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Rehabilitation of Floodplain Mining Pits: Interim Report Detailing Initial Plans and Procedures

Bureau of Reclamation Science and Technology Interim Report

Technical Service Center, Denver, CO

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, CO

September 2005

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The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

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Introduction

Over the past half century the need for quality aggregate used in concrete construction has placed a large demand on fluvial resources, which are easily obtained through mining of rivers and their floodplains. Although obtaining these resources is relatively easy, floodplain mining pits can create adverse ecological conditions and pose a threat to infrastructure. This report discusses findings from an investigation into effects of floodplain mining and potential rehabilitation strategies as they pertain specifically to the Yakima River in central Washington, but are representative of generic applications for any river. These findings come from a review of the literature, site visits to the Yakima River and discussions with many interested parties in the Yakima Basin and elsewhere. A number of publications address the impacts of floodplain mining pits (e.g. Yakima River Floodplain Mining Impact Study 2004, Grindeland and Hadley 2003, Kondolf et al. 2002, Schnitzer 1999, Schnitzer 2004, Norman et al. 1998, and Norman, 1998) however the literature lacks any detailed information addressing the rehabilitation of floodplain mining pits. A project, currently in the stages of planning and coordination, seeks to rehabilitate a selected floodplain mining pit or pits on the Yakima River. The attached study plan can be used by Yakima County to petition funding sources for in-kind services or financial contributions to the study. The report also includes a hazard analysis for qualitatively evaluating the level of risk currently posed by existing floodplain mining pits.

A meeting was convened in Yakima, Washington in July 2005 to discuss the rehabilitation of floodplain pits on the Yakima River. Present at the meeting were representatives from Yakima County, City of Yakima, Yakama Nation, Washington Department of Ecology, Yakima Basin Water Enhancement Project (Reclamation) and the Technical Service Center (Reclamation). Other interested parties involved in discussions since January 2004 include Washington Department of Fish and Wildlife, U.S. Fish and Wildlife, Washington Department of Transportation, and National Marine Fisheries Service. The U.S. Army Corps of Engineers will likely be involved with levee construction/deconstruction and permitting issues. The Reclamation research team (i.e. the authors of this report) presented a rehabilitation plan for the reach of the Yakima River, (Selah Gap to Union Gap) that was determined to be the most feasible for this initial study through thoughtful consideration and many discussions with interested parties in the months prior to the meeting. All of the attendees at the meeting reacted positively to the project and desire to take a proactive approach to address the hazards presented by the presence of the floodplain mining pits. The representative from the Yakima Nation voiced concerns regarding adverse habitat conditions during rehabilitation. This topic can be addressed if greater detail following the study when recovery times can be more accurately predicted. Next steps will involve Yakima County petitioning the above mentioned agencies for support and other planning and coordination duties.

Impacts of Floodplain Mining

When mining pits are dug in the active floodplain, dikes and levees are often constructed to discourage the interaction of the river with the pit. This action disconnects the river from the floodplain and narrows the river corridor increasing local velocity and depth. An increase in velocity and depth creates a condition of higher stresses that in turn can cause channel incision, increase of bed material size, bed armoring, and increased bed and bank erosion. The combination of increased depth and velocity and loss of floodplain increases risk of flood damage. Preventing flood flows from accessing the floodplain prohibits temporary storage of flood waters, and instead confines the flow to the main channel, thus increasing its stage. In many cases, dikes and levees separating the pits from the river are constructed using material excavated from the pit, which consists of fluvial material capable of being dislodged and transported by high flows. In the case of some of the pits on the Yakima River near Yakima, it was determined that the dike or levee material could be mobilized by flows associated with a 10-year return period (Dunne and Leopold, 1978). This creates a precarious situation, elevating the potential for unintended channel avulsion when the river is captured by pit the during channel migration. If there is a channel avulsion into a pit, an upstream migrating nickpoint can form as the river readjusts its grade (documented for the capture of the Selah Pits in Norman et al., 1998). The pit essentially becomes a sediment trap, perhaps for decades or longer, significantly affecting river in the area of the pit by potentially causing channel incision or increased bank erosion (Kondolf et al., 2002).

Another important consideration is the proximity of the pits to each other. When a mining pit captured the Rogue River in Oregon, nearby pits were placed at greater risk of avulsion due to the change in the course of the newly formed channel (Schnitzer, 2004). Table 1 lists some of the potential effects that floodplain mining pits may have on the river. Not included in this list are the potentially significant impacts on nearby infrastructure such as roads, bridges, water and wastewater treatment plants, and irrigation works. Irrigation diversions that are not dependant on dams or grade control can be severely impacted when a channel becomes incised or migrates away from a diversion. Several diversions of this type exist in the Yakima Basin.

Habitat complexity is also lost when a river is channelized, which forms a narrow, uniform, high velocity channel where most of the habitat is not beneficial to native aquatic species (Brookes, 1989). Natural processes such as channel migration, bar building, accumulation of woody debris, development of side channels and floodplain interaction can no longer take place. Side channels have been shown to be ecologically important to the survival of salmonid species (Ring and Watson, 1999, Brown et al., 1998, Weigand, 1991). Side channels that remain connected following the construction of a mining pit can be dewatered during mining operations as ground water elevations decrease when water is pumped from the pit (Kondolf et al., 2002).

Table 1:Summary of potential impacts caused by floodplain gravel pit capture (taken from Grindeland and Hadley, 2003)

Elements 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 • Loss of natural channel geometry • Increased open water area	• Increased lateral migration • Increased channel width
Sediment Transport	• Increased sediment transport capacity • Reduction in bed load deposition	• Deposition of sediment 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 fine sediment supply
Hydraulics	• Increased slope • Increased velocities • Decreased normal depth • Increased bed roughness	• Decreased slope • Increased channel depth • Increased channel width • Reduced bed reoughness	• Increased bed roughness
Hydrology		• Increased flood storage • Increased evaporation • Altered groundwater flow patterns	• Reduction of flood levels • Attenuation of flood peaks • Changes in summer low flows • Lower riparian groundwater levels due to bed lowering
Water Quality		• Temperature increase • Short-term increase in turbidity • Alteration of hyporheic zone	• Temperature increase • Short-term increase in turbidity
Aquatic Habitat	• Habitat disruption or loss due to channel incision • Potential conversion of habitat type/quality • Short and long term habitat instability	• Conversion of free flowing habitat to still water habitat • Potential capture of fish following floods • Potential release of non-native species from captured pit(s) • Alteration of hyporheic zone • Short and long term habitat instability	• Habitat disruption or loss due to erosion of bed • Habitat loss due to altered sediment supply • Potential conversion habitat type/quality • Ahort and long term habitat instability

Additionally, former riparian forest is converted to an open pond, which not only affects wildlife but disrupts the natural flow of groundwater and provides the means to affect water temperatures in the river. Large riparian vegetation can no longer moderate water temperatures. These pits are capable of supporting non-native aquatic weeds and fish species, which during overtopping flows can be introduced into the river as well as strand native species in the pit (Floodplain Mining Impact Study, 2004; Kondolf et al., 2002).

Documented Recent Pit Captures on the Yakima River

During the Winter 1996/97 floods on the Yakima River, five floodplain gravel pits captured the river. Several other rivers in the Pacific Northwest experienced similar occurrences (e.g. Rogue R., OR; East Fork Lewis R., WA; Cowlitz R., WA – Norman et al., 1998). The most severe case on the Yakima River was at the Selah Pits (Figure 1) north of the city of Yakima, where an estimated minimum of 300,000 yd^3 of gravel was scoured from the river and deposited 6 ft. deep over the 33 acre pit. It was also estimated that more than 100,000 yd^3 was moved from the river and deposited on gravel bars and private lands upstream of the pit. This severe scour was created by an upstream migrating nickpoint of 6 – 8 ft. deep (Norman et al., 1998). To put these volumes into context, Dunne and Leopold (1978) estimate the average annual sediment load for the Yakima River downstream of the Naches River at 210,000 yd^3. The Selah Pits are one to two river miles upstream of the Naches River mouth.

Figure 1: Selah Pits along the Yakima River upstream of the city of Yakima. Flow is from top to bottom of the photograph.

In 1990, Freeway pit #1 (Figure 2) on the Yakima River near Thorp, Washington, captured the river, placing Interstate 90 in jeopardy of erosion. The only engineering measures taken following the avulsion were the construction of barbs along the interstate (visible in the photograph). The highest velocities in this portion of the river are against the right bank away from the interstate. The river has been allowed to occupy the pit and continues to recover, taking the form of a split channel. The deposits visible in the middle of the former pit are new since the avulsion. This type of avulsion is the intended result, under controlled conditions, of the proposed rehabilitation of some mining pits on the Yakima River. It is evident in Figure 2 that the former gravel pit is actively reverting to riverine conditions.

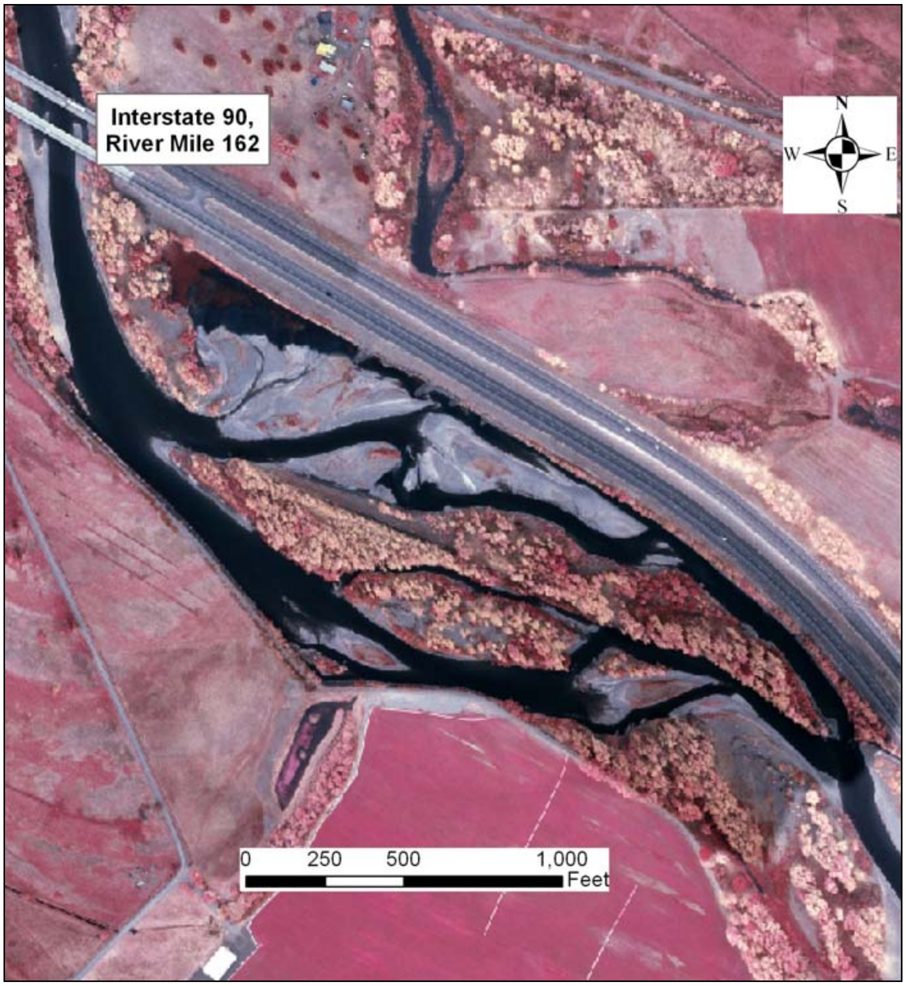

Figure 2: Freeway Pit #1 near Thorp, WA. Prior to the avulsion the river flowed along the southwest bank in a single thread. Flow is from top to bottom of the photo.

In 1996, the Gladmar Pit (Figure 3) was one of the five that caused the river to avulse during the floods that winter. This pit is located just upstream of Freeway Pit #1 (Figure 2), and north of the interstate bridge, visible in both photos. Measures were taken to limit the interaction of the river with the pit in order to maintain flows in the existing river channel and provide water to an irrigation inlet that would otherwise have been abandoned. The engineered inlet to the pit is situated high enough above the thalweg of the river to prevent significant bedload from entering the pit and helps to preserve the existing configuration.

These pits can serve as a study in progress to provide information regarding changes in river morphology and other issues related to pit capture. Bathymetric surveys or depth measurements of the Gladmar and Freeway pit #1 prior to avulsion have not yet been obtained and it is uncertain if they exist.

Figure 3: Gladmar Pit near Thorp, WA. The downstream end of this reach is at the freeway bridge and is very near the avulsion into Freeway Pit #1 in Figure 2. Note the left bank channel is maintained for irrigation flows into the canal. Flow is from top to bottom of the photo.

Gravel Pit Rehabilitation on the Yakima River

Proposed Reach for Gravel Pit Reclamation

The reach of the Yakima River near the city of Yakima, between Selah Gap and Union Gap, has many gravel pits that pose a potential threat to infrastructure (Figure 4). Rehabilitation of gravel pits in this reach of the river is critical, as pit capture presents a high risk of damage to infrastructure. The Washington

Department of Transportation is replacing the existing State Route 24 Bridge across the Yakima River and has invested additional funds to increase the distance between the abutments to accommodate channel migration and aid restoration efforts downstream of the bridge (Figure 4). Following many discussions with interested parties, it has been proposed that the reach downstream of SR 24 Bridge be investigated for rehabilitation potential.

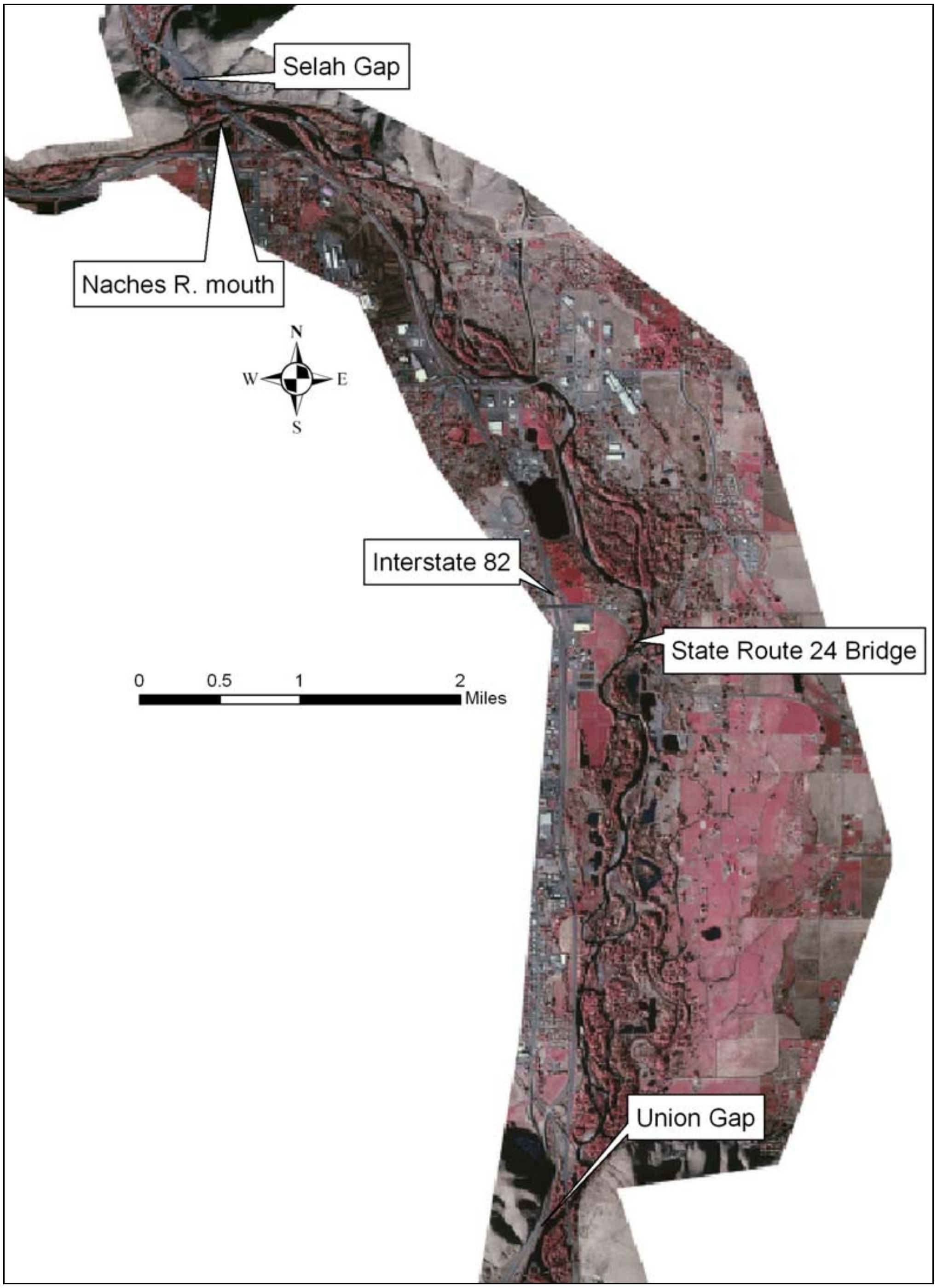

Figure 4: Reach of the Yakima River at Yakima between Selah Gap and Union Gap. Many gravel pits located in this reach are located adjacent to infrastructure. Flow is from top to bottom of the photo.

Morphologic Setting of the Selah Gap to Union Gap Reach

The Selah Gap-to-Union gap reach (gap-to-gap reach) of the Yakima River is one of several alluvial valleys in the Yakima Basin that are formed in the folded terrain of the Columbia River Plateau. The Columbia River Basalt has been downwarped in the Selah Gap-to-Union Gap reach, forming a synclinal basin or trough in which younger sediment has collected and consolidated over time into a semi-indurated sedimentary sequence. Overlying the Columbia River Basalt in this synclinal basin is the Miocene to Pliocene Ellensburg Formation, which is composed of mudstones, siltstones, sandstones, and conglomerates. This formation lies close to the surface near Selah Gap but is buried by greater amounts of unconsolidated silt, sand and gravel (termed Quaternary fill) in a downstream direction toward Union Gap (Kinnison and Sceva, 1963). The Quaternary fill reaches a depth of hundreds of feet in this part of the Yakima Basin and occurs at the surface in much of the valley.

The gap-to-gap reach is bounded at both the upstream and downstream ends by anticlinal ridges of the Columbia River Basalt. These ridges establish hydraulic controls that form groundwater basin boundaries or sub-basin boundaries and consequently exert a strong influence on river morphology and groundwater flow. The Yakima River channel narrows to a single thread through each gap; this is in contrast to the multi-thread system that is present within the gap to gap reach. After passing through Selah Gap, the Yakima River broadens to a wide alluvial valley and can be generally characterized as a braided channel with a broad floodplain. Lateral movement of the braided channel is limited by natural as well as man-made controls including bedrock, older stream terraces, levees, bridges, and highway and railroad embankments. Substantial groundwater flow into the Yakima River occurs at Union Gap, where subsurface bedrock forces groundwater flow from the north, east and west to the surface. As flow passes through Union Gap, it also crosses a groundwater basin boundary and continues in a southeasterly direction through the Lower Yakima Basin.

Due to the high sediment loads and bedrock controls, the gap-to-gap reach of the river has historically been transport-limited. These observations are born out in the braided channel morphology, which typically exists in river systems with high sediment loads and relatively steep gradients. Major sediment input to this reach comes from the Yakima River upstream of Selah Gap and from the Naches River, which enters the Yakima River from the west just downstream of Selah Gap. Since the valley floor is composed of a thick sequence of Quaternary fill, it represents a large source of stored sediment, some of which is mobilized by the Yakima River.

Channel form, complexity and width are variable throughout the reach. Changes in slope, sediment supply, the presence of man-made structures or natural controls are also important factors in shaping the channel morphology in the gap-to-gap reach. For instance, the active channel width and number of channel threads increase from state route 24 to Union Gap (Figure 5?). This appears to have been the case historically (since 1927) and suggests that natural controls have been responsible for the channel morphology in this reach. In other areas, man-made features have influenced channel morphology. For example, near Riverside and Edler pits, levees protecting the gravel pits have narrowed the active channel area and maintained the location of a relatively fixed active channel.

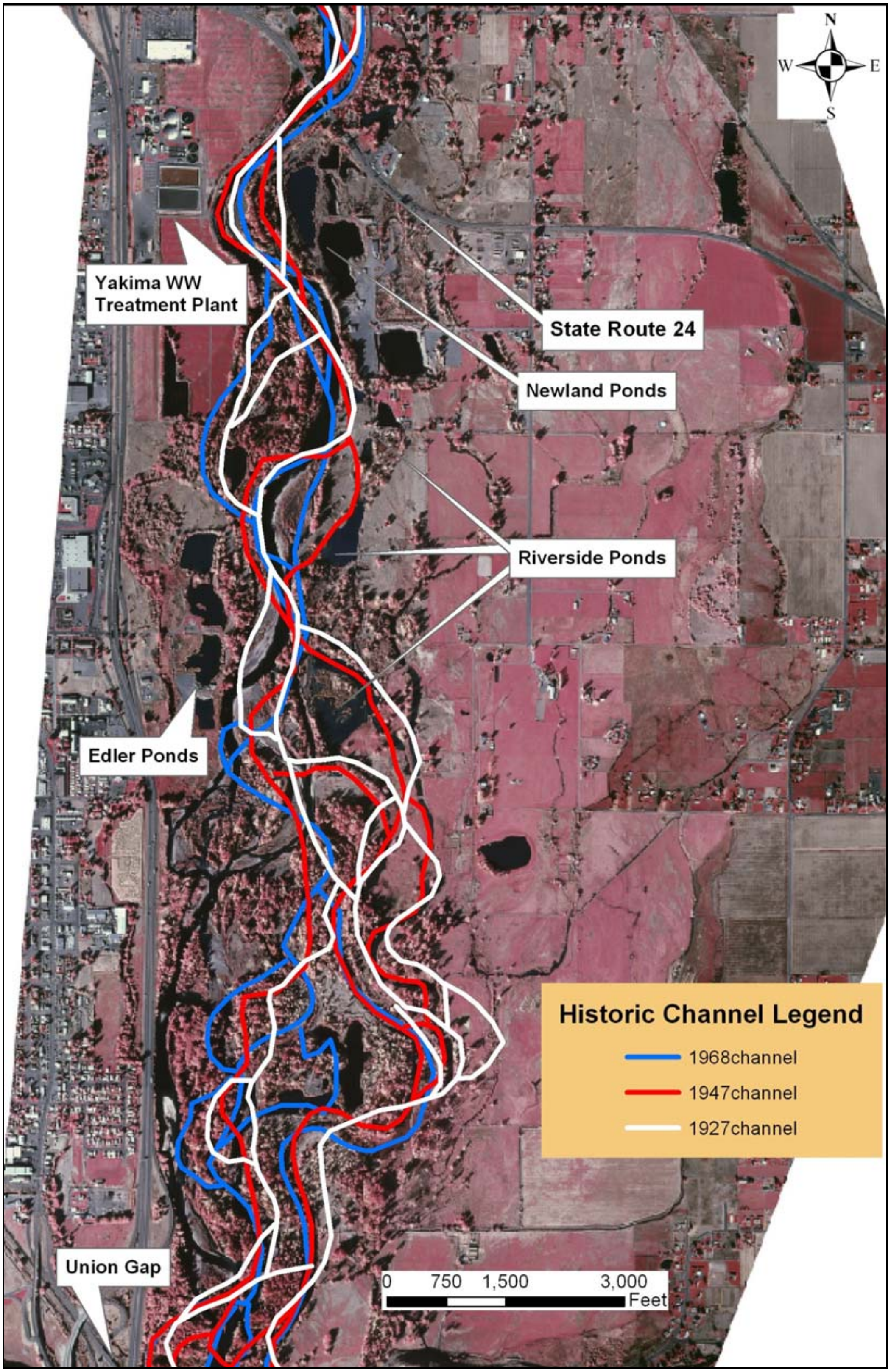

Figure 5: 2000 aerial photo showing various gravel pits subject to rehabilitation. The colored lines represent active channels in 1927 (white), 1947 (red) and 1968 (blue).

Options for Gravel Pit Rehabilitation

A few options are available for rehabilitation of floodplain mining pits. The simplest option is to refill the pit with an acceptable fill material. An acceptable fill material would consist of non-contaminated alluvium similar in grain size distribution to what was excavated. Filling the pit with alluvium will better replicate pre-mining conditions related to groundwater activity and will not introduce unnatural sediment to the river. This option is not feasible due to the volume of quality fill required compared to what is available. Moreover, the material would likely have to be mined from a river or floodplain somewhere else in the basin.

Another option, discussed by Norman, (1998) and Cederholm et al., (1988) is to reconnect the pit to the river with an access channel at a downstream location. This could mimic off stream habitat present throughout the riparian zones of the Yakima River. Although deep water does not provide rearing and foraging habitat, the shallower portions near the shoreline could serve this function. Connecting the pits to the river would also serve the function of equalizing the hydrostatic pressure on both sides of the dike or levee. This decreases the opportunity for failure of the structure. Reducing the difference in water surface elevations between a mining pit and the adjacent river channel is cited as the single most important factor in decreasing the potential for flood damage to gravel pit dikes in Oregon following the 1996 and 1997 floods (Schnitzer et al., 1999) This rehabilitation scenario is not advised in the lower portions of the Yakima River (downstream of the Naches River mouth) where water temperatures are elevated such that favorable habitat exists for undesirable (e.g. Northern Pikeminnow) and exotic fish species (e.g. Bass). If these species are provided favorable spawning and rearing habitat combined with access to the river, a proliferation of these species could occur.

It is possible to cut and reinforce notches in dikes or levees separating the river from the pit. These notches would be designed to allow flood flows into the pit and relieve hydrostatic pressure on the dike or levee during a flood, reducing the likelihood of failure. This action also provides the opportunity for introducing undesirable species into the river and stranding native fish in the pit when high flows subside.

For mining pits that are too large for rehabilitation, the reinforcement of the embankment should be verified for stability at high flows. In some locations, it may be possible to remove or setback levees on the opposite side of the river to allow floodplain interaction and relieve stress in the dikes surrounding the mining pits. This would reduce local depth and velocity and therefore scour potential at the levee. The placement of stream barbs is also an option to deter degradation of the embankment. This rehabilitation strategy is recommended for some pits on the Yakima River near Yakima and may be the best available option for very large pits.

Perhaps the best rehabilitation strategy for some pits on the Yakima River is to connect the pits to the river at the upstream and downstream ends with the intent to eventually fill the pit with natural sediment load. Great caution must be exercised when designing this type of rehabilitation scheme. It may be possible to use fill available from existing levees or dikes to supplement filling the pit, although it is not likely that the volume of fill will be adequate relative to the volume of the pit(s) to be rehabilitated. For this reason it will be necessary to divert a portion of the river's flow and sediment into the pits to complete the rehabilitation. Once completed, the former pit will become free-flowing, lotic habitat. This plan will comprise the proposed gravel pit rehabilitation scenario discussed later in this report and included in the plan of study in Appendix A.

Feasibility Assessment

Prior to rehabilitation of gravel pits, a study must take place to determine which rehabilitation scheme should take place. For the Yakima River, these subjects will be discussed individually in basic terms, as no specific plan of study has been executed and many specifics have yet to be determined.

Geomorphic Setting

The geomorphic setting should be studied to determine historical and current river channel and floodplain conditions. This will allow for a more accurate prediction of future conditions following a rehabilitation scheme. The anticipated future condition of the river and floodplain must be sustainable; considering anticipated flow regimes if the river is controlled by dams, locations of new levees, if any, changes in channel planform following the rehabilitation, and anticipated sediment transport through the reach of interest. Caution should be used in predicting the future planform and sediment transport conditions. A river that has historically been braided and is now channelized may not be able to sustain a braided planform following rehabilitation if flow regulation or sediment supply has changed from natural sediment transport and flow conditions.

Sediment Transport

In conjunction with stream flow, sediment transport through the reach to be rehabilitated is likely the most important factor related to the rehabilitation of floodplain gravel pits. The transport of sediment through the rehabilitated pit(s) will determine, among other things, the time of recovery to a flowing water habitat. It is critical to determine the implications of 'borrowing' sediment transported by the river to fill the pit(s). Taking sediment transported by the river could have negative consequences downstream of the site. The character of the sediment and transport rates should be measured to determine how and when sediment is transported locally through the system. This information should be used to verify sediment transport models, which can be used to determine an average annual budget. Sources of sediment, both mobile and stored, should be determined. Once the sediment budget is determined and whether or not downstream reaches can 'afford' the temporary sediment loss, decisions regarding the portion of transported sediment that could be routed through the pit(s) to be rehabilitated could be made. It is likely that sediment availability could increase through increased bank erosion if levees are to be removed in the rehabilitated reach. It is important to realize that complete recovery times will likely be on a decadal scale, depending on the volume of sediment available for supplemental filling and the total volume required to refill the pit(s). It may be possible to create a lotic environment is a lesser time frame.

Floodplain or Channel Migration Zone Availability

Rehabilitation of floodplain gravel pits necessarily involves allowing the river to reclaim at least a portion of the floodplain it once occupied. This requires that riparian property is either held in public trust or controlled by a willing land owner. Flood easements may be possible to allow for the setback of levees if needed. In many cases, floodplain gravel pits are situated near roads and other infrastructure. This may limit the scope of the project and will likely complicate rehabilitation plans.

Proposed Rehabilitation Action for Selah Gap to Union Gap Reach, Yakima River

The following discussion is based on a proposed rehabilitation of the Edler Pits, however the scenario discussed can be generically applied to other pits slated for similar rehabilitation. This scenario assumes that prior studies indicate such a rehabilitation will be successful with regards to sediment transport and geomorphic issues as well as riparian land availability and that all setback levees are in place.

To begin the rehabilitation, available material from deconstructed levees should be strategically placed in the pit(s) if the material is suitable. The best use of the fill material has yet to be determined. One option is to fill the pits from the sides, which will create a narrower pit, more similar to a river channel. This will increase velocities through the pits which will improve sediment transport conditions through the pits. If water temperature is a concern, the moving water will likely have a lower temperature than would a wider, slower condition. Additionally, increasing velocities through the pits will help to deter the possible proliferation of exotic or predator fish species in the Yakima River that depend on a warm, still-water habitat. The other strategy for filling the pits would be to fill from the bottom to raise the invert elevation of the pit, thus reducing the risk of an unintended channel avulsion around the grade control.

An ingress channel must be constructed as well as connecting channels between the pits and an egress channel at the downstream end (Figure 6). The dimensions and slope of the channel will depend upon local conditions as well as how much flow and sediment is to be diverted into the pits. If conditions allow, the slope should mimic local conditions in the river, as to not aggrade closed or degrade excessively. The invert elevation of the ingress channel inlet will be determined by the existing elevation of the main channel thalweg. Placing the invert of the ingress channel at or near the channel thalweg will provide the greatest potential for main channel sediment to enter the ingress channel. A channel ingress invert elevation well above the main channel thalweg will limit the size and volume of sediment transported into the pits. Grade control at the head of the ingress channel will be necessary to prevent the main channel from completely avulsing into the pits. It may be necessary to place additional grade control along the ingress channel depending on its length and slope. Placing grade control at the junction of the ingress channel and the pit will help prevent a nickpoint from traveling upstream.

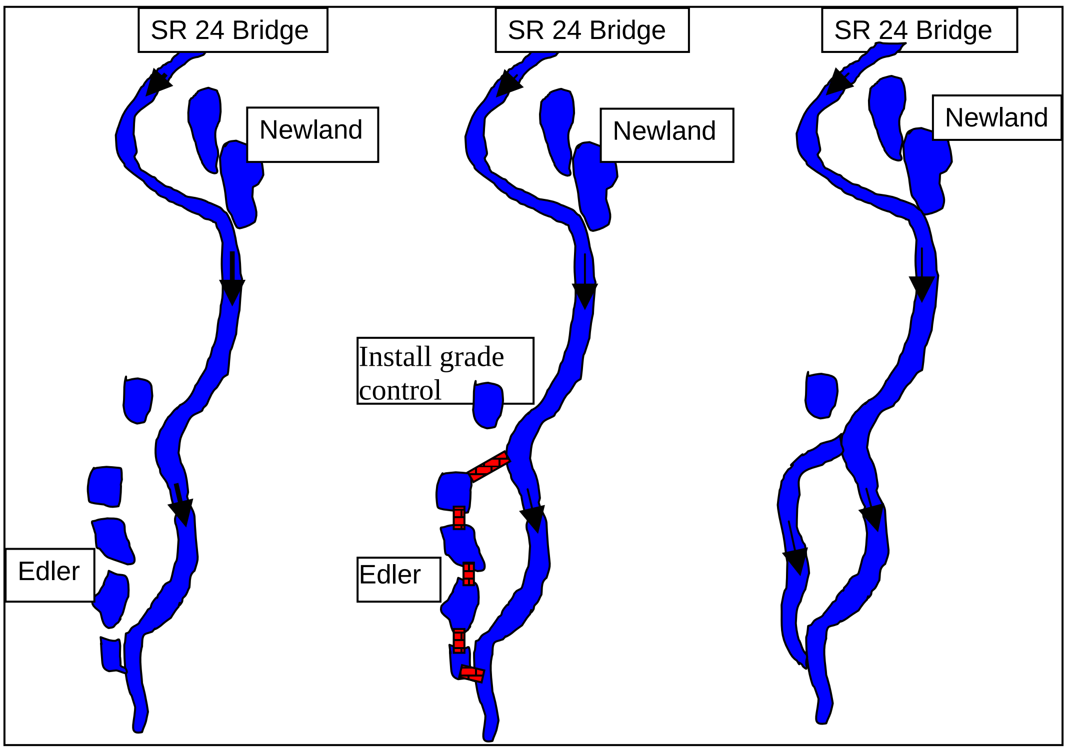

Figure 6: Series of diagrams showing the rehabilitation process of the Edler Pits. This scheme can be applied generically to many floodplain mining pit rehabilitation efforts.

A delta will form at the junction of the ingress channel and pit and will prograde downstream as sediment continues to be delivered to the pit. As with other delta formations, it is expected that the thalweg of the delta will shift laterally as sediment is delivered, fills the thalweg of the delta and forms a new thalweg. This phenomenon can not be easily documented in numerical models but can be replicated in physical models. Literature on lacustrine deltaic formations may prove helpful in predicting the behavior of sediment movement from the ingress channel into the pit.

Monitoring

A specific monitoring plan for the project will be necessary. This item has been identified in the plan of study as a final product for the research project. It is expected that monitoring will need to take place for at least 10 years. The monitoring plan will be written by the authors with assistance from partner agencies and will include tracking of habitat and fish assemblage, engineering in terms of grade control and overall stability with regards to failure (i.e. complete avulsion of the river into the pits) and geomorphic changes to the site including bank erosion, sedimentation of the pits and comparing upstream and downstream channel change to projections. The monitoring will be used to track progress and if necessary, intervene with necessary measures that could include clearing or maintaining ingress and egress channels and adjustments or removal of grade control as necessary.

In Washington and Oregon there are some projects currently underway to rehabilitate floodplain gravel pits. These efforts are generally less aggressive in scope than a complete conversion of pits to flowing water habitat as part of the main flow of the river or involve efforts to place the river back into its previous channel following an avulsion. Nonetheless, they represent case studies that can provide valuable information to this study in regards to habitat conditions during the transition period from still water to flowing water habitat and geomorphic sustainability. These projects include: the Weyco-Brisco pits on the Wynoochee River (Olympic Peninsula, WA), which are being monitored by Grays Harbor College (Norman, 1998); an avulsed pit on the Rogue River (Southwestern Oregon) which are currently being managed to force the river back into the main channel (Schnitzer, pers. comm.); a series of gravel pits on the Humptulips River (Olympic Peninsula, WA) were connected to the river at upstream and downstream locations by the mining company following mining operations. There is no formal quantitative monitoring of this project (Norman, 1998). The East Fork Lewis River avulsed into gravel pits to the south of the channel in both 1995 and 1996. The river continues to flow into and through the mining pits and it is estimated that more than 2 million yd^3 of sediment will be required to fill the pits (Norman et al., 1998). The existence of a channel survey and pit characteristics prior to the avulsions is unknown at this time.

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References

Brookes, A. (1989) Channelized Rivers – Perspectives for Environmental Management, John Wiley and Sons, p. 23.

Brown, A.V., Lyttle, M.M. and Brown, K.B. (1998). "Impacts of Gravel Mining on Gravel Bed Streams", *Transactions of the American Fisheries Society*, Vol. 127, pp. 979 – 994.

Cederholm, C.J., Scarlet, W.J. and Peterson, N.P. (1988). "A low-cost enhancement technique for winter habitat of juvenile coho salmon", *North American Journal of Fisheries Management*, Vol. 8, pp. 438 – 441.

Dunne, T. and Leopold, L.B. (1978). Water in Environmental Planning, W.H. Freeman and Company, pp. 22 - 28.

Grindeland, T.R. and Hadley, H. (2003). "Floodplain gravel mine restoration: Peril or opportunity?", in: World Water and Environmental Resources Congress, Philadelphia, Paul Bizier and Paul DeBerry (Eds.).

Kennison, H.B. and Sceva, J.E. (1963). "Effects of Hydraulic and Geologic Factors on Streamflow of the Yakima River Basin", USGS Water Supply Paper 1595, p. 112.

Kondolf, G.M., Smeltzer, M. and Kimball, L. (2002). "Freshwater gravel mining and dredging issues", White Paper prepared for Washington Department of Fish and Wildlife, Washington Department of Ecology and Washington Department of Transportation, April.

Norman, D.K. (1998). "Reclamation of flood-plain sand and gravel pits as off-channel salmon habitat", *Washington Geology*, Vol. 26, No. 2/3, September, pp. 21 - 28.

Norman, D.K., Cederholm, C.J. and Lingley, W.S. (1998). "Flood plains, salmon habitat, and sand and gravel mining", *Washington Geology*, Vol. 26, No. 2/3, September, pp. 3 - 20.

Ring, T. and Watson, B. (1999). "Effects of geologic and hydrologic factors and watershed change on aquatic habitat in the Yakima River Basin, Washington", in: Watershed Management to Protect Declining Species, Rodney Sakrison and Peter Sturtevant (eds.),. American Water Resources Association, Middleberg, VA, TPS-99-4, pp. 191 – 194.

Schnitzer, E.F., Wampler, P.J. and Mamoyac, S.R. (1999). "Floodplain aggregate mining in western Oregon", *Mining Engineering*, Vol. 51, No. 12 21-9D.

Schnitzer, E.F. (2004). “Rogue River Stakeholder Project – Phase 2: Completion Report and Year One Monitoring Report”, State of Oregon Department of Geology and Mineral Industries, Open File Report OFR O-04-14.

Weigand, D.C. (1991). “Effects of gravel scalping on juvenile salmonid habitat”, Master’s thesis, University of Washington, Seattle, 149 pp.

Yakima River Floodplain Mining Impact Study (2004), Prepared by the Yakima River Floodplain Mining Impact Study Team, Washington Department of Geology and Earth Resources, Open File Report 2004-8, June.

APPENDIX A

Study Plan for Rehabilitation of Floodplain Mines Between SR 24 and Union Gap on the Yakima River

I. Determine which portion of the river will be slated for levee setback

   a. Property ownership – Public or Yakama Nation

   b. Private land owners willing to sell property or provide a flood easement

   c. Work with USACE for permitting, deconstruction and reconstruction

II. Determine which pit(s) within levee setback reach are to be rehabilitated

   a. Depth of pits

   b. Volume of pits

   c. Proximity to main channel

   d. Geomorphic considerations

   e. Consideration of nearby infrastructure

III. Collect sediment measurement data of suspended load and bed load at strategic locations within the reach

   a. Recommend contracting through USGS

   b. Needs to begin as soon as possible to obtain a sufficient period of data collection for proper determination of sediment movement

IV. Obtain terrestrial and bathymetric data

   a. Have 2000 terrestrial LiDAR

   b. SONAR survey has been performed by USGS of Gap-to-Gap reach

   c. Obtain survey of pit(s) to be rehabilitated – this must be a survey that is tied to a known datum

V. Determine an average annual sediment load in the reach to be rehabilitated

a. Current conditions

b. Account for potential bank erosion and stored sediment following levee setback

VI. Perform geomorphic study of the relevant reach of the river

a. Location of historical channels

b. Identify controls on channel migration – CMZ

c. Determine sustainable morphology considering current hydrology and sediment load (performed in conjunction with modeling efforts)

VII. Construct a physical model of the site to be rehabilitated

a. Used to verify the 2-D sediment transport model

b. Investigate various sediment filling strategies

i. Available sediment from removed levees

ii. Sediment transported into the pit by the river

c. Investigate grade control locations and styles at upstream and downstream ends of the pit(s)

d. Help to determine the method of splitting flow and sediment between the river channel and gravel pit(s) to be rehabilitated

VIII. Concurrent with the physical model, construct and run a numerical sediment model (two-dimensional) to determine how the river will fill the pit(s) over time based on an average annual hydrograph and sediment load from 1-D sediment model

a. When run considering various strategies, will determine the final strategy to use for construction

b. Will predict the length of time required for complete rehabilitation

IX. Develop guidelines for final design

a. Inlet and outlet channels

i. Width

ii. Slope

iii. Bottom elevation

iv. Lining of the channel – if needed

b. Channel junctions with the main channel

i. Width

ii. Bottom elevation

iii. Grade control

X. Develop a monitoring plan of at least 10 years duration

APPENDIX B

Hazard Classification - Quick reference listing of the most important physical factors determining the risk of pit capture.

This hazard classification scheme highlights the most important physical factors that can be used to qualitatively evaluate risk posed by the presence of a floodplain mining pit. There are other factors less tangible that may play a role in the decision process. Although competent engineers and geomorphologists should make a final determination regarding risk, this classification can provide a general idea of the important factors related to pit capture for those less familiar with river morphology.

1. Is the average bottom elevation of the pit less than the thalweg of the main channel? If not, a complete pit capture is less likely, although the river could partially avulse into the pit to create a split channel configuration. If such a pit is captured recovery times will be relatively short and bed elevation changes will be minimal.

2. The greater the depth of a gravel pit adjacent to the river the greater the likelihood of complete pit capture and drastic effects such as an upstream migrating nickpoint, downstream sediment starvation, unpredictable channel morphology changes upstream and downstream of the pit, more severe effects to habitat, and a longer recovery time.

3. Is there nearby infrastructure that could be impacted by a pit capture? In many cases roads, bridges and other floodplain development could be threatened should the river suddenly form a new alignment. Downcutting of the riverbed can put bridges at risk of failure.

4. Are there pits nearby such that the avulsion of one pit places the adjacent pits at greater risk (see Figure B 1)?

5. Does the pit force tight bends in the river channel (see Figure B 1)?

6. Does a levee or other feature restrict channel migration on the opposite bank?

7. Is the location of the pit coincident with a former channel alignment (< 100 years)?

8. Is the dike or levee separating the pit from the river susceptible to overtopping or erosion for an event less than local design criterion? (e.g., 100-yr flood)

9. What is the distance from the nearest portion of the pit to an active portion of the channel? Pit captures have occurred at distances much greater than 150 feet.

10. Is the channel situated in such a way that channel migration is likely to capture the pit at the upstream or downstream end? That is to say, will a downstream outlet be formed following an avulsion? See Figure B 2 for further explanation.

11. Is the pit currently connected to the river?

Figure B 1: Aerial photograph showing a bend in the channel alignment (prior to avulsion the channel flowed between the groups of mining pits) forced by the presence of the mining pits. Photograph is of the Daybreak Mine Area on the East Fork of the Lewis River, Oregon (Photo courtesy of Thomas Grindeland, WEST Consultants).

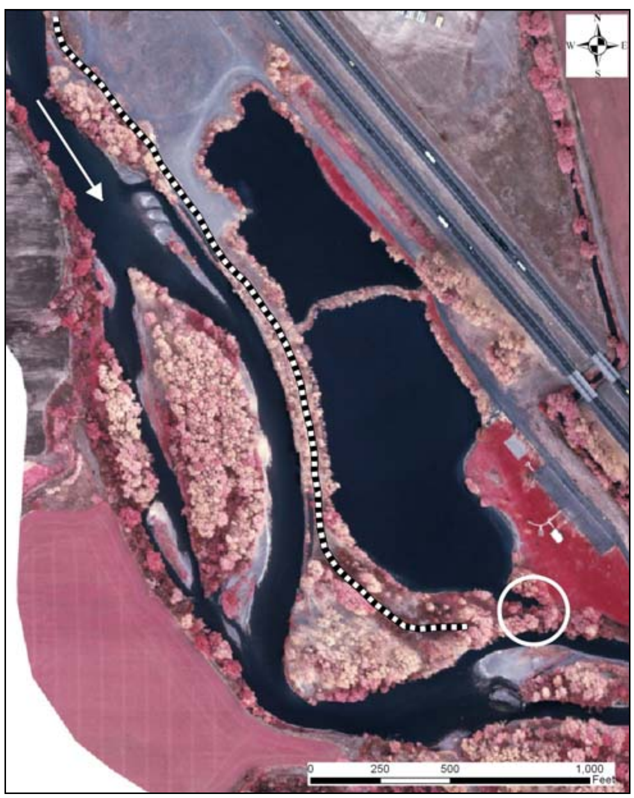

Figure B 2: Aerial photograph showing a floodplain gravel pit with a potential avulsion point at the downstream end shown by the white circle. For the purpose of this discussion, assume that there is a competent levee shown by the dashed line. An avulsion at the downstream end, indicated by the circle, would not create a situation where the river would capture and occupy the gravel pit. This situation poses a lesser risk than if the levee avulsed at the upstream end.