proposed Pits and cause head cutting similar to that which occurred in Daybreak Pit No. 1 during the 1996 flood. However, it is noted that the 1996 flood has been determined to be a 500-year return period flood (USGS, 1997). The head cut associated with the 1996 flood event was limited in extent. Practically, head cutting caused by flow splits between Sites A and B is limited by the possible magnitude of flow in overbank areas and the duration of flooding. The discharge values of the split flows for various return periods determined from hydraulic modeling are shown in Table 8-1.

Table 8-1. Split flow magnitudes.

Return Period (years)	Splitflow Q (cfs)
2	0
10	100
20	285
50	475
100	650

The hydraulic model used to define the split flow values was developed to evaluate the flood hazard potential along the East Fork Lewis River. Accordingly, the split flow values identified are considered to be conservatively large and likely overestimate the potential for split flows to affect the proposed development. In fact, an approximate 10-year return period flood occurred on the East Fork Lewis River on November 25, 1999 (Personal communication with USGS, 1999). No split flows were observed in the vicinity of the Proposed Project during this event. (Personal communication with K. Storedahl, 1999).

Split flow paths in the vicinity of Proposed Project showed no signs of erosion or tendency for channel formation due to the 500-year return period flood that occurred in February of 1996. Accordingly, there is no reason to believe that flood events with lesser magnitudes would have a significantly different erosion potential. There appears to be little or no erosion risk to the land separating the Proposed Project from the 100-year floodplain. In the case of floods greater than a 100-year return period event, or if flow paths are obstructed, overflows into the Proposed Project Pits are expected to cause minor head cutting at the pit boundaries. A delta of sand and gravel, similar to the delta that formed in Daybreak Pond No. 1 as a result of the 500-year flood event in February 1996, would be expected to form in the Proposed Project Pits and could disturb some portion of the proposed wetlands associated with the pits.

In addition, the reestablishment of floodplain forests and wetlands in the vicinity of the Proposed Project should further reduce the potential for impacts. Also, the existence of residential development and county roads (NE 269th St., Bennett Rd. and NW 61st Ave.) effectively prohibit the potential for shifting of the channel to the north of its current and historic locations. This will prevent any future channel avulsion into the Proposed Project along this overflow path. This split flow path is considered to be an overflow

path as defined by the Washington Forest Practices Board Manual (WFPB, 1999) and is effectively outside of the CMZ.

North Mill Creek (RM 9.2) to Ridgefield Pit Entrance (RM 8.3)

The planform analysis has shown the channel in this reach to have a historic southward trend. The slope decreases slightly in this reach causing increased sediment deposition. Recent field investigations have shown that the channel is depositing material on the point bar located on the south side of the main channel, at RM 9, causing erosion along the north bank (see Figure 7-5). From recent field investigations, it was estimated that the river channel has migrated approximately 200 feet to the north in this area since 1996 (halfway between Site C and D). Capture of the Mile 9 Pit in 1995 may have caused the channel to influence erosion along the south valley wall at the confluence of North Mill Creek and increasing the sediment supply to the downstream reach. No obvious evidence of incision was apparent during a recent field investigation; however, this may have been masked by subsequent sediment deposition. Continued northward migration of the river at this location may occur.

The 1854-era map (Collins, 1997) shows a former channel path that splits to the west and northwest at approximately RM 9 (Figure 7-1). The abandoned County Pits (County 1 and County 2) were excavated from within the northwest path of this former channel. In the vicinity of the County Pits, the 1854 channel was seen to split again to the west and northwest. The 1854 westerly path is directed back toward the former meander bend noted in the 1935 and 1963 photography (similar to path from Site E to G). Hydraulic modeling indicates this path to be within the hydrologic floodplain (Figure 8-1). The 1854 northwesterly path was directed toward Daybreak Pit No. 1. The location of this former channel path shows some potential for future avulsion into the abandoned County Pits and possibly the Existing Daybreak Pits if the river breached Storedahl Pit Road.

If the East Fork Lewis River continues to migrate north and capture the abandoned County Pits at site D, the new preferred flow path would most likely be from Site D to F, as the slope between these points is relatively steep. However, it is also possible that a significant proportion of the flow could follow the path from Site E to H along the abandoned meander bend located just to the south of Storedahl Pit Road. Should this abandoned meander bend begin to transmit a large proportion of the channel flow, the risk of the river avulsing into Daybreak Pit No. 1 would increase. However, the potential for an unexpected shift of the channel through the Daybreak Pits is somewhat reduced by the existence of the paved entrance road (Storedahl Pit Road) to the Daybreak processing area. It would be expected that erosion control measures would be instituted if the road became threatened by the river. It is also noted that the road is outside of the CMZ and above the 100-year recurrence interval floodplain. The risk of the river avulsing into the Proposed Pits would increase if the Existing Daybreak Pits were breached along this path.

As seen in Section 7 “Planform Analysis”, the channel between the Mile 9 Pit and the Ridgefield Pits has tended to migrate laterally at a relatively high rate (30 feet/year). The meander bend located along this reach switched flow direction from the north to the south in the early 1960’s. Further sediment deposition in this reach of the river could cause the channel to shift back to the north toward Site F. However, the recent capture of the Ridgefield Pits has increased the slope of the channel in this reach. Sediment that would otherwise deposit in this section of channel is now carried downstream and deposited in the pits. The potential for northward migration of the channel in this reach of the East Fork Lewis River has been significantly reduced by the capture of the Ridgefield Pits. The deposition of sediment in the channel upstream of the Ridgefield Pits will continue at a reduced rate until the pits have been substantially filled. In Section 5 “Sediment Transport”, it was estimated that this may take approximately 25 to 30 years.

Once the Ridgefield Pits become substantially filled, the river will again increase its bed elevation by depositing sediment along this reach. As this occurs, the potential for the channel to migrate will increase. If the channel reoccupied the former northern meander bend that parallels Storedahl Pit Road, the potential for avulsion into the existing Daybreak Pits would be increased. Storedahl Pit Road provides the only access to the gravel processing operation and provides the only separation between the abandoned meander bend and Daybreak Pit No. 1. The risk of the river avulsing into the Proposed Pits would increase if the Existing Daybreak Pits were breached at this location. However, it is expected that measures would be taken to prevent the breach of the Daybreak Pits during the life of the gravel processing operations at this site. It would be expected that erosion of the Storedahl Pit Road embankment would most likely occur over a period of time. As was the case with the Ridgefield Pits, the migration of the channel into the pits was predicted several years prior to occurrence. The avulsion may have been preventable with the installation of suitable bank protection along the road. The installation of erosion control measures along Storedahl Pit Road would be expected if it became threatened by the river and could be planned for.

Ridgefield Pits Entrance (RM 8.3) to Ridgefield Pits Exit (RM 7.6)

The avulsion of the East Fork Lewis River into the Ridgefield pits in 1996 has effectively reduced the risk of avulsion into the existing Daybreak Pits at Sites H and J and the Proposed Pits over the next several decades. The abandoned channel between Sites I and J remains within the CMZ. However, the lowering of the channel elevation by head cutting has caused the low-flow channel to be less connected to this abandoned channel. Also, there is approximately 420 feet of land that is outside of the CMZ and above the 100-year floodplain between the existing Daybreak Pits and Site H. This effectively reduces the risk of the channel avulsing along this path.

The potential migration/avulsion path between Site J and Daybreak Pond 5 is within the CMZ. Although a breach into Pond 5 could occur, the East Fork Lewis River would not be expected to shift its channel position into the Proposed Pits, as this would require up-gradient flow. It is more probable that the river would form a connection with Daybreak Pond 5 similar to its former connection with Ridgefield Pit 8.

8.4.2 Dean Creek Avulsion Potential

The potential for Dean Creek to avulse into the Proposed Project Pits is based on the ability of the Dean Creek channel to migrate over to the location of the pit or overflow its banks and erode a new channel into the pit. The ability of the channel to avulse (change location) into the Proposed Pits will depend on the energy gradient that exists between the energy grade line of the creek and the water surface of the pit at the time the creek breaches or overflows the pit wall. If the energy gradient along the path through the pit is steeper than the one in the existing channel, an avulsion will most likely occur. However, if the gradient in the existing channel is steeper than the path through the pit, a connection will likely occur without the abandonment of the existing channel. The depth of the Proposed Pits will not increase the potential for avulsion unless the water surface elevation in the pit is linked to the pit depth. Water levels in the pits will be close representations of the shallow groundwater table due to the highly permeable sands and gravels on the project site. Mitigation measures to prevent the channel from migrating or forming a channel into the Proposed Pits could be implemented and are described in Section 8.7.

It has been shown that Dean Creek has been stable in the period of available record (38 years). However, the relative stability of the channel may be due to the periodic removal of sediment deposits by Clark County in the vicinity of the J.A. Moore Road crossing of the creek. If sediment deposits along the creek continue to be removed on a periodic basis, the potential for avulsion from the existing channel to proposed pit locations is considered low. The proposed levee removal and restoration of riparian forest would further reduce any potential for avulsion into the Proposed Pits. The removal of the existing levee would dissipate flow in the left (east) overbank by broadening the available floodplain. Grading of the floodplain in the area of the existing levee will present a barrier to flow reaching the pits from the creek. The restored riparian forest and its woody vegetation and debris would slow overbank flow velocities, promote deposition of suspended sediments, increase resistance to bank erosion along the channel, and help concentrate flow in the main channel of the stream.

If the removal of sediment deposits along the channel in the vicinity of the J.A. Moore Road crossing is not continued, the hydraulic capacity of the channel will diminish, overflows from the channel will become more common, and migration or avulsion of the channel may occur. Again, the removal of the existing levee and restoration of riparian forest will serve to mitigate the potential for the channel to migrate to the east. The grading of the floodplain associated with the removal of the existing levee will prevent overflows into the pits and control any eastern migration of the channel. Since the gradient of the fan is steepest on the west side of the fan, overflows of the channel toward the west would be expected. It is noted that an overflow channel parallels the existing Dean Creek channel to the west.

If overflows of J.A. Moore Road occur to the east, the overflows could be expected to flow into the Proposed Pits. Such overflows could cause a headcut to form at the boundary of the pit. The upstream limit of such erosion would be expected to be limited by the J.A. Moore Road. Accordingly, the road is expected to prevent the formation of a

new channel required for the avulsion of Dean Creek into the Proposed Pits from a point upstream of J.A. Moore Road.

8.5 Ability to Mobilize Existing Bank Sediments

The material forming the lower river banks of the East Fork Lewis River in the vicinity of the project site are composed of sediments that have been previously deposited by the river as it migrated back and forth along the valley bottom. These sediments are non-cohesive and unconsolidated materials that are easily eroded by the river. The bank material is most vulnerable to erosion along the outside bends of the river, as was observed in the avulsion into the Ridgefield Pits. It is noted that the levees associated with the gravel pits in the vicinity of the Proposed Project were not constructed as such, but are remnants of the former land surface prior to the excavation of gravel pits as well as material stockpiles. Therefore, the “levee” sediments are comprised of the same sediments as the bank sediments and as such have the same erosion potential. The developed hydraulic model for the East Fork Lewis River in the vicinity of the Proposed Project indicates bank velocities of approximately 9 feet per second for the 2-year flood event at RM 9. Trees and other vegetation located along the riverbanks would be expected to provide some resistance to erosion, although field observations suggest that the river can effectively undermine trees and transport them downstream. The existence of vegetation could influence the direction and extent of river migration.

8.6 Characterization of Impacts from Avulsion into Gravel Pits

Impacts from the avulsion of the river into a floodplain gravel pit can be characterized as short-term or long-term. Short-term impacts are those changes to the morphology of the river that take place during and shortly after the avulsion. Long-term impacts are those that continue to effect the morphology of the river well into the future. Additionally, these impacts can be described by their location in relation to the avulsion site. Table 8-2 summarizes the impacts from avulsion described in this section.

8.6.1 Upstream Impacts

Short-term impacts upstream of an avulsion into a gravel pit include head cutting, which causes degradation of the bed and increased channel slope, channel armoring, and/or an increase in the channel armor size (bed coarsening). When a gravel pit is breached, a localized difference occurs in the energy between the higher elevation flow in the river and the lower elevation water in the pit causing a steep energy gradient to form. The increased energy gradient will increase the sediment transport capacity of the river, creating a demand for sediment. If the material forming the armor layer on the channel bed is too small to resist the forces created by the energy imbalance, the channel bed material will erode and be transported downstream. This erosion will then propagate (head cut) upstream until the channel bed has formed a stable slope and armor layer that will resist the forces of the flow. The upstream extent of head cutting is controlled by the size characteristics of the bed sediment, the hydraulics associated with the flow, and the existence of any channel grade controls such as a geologic outcrop or man-made structure.

Long-term impacts include continued bed coarsening, channel incision, bank failure due to increased bank heights and slopes caused by the incision, and reduced sediment deposition due to the increased channel slope. During subsequent high flow events, the channel bed may continue to adjust to the changes in hydraulics. Higher flow events could cause additional disruption of the armor layer, increasing degradation and coarsening the bed. The down cutting of the bed could cause an increase in channel bank height and degradation along tributaries. As the river erodes the higher banks, an increase in the amount of material input to the stream will occur for the same amount of lateral erosion. This will help satisfy the transport capacity of the river and cause a reduction in the rate of lateral migration. At the same time, excessive bank heights can cause instability and increase the chance of slope failure. The increased slope associated with head cutting will increase the sediment transport capacity of the river and reduce the amount of material that would otherwise deposit in the degraded channel reach. Upstream channel degradation can also affect the stability of hydraulic structures such as levees or bridges by undermining support structures (Collins and Dunne, 1990).

When the East Fork Lewis River avulsed into the Ridgefield Pits in 1996, the river immediately changed course and began flowing through a series of seven abandoned gravel pits. At the entrance to the pits, the channel degraded by approximately 5 feet. Later observations by Norman et al. (1998) estimated 10 feet of degradation at the entrance. Head cutting associated with the avulsion migrated upstream, however the extent of the migration is unknown. Recent field observations suggest that head cutting has extended up to at least the Mile 9 Pit. Also, the high bank on the south side of the river upstream of the pits is actively eroding.

8.6.2 Local Impacts

An avulsion into a floodplain gravel pit has many potential localized impacts. The specific impacts are dependent on the characteristics of the river and gravel pit at the avulsion site. Typically, short-term impacts in the immediate vicinity of an avulsion can include an immediate change in hydraulic conditions from a high velocity shallow river to a low velocity deep and wide lake-like system. A delta will develop at the entrance to the pits formed from material that composed the high ground that formerly divided it from the river and from material removed from the upstream channel by head cutting. Typically, the former gravel pit will act as a deposition zone for sediment, holding a large portion of the sediment load that might otherwise been deposited within or have been transported through the reach.

Additionally, a section of river channel will be abandoned as the river changes course and flows through the gravel pits. The abandoned channel may go dry during average flows if the elevation differential between the avulsion point and the exit from the pit is large enough. The downstream portion of the abandoned channel may develop into a backwater slough during moderate or low flows. During higher flows, the river may use the abandoned channel as a secondary conveyance. This channel may act as a deposition zone for finer material such as sands and silts that are carried as suspended load during high flows.

In the long-term, the former gravel pit will continue to flow as a wide and deep channel with very low velocities until substantial filling with sediment has occurred. As the delta continues to form and grow at the entrance to the pits, flow conveyance and sediment transport into the pit will decrease. Velocities will increase and depth will decrease at the entrance to the pit while further downstream, the velocities continue to be slow in the wide and deep channel. Additionally, the gravel pits can act as flood storage during high flows, which could slightly reduce downstream flood levels. Although this will decrease over time as the pits fill with sediment.

Additional impacts of avulsion into gravel pits may include impacts to water quality and ground water levels. During summer low flow periods, the wide channel that formed in the former gravel pit may cause an increase in surface water temperature. The magnitude of the temperature increase will depend on the surface area of the channel, exposure to solar radiation, residence time and discharge into the pit. Portions of the avulsed pits may provide deeper and cooler water than some of the shallower reaches of the river. Impacts on water temperature caused by the avulsion into the Ridgefield Pits was not quantitatively evaluated as part of this study. Impacts to groundwater related to the Proposed Project are described in the EIS for the project and are considered negligible.

The localized impacts of the East Fork Lewis River avulsion into the Ridgefield Pits, included an increase in channel depth, increased channel width, reduced river velocities within the pits, formation of delta sediment deposit and the abandonment of approximately 3,200 feet of channel. The new channel is of approximate equal length and is comprised of primarily deep pools with slow moving water. The Ridgefield Pits had a maximum depth of approximately 70 feet during gravel extraction operations (Storedahl, 1999). Average pit depths ranged from 12 to 30 feet (Storedahl, 1999). The width changed from a maximum of approximately 200 feet to a maximum of approximately 800 feet. In the embayments and backwaters of the former pits, river velocities are low. During the 2-year event, the average velocity in the main thread of flow through the former pits is approximately 2.5 feet per second, while velocities at cross sections upstream of the former pits, average 4 to 7 feet per second. Recent field observations showed that the abandoned channels, created when the avulsions occurred, have started to fill with medium sands during subsequent high flow events. Wetland/riparian vegetation has begun to establish in these former channels. Observations also indicate that the gravel and cobble delta at the entrance to the pits has increased in size, filling in a large portion of Pit 1 and beginning to fill the upstream portion of Pit 2.

8.6.3 Downstream Impacts

As the former gravel pit traps sediment, the supply of sediment to the downstream channel is curtailed. Until the sediment transport conditions in the section of the channel within the pits return to pre-avulsion conditions, bed degradation, bed coarsening, and increased bank erosion along the downstream channel may occur. With a reduced supply of sediment to the downstream reaches, the sediment transport capacity will not be fulfilled. This may cause erosion of the channel bed and/or banks. The river will transport the finer sediments downstream leaving behind the coarser material, causing the

bed material to coarsen or armor, protecting against subsequent high flow events. Reduced upstream sediment supply may cause the channel bed elevation to lower until it becomes controlled by armoring. To accommodate the sediment supply deficit, bank erosion may occur resulting in channel widening.

An avulsion into a gravel pit may also cause a short-term increase in the supply of fine sediment to downstream reaches. During gravel processing operations, fine sediments are typically washed from the sands and aggregate and deposited in the gravel pits ponds. A layer of fine sediment will form and build on the bottom and edges of the pit. Turbulence induced by the river flowing through the pit can entrain material previously deposited in the pit. The magnitude of such an impact is likely small since: 1) the avulsion and subsequent transport of fine sediment downstream would likely occur during high flows when large quantities of fine material are already being transported; 2) the transport capacity of the river for fine material is nearly unlimited through this portion of the East Fork Lewis River downstream to the tidal influence zone; 3) fine materials are carried as wash load; 4) a portion of the fine material will be buried under the coarse sediments transported into the pits from upstream; 5) only part of the pit will be effected by high velocities; and 6) clays are cohesive which reduces their erodability. Furthermore, such an event is typically short lived and would not provide a long-term supply of fine sediment to the downstream reaches. The magnitude of the affects to the downstream reach will depend on the characteristics of the river below the pits. In the portion of river below the pit that has the capacity to transport the wash load, the sediment will pass through it and/or deposit in the over bank areas.

Another possible impact to reaches located downstream of the avulsed pit is reduced flood levels. The increased width and depth associated with the geometry of the gravel pit creates additional flood storage. The amount of reduction in flood levels provided by the changed geometry is related to the volume of additional storage and the magnitude and duration of the flood event. Estimates of potential flood peak reduction induced by increased flood storage for the East Fork Lewis River is given in Section 3, "Hydrology".

The downstream impacts of the East Fork Lewis River avulsing into the Ridgefield Pits effects a relatively small reach of the river. The river travels a short distance (approximately 1.5 miles) before it becomes tidally influenced and the channel slope is nearly flat. Impacts on the channel within this reach may include bed degradation, bed coarsening and bank erosion, but have not been documented. Impacts from fine sediments propagated from the Ridgefield Pits are also unknown. It is assumed that a portion of this material was transported downstream to the Lewis and Columbia Rivers while the rest was deposited in the tidally influenced reach and/or over bank areas.

Table 8-2. Summary of the possible effects of a river avulsing into a gravel pit.

Element of Avulsion	Nature of Impact		
	Upstream	Local	Downstream
Geomorphic Characteristics	• Incision of channel • Increased gradient • Coarsening of bed • Undercutting and erosion of banks • +/- lateral migration rates	• Alluvial fan development • Reshaping of pits • Abandonment of former channel • Loss of natural channel geometry	• Increased lateral migration • Increased channel width
Sediment Transport	• Increased sediment transport capacity • Reduction in bed load deposition	• Deposition of sediment in pits • Short-term increase in turbidity • Erosion of gravel pit banks	• Reduced sediment supply • Erosion of bed • Coarsening of bed • Increased bank erosion • Short-term increase in turbidity
Hydraulics	• Increased slope • Increased velocities • Decreased normal depth • Increased bed roughness	• Decreased slope • Increased channel depth • Increased channel width • Reduced bed roughness	• Increased bed roughness
Hydrology		• Increased flood storage • Increased evaporation	• Reduction of flood levels • Attenuation of flood peaks • Changes of summer low-flows

8.7 Mitigation to Prevent Future Avulsion

To prevent any impacts caused by the avulsion of the river into a gravel pit, various mitigation measures could be developed. The specific mitigation measures necessary to effectively prohibit the river from avulsing into the pit should be chosen based on the relative potential for avulsion and the estimated impacts. If the potential for avulsion is judged to be likely and the impacts of the avulsion are predicted to be severe, mitigation measures should be employed at that location to prevent an avulsion. If the potential for

avulsion is less probable or the impacts of avulsion are predicted to be minor, then little or no action may be required. Possible mitigation measures include the use of monitoring programs, planting of native riparian vegetation, and the use of bank stabilization measures to control potential future river migration.

Mitigation measures should be used at locations that would do the most good while at the same time have the least impact on the environment. Vegetation along potential avulsion paths should be planted as soon as possible to allow sufficient time for growth. Channel and bank stabilization measures could be placed at locations that are the most vulnerable to erosion. Construction of these measures could be done prior to the river reaching the threatened location. This would prevent the need for in-channel work.

Mitigation measures, for the existing Daybreak and Proposed Pits should include a long-term monitoring program to track the changes of the river with respect to the site and planting of native riparian vegetation between the river and the Proposed Pits. The long-term monitoring program could be used to help predict future changes in the channel and update the status of potential avulsion locations. Establishment of mature riparian forests in areas surrounding potential avulsion sites should help slow channel migration into these areas.

The placement of channel and bank stabilizing measures along Storedahl Pit Road along with the existence of Bennett Rd. and NE 269th St. would effectively prevent the possibility of future avulsion into the Existing and Proposed Daybreak Pits by removing this area from the Mitigated Hazard Zone. The only potential avulsion location exposed to the possibility of future avulsion is at the downstream end of the Daybreak Site. A potential avulsion path into Daybreak Pond 5 is shown to be within the CMZ. All of the pits associated with the Proposed Project will be located up gradient from Daybreak Pond 5, effectively preventing any impacts to the river from the Proposed Project.

Mitigation measures to prevent an avulsion of Dean Creek include removal of the existing discontinuous levee and restoration of riparian forest along the stream. Removal of the levee restores floodplain area and dissipates flood flows. Replanting the riparian zone with native vegetation will reduce overbank flow velocities, promote deposition of suspended sediment and increase resistance to erosion.

8.8 Response to an Avulsion

The impacts of an avulsion into a gravel pit on the morphology of the East Fork Lewis River are documented in previous sections. Whether these impacts are positive or negative to the local biological communities is not known. Information on this subject may be found in the Project HCP and/or EIS. During the life of the Proposed Project, all necessary measures should be taken to prevent the river from avulsing into the Existing and Proposed Daybreak Pits. This would allow maximum utilization of the gravel resource with minimal impacts on the river. If an avulsion were to occur during this time period, measures should be taken to return the river to its previous location.

If it has been determined that the impacts of the river avulsing into the Proposed Pits are more negative than positive, a plan should be developed to monitor and prevent its occurrence. If preventative measures are not enough, the river should be returned to its previous location. If positive impacts justify the occurrence of a future avulsion into the Proposed Project, a monitoring program should be in place to document the effects. If the Dean Creek avulses into the Proposed Pits, the relative benefits and impacts of returning the channel to its prior location should be assessed. If benefits are judged to outweigh impacts, plans for returning the channel to its former location should be developed and implemented.

8.9 Summary

The East Fork Lewis River is a relatively unconfined meandering stream. Avulsions have occurred along the river due to both natural and human influences. The record of documented historic avulsions is limited. Three events characterized as avulsions have been documented. All of the events involved abandoned gravel pits located in the floodplain directly adjacent to the river channel. Assessment of the potential for future avulsions is limited by the available data and the unpredictability of future channel movements. However, available historic data and current observations allow the potential avulsion sites to be described. The relative risk of avulsion for a given location is determined by its location relative to the Hydrologic Floodplain, Channel Migration Zone (CMZ), Mitigated Hazard Zone and historic information and current observations of channel migration.

Available historic data and current observations have shown the majority of the river's potential avulsion sites to be within the CMZ. However, the avulsion sites that would cause the river to shift its channel into the Existing Daybreak Pits are outside of the CMZ and the 100-year floodplain. This does not infer that the possibility of avulsion does not exist, rather the likelihood of such an occurrence is low. The recently observed bank erosion resulting in a northward migration of the channel at RM 9 and historic data indicate an increased probability of avulsion into the abandoned County Pits (County 1 and County 2). If an avulsion into the county pits occurred, changes in the channel position are uncertain. Three scenarios exist if the county pits are breached. 1) The main channel may not change course, 2) it could reoccupy the meander abandoned by the avulsion of Mile 9 Pit, or 3) it could reoccupy the large abandoned meander bend that parallels Storedahl Pit Road. If the abandoned county pits are breached in the future, the potential for avulsion into the Existing and Proposed Daybreak Pits may increase. However, the existence of numerous improved roads in the area effectively places the Existing and Proposed Daybreak Pits outside of the Mitigated Hazard Zone. As was noted with the observed avulsion into the Ridgefield Pits, a significant period of time should be available to further mitigate against possible avulsion into the Existing and Proposed Pits Daybreak Pits.

The potential for Dean Creek to avulse into the Proposed Project Pits is based on the ability of the Dean Creek channel to migrate over to the location of the pit or overflow its banks and erode a new channel into the pit. Dean Creek has shown little tendency to migrate over the recent past. Historic evidence suggests that the Dean Creek channel has

remained stable for at least the last 38 years. The periodic removal of sediment deposits by Clark County in the vicinity of the J. A. Moore Road Bridge crossing is believed to have contributed to the stability of the channel. If sediment deposits along Dean Creek continue to be removed, the potential for avulsion into Proposed Pits is considered to be low. Proposed measures to remove the existing discontinuous levee along the watercourse and restore riparian forest would reduce the potential for avulsion further.

If the removal of sediment deposits in Dean Creek by the County were to cease, the hydraulic capacity of the channel in the vicinity of the bridge will diminish, overflows from the channel will increase, and the potential for channel migration will increase. The proposed removal of the existing levee and associated grading of the floodplain will prevent overflows from entering the Proposed Pits and dissipate overbank flow. The restoration of riparian forest will slow overbank flow velocities, promote suspended sediment deposition, concentrate flow in the main channel and provide resistance to channel migration.

If sediment deposits in the channel restrict flow through the J.A. Moore Road crossing of Dean Creek, overflows of the road are expected. Since the road slopes to the west, overflows are also expected in that direction. If overflows occur in an easterly direction, flow may enter the Proposed Pits. A headcut may form where overflows enter the pit. The road is expected to limit the upstream extent of any headcut. Since the J.A. Moore Road crossing of Dean Creek is fixed, an avulsion across the road in a new channel location is not expected.

Impacts on streams from an avulsion into a gravel pit are both short-term and long-term. Many of the short-term impacts may continue into the future but usually at a slower or decreasing rate. The impacts may also be reversed given sufficient time for pit recovery. The impacts also vary by location with respect to the avulsion site. Upstream impacts may include head cutting, channel incision, bank erosion, increased armor size, and increased channel slope. Local impacts of avulsion may include changes in channel geometry with associated changes in channel hydraulics, redirection of flow causing the abandonment of a section of river channel, deposition of sediment in a delta deposit at the breach location and changes in water quality. Downstream impacts may include the reduction of sediment supply caused by trapping sediments in the pit, bed degradation, bed coarsening, bank erosion, channel widening, and short-term increases in fine sediments propagated from the pit and entrained as wash load.

The possibility of future impacts of an avulsion of the East Fork Lewis River into the Proposed Project could be effectively prevented by the use of mitigation measures. Monitoring changes in river morphology, establishment of native riparian vegetation in potential avulsion areas, and the installation of suitable erosion protection, such as a revetment or bioengineered structure along Storedahl Pit Road, could all be used to mitigate against potential future avulsion of the East Fork Lewis River into the Proposed Project.

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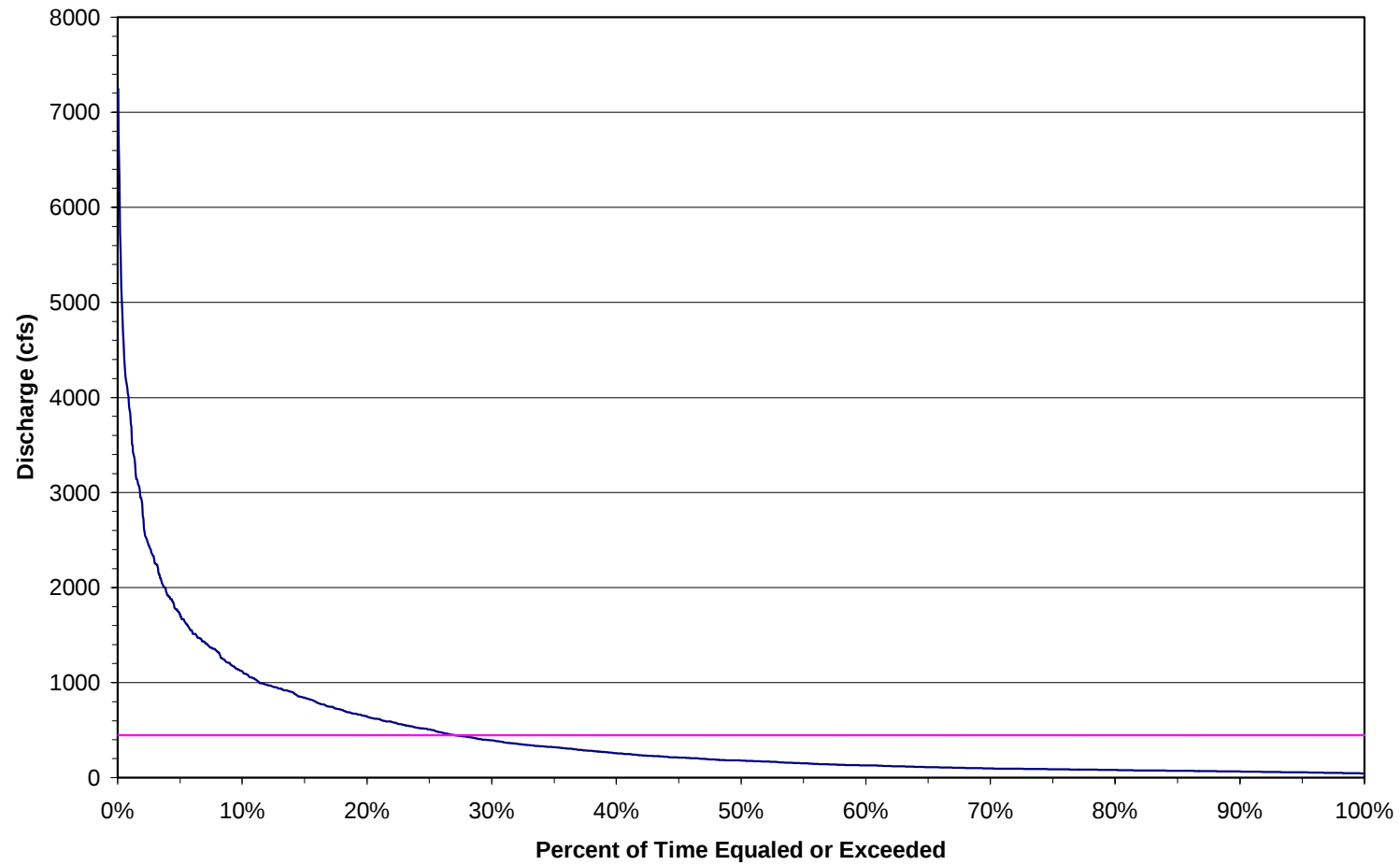
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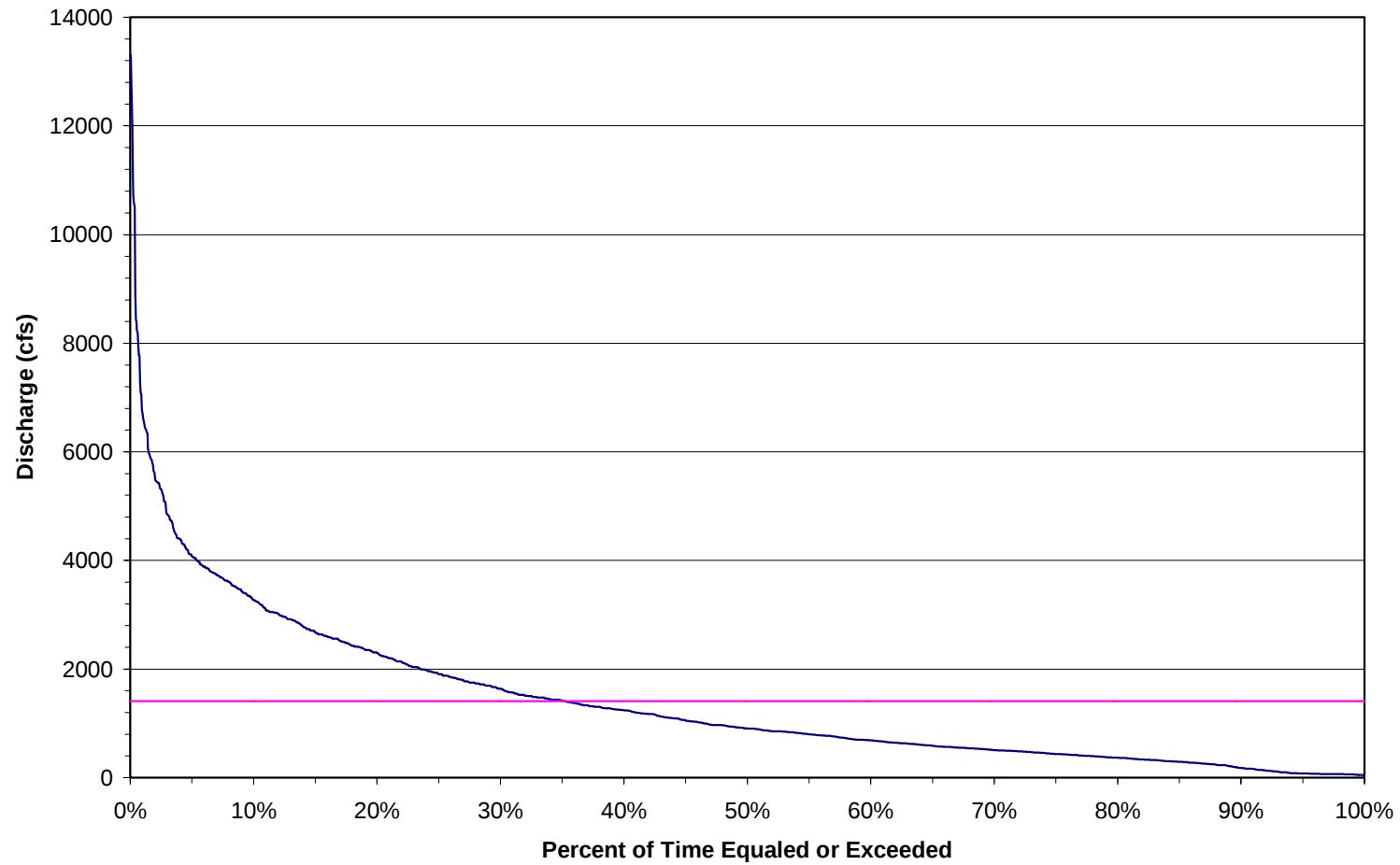
Appendix 1.

Monthly Flow-duration Curves for the East Fork Lewis River at Project Site.

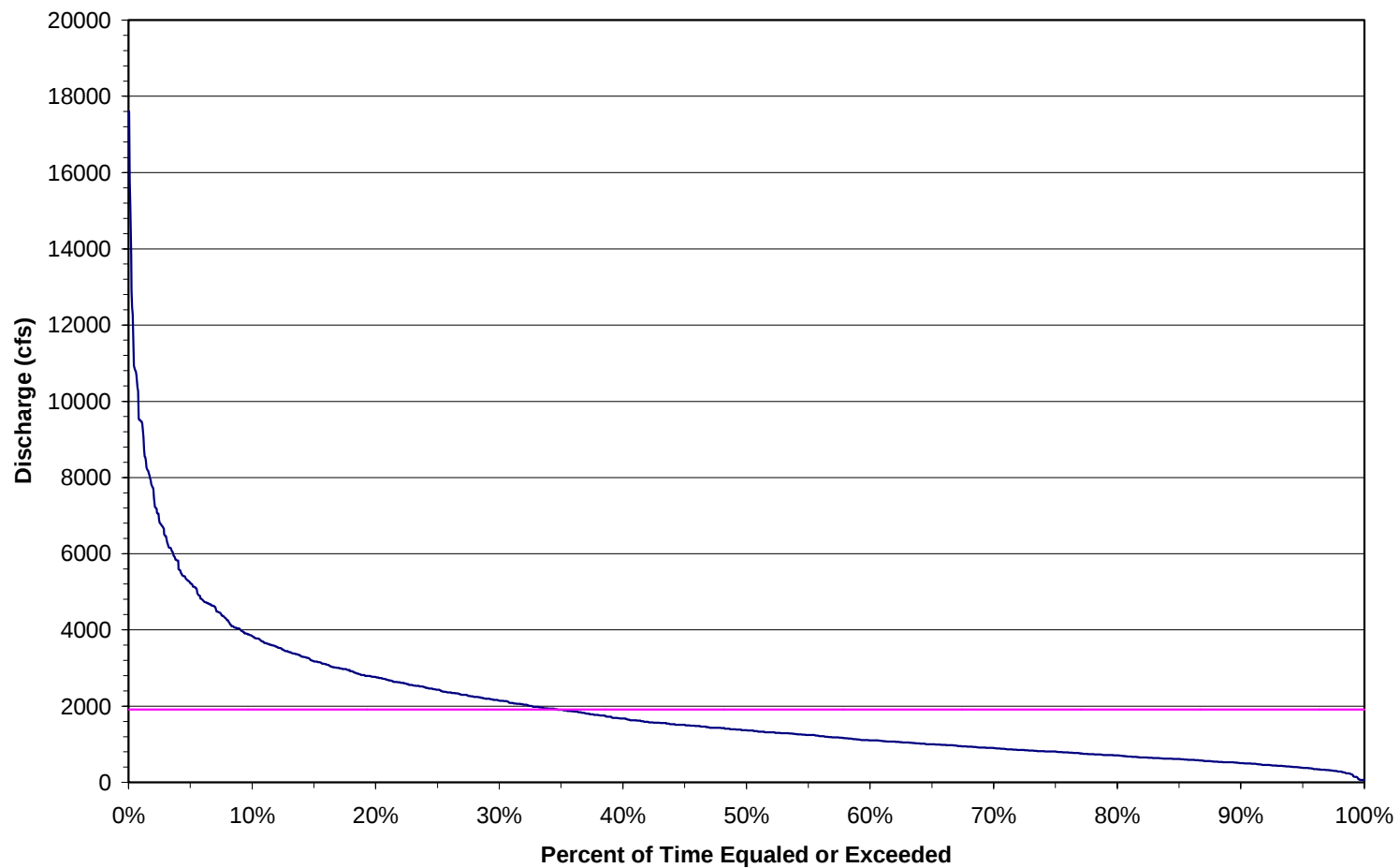
October Flow-Duration Curve
E.F. Lewis River at Project Site
WY 1930 - 1996



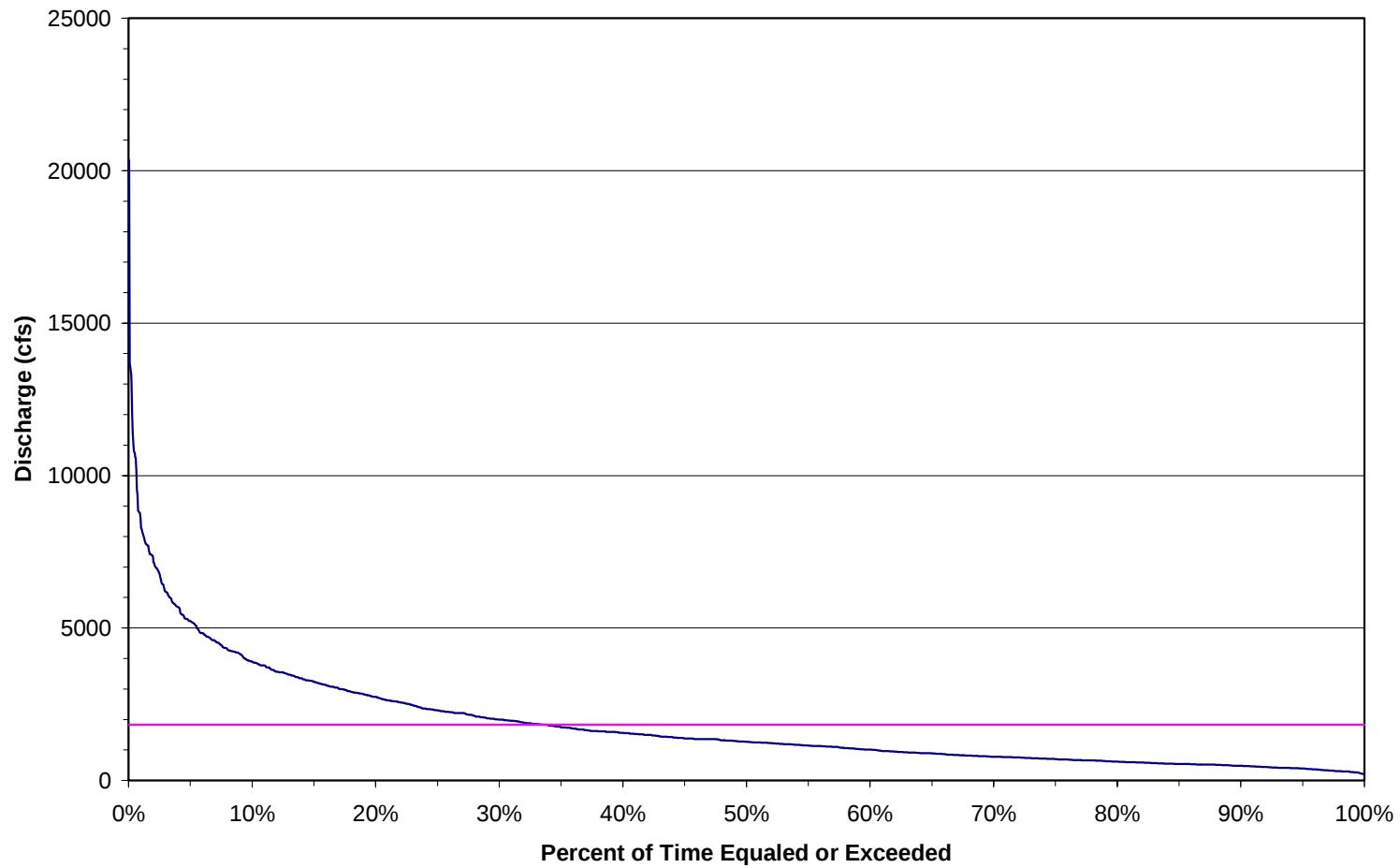
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WY 1930 - 1996



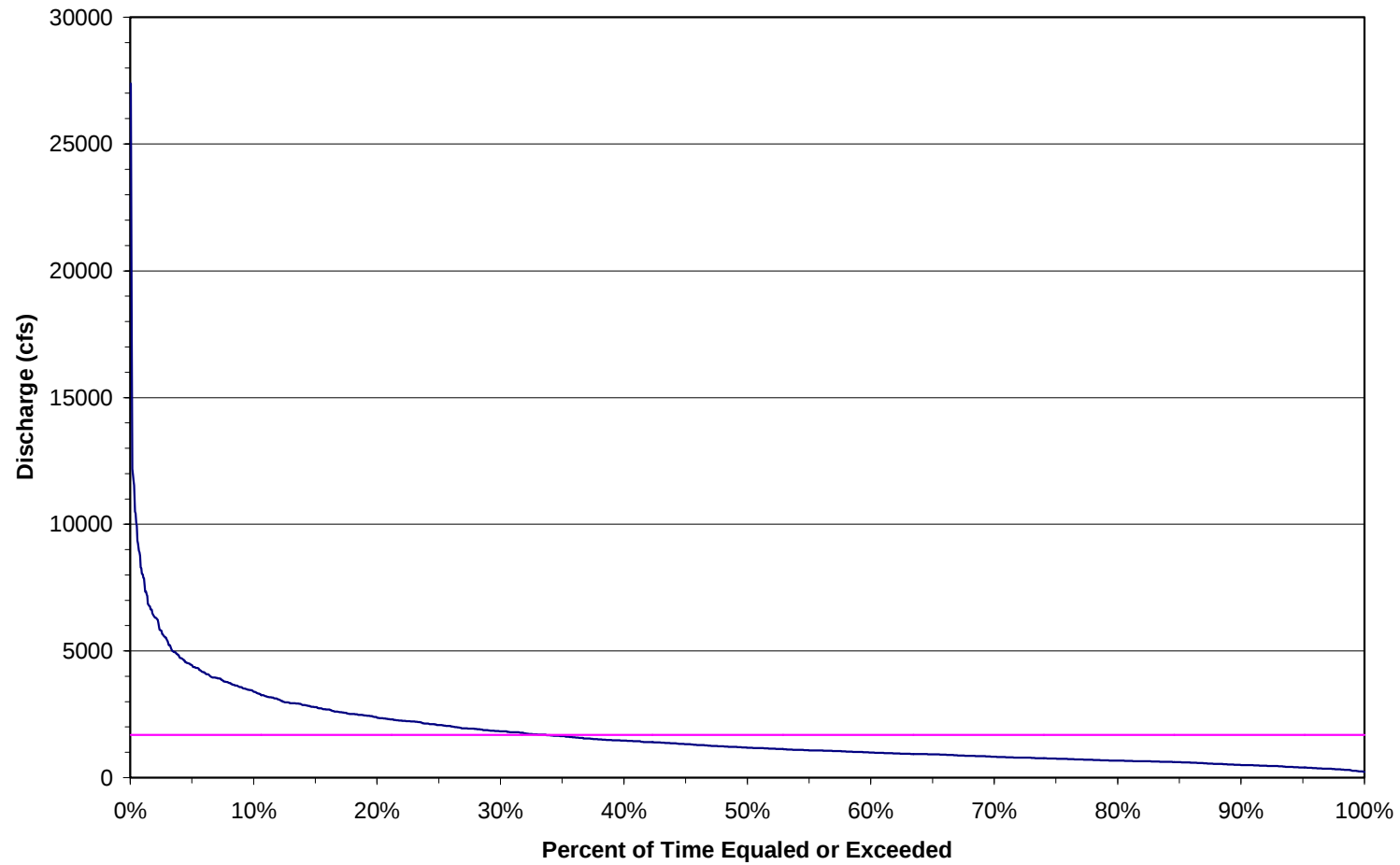
December Flow-Duration Curve
E.F. Lewis River at Project Site
WY 1930 - 1996



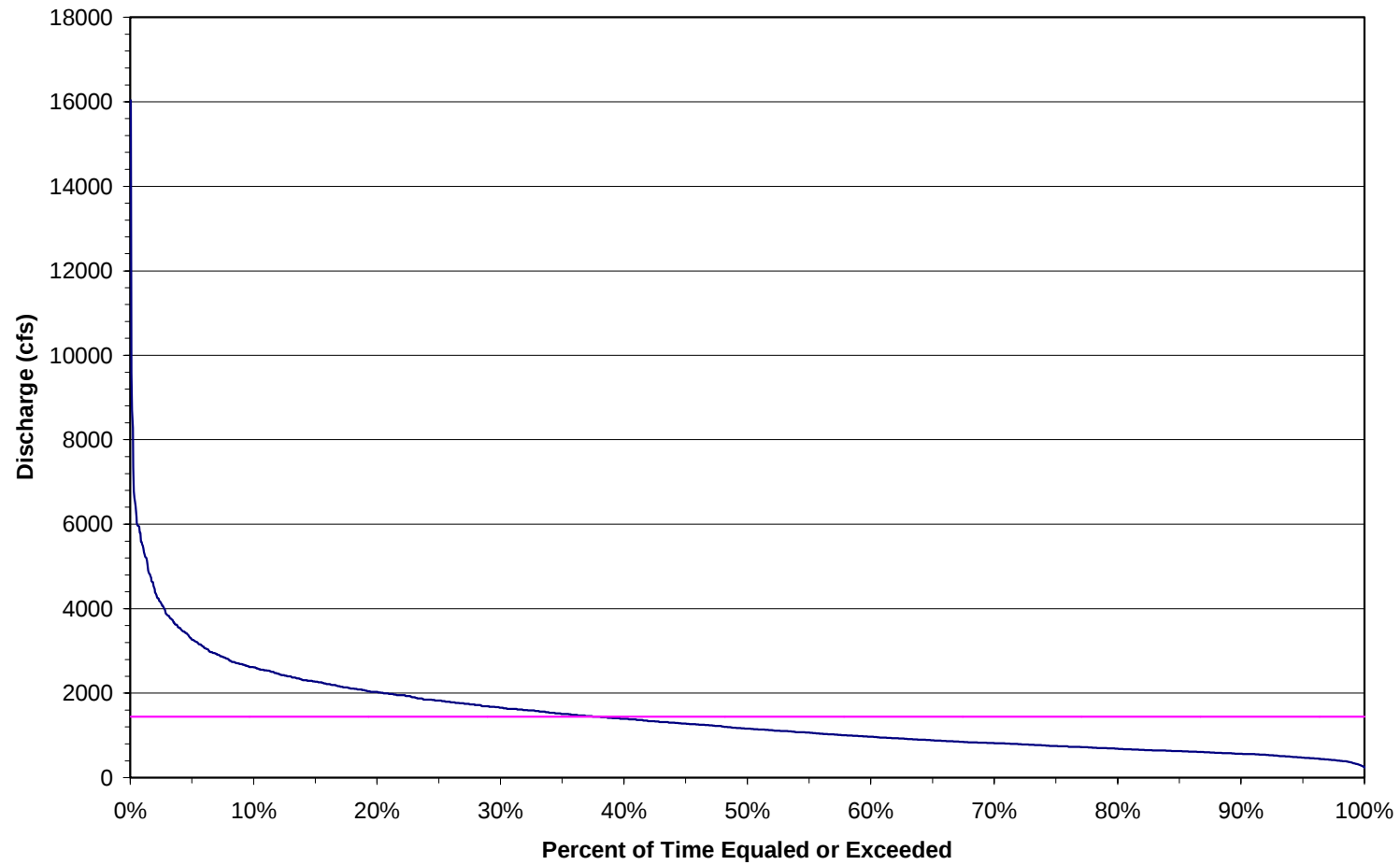
January Flow-Duration Curve
E.F. Lewis River at Project Site
WY 1930 - 1996



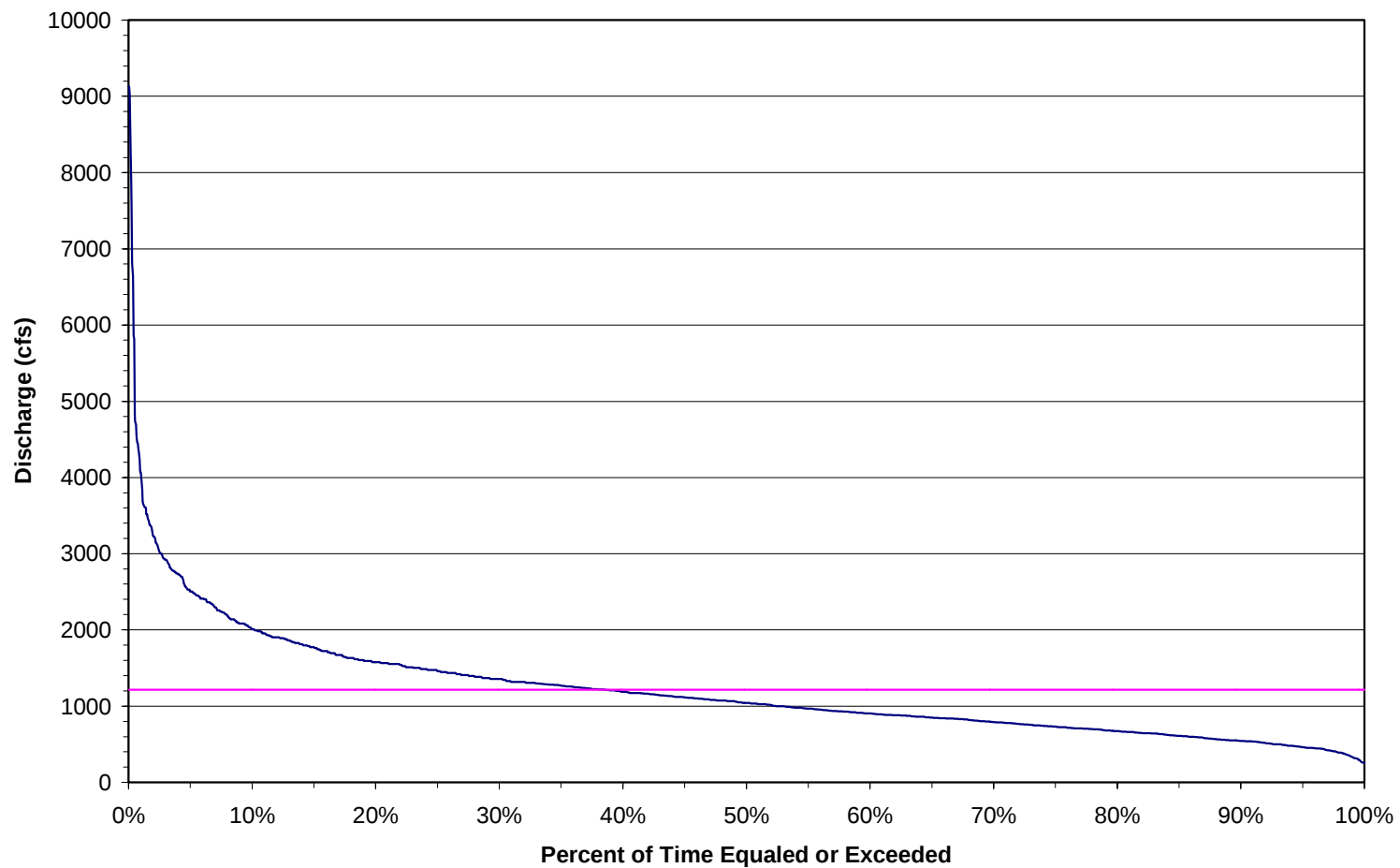
February Flow-Duration Curve
E.F. Lewis River at Project Site
WY 1930 - 1996



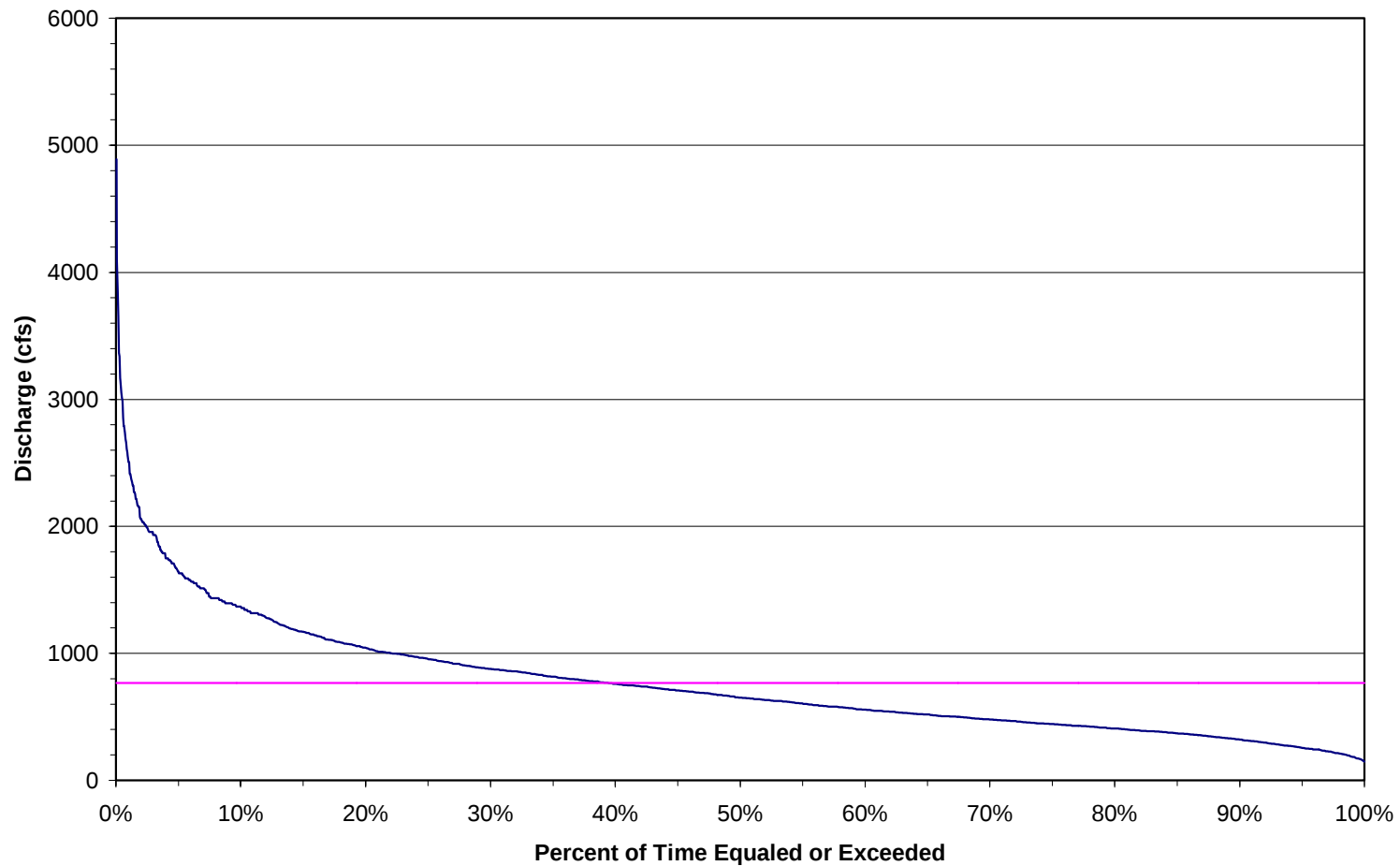
March Flow-Duration Curve
E.F. Lewis River at Project Site
WY 1930 - 1996



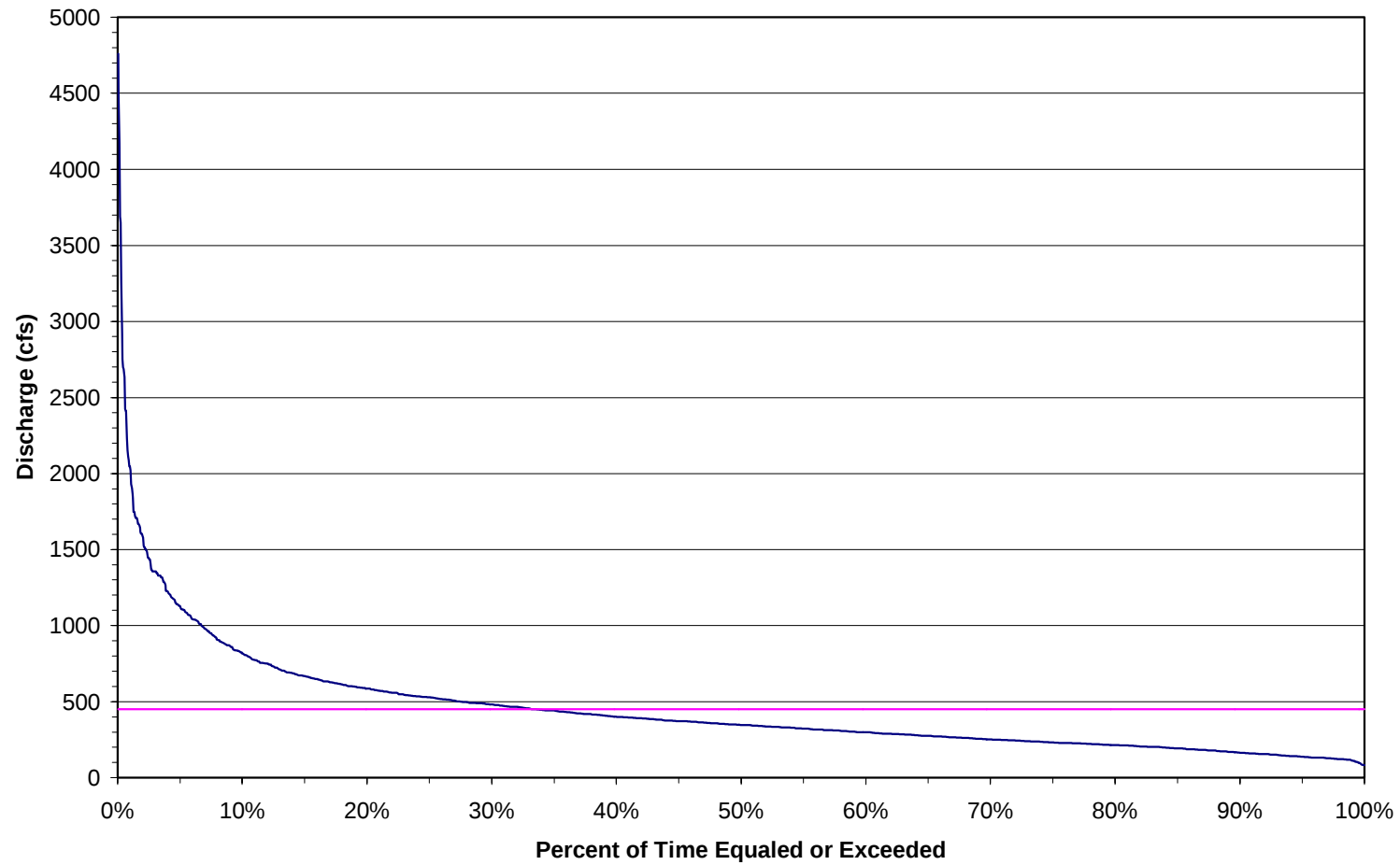
April Flow-Duration Curve
E.F. Lewis River at Project Site
WY 1930 - 1996



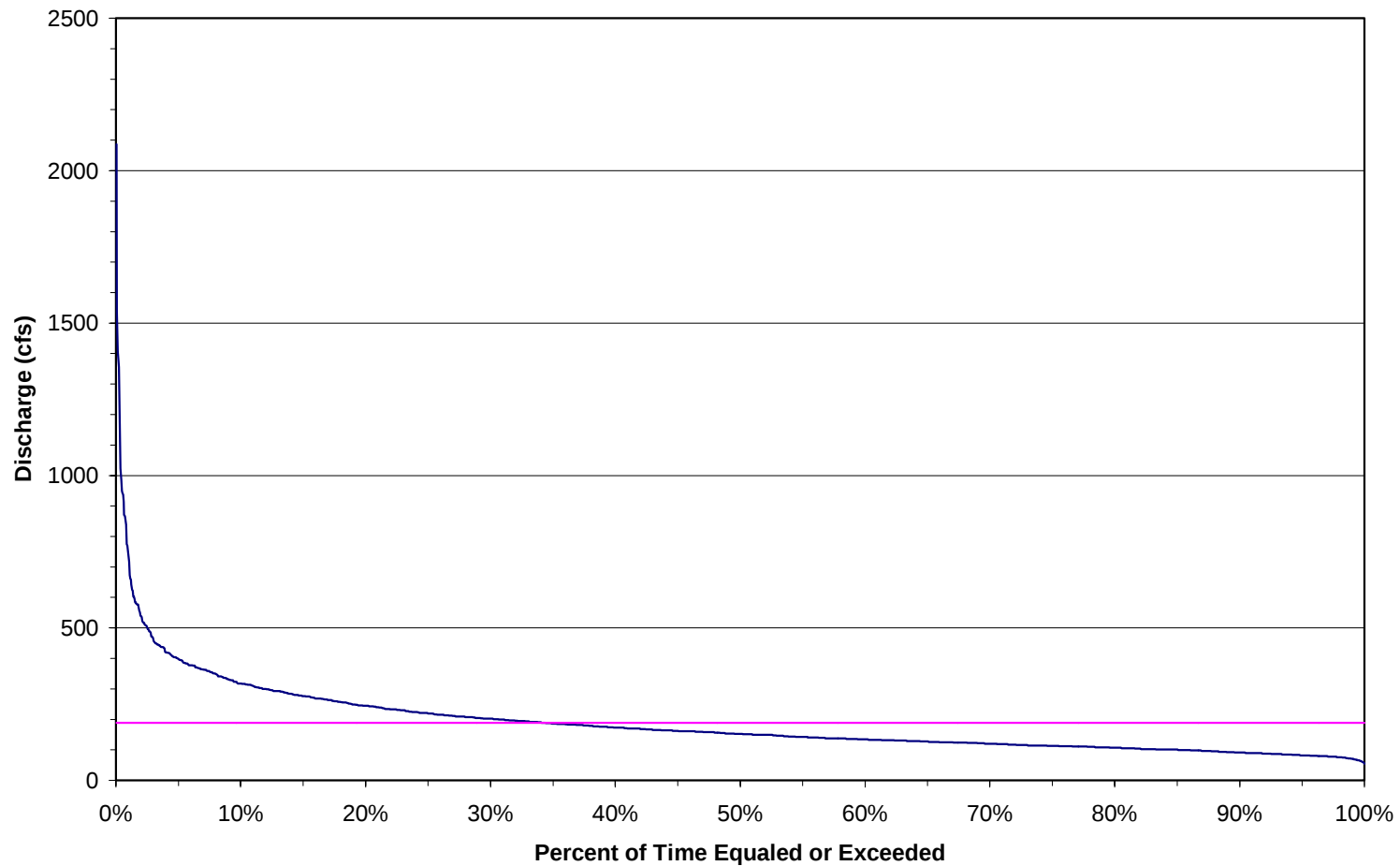
May Flow-Duration Curve
E.F. Lewis River at Project Site
WY 1930 - 1996



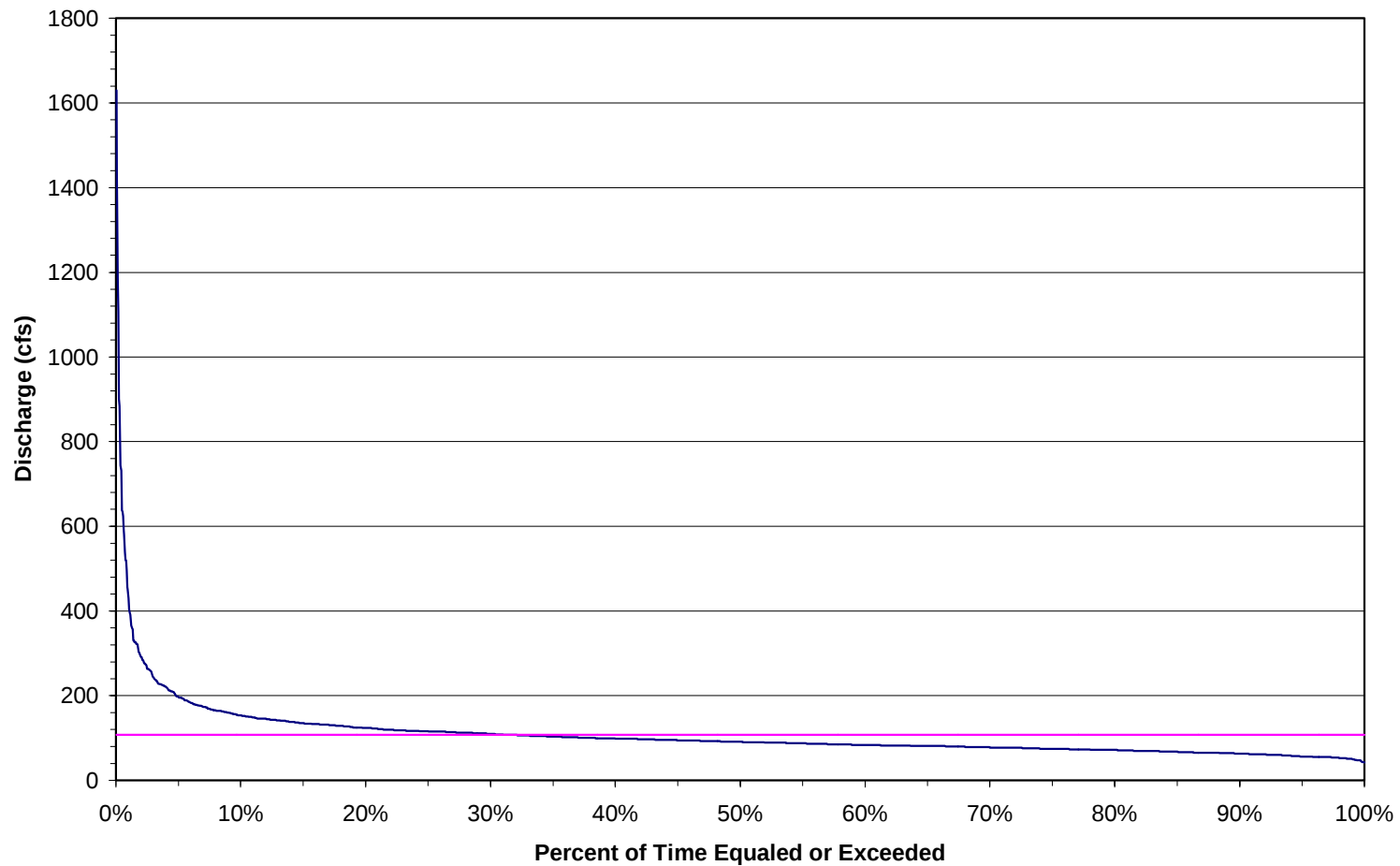
June Flow-Duration Curve
E.F. Lewis River at Project Site
WY 1930 - 1996



July Flow-Duration Curve
E.F. Lewis River at Project Site
WY 1930 - 1996



August Flow-Duration Curve
E.F. Lewis River at Project Site
WY 1930 - 1996



September Flow-Duration Curve
E.F. Lewis River at Project Site
WY 1930 - 1996

