East Fork Lewis River (RM 13 to RM 6), Including West Daybreak Park Project Reach

Fluvial Geomorphology and Erosion and Sediment Evaluation

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PREFACE

This report was developed as part of the West Daybreak-Lower East Fork Lewis River analysis and 90% design project process.

The overall objective is to provide comprehensive fluvial geomorphic and other key information perspective for the East Fork of the Lewis River. This will expedite the design of the proposed West Daybreak reach, and other reach treatments that are the most appropriate and effective in the long-term for restoration of riparian, stream channel, and fisheries components.

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INTRODUCTION

East Fork of Lewis River has a long history of anthropogenic (post cultural) changes at the watershed and reach level. Reckendorf and Associates has been asked to evaluate the existing condition to place conceptual project solutions to decrease erosion and sedimentation and associated instream impacts on aquatic habitat in a geomorphic perspective.

Solutions need to be placed in a context that the watershed has gone through phases of clear-cutting and road building. These activities cause accelerated erosion above background levels landslides, debris flows and debris torrents, as well as road culvert failures. Logging companies built splash dams that when blown to float logs have caused extensive damage to riparian areas, caused accumulated large woody debris (LWD) to be removed and causes associated streambank erosion. Log jams developed along reaches were removed that also contributed to the streambank erosion process. Downstream reach effects occur associated with agricultural development, and road and bridge infrastructure. With the availability of heavy equipment after WWII bull dozers have sometimes entered the river to straighten reaches, remove gravel or recreational dozing. This is a known historical problem at about River Mile (RM 6) where in the 1950's both recreational dozing and an attempt at in stream gravel mining. Another attempt at a gravel operation occurred at about RM 18 near the Heissen property. This was an instream dragline gravel operation In addition gravel has been extensively removed from the flood plain areas along river miles 7.5 to 9.5 from both sides of the East Fork, and these gravel pits have sometimes been captured by the East Fork, as in November 1995 and February 1996, causing extensive channel changes. Another major disturbance along the East Fork River and riparian area was the construction of the Vancouver Klickatat and Yakima Railroad. A photograph on page 67 of the Publication In and Around Battleground (Tucker 2006) , shows clear-cutting right down to the East Fork with a large accumulation of Large Woody Material (miscellaneous, cut logs, poles, railroad ties and other boards, to be referred to as LWM).

The East Fork Lewis has one of the highest levels of avulsion channel changes ever viewed by the author in his 50 years of evaluating rivers, for such a short stretch of river RM 13 to RM 6. To place so much change into perspective it is desirable to present what is needed in a basic fluvial geomorphology study of stream change . The word fluvial means rivers, and geomorphology is a study over time of landscape morphology reflected in channel cross section, profile (i.e. slope), and pattern (i.e. plan view as viewed from the air), and the processes involved in change over time.

After that there will be a section that describes what a conceptual natural stream like the East Fork Lewis River should look like. Than the existing condition can be viewed for comparison. Conceptual solutions for the West Daybreak Park reach under design will be presented in another document that reflects the evaluation in this report. This evaluation will look at stream morphology like width and depth, its profile (slope) and its planform as viewed from the air. This plan view will include an evaluation of sinuosity (channel length divided by valley length), which reflects avulsion history. The plan evaluation will also valuate the braided stream portion of the East Fork. In addition the planform of the stream bed (pool/riffle, plain bed, or step-pool etc.) will be considered. Also evaluated will be bar materials,, bank materials, and bank erosion. Riparian quantity and quality will be considered in the separate report on conceptual solutions.

The fluvial geomorphic evaluation needs to examine the applicability of the primary mechanisms of bank failure, which are cantilever failure, rotational failure, planer failure, preferential flow failure, high pore pressure, liquefaction and seepage forces, particularly from the falling stages of floods, popout failure, or whether the bank height exceeds some critical bank height at which failure occurs (Reckendorf, 2009a and 2009b). There are many factors that modify the major failure mechanisms such as stratigraphy of the bank materials, flow, depth of scour along eroding bank, root density and depth, tree throw, large woody debris accumulation desiccation, ice, and animal burrows (Reckendorf 2009a, and 2009b). Of importance for bank failure in flow are peak, duration helicoidal flow, cavitation, pre-wetting, and the orientation of the flow angle (parallel to the streambank or at an angel to the streambank). Stream geometry such as low radius of curvature divided by bankfull width at the next upstream riffle (Rc/Wbkf), is also critical. The geomorphic history of the flood plain, represented by former channels, both braided and meandering, may be important in terms of where avulsions have occurred in the past or where avulsions may occur in the future. Many of the flow factors important for bank erosion are also important for sediment transport and deposition.

The specific reach for this evaluation and conceptual solutions is from River Mile (RM) 13 to RM 6 (Figures 1). This is essentially from Lewisville Park Bridge to about the junction with Mason Creek (Dyrland, 2009) Figure 1 Richard Dyrland, 2009) shows the overall project, with USGS River Miles (RM) for reference. Also shown on Figure 1 are potential avulsion areas. Past avulsions has changed RM length locally by shortening the river in some reaches and lengthening the river in other reaches as old channels are reoccupied. However the base RM designation that appears on the 1954 Ridgefield Quad sheet showed the established reference river miles, and is the best reference for the overall river. Figure 2 (Richard Dyrland, 2009) shows the West Daybreak Project Reach and some of the important data collection sites for pebble counts, sieve analysis, and aggraded riffles as well as 2009 avulsion changes .

FLUVIAL GEOMORPHOLOGY

Stream Type, Geometry, and Dynamic Equilibrium

Over at least the last 56 years several attempts have been made to try and generically characterize streams. For many years people were satisfied with the simple classification of Leopold and Wolman (1957). They separated streams into braided, meandering and straight. Because most streams are sinuous to some extent Leopold et al (1964) suggested that meandering streams be restricted to channels of some symmetry. In contrast straight streams were ones of little symmetry but that may still have a deep channel thalweg that wanders back and forth between opposite streambanks. One of the requirements to obtain pools and riffles in non-meandering streams is that the streams have some degree of heterogeneity of bed-material size (Leopold et. al. 1964). Leopold and Wolman (1957) looked at channel length (Cl) to valley length (Vl) and decided to separate out the meandering streams as streams with a Cl/Vl greater than 1.5. These streams also had pool/riffle stream bed planform. Straight streams on the other hand had Cl/Vl less than 1.5 and very few pools and riffles. Braided streams have multiple channels that split and rejoin. They are often referred to as anastomosed which is a term borrowed from medicine where it is used to describe the dividing and joining of blood vessels. The individual channels of a braided stream are described as anabranches. The anabranches of braided streams definitely meander (Leopold et. al (1964). However in plan view, the overall channel course of a braided stream shows much lower meandering than a braided stream. This is in large part because even though at low flow the anabranches may meander, at bankfull flow the river moves nearly straight down the valley (Leopold et. al. 1964). This condition brings out a major misunderstanding of how the meander part of braided streams work. The excess sediment deposition in braided streams often results in anabranch channels that are higher than their low flow channels. These higher anabranch channels have an opportunity to establish vegetation and accumulate woody debris such that during flood flows these channels grow even higher. I would refer to these anabranch channels as passive braided channels, as they play essentially no role in the channel geometry and pool/riffle development of the dominant active anabranch, where most aquatic habitat conditions are developed.

Leopold and Wolman (1957) developed a relationship based on slope and bankfull discharge to separate the three types of streams, braided, meandering, and straight.

What they showed was for the same stream type the river slope decreased at discharge increased. In other words for the same slope higher discharge streams tended to be braided rather than meandering. One could also interpret the Leopold and Wolman (1957) relationship to reflect that the braided streams were those that carried a higher sediment load.

The variability of the many rivers in the world make it difficult to establish a set of parameters that reasonable place every river, creek, gully, arroyo, or delta in the same system. The system developed over many years, that is based on the geometry of the rivers, creeks, gullies, etc., that works the best for stream classification is that of Dave Rosgen (1993). His hydraulic geometry parameters reflect both a flow condition and the stream morphology parameters of plan view (pattern) , slope, and cross section. Over the years what has been developed as natural streams has been anthropogenically altered by a variety of reasons previously mentioned. Some of these changes to pattern slope and cross section can best be evaluated by changes in dynamic equilibrium.

Another aspect of streams is the bed and bank materials that have an influence on classification. Braided stream are multiple channel streams are classified as D stream types with very wide width to depth ratios, a channel slope close to the valley slope, and very low meander width ratio (beltwidth/bankfull width) (Rosgen 1994). Braided streams tend to be classified as D stream types if they have more three or more stream channels. However there is a major difference between active braided streams (D stream type) in which most of the anabranch are occupied throughout the year, and passive braided stream (D stream type) where these is a dominant anabranch that functions as a meandering stream, and the other anabranches only transport flood flow at or above bankfull stages.

Braided streams are often described as overloaded such that braided streams are described as being in the process of aggradation. However, braided channels may also represent an equilibrium pattern in the transport of available discharge and load (Leopold et al.,1964). Natural active braided streams tend to have the same bed material (i.e. cobble, gravel, sand) In addition the channels we look at today, may be reflection a past paleo-hydrology, so they represent the past higher past discharges and sediment load. What complicates the fluvial geomorphic evaluation even further are the processes that cause formerly meandering streams to become braided. These streams will than have a mixed stratigraphy within the bankfull depth of cobbles, gravels, sands, and silt. The other broad category of streams the meandering or C stream types, tend to have a mixed stratigraphy because of different processes. Meandering streams are moveable boundary streams that tend to show lateral accretion of material on the inside of the curve because of heicoidal flow (at the bend of a river, a coiling type of flow motion that results in erosion of the concave outer bank and deposition on the convex in bank, Neuendorf, et al, 2005), as the river erodes the outside of the curve. A stream operating in dynamic equilibrium will keep the cross-sectional area of the stream a constant, with the volume of erosion of bank material on the outside curve , is offset by deposition on the inside curve. However in the case of meandering stream C types there is another process that takes place when the river floods. This process is called vertical accretion. It dominantly occurs during the falling stage of the flood. In cobble and gravel bed C stream types such as the East Fork the vertical accretion deposits tend to be sands but may have small layers of sand and silt. These vertical accretion deposit areas become the broad flood plains along streams. What is of significance for the East Fork is that through various floods and various anthropogenic effects, along some reaches, the top layer of primarily sandy material gets eroded off, so that the historical 1939 flood plains are eroded down to bars. Therefore reaches that would have classified at C3/C4 don't have the bankfull flood plain bench anymore, just broad expansions of bars that may have high tops in places that are remnants of the former flood plain bankfull bench. The other item of importance along East Fork of the Lewis is that much of the former braided channels have changed to a dominant anabranch channel that performs as a meandering channel and passive anabranch channels that only flow during bankfull stage or above and that occasional create avulsions.

Research for many years has shown that natural rivers have a tendency to establish a dynamic equilibrium by maintaining a balance between stream energy and sediment load. Lane (1953) was the first to establish an empirical relationship for this dynamic equilibrium with his empirical relationship

$$\mathbf{QwS \sim Qsd50}$$

This proportionality states that the stream power expressed by discharge Qw and slope S is proportional to bed material load Qs times the d50 (size that 505 is smaller) of that bed material load. Technically the stream power is shown as a rate of doing work per unit length, and includes the term for the specific weight of water. However for general discussion that is not shown in the relationship. What is important is that the relationship shows that if the river is shortened by channel straightening or avulsion the river will adjust to get back to a condition of dynamic equilibrium. In other words the erosion of the streambed and streambank are rivers negative feedback mechanism to return to dynamic equilibrium. The river increases the quantity of sediment Qs and size of sediment d50, to stay in proportion with the increased slope on the other side of the relationship. This discussion is very applicable to the Lewis River because of the long history of gravel mining and associated channel straightening of localized avulsions straightening the channel. In addition channel straightening mining, general dozing, or avulsion, cause channels to move from natural Type 1 channels in Schumm et al (1984), to Stage II downcutting and Stage III widening. This progression occurs with the development of headcuts that move upstream, and that form knickpoints (sudden changes in grade like steps of falls) along the rivers course.

Stable natural channels can be meandering (C, E, B, and F) or some altered version of these, as well as stable braided D stream types, or alterations of these. Streams can be altered so severely that they cross a threshold of stability to become essentially unstable. The best way to describe such streams is that they are streams that operate in chaos. Unfortunately the concept of streams being in chaos applies to the East Fork of the Lewis River.

Conceptual Natural Condition

East Fork of the Lewis River would be classified as a combination of C3/C4, F, B, and D stream type. The C3/C4 streams is a meandering stream with a flood plain, with a stream bed of cobble or gravel. In general that stream type would have an entrenchment ratio (flood plain width divided by bankfull width), of >2.2; a moderate to high width to depth ratio (bankfull width divided by bankfull depth, w/d) of >12; a moderate to high sinuosity (channel length divided by valley length) (K) of >1.2; a slope that varies from .001 through .039. and a bed material that varies from bedrock and boulders to clay. B channels have only minimal flood plains with an Entrenchment Ratio (ER) of 1.4 and 2.2) and only moderate sinuosity >1.2. F stream types have no flood plains (ER < 1.4) but moderate to high width to depth ration >12. F channels are essentially equivalent to Stage II to Stage III in Schumm et al (1984) channel evolution model (CEM). F channels in effect represent a stream that has downcut and widened so that all flow is confined in a U shaped to trapezoidal shaped cross section.

Once bankfull channel w/d ratio exceeds 40 the natural channel will tend to have multiple channels like D channels, but these can be combination of active and passive D channels. The active D channels will have a dominant anabranch channel that functions like a meandering channel with outside cut bank high shear stresses, and a pool/riffle sequence similar to typical C meander channels. The passive D channel will have several anabranch channels that only flow during the bankfull channel or higher flow stage.

A natural stream tendency is for the bankfull or channel forming flow to establish a channel forming shape that develops the natural width to depth ratio.

The sinuosity (K) along with the width to depth ratio, along with channel and bank materials, large wood materials and valley slope, establish a planform for the stream bed. Leopold et al. (1964) established the linear distance between pools and riffles in meandering streams with flood plains to be equal to one half a meander wavelength or about 5 -7 bankfull widths. This is commonly referred to as pool width ratio or riffle pool ratio. Theses pools are not only important for aquatic habitat but have fluvial geomorphic importance as mechanisms in combination with sinuosity to dissipate the streams energy. Rosgen (1994) confirmed the spacing relationship of 5 -7 bankfull width for C3/C4 stream types. Montgomery and Buffington also established the common pool/riffle of 5-7 for streams they studied in the early 1990's which was published in 1997.

Present Stream Geometry

Historically the 1858 line map, with a scale e of one inch equals 3300 feet show the upper reach of the East Fork from RM 16 to RM 9.3 has K = 1.15. (Table 1) This slightly meandering C stream type suddenly changes at RM 9.3 to a Braided D stream type for 1.3 miles. By RM 7.2 the stream down to RM 5.9 is again a meandering C stream type with a sinuosity K of 1.4. Table 2 shows valley slope for various reaches as well as channel slope as of about year 2002 (Steady Stream Hydrology). The channel slope is mostly the same as historical except where mined. Table 2 shows a sudden change in valley slope from 0.8% at roughly RM 10.5 to 0.54% at about RM 9.3, the start of the braided 1858 channels. This valley knick point is reflected in the channel changes in slope from 0.72% to 0.48%. Channel slope drops to 0.25% or less through the braided reach. What is significant is that the upper part of the braided D channel in 1858, has become primarily a dominant anabranch meandering channel by 1939. The coverage of the 1939 channel is from RM 11 to RM 5.9. The river anabranch is shown to be a single thread predominant meandering stream from RM 11 to RM 9.3. At 9.3 there is still a predominate anabranch channel, but as many as two other passive anabranch channels down through RM 7.2. The sinuosity was extended down the dominate anabranch channel between RM 9.3 and 7.2 to determine an overall K of 1.4, at a scale of about 1 inch = 1,000 ft. The 1939 channel shows what looks like a meandering C stream type, but one is only looking at the dominant active anabranch channel, which at bankfull flow has at least in part two other passive anabranch channels that transport flood flow. The old channels have become vegetated and are hanging channels along the streambank of the dominant meandering anabranch, and the other multiple channels only transport flow during bankfull and higher events. In other words the river still classifies as a D stream type at bankfull flow as shown in Table 3.

The sinuosity by 1954 as shown on the Ridgefield Quad from RM 5.9 to 7.3 is 1.65. For the remainder of the reach from RM 7.3 to RM 13 on the Battleground Quad (on inch equals 2,000 ft) the sinuosity is 1.27, but this included the dominant anabranch channel of the former braided, and presently altered gravel pit . On the larger scale (1 inch = 660 ft.) 2000 aerial photo the K for the project reach is 1.56. Basically the 2000 data shows that even though there has been river shortening through avulsions, the negative feedback mechanisms of erosion to try and return to dynamic equilibrium has recreated some new meanders. Ortho photos form 2007 were evaluated from RM 13 to RM 6. The sinuosity was determined to be 1.67, showing a continuing attempt to return to dynamic equilibrium. Comparing 2000 to 1939 shows that one old channel apparent on flood plain in 1939 was-occupied again in by 2000 adding 2400 ft of sinuosity. In addition a neck cutoff avulsion shown in 1939 between RM 7 and 8 (former braided reach) was re-occupied by 1990. This is not surprising considering a lot of these avulsion changes are just a reoccupation of passive anabranch channels during floods that became a new predominant anabranch. These changes are not necessarily in the best interest of aquatic habitat as spawning areas become isolated dry channels and avulsion sedimentation smothers other spawning areas and fills in pools.

Table 3 shows some of the existing geometry at cross sections from RM 13 to RM 5.9, from data developed or provided by Richard Dyrland (2009). The data reflects excessive downcutting and widening in Stage II and Stage III of CEM with historical meandering C3/C4 stream types now being primarily an F stream type. Basically the top of the vertical accretion deposits have been eroded off, so just a main channel and bars exist between confined streambanks. Cross sections taken in 2002 of the channel but not necessarily the flood plain, show slopes that vary from reversed or flat to 0.5%.. Based on a bankfull discharge of 4,577 cfs, average velocity of bankfull channels varied from 4.0 to 5.9 ft./sec. for these cross sections (Steady Stream Hydrology, 2002).

Pool/Glide length and riffle distance are shown in Table 4 developed by Richard Dyrland (2009a). Table 5 shows the linear distance between pools/glides and riffles verse bankfull width. As shown the distance varies from 2.7 to 13.4. with 9 out of 16 measurements above 7 (the natural condition is 5 -7 bankfull width). This spacing above 7 reflects the excessive sedimentation and a system in chaos. The pools have very little submerged cover and their shallowness make them poor for any deep water cover. The very wide bankfull width associated with the pools means that riparian vegetation is set back hundreds of feet from most of the pool and provides little overhead cover. This will significantly impact the riparian area usefulness to aquatic organisms, particularly macroinvertebrates and fish.

This wide shallow condition results in very high stream temperatures for June, July and August. As shown in Figure 25 or RM 7 there were 12 days in 2009 that were over 74 degrees Fahrenheit. Of these 12 days four days were more that 80 degrees Fahrenheit, which killed a lot of salmonid fry and smolts and even skulpins (Dyrland, 2009a). The flow at the Heisson gage varied from 45 to 70 cfs during the very high temperature days and flow was mostly less than 1.0 ft deep over the Hobo gage taking the measurements (Dyrland, 2009a)

The stream geometry of Rc/Wbkf is critical to erosion at tight meander curves. As shown by Bagnold (1950) Welch and Wright 2005, and Southerland and Reckendorf, 2008), streams with a Rc/Wbkf of <2.5 have exceptionally high scour depth, and are likely to fail. At RM 9 the radius of curvature divided by the bankfull width has a value of about 1.5. This is along a very high sandy textured streambank where landslides have occurred, and where deep scour is likely occurring along the outside curve of the meander. However the avulsion at the avulsion at RM 9.2 cut off half the flow to the RM 9.0 tight meander so the tight ratio of 1.5 which would now have a higher value, no longer reflects as much failure. The avulsion channel and the main channel come back together to go around the tight curve at RM's 8.7 to 8.8. This tight curve would also have a Rc/Wbkf of less than 2.5 so it would be vulnerable except that a bankfull bench was built as part of the of Lewis River Ridge Project .That bench reduces the radius of curvature, and has log vanes and J's for habitat and bank protection.

High Bars and Coarse Sediment Associated with Avulsion Alterations

Several reaches of the study reach have a bi-modal distribution for the sediment on the bars. These bi-modal distributions of particle size occur at coarse high bars, that are 3 - 4 feet above bars with smaller gravel size. (see Figures 3 and 8).

Figure 3. Gravel bar at RM 10.2 and below the high bar at RM 10.25. Looking upstream of the former pre avulsion bar in the foreground that is overlain by the higher avulsion created bar in the background. The former main channel is to the left of photograph.

The coarser high bar in the background of Figure 3 is downstream of recent partial avulsions in 2008 - 2009 runoff year. The 2008-2009 winter runoff partial avulsion occurred below RM 11, and created the bar immediately downstream starting at about RM 10.25. This high bar has a d50's of 43.92 mm-verses the adjacent bar (RM 10.2) with a d50's of 19.3 mm. This left bank bar is shown in Figure 3, occurs at the mouth of where the avulsion channel meet the mouth of the former main channel. Figure 4 looks up the avulsion channel at the mouth with the main channel and Figure 5 looks down the avulsion channel a few hundred feet upstream of the mouth of the avulsion. Figure 4 shows a coarse cobble material at the mouth of the avulsion channel and Figure 5 shows the downcut through the former point bar. The avulsion occurred between RM 10.75 and 10.25 along and old channel and was a neck cutoff. The river not only developed a straighter channel , but a change in grade was created. The avulsion would have created a headcut at the bottom end that migrated upstream across the neck cutoff and created the downcut of 2.5 -3.5 feet down into the former point bar material shown in Figure 5.

Figure 4 is an upstream view from the avulsion deposition bar across the avulsion.

Figure 5 of partial avulsion channel downcutting between RM 10.75 and 10.25 Avulsion is partial because there is still flow in the main channel in the background.

Figure 6 looks upstream along the upstream reach of the avulsion. Downstream and across from the avulsion caused bar at RM 10.25 the right bank streambank is severely eroded (Figure 3 and 7). This is possibly because it was easier to wash out the fines and sands of the streambank gravel than to erode and transport the coarse the sediment load from the avulsion channel. The bank erosion is shown in Figure 7 along right streambank of the main channel.


Figure 6. Upstream end of the avulsion between RM 10.75 and 10.25.

Figure 7. Streambank erosion with stratigraphy cantilever failure at RM 10.25 across for the flood deposition bar created from the avulsion.

Another example of an avulsion leaving a coarse high bar occurs at the lower end of the project at about RM 6.8 (Figure 8).

Figure 8. Sediment deposition at RM 6.2 in 2009, with d50 of 33.7 on high bar.

Streambank Materials

Streambank materials have played a role in the widening process and in the sediment load that is detrimental to aquatic habitat. There are at least six different streambank conditions observed along the streambanks between RM 13 and 6. At RM 13 at power line (Figures 9 and 10) there is a silt loam (sl) over a fine sandy loam (fsl) soil layer over a gravel, over a fine sandy loam (fsl) to fine sand (fs) over another gravel. The contact of the upper fsl to the gravel is cantilevered. The sands and fines matrix are being washed out of the gravel so that the gravel sluffs to the base of the slope and collects at the angle of repose (angle of rest). The lower fsl layer tends to pinch out upstream to leave only the upper fsl layer cantilevered. Smaller material at the base of slope is being washed out causing a concentration of coarser material at the base of the slope.

Figure 9. at RM 9.7 of silt loam over fine sandy loam over a cantilevered gravel that is cantilevered over another fine sandy loam.

Figure 10 RM 9.7 cantilevered streambank gravels have been washed out at bankfull flows or higher flows and sluff to the angel of repose (rest).

Figure 11. RM 9.7 – 9.8 with wide-shallow channel, and very long pool/riffle ratio, at 8 to 10 bankfull widths. Summer stream temperatures in this reach would be commonly above 74 degrees Fahrenheit and higher which becomes lethal to aquatic habitat as shown in Figure 25.

The coarse material shown at the base of the slope in Figures 10 and Figure 11 was not sufficient to protect the toe slope to prevent 15 feet of cutback of this streambank during the November 2008 through January 2009 flood events. The final flood peak on January 8 , 2009 was 11,300 cfs. or about twice bankfull. This streambank roughly retreated 15 feet in that event (Dyrland, 2009a). This very wide reach has a very long pool/riffle spacing of between 8 and 10 bankfull widths (Table 5).

The second bank condition is where the entire streambank is gravel and as shown in Figure 12 at RM 9.8. This was severely cut back in Nov. 2007 through January 2008 events (Dyrland, 2009a). For the full gravel streambank, bankfull and higher flows washes out fines and sand from gravel which sluffs, but there may not be a cantilever, because bankfull flow reaches top of bank.

Figure 12 at about RM 9.8 shows a gravel streambank from top to bottom of slope that is failing because fines and sand are being washed out of the gravel and the loss of matrix material causes the streambank to fail. Gravel sloughs and lies at an angel of repose.

A third condition is where there is a fine sandy loam streambank with a gravel base. Scour of the gravel, likely from fines and sand matrix material being washed out, keeps the upslope fsl actively failing. This condition is shown in Figure 13 at RM 10.9.

Figure 13, of fine sand loam streambank, along RM10.9. There is gravel at the base of the slope.

The fourth condition is a fsl bank at RM 6, across from a bi-modal bar in Figure 8. This finer textured material is being scoured down to create a steep slope, and tractive stresses during floods, causes bank erosion.

The fifth condition is the very high sandy textured streambank where the bank height exceeds a critical bank height such that a mass failure occurs. This occurs at Lewis River Ridge. High streambanks like at Lewis River Ridge (Figures 15 and 16) show evidence of mid slope seepage and gullies down the face of part of the steep bank. This condition which lends itself to mass wasting wedge failure as shown in Figure 16.

The sixth streambank condition is the rip-rapped built up dike section along RM's 11.6 to RM 11.7. This is shown on the right side of photo in Figure 14.

Figure 14 . Rip-rapped section along dike Rm11.6 to 11.7. Brush has been trimmed, but the bank has open areas in rock where one could joint plant or whole plant transplant, if a sufficient moisture regime can be established.

Figure 15. High cliff of sandy material at about RM 8.8 that shows seepage gullies on cliff face. Material has high pore pressure from drainage problems above the slope (Lewis River Ridge) likely contributes to bank instability.

Figure 16. Wedge planer failure of large blocks of sandy material, that is readily reworked by river as part of sediment load. Placing a bankfull bench with J's or Vanes would re-direct flow away from the streambank and allow side slope materials such as shown in Figure 16 to deposit at the base of the slope and on the bankfull bench, such that off-site sedimentation would be greatly reduced.

Erosion and Sedimentation Relationship

There are some watershed and upstream reach problems that create downstream sedimentation problems in the study reach. Although important, these sources of sediment are minor to problems being created by the sedimentation associated with the avulsions and local streambank erosion. Once the avulsion occurs a sudden increase in coarse sediment exceeds the rivers capacity to transport the large load, and deposition occurs a short distance downstream. This is what is being shown in Figures 3, 4, 5, and 6. The large load also influences the streambank erosion. The river finds it easier to erode the stream bank across (Figure 7 across from the large new bar (Figure 4), than to move the coarse material in the large bar.

The large bar in the background of Figure 4 at RM 10.25 has a d50 of 43.92mm. The d50 in the foreground of Figure 4. at RM 10.2 is 19.3mm . In other words there was a large dump on the bar with smaller bar material . The large new bar from the avulsion both smothers prior spawning beds, in channel that are not readily recovered because of the coarse deep sediment, but also removes stream capacity to carry flood flow, so causes opposite stream erosion. The magnitude of the flood and its duration has some significance in this process, as wood local accumulations of LWD. Streambank erosion, particularly of the fine sand loam textured streambanks, provide local large quantities of sediment for sediment intrusion into spawning gravels. As shown Reckendorf and Van Liew, (1989), the sand fraction of sediment intrusion, is enough to pack the redds such that lethal levels of dissolved oxygen occur next to the eggs.

The avulsion at RM 9.2 to RM 8.7 was very obvious on aerial photographs 2008 that it was going to occur. The avulsion occurred on the alignment of Alternative 6, of Lewis River Ridge project. This small stable channel re-alignment if it had been implemented would have prevented the avulsion downcutting, and would have decreased high sediment loads from two tight meanders. Reducing this sediment impact was a major fisheries benefit, that had the secondary effect of reducing the bank erosion along the two high streambanks. The avulsion had two sediment dumps. One was similar to the one shown in Figure 4 , where at the end of the avulsion the sediment is dumped suddenly. Unfortunately at RM 8.7 is where the bankfull bench had rootwads for fish habitat. The bankfull bench was buried for several hundred feet, so the project has temporally lost the fish habitat function.

Over the long run future floods and outside curve cutting will remove the sediment, and cut back to the log vanes (LV/J's) 1 to 4,) to provide future habitat. There is some loss of log vane buttress and bankfull bench at the downstream end LV /J, 5 and LV/ J, 6 was eroded out. The rock J upstream of the curve and across the river functioned as it was supposed to function to re-direct the flow away from the bank , and create backwater condition that favors sedimentation on the upstream side of the vane, against the streambank. There may be a little sedimentation out into the fish scour hole out at the end of the J but that can be easily dealt with as maintenance. In addition the excavated winter rearing habitat is performing its function nicely.

The second sediment dump from the avulsion at RM 9.2 , was immediately downstream along the main stem about 300 ft. The 2009 flood that blew out the avulsion had a discharge of about 11,300 cfs. which is about twice bankfull conditions. When the avulsion occurred about half the flow went across the avulsion between RM 9.2 and 8.7 . The other half of the flow went down the old main channel from 9.2 to about 9.1 ft. where the sediment dump of about 3.0 ft. occurred and is shown in Figure 17. The sediment is being dumped on a bar that had coarser sediment and that was found in 2007 to have a d50 of 53.68 mm. The particle size on the new sediment deposition is yet to be determined.. This sediment deposition is representative of the sediment load being carried by the East Fork River until the rivers sediment capacity (ability of the stream to transport its load), was suddenly reduced by removing half the discharge. The d50 of this sediment dump is similar to the smaller material presently overlying coarser material along the bar at RM 9.3 – 9.4.

Figure 17. This sediment dump occurred along the main channel at about RM 9.1 after the avulsion at RM 9.2 split the flow and sent about half the flow down the avulsion created channel. The coarser sediment in the foreground was found previously in 2007 to have a d50 of 53.68 mm

Overall there is considerable variation of materials being deposited on East Fork of Lewis River bars, which is not surprising if one has a system in chaos. For example at RM 10.4 the very coarse bar has a d50 of 81.46 mm. This is considerable coarser material than deposited at RM 9.1 measured in 2007. In addition even though there is evidence of several bi-modal distributions of sediment such as discussed at RM 10.25 versus 10.2 (Figure 4), at RM 9.1, those two conditions show a reverse in bi-modal deposition. At 10.25 the coarser material at the end of the avulsion is on top. At 9.1 the coarser material is beneath the finer deposition, that occurred because of reduced sediment transport capacity once half the discharge was removed at the avulsion.

Hydrology, and Sediment Transport

There is a USGS stream gage on the East Fork of the Lewis River at RM 20.2. The drainage area for the gage is 125 square miles and the bankfull flow is 4,577 cfs. which has a recurrence interval of about 1.1 years). The flood of record in 2/8/96 had a discharge of 28,600 cfs. and exceeded the 1% chance event (i.e. 100 year average recurrence interval). There are four recent floods (last two flood years) that were at least twice bankfull and one more almost bankfull. They are as follows: 17, 400 cfs on 11/4/07; 9,800 cfs. on 12/3/07; 10,900 cfs on 11/12/08; 8,300 cfs on 1/2/0709; and 11,300 cfs. on 1/8/09 The November 4, 2007 flood peak has an average recurrence interval at the Heisson Gage (14222500) of about 13.2 years or about 3.8 times bankfull. The January 8, 2009 flood which was the highest of the three sequential floods has an average recurrence interval of about 2.9 years. In examining the 70 years of history on the stream gage, it is apparent that there is no comparable group of five floods of this magnitude so close together. On wonders if this recent high flood activity reflects a change in storms and precipitation as a result of climate change.

Using the Continuity Equations Q + AV, where Q is discharge, A is area and V is velocity, one can calculate discharge. Using a bankfull discharge of 4,577 cfs. and bankfull area from the cross sections, average velocities were determined and shown in Table 3. As expected the wide cross sections have lower velocity and the river has less competence to transport its sediment load at those locations. The widening results in sediment deposition that forms long riffles as show in Table 4.

At average velocities of 4 fps in 5 ft. of water can cause significant (d50) bed material motion of particles smaller than 6 mm (0.02 ft.). An average velocity of 6 fps for 5 ft. of depth can cause significant bed material motions of particles smaller than 22 mm (0.7 ft.) (Simon et al, 1977). The d50 of the avulsion created bar at RM 10.25 is 43.92 mm, and the d50 of the underlying bar before the avulsion was 19.3 mm. In other words the average velocity cannot readily transport the bar material created by the avulsion (d50 of 43.92 mm) at RM 10.25, so it deposits were it is located today. The flood in the winter of 2007 – 2009 were for floods higher than bankfull frequency, and they did locally move some sediment a short distance until deposited as shown in Figures 3 , 8, 9, and 18.

Causes of Avulsion

There are several causes of stream avulsion during floods Most causes are physical reasons along the stream, but some are administrative reasons.

As natural streams meander they develop point bar lateral accretion deposits that get overlain by vertical accretion deposits. The height of deposition varies, such that as meander migration occurs, remnants of the former channels exist on the point bars. The remnants tend to be closely spaced arcuate ridges and troughs on the inner bar and are called meander scrolls. The troughs tend to be re-occupied in floods and on occasion these troughs are downcut to become the main channel again because of meander scroll avulsion. . In addition in the course of meander migration the river sometimes doubles back on itself to create such a short distance between one meander and another, that when a river overtops the flood plain land gap between meander loops, the lower elevation of the downstream meander starts a headcut back across the meander. This kind of avulsion is cause a neck cutoff. Another major type of avulsion that appears to be common along the East Fork of the Lewis River is the avulsion of passive anabranches of braided stream D stream types that had developed a single active anabranch that functions essentially as a meandering stream. The passive anabranches are actually at an elevation above the active anabranch meander, but during one or more floods the passive anabranch downcut and widened. There is an elevation difference between the top of the avulsion channel (like at RM 9.2) and where passive anabranch channel joins the active ananbranch channel downstream such as between RM 8.7. This elevation difference would allow a headcut to start of RM 8.7 and work upstream to RM 8.7. The downcut between RM 9.2 and 8.7 is about 5 feet, verses the downcut between RM 10.75 to RM 10.25 where downcut is less than 3.0 feet (Figure 5). In the case of the avulsion shown in Figure 5 the main channel (Figure 3) is still the dominant channel, over the new avulsion channel. In the case of the RM 9.2 to 8.7 avulsion the flow is about equally distributed between the main channel show in the left of Figure 19 and in Figure 20, and the new avulsion channel shown in the center of Figures 19 and 20. The prior discussion of the 1939 channel reflected the frequent avulsions of passive anabranch channels to remove most flow from the active anabranch channels, as reflected in the former 1858 braided reach changing course, by avulsion prior to 1939, but re-occupying the 1858 anabranch by 1990.

Another cause of avulsion that is mostly natural, but can be severely anthropogenically altered, is the avulsion caused by LWD accumulation within stream meanders.

This happened recently (November, 2006) along the Sandy River in Oregon, when the LWD essentially blocked the river from following its normal meander path parallel to streambank. Instead the river cut across a meander scroll and struck the stream bank at a cross over point (where the river flow is moving away from the streambank toward the opposite streambank and the next downstream meander). The LWD causing the straighten channel along with other factors caused a rip-rapped streambank and dike to fail which created another avulsion downstream. This avulsion not only destroyed property but also a home. The damages were a subject of a recent litigation where the author was an expert witness for the defense, and where he explained to the jury successfully why a set of fluvial geomorphic conditions along with an administrative action were the cause of the failure (Clackamas, County Court 2009).

A cause of avulsion seldom evaluated is the erodibility of the materials along the chute or neck cutoff. Sometimes it is just easier to erode the material along the chute or neck cutoff than other stream banks along the streams course so the stream chooses the easier erosive path.

Gravel pit avulsion has been a know problem for many years. This has been a particular problem where gravel pits are located in the meander scroll area of point bars, and along old multiple channel D stream types. The avulsion problem has often been attributed to gravel pit operations occurring to close to the stream channel and the river capturing the pit during floods by overtopping the barrier between the pit and river meander, or the streambank meander erosion cuts through the barrier separating the pit from river meander. The problem could be insufficient set-back of the pit, and or lack of protective work outside the pit along the meander or inside the pit to cut off the meander from breaking through.

In the case of the East Fork of the Lewis River, an avulsion occurred into the gravel pit operations, during the November 1995 and February 1996 floods During the February 1996 flood the river avulsed through the Weisman-Hwy 205 gravel pit berm at RM 8.9 and abandoned about 1,700 feet of channel, and spawning gravel (Norman et all 1998). The February 1996 flood washed out the Heisson gage located 10 miles upstream. The peak flow for that event has been indirectly estimated to be 28,600 cfs. Since the February 1996 event the 100 year event has been recalculated at the gage to be 22,200 cfs. (Norman et. al., 1998). No avulsion in the lower pits occurred during the February 1996 events, but the stage was set by significant bank erosion for future stream capture.

In November 1996 the East Fork avulsed through six closely spaced pit ponds on the south side of the river, and the river eventually abandoned 3,200 ft of channel and spawning gravels (Norman et. al., 1998). The avulsion began along the outside bend of the river near a haul road. Streambank erosion during the floods has allowed the main stem of the East Fork to capture the pit so that the East Fork would flow through the south bank gravel pits.

When the Ridgefield ponds were abandoned there was a setback to the East Fork of the Lewis River. However by 1990 as shown on the quad sheet and the West Consultants “Approximate Historic Channel Locations” map (Klingeman 2004), the channel is immediately adjacent to Ridgefield ponds 1, 7, 8, and 9. During the River Restoration Northwest (RRNW) field trip in 2004 it was stated that the avulsion was recognized in 1996, and that the avulsion was likely to occur in the next runoff year. The gravel pit owner wanted to place rip-rap along the expected potential avulsion but that decision was overridden by the fisheries agencys. The resulting avulsion captured the pit, and caused loss of 3,200 ft. of spawning beds. One wonders if it is not far more damaging to aquatic habit, to have the loss of 3,200 ft. of spawning area than would have occurred if rip-rap had been allowed to protect the pit area from the bank erosion that caused the avulsion. However, the pit may still have overtopped, because of the magnitude of the November 1996 event.

Regulator constraint is an administrative contributing cause to avulsions. In the litigation along the Sandy River mentioned previously (Clackamas County Circuit court, 2009) instructions from USFWS< and NMFS to the construction agency were that they would not get an approved biological assessment if the agency included the excavation of a toe trench at the base of the rip-rap. The agency reluctantly agreed to not excavate the toe as part of the design. When deep scour occurred where the channel was force to take a right angle turn at the rip-rap the deep scour undermined the rip-rap that had no toe protect. The amount of sediment that resulted from the avulsion is estimated to be 26,516 cu. yds. of which 2,026cu.yds was sand and fines . This compares to an estimated 12 cu. yds of sands and fines that would have occurred in the river if the toe was properly excavated. Therefore using the endangered species act as a mechanism to prevent toe excavation, because the potential sediment created during construction is considered a taking, actually resulted in more than 1000 times more sediment entering the river, than if regulatory accommodation had been made for doing the toe excavation needed in the design. As usually happens when a large slug of sediment is suddenly provided to the river, sedimentation occurs in the next few thousand feet downstream.

This sediment would have smothered spawning areas , filled in pool rearing habitat, and caused sediment intrusion into spawning gravels. All of this was a lot more detrimental on aquatic habitat, including endangered species, than in allowing a toe excavation needed in all bank protection, whether it be rock or wood. The only exception is for deflector vane bank protection for redirection of the bankfull flow but even that needs to be secured down below the streambed.

There is one more administrative cause of avulsion. This is the second guessing by regulatory and funding agencies that prevent the correct alternative from being implemented. The case in point is the Alternative 6 option for the Lewis River Ridge Project (Lawrence et. al. 2008). Constructing a protected bypass channel along the old passive anabranch channel would have allowed flow to be transitioned across the site of the avulsion. A rootwad and boulder complex and four wood & rock J-Hook vanes shown in Figures 18 and 19 were buried by sediment in 2009 and one J-Hook at the lower end of the project was washed out. The purpose of a J-Hook is for the vane portion to redirect the flow perpendicular to the orientation of the log and in doing so creates a backwater. The backwater effect is to encourage sedimentation near the bank. That actually happened at the installed rock vane, and J's, across the river which prevented some sediment from going downstream. The rootwad and boulder complex and four J's buried, are still available for future use as the river erodes back through the sediment and the J tip will start to show rock vortex weir effects and develop a fish habitat scour hole. In addition the bank full bench into which the log vanes portion (of four remaining vanes) were tied into is mostly still there (Figures 18, & 23), even though buried by sediment, and having survived significant flooding of at least twice bankfull flow as shown in Figures 20, 21, and 22. Figure 21, taken during the high flood event shows flood waters entering other potential avulsion channels shown as dotted lines on Figures 1 and 2.

The project objective to reduce sedimentation from the high cliff bank is being accomplished, so there is still considerable project benefit being achieved. However, all of the project benefits could have been accomplished had the regulatory agency not gotten in the way by claiming that the bypass could not be approved under the existing NOAA 10a1A permit. The funding and regulatory agency wanted Engineering Log Jams to be installed. However as previously pointed out the low radius of curvature divided by bankfull width (toruosity of <2.5) along the cliff areas showed that ELJ's were a poor choice because of the low toruosity.

When funding and regulatory agencies second guess the designers there is a break down in communication. If regulatory and funding agencies want to staff up to do the cross sections, hydrology and hydraulics, and overall fluvial geomorphology data collection and analysis, than they might have the staff background to override a designers field determined alternative that was based on science. To do otherwise is to be part of the problem causing the avulsions rather than part of the solution to prevent destructive avulsions from occurring.

Predicting avulsions is not an exact science. However there are some field conditions that lend themselves to prediction being a reasonable projection. The potential Lewis River Ridge avulsion shows up quite well on the 2005 and 2007 aerial photos, where the partial avulsion occurred in 2009. Had the recommendations in Lewis River Ridge (Lawrence et. al. 2008) report been followed this large sediment impact on reduced aquatic habitat created sedimentation on the J's could have been substantially reduces. The same was true for the February 1996 avulsion into the gravel pit. If the proposed rip-rap had been installed than the aquatic damage of loss of spawning area, could have been substantially reduced. The potential avulsions shown in Figure 1 at RM's 9.4, 9.0 and 8.35 are along passive anabranches of braided channels that carry flow during bankfull and above discharge. If nothing is done to reduce high velocity flows from entering these old anabranch channels than future avulsions can be expected along these passive anabranch channels.

Figure 18. Lewis River Ridge, on 12/18/ 2008 with a flow of 387 cfs. This is after the flood of 10,900 cfs on 11/12/08, with a 2.8 yr. average recurrence interval event. No damage is apparent along the construction reach

Figure 19. Lewis river Ridge on 12/18/2008 with a flow of 387 cfs. This is after the flood of 10,900 cfs. on 11/12/08, which is a 2.8 yr. average recurrence interval event. No damage is apparent along the construction.

Figure 20. Lewis River Ridge on 1/8/09 at about 9,360 cfs. The peak reached 11,300 cfs at the Heisson Gage. The deep part of channel (thalweg) is shown by white current marks and J's are keeping deep channel away from high cliff, so no erosion is occurring along the cliff. Some sedimentation is occurring below mouth of avulsion channel, which can be observed at the upstream end of the tree line in the center of the photo.

Figure 21. East Fork Lewis river at about 9,360 cfs, at next meander upstream of Lewis River ridge. Potential new avulsion channel for braided anabranch at RM 9.0 is shown in center of photo.

Figure 22. East Fork Lewis river after avulsion. Sedimentation in upper left of photos from loss of flow capacity, do to most of flow going down the avulsion channel. Avulsion channel (which is now wider than the former main channel), is shown as two flow paths around a center bar.

Figure 23. Sedimentation on bankfull bench has temporarily buried rootwad and boulder complex below outlet of avulsion and Log Vane/J-Hooks No. 1-4 and there is erosion around LV/J No. 5. LV/J No. 6 was washed out when the sedimentation caused a redirection of the former channel meander. There is also increased sedimentation on lower end of point bar, across from downstream J's as shown when comparing to Figure 19.

Figure 24. Post avulsion aerial view, showing avulsion channel at left, and new sedimentation along Lewis River Ridge project reach. Pre-project and project channel has shifted to the right (west).

Criticism of Fish First Evaluation and Installations

It has been brought to the author's attention that Fish First has been criticized for using the classical Luna B Leopold concept of bankfull flow (Leopold, et al, 1964, Leopold, 1994) with an originally established return interval of roughly 1.0 to 2.0, with an average of 1.5 years, for evaluation for habitat structures on Western Washington streams, and specifically the East Fork of the Lewis River. Typically bankfull flow is used as a surrogate for channel forming flow. This practice has been criticized as not applicable to Western Washington streams and that channel forming flows are from much larger flow events. It is the author's belief, that even though there is extensive controversy over whether bankfull flow best represents channel forming flow (Knighton, 1998), bank erosion rate, sediment transport rate, and bar building deposition are thought to be most active when the stream discharge is near bankfull and that bankfull is an acceptable surrogate for channel forming flow.

W. Barry Southerland (2003) in his extensive work on channel formative stream flows and classification on both the west and east side of the Cascades in Northern Washington showed bankfull frequencies with average recurrence intervals that varied from 1.05 to 1.4 years. On the West slope of the Cascades in Washington State Southerland (2003) found return intervals for channel formative flow (i. e. bankfull discharge) with a range closer to 1.05 to 1.2 years. Castro (1997) in her work evaluating streams in Washington, Oregon and Idaho, found that bankfull streams in western Washington and Oregon had bankfull return intervals of 1.1 to 1.2 while eastern Oregon and Washington, and Idaho had average return intervals of 1.4 to 1.5 years. These numbers are entirely consistent with typical bankfull flow evaluations used in the Rosgen streams classifications throughout the US (Rosgen ,1996). Reckendorf and Steffen (2006) looked at bankfull flow as part of Rosgen stream classification in 22 US States including Washington, and found the concept to be applicable in every state where used, and the bankfull flows had average recurrence intervals between 1 to 2 years. Lawrence (2003a & b) found that for regional bankfull discharge curves (relationship of bankfull discharge to stream geometry) that he developed for the Willamette River Watershed OR, found no statistical difference between east or west sides of the Willamette River watershed. In other words the concept of bankfull flow as stated by Leopold et al. (1964) has been found by practicing fluvial geomorphologists to be applicable to the Pacific Northwest even on west slope streams off the Cascade.

The author's field evaluation supports the concept's applicability to the East Fork of the Lewis River and a frequency of bankfull flow of 1.1 years, which is consistent with the regional analysis by Southerland (2003), Lawrence (2003a) and Castro (1997).

Part of the confusion may be that people have criticized the evaluation of the East Fork Lewis is being evaluated as a single tread meandering stream rather than being a braided stream (three or greater channels adjacent to one another that are distributary channels formed in a depositional environment). Braided streams are characterized as having high sediment supply, excessive deposition, which have both longitudinal and transverse bars, and that experiences annual channel shifts, such that the dominant channel, that does most of the streambank erosion, changes every year. As discussed previously, an evaluation of the 1858 Government Land Office survey maps (GLO files) showed that the Upper East Fork of the Lewis is a meandering stream from (RM 19 to 9.3) with less than three closely spaced distributary channels, that become braided at about river mile 9.3 and then returns to a meandering stream below RM 7.2, and continues as a meandering stream down to RM 5.9. There are rare localized places of three channels in 1939, such as in the Stondahl Gravel Pit area. There is an active anabranch channel that performs like a meandering stream. It appears that the extra channels stop flowing as active channels because of sedimentation, vegetation and LWD collection but are picked up as channels in the flood plain evaluation (i.e. the cross section would include these extra avulsions channels as part of the flood plain, and there role as far as establishing pool/ riffle relationships, and meander wavelength are no longer relevant). Once removal of LWD from active and passive braided channels became a common practice, channel changes between where there were two threads of a meandering channel became less frequent, and a dominant channel forming flow or bankfull single thread channel developed. This active anabranch channel has stabilized in the meander condition except for localized avulsion changes, where you commonly find at least two channels on a temporary basis.

Fish First use of wood &rock Log Vane/J-Hooks (J's) in habitat restoration has been criticized because of the partial failure of J's at the Lewis River Ridge (LRR) project. One needs to view streambank work failures in perspective on what happens in general to work along streams. Traditional rip-rap probably has a failure rate of at least 5 -10%, but the author is aware of a recent rip-rap failure of 60% (Clackamas County Court, 2009).

With respect to habitat restoration, the “Holy Grail” of habitat restoration is supposedly the Engineering Log Jam (ELJ). Southerland and Reckendorf (2008) showed that of 70 ELJ’s evaluated 30 or 43% had washed out. Thirty of 38 ELJs evaluated were installed as bank protection bend jams (designed to protect the attached streambanks). Thirty percent of the bend jam style log jams were gone. Of the 38 ELJ’s evaluated that had at least 5 years since installation 76% are still present, but three of those are at risk of loss as of 2008.

Southerland and Reckendorf (2008) stated that site conditions such as tightness of radius of curvature (i. e. tortuosity), streambed and bank materials, and flood history were extremely important in evaluating why any given structure failed. The same criteria (i.e. some likely level of failure) should be applied to Lewis River Ridge (LRR) project. Alternative 6 (Lawrence et al , 2008) was desired and recommended by the designers of Lewis River Ridge project, to reduce tightness of radius-of-curvature along the base of the cliff. Alternative 6 (Lawrence et al., 2008) was designed to reduce radius of curvature along the base of a severely eroding bluff Figures 15 and 16. The alternative reflected how to maintain lateral and vertical stability for at least one meander wavelength upstream i.e. to a vertically stable point. The regulatory agencies would not permit that alternative in a timely manner (Dyrland, 2009b 2009c).

NOAA Fisheries made the interpretation that the 10a1A stream restoration permit would not cover the Alternative 6 design, even though a 10a1A for similar project objectives by a different stream restoration group for Southwest Washington work was not held hostage (Dyrland, 2009b). Therefore a greatly reduced project scope with acknowledged risk was installed . During the first winter following construction the project was subjected to three greater than bankfull flow (4,577 cfs. at Heisson gage, RM 20.2), that activated an upstream old channel, creating an avulsion. The first flood was on November 12, 2008, and was 10,900 cfs, which has an average recurrence interval of about 2.8 yrs. Some flow was observed coming out of the old overflow channel that became the avulsion, and there was no observed damage apparent along the construction reach of the stream as shown in Figure 19. (Dyrland, 2009b, 2009c). After the November flood receded below bankfull, monitoring showed that some erosion had started along the eventual avulsion channel, and that sediment was depositing on the multi rootwad complex, near the mouth of the avulsion, and there was some erosion of the bankfull bench at its lower end. The remaining five project structures in LRR project were not damaged and were functioning as designed (Dyrland, 2009b, 2009c).

The <u>second flood</u> of 8,100 cfs occurred on January 1 and 2 2009, and caused more downcutting along the avulsion route, and sedimentation on top of project work. The rootwad complex no longer functioned to provide habitat, and some deposition was occurring on the next structure, which was a LV/J hook (Dyrland 2009b). The base of the cliff along the bench had not been undercut and was meeting project sediment reduction objectives. Fisherman were still fishing off the structures and catching salmonids. The <u>third flood</u> of 11,500 cfs (about 2.9 yr. average recurrence interval) occurred on January 8, 2009. It caused substantial downcutting along the avulsion channel and became the dominant channel. There was a substantial increase in the sedimentation along the LRR project. The pre-avulsion old channel which was measured to be 12 feet wide in October of 2008, was now over 70 feet wide at the downstream end and over 100 feet wide at the entrance. Sediment covered all but the last two of the six instream structures, and shifted the channel further west. The orientation of the avulsion channel now influenced the orientation of the downstream channel along the project reach , and with the effects of the sedimentation, the flow was directed between structures five and six. The shifting caused some bank erosion along the last 200 ft, out of 1300 ft of project, and the erosion was enough to flank and cut behind structure five, (which is a LV/J that is still there), and to wash out structure six which was a log vane. (Dyrland, 2009b). The East Fork had now shifted several stream widths west of the original project design flow channel.

The objectives to provide toe erosion protection and reduce sedimentation from the cliffs were mostly accomplished. The construction staking at the base of the cliff is still there reflecting the lack of cliff side erosion. The rootrwad complex and four other vane LV/J's are buried by the sediment, they are still there to provided habitat in the future as the river erodes back though the sediment to the rootwad, and the desired alignment over time. The rock vane/J across the river constructed to protect the by-pass flow channel accomplished its purpose to prevent avulsion into that temporary channel (as required by the permit) , traps sediment and has created a scour hole for habitat. This happened in spite of the three greater than bankfull floods, substantial sedimentation, and channel change. The winter rearing channel worked as designed. Therefore, even though a partial failure of the Lewis River Ridge project occurred, much of the project is still there as is the case with some of the ELJ's evaluated by Southerland and Reckendorf (2008).

Hundreds of log vane/J’s have been installed successfully in the US including some along the South Chelatchie, a tributary of Cedar River in WA (Dyrland 2009b) , so the log vane J combination is not an unproven technology. There is no reason to believe, from a fluvial geomorphic perspective, that LV/J’s would not work on East Fork of Lewis River. In Southerland and Reckendorf 2008 ELJ Post Project Appraisal, the sedimentation of bank protection ELJs and loss of adult holding pools due to meander re-adjustment was and still is common (Southerland and Reckendorf (2008). Like the buried rootwad J complex, the long term impact of sediment is yet to be determined. (i.e. if the sedimentation will be removed at many ELJ’s to allow the objective of summer rearing habitat to be achieved).

It has also been brought to the author’s attention that the media has decided to get involved with the criticism of the East Fork of Lewis River Ridge Project. One would wonder if the individuals providing input to the media, were basing their criticism on analysis and evaluation of the facts of the field conditions as described herein, or just making wild speculative statement based only of parochial understanding of the use of wood along streams for streambank protection and for habitat restoration. It is well to have constructive scrutiny of structural performance and of individuals that do stream work but this criticism and its source should be based upon the same criteria of competence as the designers of the LRR Project.

The author a few years ago did an abstract and presentation to the Oregon Academy of Science (OAS), entitled, “Will the Real Fluvial Geomorphologist Please Stand Up”. This was a take off on the old television program “Whats My Line”. The presentation was based on the experience of the author as a fluvial geomorphology expert witness in a litigation (Oregon Appellate Court, 2000), where there were three expert witness testifying on the subject of “Fluvial Geomorphology” as applied to the Emmonds et. al. vs. Oregon Department of Transportation et. al. litigation. One witness for the plaintiffs, who was a licensed Engineering Geologist in Oregon, was challenged by the defense as not being qualified to testify as an expert in “Fluvial Geomorphology”. The judge dismissed the jury, and the attorneys argued who could be an expert in court on any subject, based on the Oregon Evidence Code. After they completed their arguments the judge retreated to his chamber and in about two hours decided that the individual could not testify as an expert in “Fluvial Geomorphology” (i.e. describe cause and effect based of field conditions and analysis), and only be a fact witness. The authors interpretation of the Oregon Evidence Code as applied to fluvial geomorphology was what was presented at the OAS meeting.

It is as follows: (1) has the individual taken courses on the subject; (2) does the individual actually do field work, analysis and write reports and publications about the subject of fluvial geomorphology; and lastly (3) does the individual teach the subject of fluvial geomorphology (i.e. workshops, and college classes). As explained in this report, understanding the fluvial geomorphology of streams is essential to understanding how streams function and to do long term stream restoration. In effect it is physics before fish as stated by US Fish and Wildlife Service, " A stream manifest these laws of physics through self-stabilization and the natural tendency to evolve in a particular form," (USFWS, 2000a, 2000b). Those that would tell the media that they don't need to know and understand fluvial geomorphology to do stream restoration are selling the media a bill of goods by hyping the partial failure of Lewis River Ridge project, to remove focus on their own lack of understanding of fluvial geomorphology and log vane-J technology. The expression of failure in media reports and presentations has been out of context of the circumstances under which the failure occurred, as well as the extent of failure. The media should hold the individuals who provide the criticism to the same standard that they hold the Fish First designers. The media also needs to tell the whole story from second guessing the designers on the preferred alternative to the three floods with the third largest flood event (11,500 cfs.) eventually causing most of the avulsion and meander shift downstream. In addition they should understand or consult with the designers about what still remains a viable part of the installation.

CONCLUSION

There is very little natural channel condition presently left along the East Fork. Instead the excessive bed and bank erosion, along with common avulsions and excessive sedimentation, has created a stream system in chaos. The stream acts as if partly meandering and partly braided, and sometimes switches active anabranch channels back and forth. The stream also has sections that cross over into a threshold condition for which it cannot return through normal dynamic equilibrium recovery. It makes a big difference to the aquatic habitat, especially fish, what the stream condition is in terms of width/depth, pool/riffle, slope, as well as submerged and overhead cover. For example when the meandering sections get too wide the river gets too shallow, summer temperatures reach lethal levels, and the stream no longer can provide viable salmonid habitat.

The geometry data shown in (Table 3) shows the wide departure from the C and D stream types that were the primary natural channels. Bank erosion and eroding off the upper stratigraphy of meander stream C stream types, created wide shallow F stream types. This occurred simultaneously with downcutting and widening through channel evolution model stages II and III. The downcutting and widening is a response to the numerous historical channel alterations, of gravel removal, straightening, removal of large woody debris, and removal of the natural riparian vegetation. In addition avulsions cause channel downcutting and widening as discussed for Figure 5 where 2.5 to 3.5 feet of downcutting occurred in a single avulsion. Much of the historic (1858) braided channel had become by 1939 a dominant active anabranch of the braided channel that functioned as a meandering stream. The other anabranches were passive vegetated channels which today can be seen as hanging channels in the streambank. These passive anabranch channels only carry flow during floods and play no role in the pool/riffle planform important for salmonids along the active anabranch. However the passive anabranch channels sometimes are subject to downcutting and widening during floods and create avulsion channels. Several of the cross sections in Table 3 are D stream types, that reflect former braided channels on the 1858 map. Over the years there has been much confusion as to how people used the Rosgen Stream Classification system in western Washington. Much of this confusion results because people only looked at the active anabranch channel that performed as a meandering stream and said C stream types were having three or more channels so that the classification system must not work in the Northwest.

The Rosgen Stream Classification System works just fine if put in the proper context of still using the active and passive channels to determine at bankfull that many of the former stream reaches classify as D stream types that were former braided channels. That does not mean that one does not use the concepts and process normally used on meandering streams to analyze the active anabranch channel (i.e. developing point bars and meander scrolls from helicoidal flow, high sinuosity, and extended meanders with low tortuosity), that functions just like a single thread meandering stream. People who think you should not do habitat work on the active ananbranch channel as one would on meandering streams just plain don't understand the complexity of the fluvial geomorphology. The wide shallow channels reflected in the high to very high width to depth ratios shown in Table 3, do not readily transport the streams sediment load. This causes pools to fill and a loss of pool habitat. The general lack of large woody debris accumulation further reduces the potential to create pools under the rootwads that point upstream.

Instead of natural pool/riffle values occurring about every 5 -7 bankfull width, pool/riffle frequency is as high as 13.4 bankfull widths. As shown in Table 5, only four of the sixteen measurements fall in the range of 5-7 bankfull width. The pools that are present are mostly very shallow and historically many deep pools fished in the past have become shallower and of lower quality.

The wide shallow channels reflected in Table 3, result in an overhead cover that is set back too far of be effective as overhead cover for fish. The lack of large woody debris means there is also a lack of submerged cover. Installing large woody materials to create submerged large wood salmonid habitat is desirable. This can be done in combination with providing streambank protection using large woody materials to re-direct streamflow away from streambanks. This action along with shaping the streambanks and doing soil-bioengineering above the streambank toe, will reduce streambank erosion and associated sedimentation. In addition this will start the process of narrowing the channel that will be a deeper channel along the installed wood structures. The direct result is a decrease in water temperature, in the deeper pools created. The high temperatures reflected in Figure 25, should decline in the locations where project added wood both causes a deepening and narrowing of the channel.

Soil bioengineering (using native materials) installed as part of project work will add overhead cover that will eventually grow to sufficient height to contribute to the reduction of stream temperatures. Soil bioengineering by itself has some potential to start the process of regaining the historical overhead cover, such as joint planting into the rip-rap along RM 11 to 10.6. Soil bioengineering at this location and other project installations such as LRR bankfull bench , and West Daybreak Park, can be greatly expedited using volunteer labor. Fish First has a really good opportunity to enhance the riparian areas along stabilized reaches, and the local community is a great asset to help in that process. However, there will still be long reaches along the East Fork that are way too wide, with riparian vegetation set back to far, to be effective using Soil Bioengineering to reduce temperature. Continuing restoration projects can make a difference in reducing the high priority problem area.

Five of the four bank conditions lend themselves to treatment with rock and or wood, and associated upslope soil bio-engineering on sloped banks. Bank type five is a special case as it will necessary to get the streambank away from the high bank by creating bankfull benches to secure log vanes, J's or other rootwad and boulder complex that will sustain a long term stable condition.

Excessive floods and upstream avulsions to any proposed work, present a continuing challenge to stabilizing work installed.

Conceptual treatments to deal with the anthropogenic streambank for the various bank conditions, as well as with potential future avulsions will be discussed in another document. That document will focus primarily on East Fork of Lewis River West Daybreak Park Alternatives to reduce streambank erosion and associated sedimentation, reduce frequency of avulsions, reduce width/depth ratio, decrease pool/riffle ratio, decrease stream temperature, increase submerged and overhead cover, and increase winter rearing habitat.

For the Lewis River Ridge Project one rootwad complex is under sediment, one LV/J constructed in 2008 washed out, one is damaged, four are under sediment and will be useful in the future as fish habitat and to deflect flow, The one partly washed out can be repaired. The main thalweg (deep channel, Figure 19)) has been moved away from the cliff by the log portion of the J's redirecting flow away from the cliff, so served their purpose to reduce bank erosion along the cliff. The rock J hook upstream on the opposite side of the river and upstream is also accomplishing its purpose to reduce bank erosion and increase sedimentation (because of the backwater effect above the vane) on the upstream side adjacent to the streambank. The winter rearing side-channel at the lower end of the project, is functioning as designed.

The project objective to reduce sedimentation from the high cliff bank is being accomplished, so there is still considerable project benefit being achieved. However, all of the project benefits could have been accomplished had the regulatory process not gotten in the way. When funding as well regulatory agencies second guess the designers there is a break down in communication. If regulatory and funding agencies want to staff up to do the cross sections, hydrology and hydraulics, and overall fluvial geomorphology data collection and analysis, than they might have the background from their staff to override a designers field determined alternative that was based on science. To do otherwise is to be part of the problem causing the avulsions rather than part of the solution to prevent avulsions from occurring.

It would be desirable to continue into the next phase of the Lewis River Ridge project. First, replacement of the J washed out is needed, along with repair of the J presently at the downstream end of the bankfull bench. Then it is recommended that there be a continuation of the bankfull bench along the cliff. Much of the sediment is likely available in the sediment dump on the initial project. The excess sediment can be moved down to assist in finishing the bankfull bench, and reduce sedimentation from the cliff area.

In addition the J's for that part of the project not installed need to be evaluated and completed, as they will provide habitat features and protect the existing bankfull bench.

It might be desirable to place some rock or log vanes or J's at the upstream end of the avulsion at about river mile 9.1 or even slightly above. In other words, conceptually a backwater condition could to be established above the avulsion to reduce velocity through the avulsion channel In addition some treatments within the avulsion are also desirable. Conceptually if secured large woody debris is added through the avulsion, both a backwater condition could be created to encourage sedimentation and narrowing of the avulsion channel. It is yet to be determined as to which of the channels (former main channel or one of the two avulsion channels would be best to develop for winter rearing habitat. Using the former main channel downstream from RM 9.1 as a winter rearing channel has some potential because it might be easier to modify the flow through that channel to prevent the potential avulsion at RM 9.0 from occurring. However, preventing the potential avulsions at RM 9.4 and 8.35 still need to be addressed.

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Figure 25. Summer Temperatures On Lower East Fork L. R. At Swanson Powerline Bend At RM-7: 2009

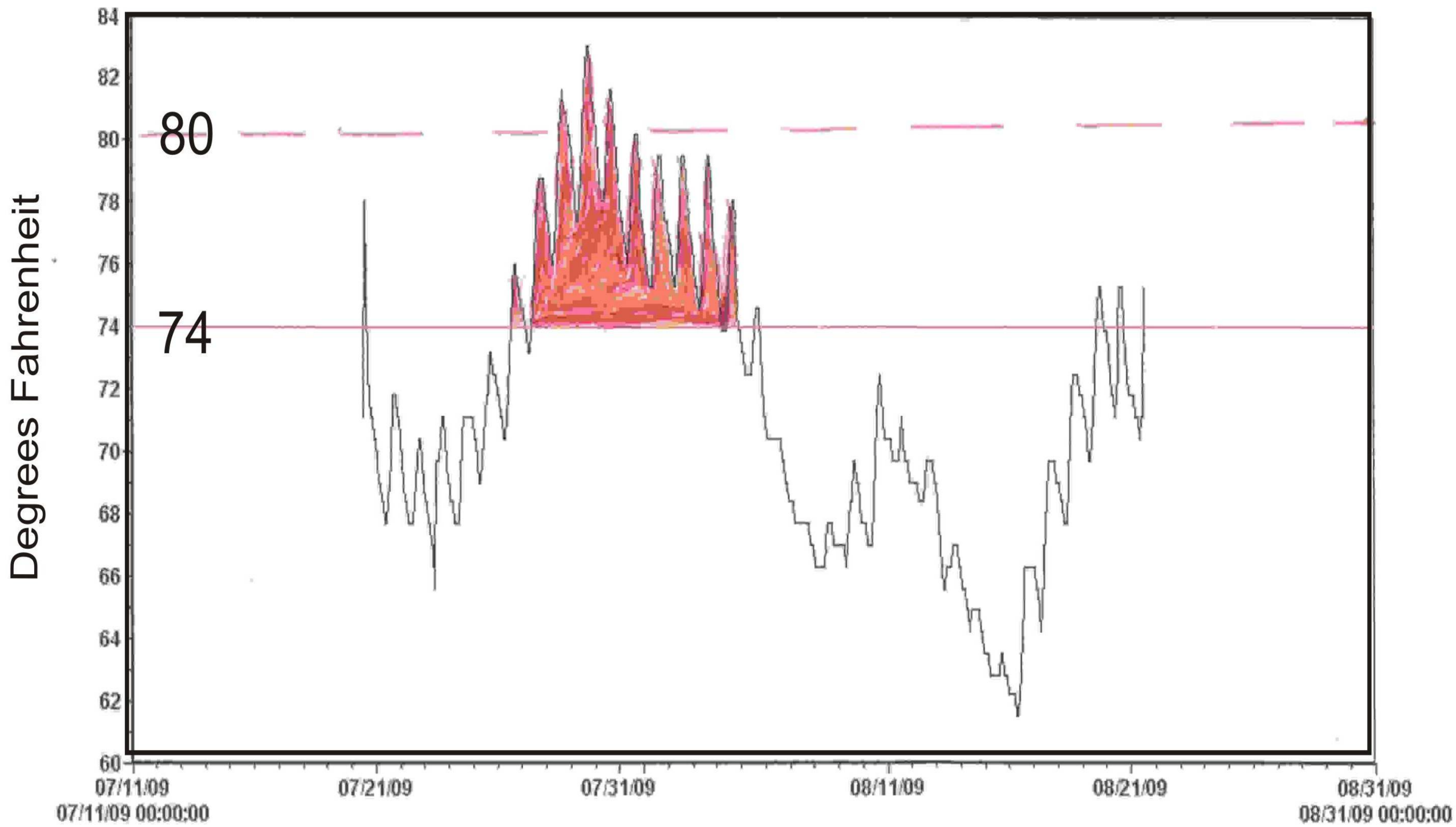

TABLE 1
SINUOSITY

DATE	RM	CHANNEL	VALLEY	SCALE	SINUOSITY
		ft.	ft.	ft./inch	K
1854	16 - 9.3			3300	1.15
	7.2 - 5.9				
1939	11.3 - 5.9	32,775	23,400	1,000	1.4
1954	7.3 - 5.9	10,200	6,200	2,000	1.65
1990	13 - 6.0	42,240	25,344	2,000	1.67
2000	12.8 - 5.9	36,700	23,400	600	1.56

TABLE 2

VALLEY AND CHANNEL SLOPE FROM INTERNET QUADS @ 2,000 ft SCALE & 10 ft CTR

RM	CONTOUR	NEXT CTR.	CH. LNGTH	VLY. LNGTH	INTERVAL	CH. SLOPE	VL SLOPE	2000 MAP
	ft.	ft.	ft.	ft.				
12.9**	130	120	2,500	3,000	10	0.004	0.0033	
12.5	120	110	1,900	2,500	10	0.0053	0.004	0.0025
11.7	110	100	2,300	3,300	10	0.0043	0.003	
11	100	90	5,000	2,000	10	0.002	0.005	
10.7	90	80	1,700	2,500	10	0.0059	0.004	0.0048
10.5	80	70	1,400	1,200	10	0.0072	0.008	
9.7	70	60	2,100	1,850	10	0.0048	0.0054	
9.3*	60	50	4,000	2,300	10	0.0025	0.0043	0.0039
8.2*	50	40	5,400	3,100	10	0.0019	0.0033	
7.6 ***	40	30	2,800	3,800	10	0.0036	0.0026	
5.9***	30	20	5,200	3,900	10	0.0019	0.0027	

* DBRAIDED REACH STARTS AT RM 9.3 AND EXTENDS THROUGH RM 7.2

** SINUOSITY DETERMINED FROM RM 12.9 - 9.3 ABOVE BRAIDED HAS CL + 20,900, VL = 18,650 & K = 1.12

*** K FROM RM 7.6 - 5.9 = 1.4

TABLE 3 STREAM GEOMETRY

RM	DESCRIPT	TYPE	DATE	ER	AVE DPH	W bnkfull	W/D	VELOCITY
					ft.	ft.		ft./sec.
6.0 - 6-3	Car Body H		? 2001		5.96	210	35	
6.6	Swanson RR	F	7-Dec	1.01`	8.04	122	15	
6.6		F	1-Nov	1.02	6.57		18	
7.1 - 7.2	Pwr Line	F	10/30/2002	1.32	5.53	157	29	4.64
8.7	SB Gabion	F	2006	1.08	2.52	327	148VH	4.88
	SBG XS100	B	2/5/2007	2.02	3.95	276	70VH	
	XS-3				2.9	288	99VH	5.42
	XS-1				2.9	99	34	
	XS-1A				2..7	284	105VH	
8.8	C NO Lft Bar	D	1996	1	5.41	128	24	
8.8	YDS	D	6/15/1997	1.03	3.06	191	63H	
8.8	YDS	D	1998	1.15	2.67	239	70VH	
8.8	YD XS3 AVUL	D	2003	2.7	5.48	187	34	
	YDS XS -2	D	7/22/2003					
8.8	LRR XS-1	D	10/10/2004	2.01	2.7	278	103VH	
8.8	LRR XS-3	F	10/7/2004	1.04	2.92	290	99VH	
	XS -1		10/7/2004	1.06	2.94	274	94VH	6.09
9.1	LR XS-70A	D	3/6/2005	3.35	3.91	203	52H	
	LRR-ALV A69		3/26/2005					
	XS-4							
	XS-1							
	XS-2							
9.6	XS NELSON	D	6/8/2004	4.31	4.3	191	44H	5.58
9.7	LW PUD LINE		10/7/2009	1.06	3.79	210	55H	
10	LLR?	D	8/19/09?	1.2	3.39		55H	
10.1	TOM NELSON		6/8/2004	1.99	5.73	205	36	
10.9	XS-1	F	9/14/2007	1.06	3.69	155	42H	8.46
	Abv XS-2	F	9/14/2007	1.14	6.5	126	19	5.53
	Avul XS 3	F	8/27/2007	1	5.2	140	27	6.27
	X sec at 400 ft. F	F	8/22/2007	1.1	4.16		31	

Table 4. Pools & Riffles Lower East Fork L. R.

Est. USGS River Mile	Air Photo 2007 Otho & Location Description	Pool/Glide Ft.	Upper Riffle Ft.	Lower Riffle Ft.	
6	41113 Very unstable small pools & riffles	NA	NA		
6.3	41113 Large Bar & Meander on eroded bend by runway	376	181	185	Very unstable reach & shifts year around
6.5	41113 long pool on bend above below pump house	927	208	181	Old rip rapping in the reaches both banks
6.6	41113 RipRap Bend & Old Ref Reach above Pump House	1240	186	208	Old Reference Reach Now Becoming Unstable
6.7	41113 Lower End of Large Point Bar & Eroding S Bank	542	94	53	Old photos show Point had been very stable
6.9	41113 Around Curve Below Landing Strip Bend	412	53	94	
7	41113 Below Channel Reach Bend at Landing Strip Bend	135	135	53	
7.1	41113 Chum Channel Bend At Landing Strip S. End	544	197	135	
7.2	41113 BPA Power Line Bend & Eroding Severely	539	93	197	
7.4	41113 Just Above BPA Line in Bend	401	306	93	
7.6	41113 Ridgefield Pits Outlet & Pool Below	486	140	306	
7.8	41124 Old Ridgefield Pits	NA	NA		Pits Unstable, accumulating sediment, meander
8	41124 Entrance to Ridgefield Pits	578	130	217	
8.5	41124 Long Pool & Glide Upstream of Pits	894	607	130	
8.8	42119 Lower End Bend Cliff at Lewis River Ridge Site	902	327	607	
9.1	42119 Eroded N Bank Avulsion Bend Above LRR Site	1248	377	327	
9.3	42119 Blue House Eroded S Bank Cliff Below Arabs	996	492	377	
9.5	42119 Riffle & Pool Opposite Arabs & Clark Co Mnt. Yard	903	536	492	Aggrading Lower riffle & stable banks since 1996
9.8	42119 West Daybreak Project Reach Below Bridge	799	341	536	Severely eroding S. bank & large moving riffles
10	42119 Short Pool above WDbrk reach at Wally Schriers	678	411	341	Channel very wide & shallow
10.2	42119 Below & Slightly Above Daybreak Bridge	524	48	411	Deep Pool at Bridge, Right Angle approach Rock
10.3	42119 Daybreak Park Recreation Area w/long riffle	212	518	48	Small pool but long riffle upstream
10.4	42119 Downstream from Avulsion lower end	378	433	518	Pool & riffles just below growin Avulsion channel
10.5	42120 North Bank Slide area above lower end of Avulsion	538	141	433	Bedrock & slide debris & erosion upstream
10.7	42120 Eroding Bend above Slide reach	245	107	141	Series of relatively small pools & unstable banks
10.8	42120 Short Pool below Avulsion Inlet & Reference Reach	267	258	107	Aggrading upper riffle
10.9	42120 New Reference Reach Above Daybreak Bridge	986	324	258	Beginning to Show erosion on South Bank
11.2	42120 &4212 Just Above Reference Reach	688	681	324	Long south side bar
11.3	42121 Reach just below large Dike & Right Angle Turn	432	114	681	Dike affects flow, causing erosion downstream
11.4	42121 Middle of large SW Dike with short pools	249	105	114	High SW Bank Dike with several short pools
11.5	42121 Upper end of Dike	643	549	105	Sharp bend on upstream end
11.7	42121 Above Dike Reach- long pool-glide-run	893	872	549	Long reach
12	42121 Short pool above long reach with erosion upstream	377	212	872	long riffles
12.5	42127 Below Lewisville Bridge, rocky & bedrock	1464	482	212	channel downcut but bedrock present
12.7	42127 Rock Reach Below Bridge	1367	869	482	Hard to see riffles VS wind, photo angle not good
12.8	42127 Immediately below Lewisville Bridge	991	672	869	Hard to see riffles VS wind, photo angle not good
13	42127 Lewisville Bridge				

TABLE 5

POOL FREQUENCY RELATIONSHIP

RM	POOL LNGTH	RIFF. LNGTH.	TOT. PL/RIF	Wbkf.*	FREQUENCY
6.3	376	557	933	122	7.6
6.5	927	384	1311	122	10.7
6.6	1240	394	1634	122	13.4
6.7	542	147	689	122	5.6
6.9	412	147	559	122	4.6
7	136	188	329	122	2.7
8	578	347	925	122	7.6
8.8	902	934	1836	290	6.3
9.1	1248	704	1952	203	9.6
9.3	996	869	1865	202	9.2
9.5	903	1028	1931	190	10.2
9.8	799	877	1676	210	8
10.5	538	574	1112	206	5.4
10.8	257	365	622	182	3.4
11.5	643	654	1297	194	6.7
12.5	1464	694	2158	195	11.1