Flood Plains, Salmon Habitat, and Sand and Gravel Mining

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INTRODUCTION

People who live or work along rivers and their flood plains know these are hydrologically and biologically dynamic environments. Rivers flood and shift their courses from time to time, resulting in natural cycles of erosion and deposition of sand and gravel. The river and its banks are also home to many fish and wildlife species. In this age of rapid land development, however, people have turned to rivers (dredging and gravel bar mining) and flood plains (gravel pit lakes) as sources of sand and gravel for construction aggregates.

Gravel mining practices such as channel dredging are typically done with either a dragline or suction dredge (Fig. 1) and are conducted mostly in the Columbia River, where a shipping channel is maintained, and the Cowlitz River, where large volumes of sediment from the 1980 Mount St. Helens eruption are still being deposited. Gravel bar mining (scalping) (Fig. 2) is performed in many Washington rivers for aggregate and in an attempt at flood control (Collins, 1996). Miners no longer dig into the banks of rivers (Fig. 3). Also, the Army Corps of Engineers, state agencies, and some local governments have recognized the environmental effects of in-stream mining. The Grays Harbor County Planning Department, for example, has mandated reduced rates of gravel removal on the Satsop, Wynoochee, and Humptulips Rivers (Collins and Dunne, 1990). (See Fig. 6.)

Flood-plain mining, digging gravel pit lakes adjacent to rivers, is a common activity in Washington. "Flood plain" as defined in Washington's Shoreline Management Act (Revised Code of Washington [RCW] 90.58) means the 100-year flood plain, the area susceptible to flooding by a stream for which there is a one percent chance of inundation in any given year (Washington Department of Ecology, 1994). The 100-year flood plain definition must be used with caution because the small flood-frequency data sets result in large potential for error in identifying the 100-year event and determining the area affected (Mount, 1995). Also, as watersheds become more developed and roofs and roads present large areas of impermeable surfaces, high-intensity peak runoff occurs more frequently and with greater volume (Booth, 1991). The definition of the 100-year flood plain is important in Washington because most regulation of development and mining depends on where this "line" is drawn. Furthermore, the geomorphic flood plain, or the area where fluvial erosion has created a flat valley, is generally much larger than the "calculated" 100-yr flood plain and is where mining occurs.

Flood plains support diverse plant and animal populations, as well as much of our agricultural system (Teskey and Hinkley, 1977). Vegetation along river banks provides habitat for most wildlife. Significantly, the riverine environment is home to the many species of Pacific salmon (*Oncorhynchus* sp.) indigenous to Washington (Palmisano and others, 1993; Washington Department of Fish and Wildlife, 1997; Sedell and Luchessa, 1982). The riparian area is where aquatic and terrestrial ecosystems interact and is essential to both fish and wildlife. Streamside plants shade the water, help moderate water temperature, and promote stream-bank stability, as well as providing the organic nutrient load in the aquatic ecosystem. These plants are the source of large in-stream woody debris that provides refuge and food sources (Washington Department of Natural Resources, 1996). Salmon use gravel channels for spawning and clay-bottom channels, with their rich subaqueous flora, for overwintering, feeding, and refuge. Side-channels (yazoo tributaries) and oxbow lakes are types of wallbase channels (Fig. 4A) or off-channel sites that are primary overwintering habitats for juvenile coho salmon and cutthroat trout (Peterson, 1980; Cederholm and Scarlett, 1981;

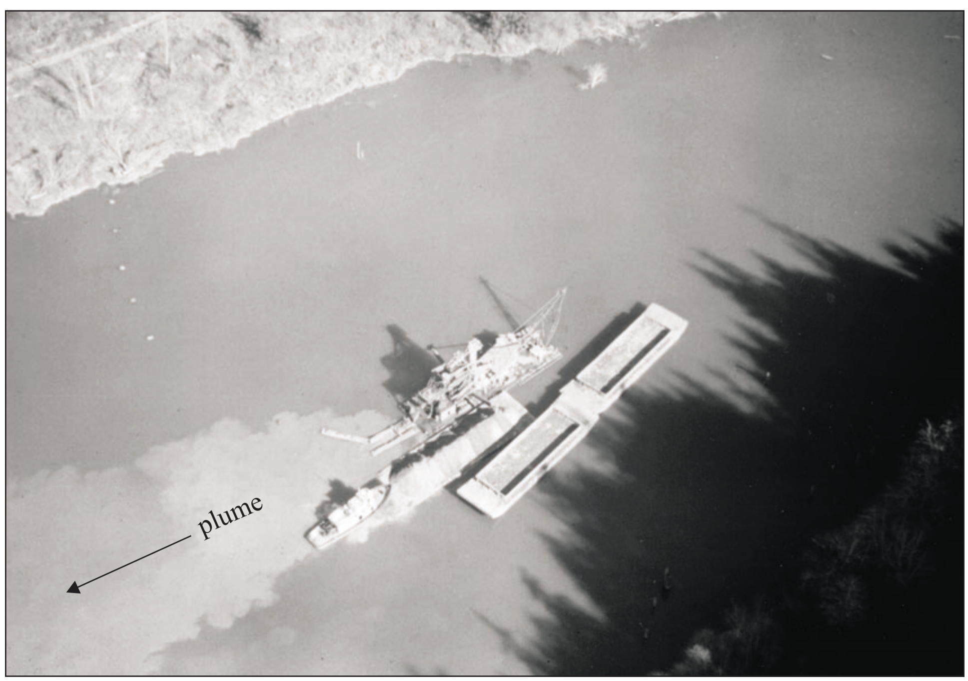


Figure 1. A suction gravel dredge and barges at work in the Chehalis River in the mid-1960s. This type of mining now occurs chiefly in the Columbia and Cowlitz Rivers to remove sediment deposited after the Mount St. Helens eruption. Note the suspended sediment plume moving downstream. (Photo by Lloyd Phinny, Washington Department of Fisheries.)

Peterson and Reid, 1984; Cederholm and Scarlett, 1991). Wallbase channels commonly look like swamps, ponds, or small tributaries and are connected to the main stem of the river by a small stream called an ingress/egress channel.

Rivers in Washington generally have steep gradients and V-shaped cross sections in their upper reaches. Headward erosion occurs where stream gradients rapidly steepen, as in the Olympic and Cascade mountains. As the rivers approach the ocean or find their way across the Columbia Basin, gradients decrease, valleys broaden, flow velocity decreases, and gravels are deposited. Deposition is greatest at the gradient changes. The river accommodates this aggradation by lateral (horizontal) migration. Traces of channel shifts and stream meanders are common flood-plain features; oxbow lakes and side channels are testament to the history of this activity (Fig. 4A,B).

Flood-plain gravel mining generally occurs where the gravel bedload has been deposited, for example, at gradient changes or above or below topographic constrictions through which a river flows (such as Union or Selah gaps on the Yakima River). In Washington, many gravel pits near rivers have been excavated for fill material for major highway projects, a process that further complicates flood-plain functions. Examples are I-90 along the Yakima River, I-5 where it crosses the Skookumchuck River at Centralia, I-82 near metropolitan Yakima on the Yakima and Naches Rivers, and in several places along the East Fork Lewis River near Vancouver. Gravel sources located near the point of use significantly reduce the cost of the aggregate.

Seeking the lowest cost material, gravel miners commonly choose to excavate large, deep ponds adjacent to active river channels (Fig. 4A). These pits have the potential to significantly change the physical and ecological function of flood plains (Collins, 1996, 1997). Wherever a channel shifts into a gravel pit or multiple pits that are large relative to the scale of the flood plain and the river's sediment transport regime, natural recovery of original flood plain environment and similar channel morphology could take millennia (Collins, 1997). The time for recovery is highly dependent on the availability of sediment, particle size, gradient, and the size of excavations to be filled.

Regardless of the best planning and intentions, impacts of flood-plain mining may simply be delayed until the river is captured by the gravel pit. While capture may not occur in the next 100-year flood event, it is likely to occur in the future as development and consequent flood magnitude increase. In the long term, stream capture by gravel pits is a near certainty. Because the gravel pits have a lower base elevation, there is risk of rapid channel change into the pits during high flows, a process termed avulsion. The flooded pits "capture" the stream. The effects of avulsion are similar to those of in-stream mining discussed in Evoy and Holland (1989), Collins and Dunne

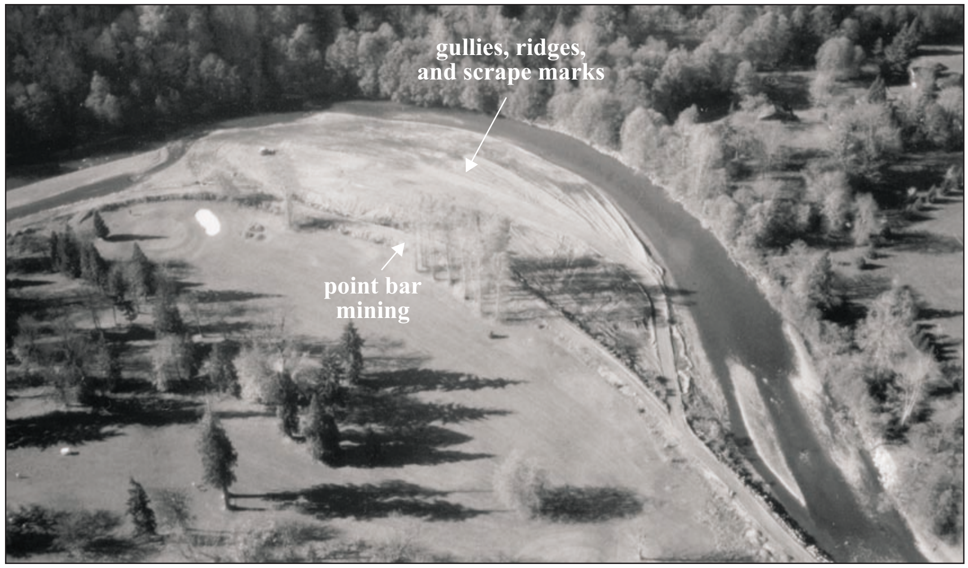


Figure 2. Scalping a point bar in the Wynoochee River in about 1965. Current rules require that the post-mining ridges and gullies on the gravel bar to be graded to 2 percent toward the river and that no areas where fish could be trapped remain. Gravel bar mining has been restricted in several rivers, such as the Wynoochee where over-mining of gravels was proven by gravel bedload transport studies conducted for Grays Harbor County (Collins and Dunne, 1990). (Photo by Lloyd Phinny, Washington Department of Fisheries.)

Figure 3. This plume of turbid water (lighter gray area at top) from a gravel mine on the Wynoochee River was created by bar scalping and shoreline mining, no longer practiced in Washington. The small pond at the left center of the photo was used as a settling pond. Note turbid water discharge from the sediment pond to the river at the center of photo. (Photo taken about 1965 by Lloyd Phinny, Washington Department of Fisheries.)

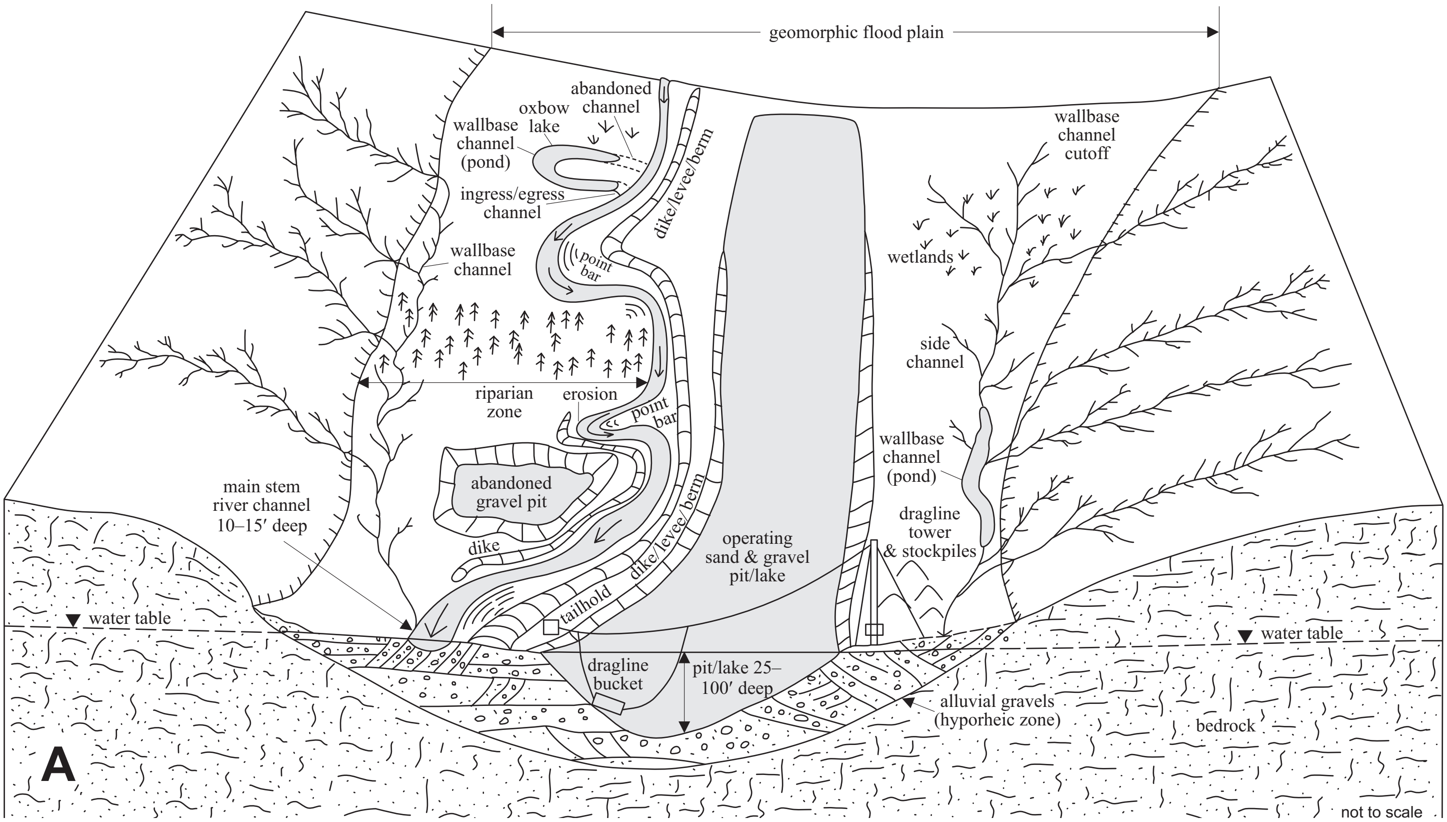
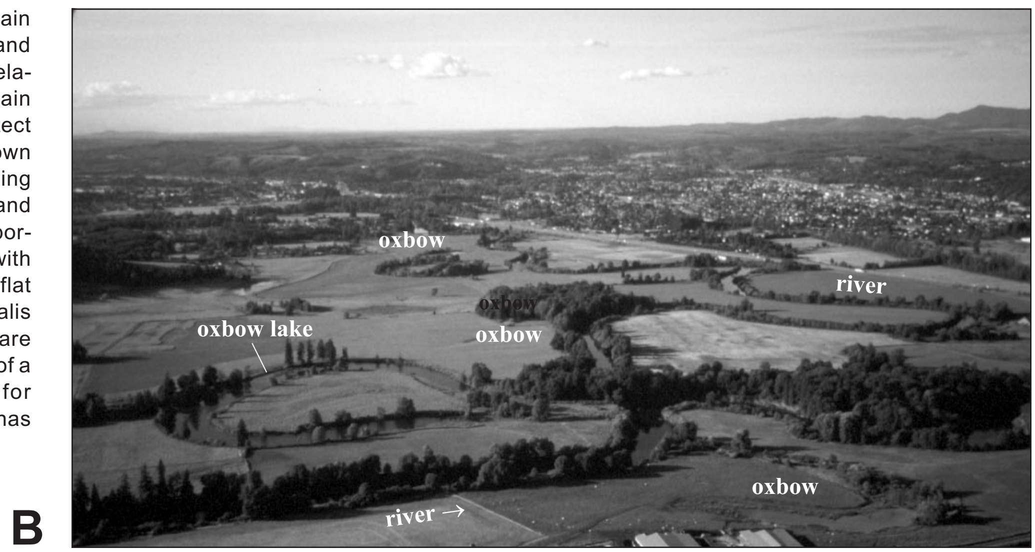


Figure 4. **A.** Diagram showing a flood plain with an active, meandering river channel and dragline digging a gravel pit. Note the relation of the pit to the water table and main stem river channel with dikes built to protect the pit and channelize the river. Also shown are point bars, wallbase channels (including side channels, ponds, and oxbow lakes) and associated wetlands, all of which are important for salmon habitat. **B.** Oxbow lakes with narrow riparian zones on the broad and flat Chehalis River flood plain near the Chehalis airport. Oxbow lakes such as these that are hydraulically connected to the main stem of a river can provide off-channel habitat for salmon. Here, much of the riparian zone has been removed for agriculture.



(1990), Netsch and others (1981), Kondolf and Graham Matthews (1993), Kondolf (1993, 1994), and Williamson and others (1995a,b). They may include:

- lowering the river bed upstream and downstream of mining operations, causing river bed erosion and (or) channel incision and bank erosion and collapse,
- eroding of footings for bridges or utility rights-of-way,
- changing aquatic habitat,
- unnaturally simplifying the complex natural stream system,
- increasing suspended sediment, and
- abandoning reaches of spawning gravels or damaging these gravels by channel erosion or deposition of silts in spawning and rearing reaches.

Flood-plain mine lakes, the loss of natural flood-plain habitat, and the isolation of the flood plain from its river by armoring and dikes that protect against avulsion are semipermanent consequences of flood-plain mining. Careful reclamation may restore some of the previous function of a flood plain; however, it may be impossible to replace lost habitat in the near term if a substantial amount of a flood plain has been converted to pit lakes (Collins, 1996, 1997).

Careful siting, planning, limiting mining, a thorough hydrogeological analysis, use of alternative resources, and innovative reclamation can mitigate and reduce some mining impacts. This article describes river processes and mining operations and discusses some examples of flood-plain mines. Reclamation of these mines is the subject of the article by Norman (this issue, p. 21).

FLOOD-PLAIN HYDRAULIC PROCESSES

Many Washington river valleys reflect millions of years of fluvial processes and in some places modification by glaciers. Most lowland river valleys are filled with alluvial sand, gravel, silt, and clay, which have been spread out across the adjacent vegetated flood plains wherever flood flows have left the main channel. Small irregularities in the channel cause local variations in flow velocity, which in turn contribute to variations in erosion and sediment deposition. From these variations, the river begins slow lateral displacement, depositing on one stream bank while eroding, scraping, and undercutting the other bank as it gradually migrates from side to side across its valley floor. The valley widens over time by erosion, particularly on the outside of river bends and where the flow impinges against the valley walls. The river's course appears snakelike when viewed from above (Leopold and others, 1964).

The water strikes with greatest force against the outer (concave), downstream bank of the meander bend, causing erosion. Flow is slower on the inside (convex) bank of a meander where deposition occurs. These deposits are called point bars, gravel bars, or lateral accretion surfaces. Over time, meanders can enlarge sideways and shift downstream by a combination of erosion and sedimentation processes. A meandering river generally retains the same approximate channel width, but a given river channel may eventually occupy most parts of a flood plain throughout its geologic history (Fig. 4A,B).

Meander bends do not enlarge indefinitely because they become sizable detours for the flowing water. Eventually, the river will cut off a meander and abandon the longer, curved channel for the shorter, more direct route. The cutoff meander sections are termed oxbows. Where they are filled with water, they are called oxbow lakes or ponds (Fig. 4A,B). Meander cutoffs most commonly occur during floods, when large volumes of water have enough additional momentum to carve the shortcut and bypass the meander bend.

As river profiles or individual reaches become stable over a period of years, they achieve a balance between erosion and deposition. At equilibrium, the river or a reach is a graded stream, one in which the slope, velocity, and discharge combine to transport its sediment load with neither erosion nor sedimentation (Mackin, 1948). That balance is governed by the elevation of its base level (for example, an adjacent ocean or lake level) and the many physical and biological factors that control equilibrium. Base levels and the stream's equilibrium profile can be altered by human intervention, such as dam building, activities that cause river avulsion, or removal of gravel bars. Gradually the stream's profile will reach a new equilibrium, but this may change the distribution of erosion and deposition sites and also the shape of the channel.

A flood plain is a flat or gently sloping region along a stream channel, typically extending laterally to the adjacent slopes, onto which the stream expands during floods (Fig. 4A,B). With time, lateral erosion associated with meandering, channel sediment deposition, and additional overbank sedimentation during floods combine to create a flood plain. The width of the flood plain is a function of many factors, including the size of the stream, relative rates of meander migration and downcutting, and the ease with which the valley walls are eroded. During periods between floods, the meandering stream occupies only a portion of the breadth of the flood plain. Slow lateral channel migrations over long periods of time tend to maintain a single flood plain with a fairly level surface. In aggrading reaches, where cobbles and boulders are the dominant bedload and sediment transport rates are high, the river may take on a braided morphology. Braided rivers are characterized by a channel dividing and reuniting in an intricate interlaced fashion. Early maps of the state show that many rivers flowing from the Cascades had braided channels.

If conditions are suddenly and significantly changed, relative rates of meandering and downcutting may accelerate, and the old flood plain may be cut up by development of new, narrower channels. Incision can result from an increase in the river's discharge, reduction in the size of its bedload, dredging, avulsion into a gravel pit, or upstream levee construction.

As a valley widens, the stream's flood plain also widens. The flood plain width can be limited, as it is along the entrenched Yakima River canyon between Ellensburg and Roza dam (Figs. 5, 6), or very broad, as it is along the Chehalis River downstream of Oakville, where it is more than 2 mi wide (Waitt, 1979; U.S. Army Corps of Engineers, 1970). A flood plain's width can also be out of proportion to its river channel. For example, the Chehalis River appears to have an undersized channel in the wide valley along its lower reaches. During the Pleistocene epoch, the Chehalis River valley was the outlet for the enormous amounts of glacial outwash and meltwater from the Puget ice lobe (Bretz, 1913; Eddy, 1966). The modern Chehalis River drains a much lower and smaller watershed area. The upper reaches of rivers such as the Stillaguamish, Cowlitz, and east fork of the Lewis (Mundorff, 1984) flow in more restricted glacier-carved valleys; only in the lower parts of these valleys do they appear underfit in proportion to their overall flood-plain size.

Figure 5. Yakima Canyon near Umtanum gaging station; view to the north, toward Ellensburg. Note the entrenched river with meander loops cut into the basalt flows. The resistant basalt constrains the channel, and no flood plain can develop here, and no off-channel habitat can be created as on a flatter flood plain.

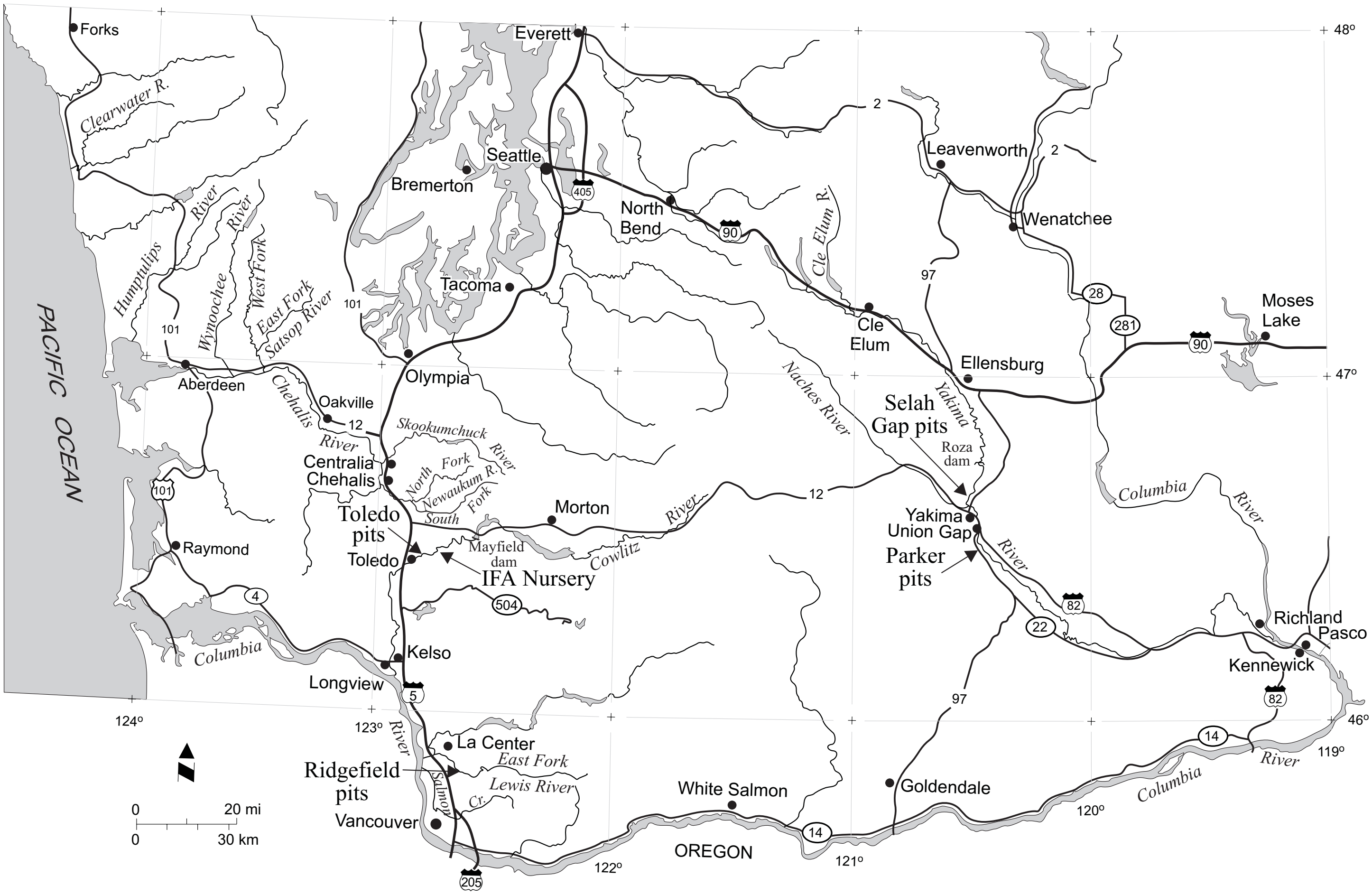


Figure 6. Rivers, towns, and flood-plain gravel mines in Washington referred to in this article.

BIOLOGICAL PROCESSES IN FLOOD PLAINS

Off-Channel Habitat for Salmon

Rivers are not isolated ribbons of water flowing through a valley; they are connected to their valleys and flood plains by both surface water and shallow ground-water sources (Collins, 1996). Wallbase channels (Fig. 4A,B) form on flood plains where runoff reoccupies abandoned channels created by the migration of main stem rivers (Peterson and Reid, 1984). Wallbase channels develop along meander scars and oxbows or behind gravel bars; in most places they appear as swamps, ponds, or small tributaries and are connected to the main stem (Fig. 7).

During spring and fall, juvenile salmon migrate out of main rivers into tributaries, including wallbase channels, where they seek refuge from high flows and turbidity for varying periods of time (Cederholm and Scarlett, 1981; Peterson and Reid, 1984; Peterson, 1982; Scarlett and Cederholm, 1984; Brown and Hartman, 1988). In fall, these movements are initiated during the first freshet (Peterson, 1980). Increased discharge and turbidity in the main river relative to clear water flowing from wallbase channels attracts large numbers of juvenile coho and cutthroat. While in these channels, salmon take advantage of a rich food supply of aquatic insects and relatively stable hydrological conditions. Juvenile salmon typically feed in the shallows and seek cover from predators in deeper water or in woody debris complexes and emergent vegetation. The growth that the juvenile salmon immigrants (Fig. 8) are able to acquire in these habitats improves their overall size and survival rates (Peterson, 1980; 1982).

Poorly planned mining exposes these salmon habitats to potential avulsion. Many gravel pit mines have been established in active wallbase channels, sloughs, and (or) marshes (Collins, 1996, 1997), resulting in destruction of salmon habitat. In rare instances, flood-plain mining has created effective off-channel habitat (see Norman, this issue, p. 21).

Benthic Insects and the Hyporheic Zone

Benthic macroinvertebrates are an important food source for juvenile salmon (Mundie 1969). Many benthic invertebrates, such as caddis flies, mayflies, and stone flies, spend all or part of their lives in a clean gravelly substrate that has abundant oxygenated water (Pennak 1978; Merritt and Cummins, 1984). Healthy streams are characterized by a high species diversity of benthic macroinvertebrates and a moderate number of individuals of any given species group (Brookes, 1989). Unhealthy streams, on the other hand, are characterized by low species diversity and large numbers of individuals in any species group.

The hyporheic zone (Fig. 4A), the shallow unconfined aquifer under the flood plain that is in hydraulic continuity with the river, may extend miles horizontally across the width of the flood plain and many yards beneath the surface (Stanford and Ward, 1988). This zone provides extensive interstitial (intergranular) habitat for benthic macroinvertebrates. The hyporheic zone serves as a refuge for benthic insects during droughts and high-flow events, and it is capable of resupplying the population of an area at and immediately below the stream bed once conditions in the stream improve. This zone plays a major ecological role in streams, especially those

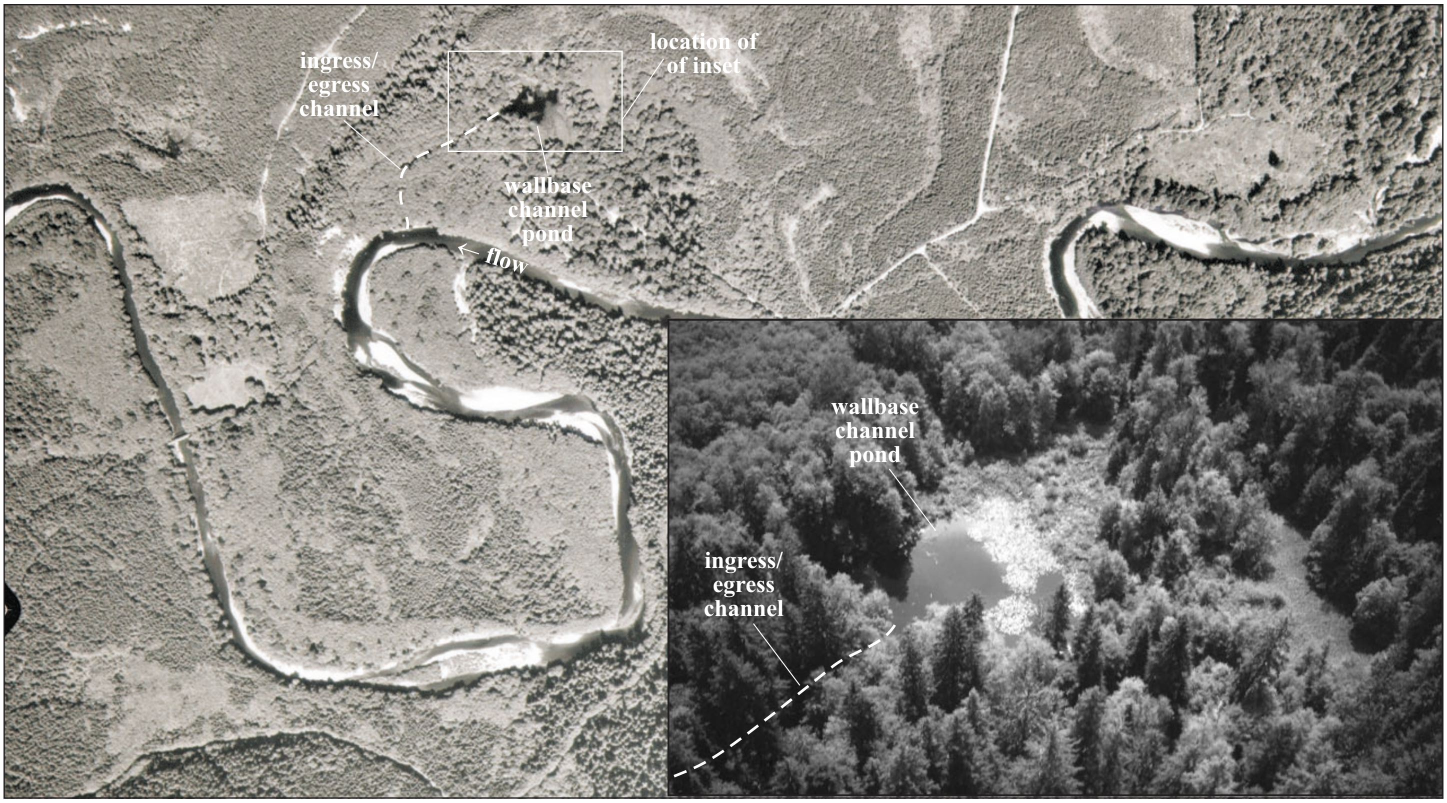


Figure 7. A wallbase channel pond on the Clearwater River that serves as off-channel habitat for salmon. This pond covers only 3 acres and has a maximum depth of 12 ft. This remnant of a channel cutoff is partially covered with lily pads and is surrounded with a robust riparian zone. The inset shows a close-up of the pond area.

that have coarse substrates where most aquatic insects spend important parts of their life cycle (Ward, 1992). Overly large and deep flood-plain mines may significantly interrupt local hyporheic processes through removal of gravels and (or) by changing water-table elevations.

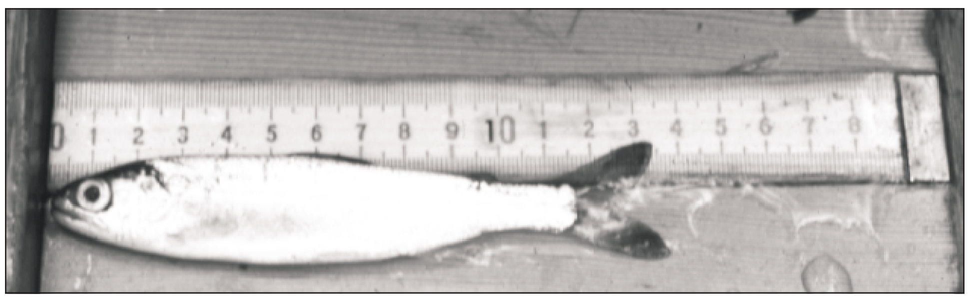


Figure 8. Coho smolt being measured for growth after spending the winter in the pond shown in Figure 7. Scale is in centimeters. Smolts that spend the winter in wallbase channels and ponds are 25 percent longer and weigh more than smolt that migrate immediately to the ocean (Cederholm and Scarlett, 1991). Coho that overwinter in ponds such as this one grow larger and have a better chance of survival once they migrate to the ocean.

Effects of Avulsion

Salmon depend on a river system that functions well. Salmon lay their eggs in gravels, where cool, oxygenated water flows freely over the eggs, assuring their normal development. Generally, the most productive river substrates are those that are stable and have a wide range of particle sizes. They also produce the most diverse invertebrate populations (Brookes, 1989). If the gravel substrate is disturbed or is filled and covered by silt and clay, as can happen during floods and avulsion episodes, salmon egg nests (redds) can be eroded away or smothered. Additionally, the benthic invertebrate community is likely to change and become less productive when the stream bed is altered. Where velocities are persistently high, many kinds of benthic macroinvertebrates may be absent.

When a river breaches a pit, the river biota can be catastrophically changed. Water temperatures may rise during summer and early fall because the relatively slack water in the pits is exposed to sunlight for long periods. Water temperatures above 75°F may be fatal to some salmon species, and temperatures between 60° and 75°F can increase their metabolic rates and stress levels. While moderate increases in water temperature can increase growth rates, large increases can cause disease outbreaks and may kill significant numbers of adult and juvenile fish (Bjornn and Reiser, 1991).

Pits that are warmer than the adjacent river may be ideal habitat for warm-water fish, such as large mouth bass or yellow perch, which are predators of juvenile salmon (Kondolf and others, 1996). This may be particularly applicable in the lower reaches of the Yakima River, where low flows and warming river water during summers is a chronic problem. Additionally, smolting juvenile salmon may become disoriented in the quiet waters of a pit that has been captured by a river (Ken Bates, Washington Department of Fish and Wildlife [WADFW], written commun., 1998).

RIVERS AND FLOOD PLAINS AFFECTED BY MINING IN WASHINGTON

Flood-plain mining has occurred on many rivers in Washington State and is highly concentrated along the Yakima River and its tributaries (Naches and Cle Elum Rivers), the Chehalis River and its tributaries (Wynoochee, Satsop, Newaukum, and Skookumchuck Rivers), and the Cowlitz River and East Fork Lewis Rivers (Fig. 6)(Collins, 1996, 1997). Collins estimates that about one-sixth of Washington's gravel production was removed from riverine sources between 1970 and 1991, and most of this mining was located on flood plains and active gravel bars. However, this paper does not attempt to address all the flood-plain gravel pits in the state.

Many currently permitted mines cover several hundred acres of flood plain that have been excavated or are scheduled for excavation. The depth and size of many of these mines was restricted by economics and the types of machinery used.

Gravel mining has created pit lakes ranging from a few acres to several hundred acres and with depths averaging about 30 ft. Several mined lakes are as deep as 90 ft, and some are as much as five times as deep as the adjacent river. Some of these deep lakes are within 50 ft of the active river channels. This head differential makes them highly vulnerable to river avulsion during high flows. Rivers have avulsed at several mines in Washington (see Table 1) in the last 14 years, most of them during storms in 1995 and 1996.

Some Effects of River Diking and Channelization

Mining in depositional reaches commonly occurs on both sides of a river (for example, mines on the north and south banks of the East Fork Lewis River). The typical method of attempting to prevent a river from flooding a pit is armoring the active channel bank with riprap or building dikes and levees. Where bank armoring and dikes tend to minimize lateral erosion, they may reduce the supply of sand and gravel to the active channel and prevent maintenance or creation of habitat diversity in both the main stem river and side channels.

Channelization using bank armoring and dikes attempts to confine the river to one main channel and prevent it from migrating across the flood plain. Channelization can smooth and (or) straighten a channel, a process that reduces energy dissipation and moves channel and bank instability and flooding problems (as well as increased sediment load) to downstream reaches. When the channel or thalweg (the deepest part of the channel) is moved or deflected by levees or dikes, the realignment may temporarily affect the downstream channel and banks as the thalweg scours through salmon spawning habitats or impinges on channel banks (WADFW, 1998).

Channelization can change flow velocity and the substrate, which may change benthic macroinvertebrate populations on which fish depend for food (Brookes, 1989). Additionally, where armoring interferes with natural meander patterns, any deposition will be confined to the active channel. Sediment may have to be removed on a regular basis just to maintain channel depth and flow capacity (Brookes, 1989). Gravel buildup in channelized rivers can result in the river being perched above adjacent flood plains—and the adjacent gravel pits—and making it prone to avulsion.

Some levees (also called flood berms) that are used to protect gravel pits from flooding and avulsion are composed of materials originally carried by the river to the pit site. The materials are, therefore, of a size that the river can easily transport again. These dikes can be washed away during a flood or gradually made porous as fines are washed out. Through this washing process a levee can become a windrow of unconsolidated gravel that is highly vulnerable to collapse. Channel migration and single-event bank failures reduce the width of the dike and weaken it.

Additionally, dikes and levees can be damaged by dewatering an adjacent pit by pumping or flow though an outlet channel. During floods, when the river's level is abnormally high, a large static head exists between the higher river water surface and that of the pit. Here, the potential for dike collapse and avulsion is great. The dikes are weakened by the constant head difference. Floods that overtop dikes can allow a river to rapidly cut through these structures as the flow drops from the river surface into the pit, causing headward erosion. In effect, dikes and levees are only short term solutions to long term natural processes such as channel migration and flooding.

Consequences of River Avulsion

Typically, avulsion occurs during floods. Avulsion is characterized by a sudden change in the course of a river that causes it to break through a low point such as a meander neck (to form an oxbow lake) or to rush into a gravel pit. Avulsion events occur in gravel pit lakes because the pit surface is lower than the river. The old river channel can be partially or completely abandoned in the avulsion process.

Pits are typically wider and deeper than the river (Fig. 4A) and out of proportion to the overall scale of the river (Collins, 1997; Woodward-Clyde Consultants, 1980a,b). The severity of the consequences of breaching pits depends on the relative scale of the mining operation and the river. Significant amounts of material must be moved from the river bed and banks to fill a deep pit.

Once avulsion and breaching begin, the knickpoint, where the river enters the pit (Fig. 9), immediately moves upstream, and the riverbed starts to be scoured (Kondolf, 1993; Kondolf and others, 1996; Collins and Dunne, 1990; Collins, 1996, 1997). This scouring cuts downward and lowers the river elevation, a condition called incision. Avulsion into gravel pits by the Clackamas River at Clackamas, Oregon, in February of 1996 resulted in incision of more than 2 yards over a distance of one-third of a mile upstream of the pit (Kondolf and others, 1996). Hazardous consequences of this kind of erosion can be undercutting of levees, bridge supports, pipelines, and utility towers and other structures. For example, when a gravel pit on the alluvial fan of Tujunga Wash near Los Angeles, California, captured the river, the knickpoint migrated upstream to undermine nearby highway bridges (Scott, 1973).

The negative effects caused by breaching a small (5 acres or less) or shallow (10 ft) flood-plain pit may be negligible and may add channel complexity to a channelized river. If the pit is small and shallow relative to the river, it may quickly fill with sediment. However, even small gravel pit lakes in locations that are prone to avulsion or near structures can be problematic. For example, in Clark County near Vancouver where Salmon Creek crosses I-5, an avulsion in 1996 into small (<5 acres) gravel pits caused 4 ft of knickpoint incision at a county bridge 1/4 mi upstream and has created a fish passage barrier for steelhead, a threatened species on Salmon Creek (Ken Bates, WADFW, oral commun., 1998).

After avulsion has occurred, the temporary fluvial base level is the pit bottom. Therefore, for a considerable distance upstream, the river channel tends to incise and straighten as it works to establish a new equilibrium and grade. Because of this, existing channels (and salmon habitat) may be abandoned and replaced by a deep channel as wide as the pit. Sediment eventually fills the pit, and a new stream channel is formed. While the breached pit is gradually filling with gravel from upstream sources, little gravel will be transported past the pit to downstream areas. The downstream channel and bars consequently will erode if they are not replenished with coarse bed material. The river, in essence, mines its own gravel bars, becomes less stable, and is inhospitable to salmon.

The time required for the river to re-establish equilibrium depends on the size and depth of the pit, the river's ability to transport sediment, and the availability of sediment (Woodward-Clyde Consultants, 1980a,b). It can also depend on the instabilities caused by the headcut upstream or bedload depletions downstream. If the river has already eroded down to bedrock in its upper reaches and sediment is not available, equilibrium may not be re-established for a very long time.

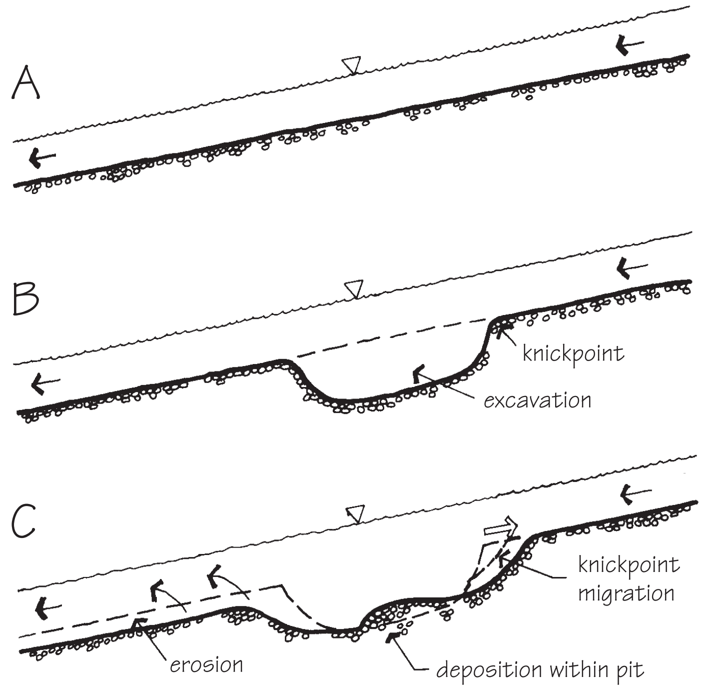


Figure 9. **A.** A profile of a streambed before mining. **B.** The same profile showing a depression excavated in the stream bed when stream flow is not strong enough to move the bedload. The knickpoint is where the stream profile abruptly changes. **C.** During high flows, or once avulsion and breaching begin, the knickpoint immediately retreats upstream as the sediment at that location is removed by erosion and deposited in the pit or downstream and the river tries to re-establish its grade and equilibrium. The high flow also attacks the downstream side of the depression where the slope also changes. (Modified from Kondolf, 1993.)

EXAMPLES OF FLOOD-PLAIN SAND AND GRAVEL MINING AND STREAM CAPTURE

Recent avulsion and stream capture events at gravel mines in Washington are listed in Table 1. The following paragraphs discuss some of these events.

Cowlitz River Upstream of Toledo

In November 1995 after heavy rains, the Kirkendoll revetment at river mile 38 on the Cowlitz River failed (Fig. 10). About a quarter of the Cowlitz flow rushed through the opening and across the IFA Nursery, then found its way to a gravel pit near the river 3,200 ft downstream between river miles 36 and 37. The mine pit partially filled with sediment and debris in a matter of days. Part of the river severed access to about 13 homes until residents were able to construct a temporary dike of loose sand and gravel across the breached area as waters receded. During the February 1996 (Fig. 11) event, the Cowlitz River breached this temporary dike and re-established itself in the 1995 channel. During the November 1995 event, the Cowlitz River flow was greater than 68,400 ft^3/sec as measured below Mayfield dam, approximately 18 mi upstream. (This value is the maximum flow that can be recorded on that instrument, and no estimate was made as to amount of flow above that value.) During February 1996, the flow at the Mayfield dam was not as high, but tributaries downstream of the dam were contributing more water than they had in November 1995 (Stephanie Zurenko, Washington Department of Natural Resources [WADNR], oral commun., 1997).

Because the pits behind the Kirkendoll revetment were only 20 acres in area and less than 20 ft deep, no obvious changes to the grade of the river occurred. During flooding and filling of the pit, scouring deepened the new channel and a knickpoint migrated upstream, as evidenced by a moving wave immediately upstream of the pit and at the revetment (Stephanie Zurenko, WADNR, oral commun., 1997). However, no agencies did a survey of the elevation of the river bed before and after the avulsion to determine if the event had caused incision.

When the February 1996 flood receded, water was diverted back into the pre-November 1995 channel by repairing the dike. The scouring and downcutting between the IFA Nursery and the gravel pit were then evident. According to the U.S. Army Corps of Engineers, complete abandonment of the 1995 channel would likely have occurred if the revetment had not been replaced and reinforced with riprap in the summer of 1996 because the existing Cowlitz River bed was higher than the area protected by the revetment (Stephanie Zurenko, WADNR, oral commun., 1997). Most of the material deposited in the pit consisted of fine sediment. The large amount of sand, silt, and soil present was probably derived from the nursery. Stumps and logs were also deposited in the pit. Because of the debris, miners now use an excavator rather than the former dragline to excavate gravels. The large volume of sand, soil, and debris in the pit likely makes this gravel mine less valuable.

Table 1. Recent avulsions or stream captures

Location or operation	River	Year	Location	Date mined	Acres
Upstream Ridgefield pits	East Fork Lewis	1995	sec. 19, T4N, R2E	1960s	6
Ridgefield pits	East Fork Lewis	1996	secs. 13, 24, T4N, R2E	1980s-90	70
Salmon Creek Park ponds	Salmon Creek	1996	sec. 35, T3N, R1E	early 1970s	5
Pits upstream of Toledo	Cowlitz	1995, 1996	sec. 10, T11N, R1W	ongoing	20
Gravel pits at Toledo	Cowlitz	1995, 1996	secs. 8, 17, T11N, R1W	ongoing	108
Mouth of Wynoochee River	Wynoochee	1984	sec. 18, T17N, R7W	1960s	20
Walker pit	Yakima	1996	sec. 36, T11N, R20E	ongoing	12
Parker pit	Yakima	1996	sec. 20, T12N, R19E	1980s	35
Selah Gap pits	Yakima	1996	sec. 31, T14N, R19E	ongoing	250
Gladmar Park	Yakima	1996	sec. 13, T18N, R17E	1960s	30
I-90 pits	Yakima	1996	sec. 29, T18N, R18E	1960s	20

Cowlitz River at Toledo

Extensive gravel mining occurs along the Cowlitz River at Toledo (Fig. 12). Before the mid-1930s, the course of the Cowlitz River near the gravel pits between river miles 34 and 35 consisted of two or more channels (Collins,

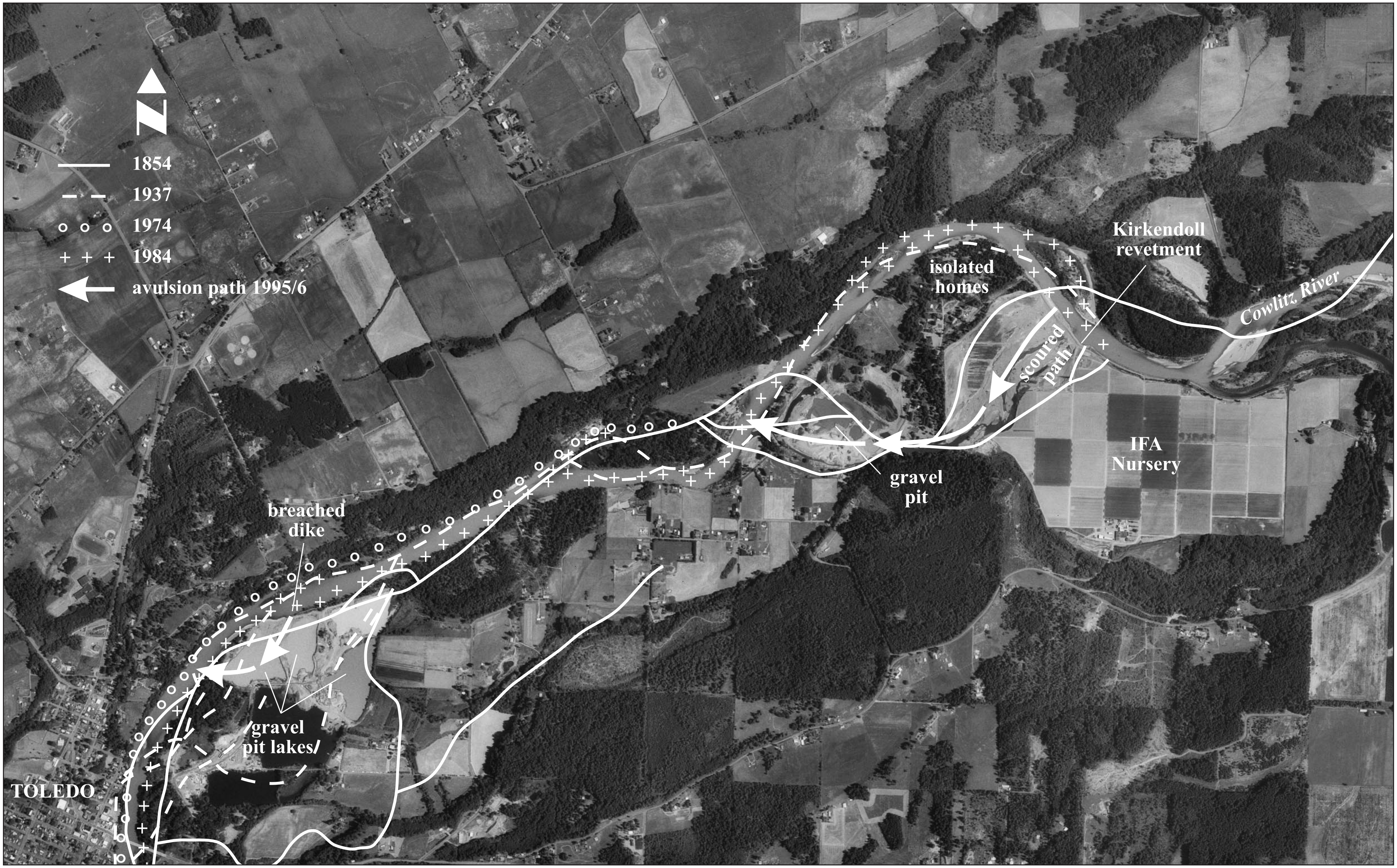
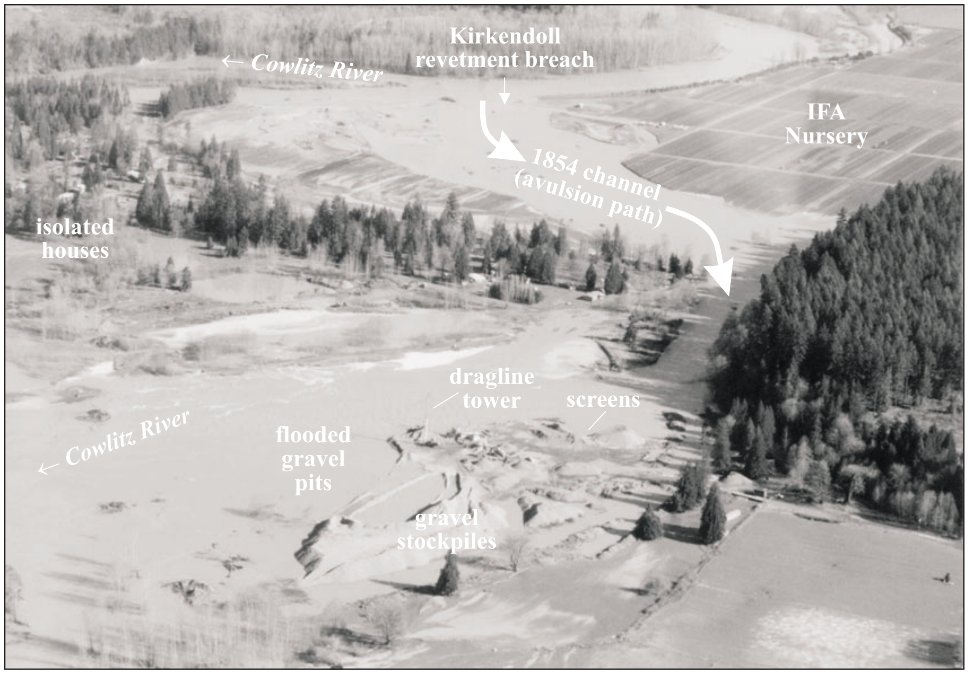


Figure 10. Vertical air photo (July 1996) of the Cowlitz River from Toledo to approximately 3 mi upriver. Flow is to the left. Arrows show the scoured paths of the November 1995 and February 1996 floods. The Kirkendoll revetment was designed by the U.S. Army Corps of Engineers to contain a flow of 48,000 ft^3/sec. Homes labeled are those isolated by the 1995/1996 floods. The river broke through the revetment into the 1854 channel because it was higher than the adjacent flood plain downstream of the revetment. The gravel pit had filled with sediment during the November 1995 flood, so there was no significant deposition there from the February 1996 flood. Peak flow during the November 1995 flood may have exceeded the 68,400 ft^3/sec measured at the Mayfield Dam station 13 mi upstream of Toledo, but the February 1996 peak flow was less than 44,900 ft^3/sec at the dam (Luis Fuste, USGS, oral commun., 1998), where average winter flows are approximately 20,000 ft^3/sec. The USGS calculates the 100-year event flow to be 91,448 ft^3/sec (Williams, 1985). The pits at Toledo are predominantly in the 1937 and 1854 channels. Note that prior to 1937, the Cowlitz River had more than one channel at the Toledo gravel pits (Collins, 1996). After 1937, the Cowlitz was channelized. Arrows indicate the locations of the November Toledo dike failure and partial capture of the Cowlitz. Dike failure continued until water receded after the February 1996 event. There is no longer a gaging station at Toledo, so there is no information about flood flow at the pit. The dike at the upper end of the gravel pit lake was rebuilt by the mining company. The pit is still connected to the river at the lower end to allow fish access.

Figure 11. The area of the Kirkendoll revetment failure on the Cowlitz River and the new channel established during the February 1996 flood. The dragline tower (to the left of the mine equipment at the center of the photo) is about 60 ft high. The houses isolated by flood waters are in the upper left. During maximum flood flows, the fields in the lower right were inundated. (Photo by Alex Nagygyor, DNR Central Region, 1996).



1996). The Cowlitz River, as mapped in 1854 and even in 1941, had a much more complicated course and flood plain than it does today (Fig. 10) (Collins, 1996). The river is now channelized and pinned between the gravel pit lakes and the bluffs on which the town of Toledo has been built. Mining occurs in the 1937 and 1854 channels, the side channels, sloughs, marshes, and oxbows along the river.

During the November 1995 and February 1996 floods, the gravel pits, including stockpiles, and processing areas were inundated (Fig. 13). The dike (constructed of sand and gravel) protecting the gravel pits from the river failed and allowed some of the water to flow into one of the ponds close to the river. The river breached a riparian buffer area as it exited the lower pond. After the flood, sand and gravel was bulldozed by the mine operator to form a new dike in the area of the upper breach, forcing the river into its former channel. The lower breach was left open to allow fish access to the ponds, which are no longer mined. The remainder of the site is being mined. As at the pits upstream of Toledo, the effects of the avulsion at Toledo on the bed of the Cowlitz River were not measured, and the total volume of material moved was not estimated.

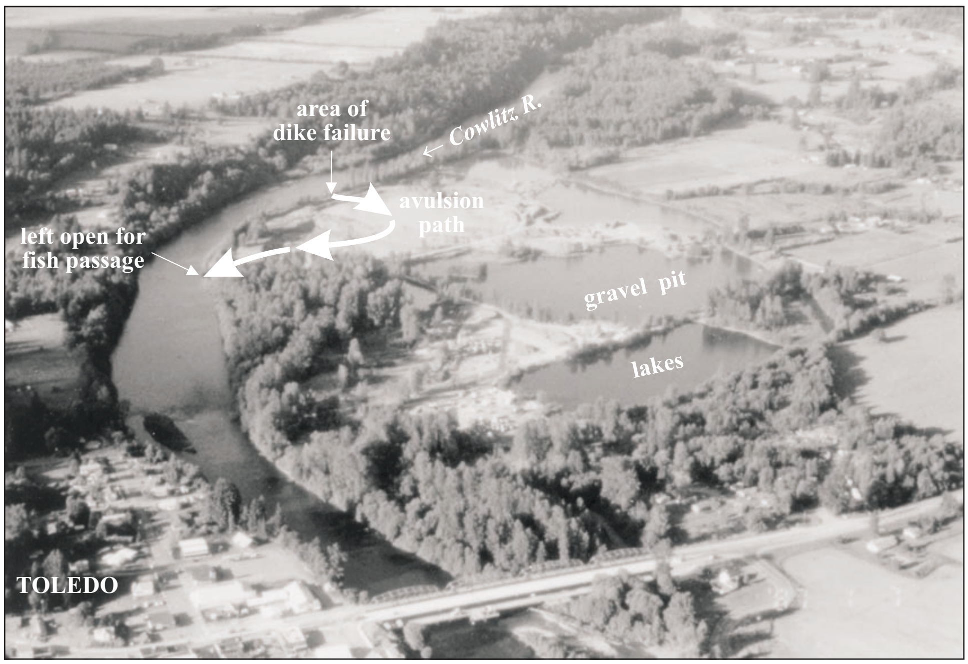


Figure 12. The gravel pits near Toledo on the Cowlitz River in 1994, prior to partial avulsion into the pits closest to the river. Large arrows indicate the position of the channel during the flooding; small arrows, where the dike failed and the lower end of the pit lake left open for fish passage.

Yakima River at Parker

During the February 1996 flood, part of the Yakima River avulsed through the gravel pits near Parker between river miles 105 and 106 on the south side of Union Gap (Fig. 14A,B). Ice jams may have played a role in stream diversions in this instance. The river entered several gravel pit ponds totaling 35 acres and averaging 10 ft deep. Mining stopped at this depth because a 100-ft thick clay layer underlies the gravel in this reach (Len Sali, Columbia Redi-Mix, oral commun., 1998). Because the surfaces of the gravel pit lakes were lower than the river level and the low-flow course of the river was around the

Figure 13. The flooded Toledo pit, February 1996. Both the 1995 and 1996 floods inundated the sand and gravel pits, stockpiles, and processing areas across the river from Toledo. Dams upstream were forced to release water at high rates to prevent the impounded water from overtopping, so "flood control" efficiency was lower.

gravel pits, it was inevitable that the river would avulse at flood stage.

The flood breached the dikes in two places at the north end of the ponds. The miner attempted to fill the breaches with rip rap; however, the Washington Department of Fish and Wildlife stopped the operation before filling was complete because the miner had no permits. One breach was partially filled, and the other remains as it was after it was breached during the flood. The dike openings where the channel flows into the ponds are approximately 100 ft in width. On their upstream ends, the pits have begun filling with gravel and are now about 4 ft deep. At the lower end of the mine, the river exits through two outlets that are about 50 ft wide (Len Sali, Columbia Redi-Mix, oral commun., 1998).

The river currently has a braided, meandering course through the ponds. In this instance, the channel has become more complicated, and because the ponds were shallow, no negative effects have been recorded by regulatory agencies. However, there is no monitoring of the site. No further extraction will occur at the site, but crushing and asphalt batching of material brought to the site is ongoing.

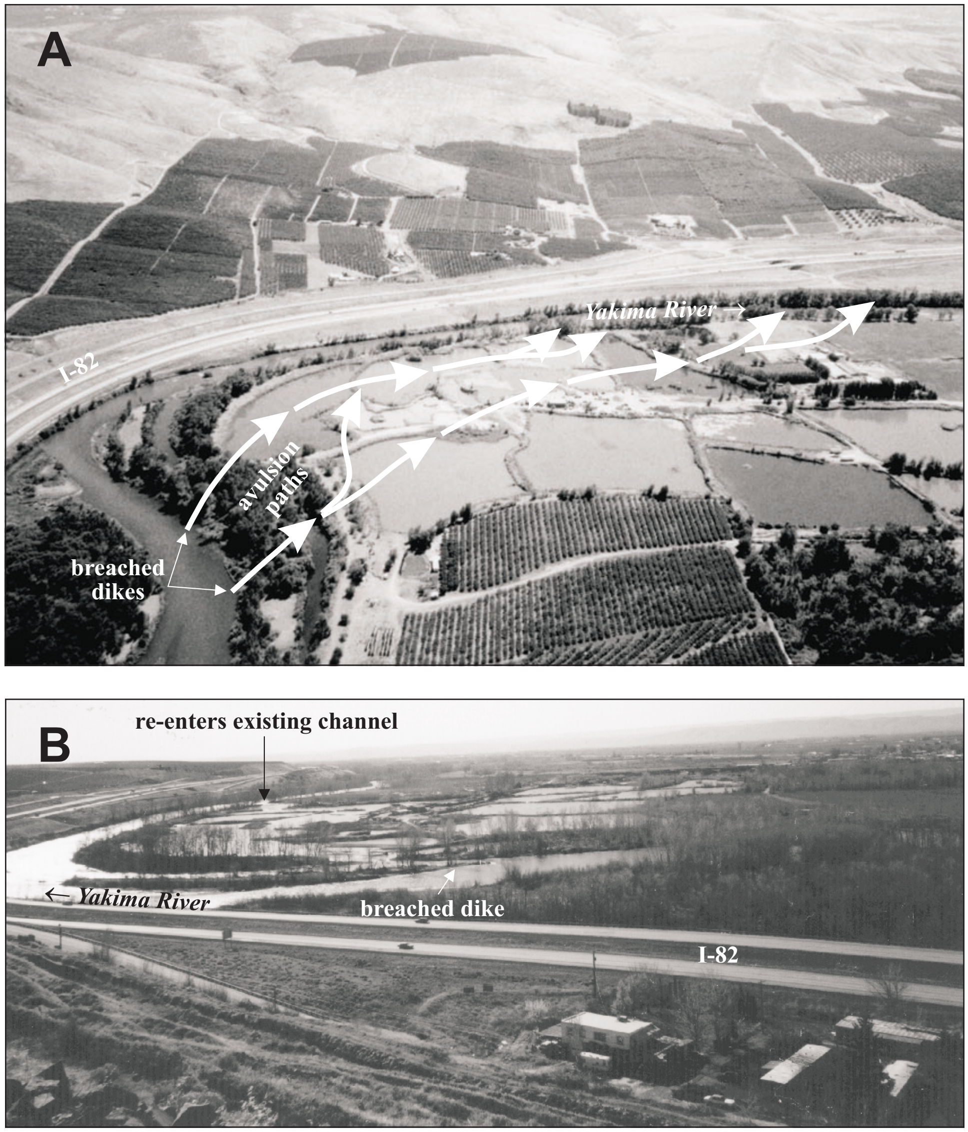


Figure 14. A. The Yakima River and gravel pits near Parker in 1994. A portion of the river avulsed through these gravel pits between river miles 105 and 106 on the south side of Union Gap. Flow is to the right, and the airplane from which this photo was taken is positioned above Union Gap. The point of dike breaching and the new path of river and abandoned channel are indicated by the lines. **B.** In this 1998 photo, a portion of the Yakima River is flowing through the Parker gravel pits. Photo is taken from above Interstate Highway 82. Points of breaching are indicated by arrows. (Photo by Mary Ann Shawver, WADNR.)

Yakima River at Selah Gap

During the flood of February 1996 at Selah Gap, ice jams, high water flow, and gravel mining combined to cause avulsion into Washington's largest (areally) flood-plain mining area. The mined area covered approximately 250 acres, and the maximum depth of excavation was about 25 ft (Fig. 15). When the dike upstream of the pit was breached, the entire Yakima River flow entered the gravel pits between river miles 118 and 120, exiting at the downstream end of the site (Fig. 16).

During this flood, the peak flow of the Yakima River was 27,200 ft^3/sec as measured at the Umtanum gaging station 18 mi upstream and above Roza dam. The calculated 100-year event at Umtanum station is 27,459 ft^3/sec (Williams and Pearson, 1985b). Large ice jams played an undefined but likely significant role in the avulsion. Approximately 8,000 ft of channel was abandoned when the flood waters receded.

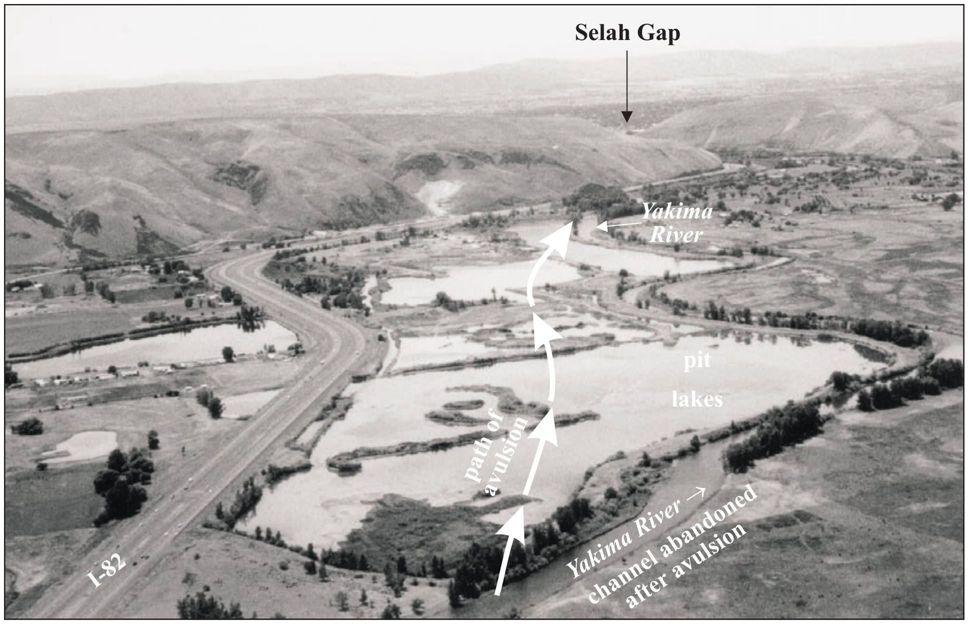
Results of the avulsion are difficult to quantify. About 6 to 8 ft of incision occurred immediately upstream. There was local knickpoint migration as evidenced by a migrating standing wave and increased bank erosion as the river began to re-establish its grade (Lorraine Powell, WADNR, oral commun., 1996). We estimate that at least 300,000 yd^3 of gravel was scoured from the river bed and deposited as a layer a minimum of 6 ft thick in the excavated pits over a 33-acre area. We also estimate that more than 100,000 yd^3 of gravel was moved from the river bed during the flood and deposited on gravel bars and private lands just upstream of the pits.

Dike building (Fig. 17) forced the Yakima River back into its pre-February 1996 channel by September 1996. As a result, river bed disruption and incision were halted or slowed. However, because of concerns about such floods in the future, the mining company decided to rebuild the dikes that tightly constrain the river. These dikes increase the erosive power of the river further downstream. The mine operator also installed an engineered armored spillway at a low point in the dike that allows the river to overtop it there and reduce its flow. This sill keeps the bedload in the main channel and reduces the potential for incision in this area.

East Fork Lewis River near La Center

On the East Fork Lewis River, in Clark County, intensive mining has occurred between river miles 8 and 9. The river has not

Figure 15. The Yakima River and gravel pits near Selah Gap in 1994. During the flood of February 1996, breaching of the dike caused the entire flow to enter the gravel pits between river miles 118 and 120 and eventually exit at the downstream end. After the flood, diking and other river training devices built by the mining company diverted the river back into its original channel.



been dammed and has one of western Washington's few remaining wild (native) steelhead runs. This fish has been listed as threatened on this river. Gravel mine ponds on both sides of the river cover approximately 200 acres, average about 30 ft deep, and are sited in abandoned channels in this formerly braided river system (Fig. 18) where the river issued from a V-shaped valley onto a broad complex flood plain. The

Figure 16. Selah Gap pits between Interstate Highway 82 and the Yakima River. Most of the gravel pit lakes are located in the 1866 and 1936 channels. Traces of numerous meander scars and oxbow cutoffs from earlier, natural lateral channel migrations remain, west of the river. Note the path of the February 1996 avulsion. In this September 1996 photo, dikes have returned the Yakima River to its February 1996 channel.

Figure 17. In the spring of 1996, the mining company rebuilt the dike along the Yakima River by dumping oversize rock in the area near the old gravel pits; this dike eventually rechannelized the river.

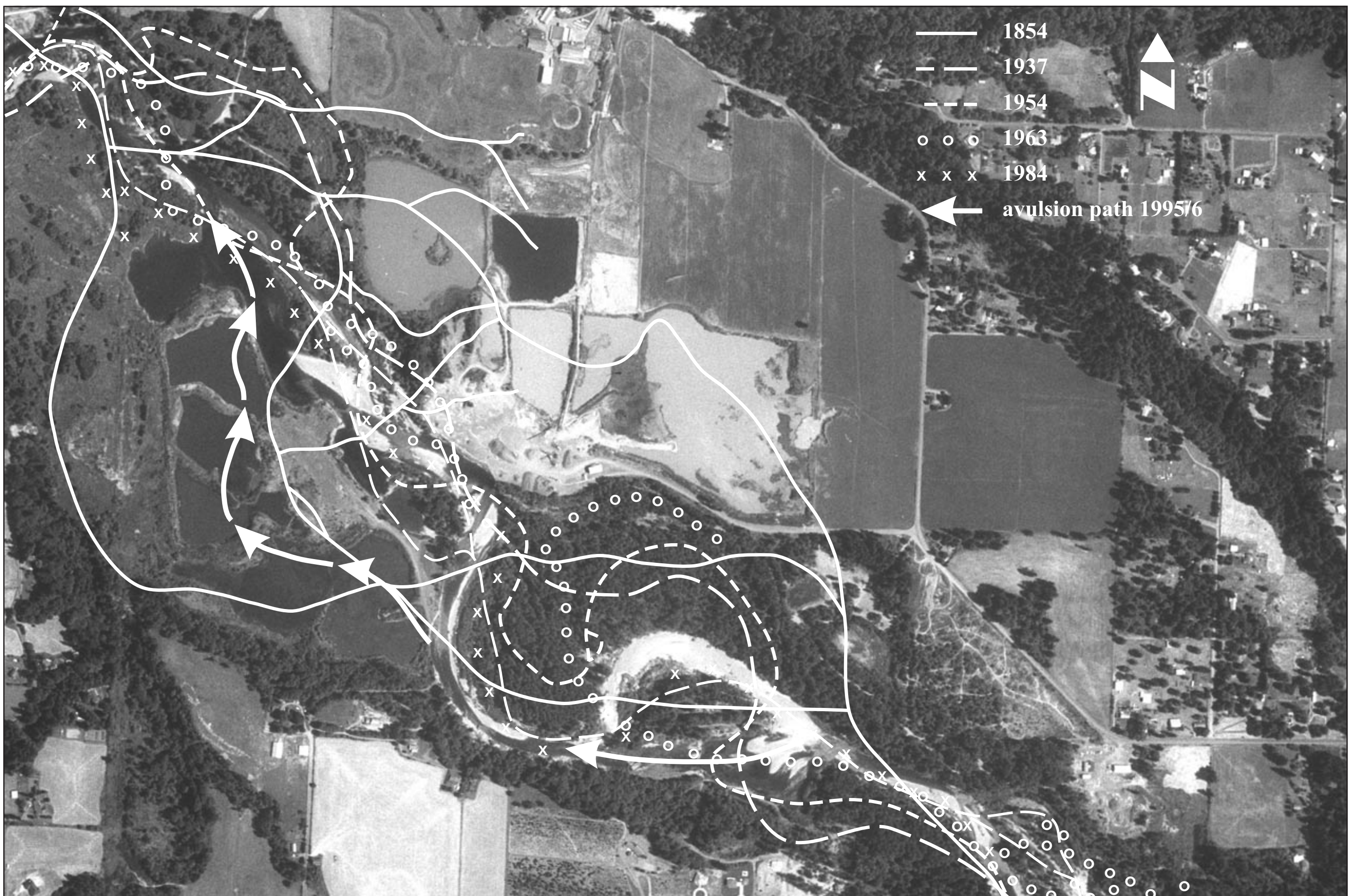


Figure 18. Vertical air photo (1996) showing the paths of abandoned river channels from the 1995/1996 avulsions and older channel scars. The braided channel shown in 1854 and 1858 surveys is now occupied by gravel pit lakes. At that time, the river course was much more complicated (Collins, 1996) and exhibited a braided morphology.

current pits occupy approximately two-thirds of the mile-wide valley and most of the 100-year flood plain in this reach. Several dike failures, avulsion events, and diversions have occurred along the river.

During November 1995, the river avulsed through a gravel pit pond at mile 9 (sec. 19) and abandoned about 1,700 ft of channel (Fig. 19) and spawning gravels. During February 1996, the east fork flooded again. The Heissen gaging station located approximately 10 mi upstream of the gravel pits was washed out in this flood, but the peak flow was indirectly estimated at 28,600 ft^3/sec by a U.S. Geological Survey (USGS) hydrologist. Earlier calculations (Williams and Pearson, 1985a) indicated the 100-year peak flow event at Heissen to be 20,046 ft^3/sec. Since the 1996 flood event, the 100-year event has been recalculated by the USGS at 22,200 ft^3/sec, using the 28,600 ft^3/sec observation as the maximum peak flow (Sumioka and others, 1998). No avulsion of the east fork into the lower gravel pits occurred during this event. However, significant bank erosion set the stage for eventual stream capture.

In November of 1996, the river avulsed through six closely spaced gravel pit ponds on the south side of the river and the river eventually abandoned about 3,200 ft of channel and spawning gravels. Avulsion began near an outside bend of the river near the haul road from the pits (Fig. 20). Lateral channel migration and the series of floods severely eroded the road, which had acted as the dike to keep the river out of the pits. The main stem was captured and now flows through the south bank gravel pits (Fig. 21).

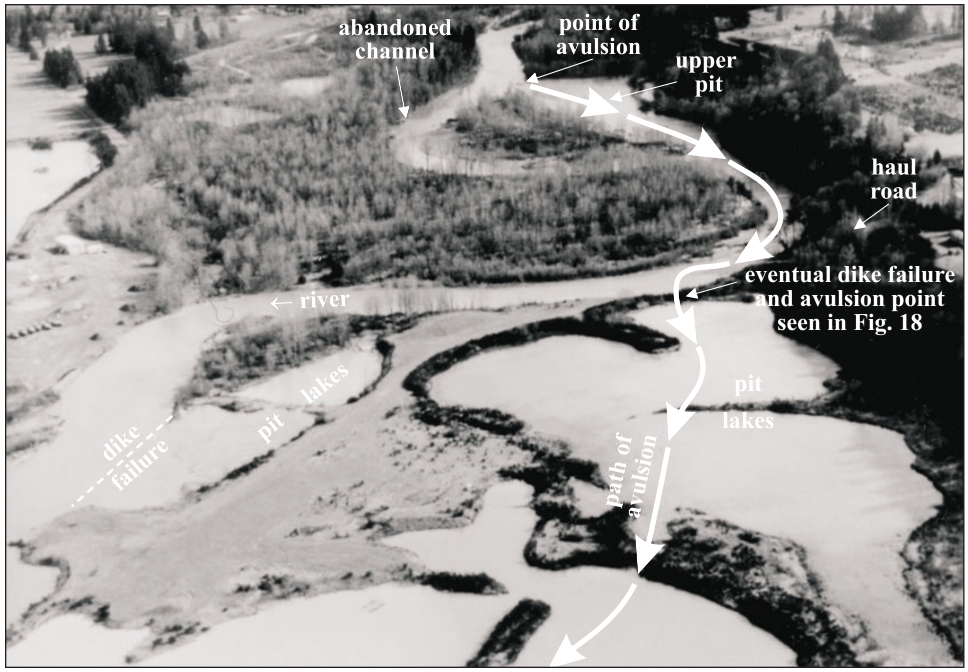


Figure 19. The East Fork Lewis River at flood stage in February 1996. The river had already avulsed through an upper gravel pit at the top of photo and later avulsed into the pits at the center and bottom right of photo. Avulsion into the downstream pits began near an outside bend of the river located near the severely eroded haul road out of the pits. (Photo by Dan Miller, Friends of the East Fork.)

Some of the results of the avulsions are:

- about 10 ft of channel downcutting as the knickpoint migrated upstream,
- increased erosion along the south bank,
- abandonment of about 4,900 ft of channel where salmon and steelhead had spawned, and
- sluggish flow through the gravel pits.

The depth of downcutting was estimated as the height difference between the bed of the abandoned channel and bed of the current channel. The severity of the effects may be related to the fact that these ponds were much deeper and wider than the normal river channel. We estimate that it will require more than 2 million yd^3 of sand and gravel, which must be derived from the channel and banks, to refill the 70-acre pits through which the river flows.

STATE MINING REGULATIONS

The principle law regulating activity on the shorelines of the state is the Shoreline Management Act (RCW 90.58), which is administered by cities and counties. Many local jurisdictions also regulate flood-plain mining under provisions of conditional use permits or other land-use ordinances and the Growth Management Act (RCW 36.70A). Several counties also have mining ordinances. The Shoreline Management Act generally applies to mining activities on the 100-year flood plain and associated wetlands. Regulation may vary according to the "master plan" of each local jurisdiction. For instance, in Lewis County, the Shoreline Management Act applies only to areas within 200 ft of the floodway of flooding that occurs with reasonable regularity, although not necessarily annually, or the ordinary high water mark if the floodway is not mapped. When mines are proposed, the local jurisdiction becomes the Lead Agency under provisions of the State Environmental Policy Act (SEPA). The Washington Department of Ecology (Ecology) must also give its approval to terms of a Shoreline or Conditional Use Permit issued by a local jurisdiction. Ecology's 1994 Shoreline Management Guidebook recommends that local governments encourage miners "to locate activities outside the shoreline jurisdiction"— in other words, generally 200 ft from the floodway, or off the 100-year flood plain.

Several other agencies of secondary importance have responsibility for regulating mining on flood plains and rivers. Any work, including mining, that uses, diverts, obstructs, or changes natural flow or the bed of any waters of the state requires a Hydraulic Project Approval (RCW 75.20-100) from the Washington Department of Fish and Wildlife (WADFW). However, because WADFW jurisdiction is restricted to waters of the state, the agency may not have jurisdiction over flood-plain mining if mining does not involve the active channel. After an avulsion has occurred WADFW would have jurisdiction over any work occurring in the pits/river. The Department of Natural Resources administers the Surface Mine Reclamation Act (RCW 78.44), which generally requires mines to be reclaimed immediately after each segment is mined. The 1993 revision of this law requires that most mines in flood-plain environments be reclaimed as beneficial wetlands. As part of the reclamation plan for a mine, the act also requires that "where mining on flood plains or in river or stream channels is contemplated, a thoroughly documented hydrologic evaluation that will outline measures that would protect against or would mitigate avulsion and erosion as determined by the department" be included.

The U.S. Army Corps of Engineers regulates excavation or filling of wetlands through section 404 of the Clean Water Act

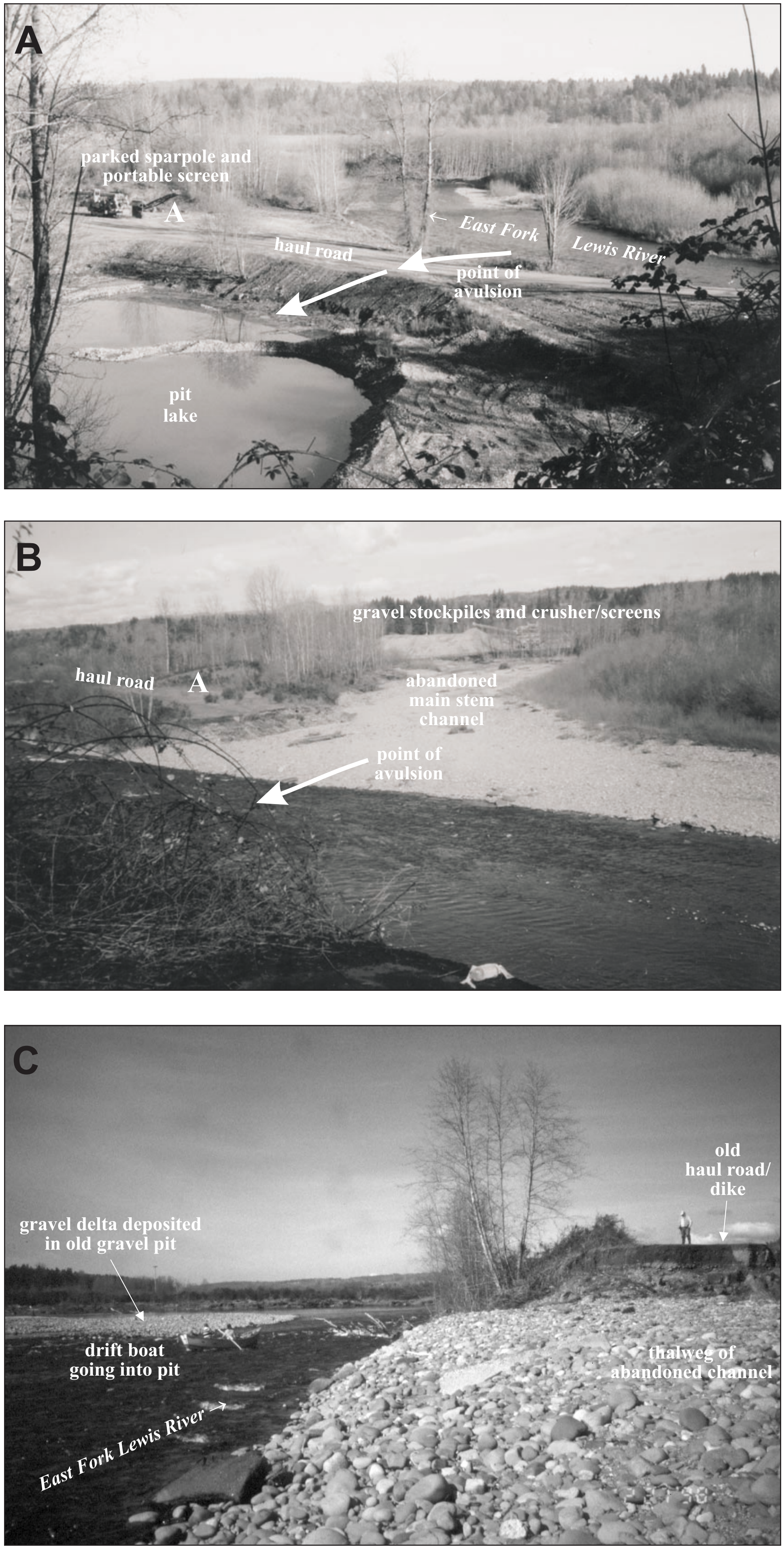


Figure 20. A. Before avulsion of the East Fork Lewis River. In the center of this 1990 photo are the bank and haul road that were breached in 1996. The river is at the top right. A gravel pit lake is at the lower left. A pole and portable screen are at the left. **B.** After avulsion, the haul road/dike has been breached, and the river flows into gravel pits. The remains of the haul road can be seen on the left across the river. "A" indicates same spot on each photo. The abandoned channel of the river is shown in the center right of photo. Approximately 10 ft of incision has occurred immediately upstream of where the river entered the pits. Taken February 1998 from approximately the same position as A. **C.** This February 1998 view shows the present position of the East Fork Lewis River; the drift boat is entering the former pit area. At the top right is the remnant of the old haul road. The gravels and cobbles in the foreground are the old river bed after avulsion. About 10 ft of incision has occurred here, on the basis of the difference between the height of the abandoned channel thalweg and the present-day channel.

(Title 33). Most flood-plain mines would occur in wetlands or portions of wetlands and would be required to apply for a section 404 permit.

The Growth Management Act (RCW 36.70A) directs counties to designate "mineral resource areas" and "critical areas" such as wetlands or "fish and wildlife conservation areas" that include water of the state (Lingley and Jazdzewski, 1994). However, the Growth Management Act has not been fully implemented and does not apply to all counties.

As wild salmon populations dwindle and the fish are listed as threatened and endangered species, the Endangered Species Act may play a role in future siting of riverine mining. It is not yet clear what that role will be.

A complete discussion of regulations for mining is given in Norman (1994).

Recommendations for Planning and Siting

Mine site selection or plans for mine expansion should not be made on the basis of a perception that, because gravel mining has occurred historically in an area, it is appropriate to continue mining or that river rock is the only source of construction aggregate in that market. Potential consequences of mining can be severe, and the function of the flood plain can be lost, along with fish and wildlife habitat. Wherever possible, large gravel mines should be located in uplands away from the river

Figure 21. Vertical air photo of the East Fork Lewis River showing the course of the river in November 1997. At A, the river changed its course into a gravel pit in 1995. The river re-entered its channel at B. The channel between A and B is now abandoned. C indicates where the haul road was breached and the river avulsed into the gravel pits in 1996. D marks the start of the channel abandoned in this event. E is along the avulsion path as the river finds its way through the series of ponds. The river re-enters its old channel at F. The valley walls are approximately 1 mi apart near the gravel pits.

valley floors. A poor second choice is to locate mining on terraces and the inactive flood plain, that is, above the 100-year flood plain. In Washington, upland deposits offer ample rock supplies. Mining these deposits eliminates potential for stream capture or river avulsion. Furthermore, pits in these locations have a good potential for successful long-term reclamation.

In parts of Europe and the eastern United States, gravel is slowly being replaced by crushed quarry rock for use as construction aggregate. In these areas, the transition is occurring mainly because limited gravel resources are nearly depleted. However, substitution of crushed quarry rock for gravel has distinct environmental advantages in that considerably more rock is produced from quarries for the surface disturbance and quarries can easily be located away from flood plains and aquifers. The relatively small disturbance occurs because most quarries contain 100 percent usable rock, whereas gravel deposits have high porosity (meaning less material per volume) and fines that are not economic.

If mine plans call for sites on flood plains, then wide, topographically higher, and thickly vegetated buffers should be considered as a means of reducing the probability of river avulsion in the near term. In some places, buffers may be effective because the river may not utilize the entire flood plain. However, in most instances, buffers only delay the inevitable. Determining an adequate distance between the flood-plain mine-pit lake and the river will depend on understanding the rate of river meandering and the risk of avulsion.

If flood-plain mining is approved, the main goals of planning, siting, and reclamation are:

- The mining should not increase the potential for river avulsion.
- Fish and wildlife habitat should be protected.
- Riparian areas should be protected, both to provide habitat and to improve flood-plain stability.
- Reclamation should ultimately enhance salmon habitat (Norman, this issue, p. 21).
- If there is potential for migration of the river into a gravel pit, the site must be reclaimed in a way that is hydrologically compatible with the adjacent river.

Environmental Analysis

Before any new mining or expansion is allowed on a flood plain, miners must make a rigorous environmental analysis of the mining plan. This should include, at minimum, a geohydrological analysis of the affected reaches of the river system. A thorough plan will also include:

- a topographic map of the existing conditions and surrounding lands at a 2-ft contour interval and at an appropriate scale, as well as flood profiles;
- maps and cross sections that show depths and locations of all bodies of water, the stream profile, and the elevation of the river bed measured from a permanent station, such as a nearby bridge, near the gravel mine;
- a geomorphic analysis that identifies historic channels and channel migration trends on the basis of examination of all available data, such as historic air photos and maps, and that considers geological and artificial controls of the channel, such as armored banks, dikes, bridges, dams, and other mine sites;
- a detailed chronology and description of historical precipitation, flooding, discharge, sediment transport, including description of sediment sizes in and adjacent to the proposed mine site;
- maps of vegetation and analysis of its role in flood and erosion control, as well as a description of the relation between the sediment distribution and the biota, especially as it applies to bank erosion and avulsion;
- an analysis of avulsion or stream capture potential, including the consequences of stream capture, channel incision, and scouring;
- an analysis of potential damage to neighboring properties, fish and wildlife habitat, bridges, and rights-of-way and the effects of existing or proposed dikes and levees and their long-term maintenance;
- an analysis of channel stability, magnitude and frequency of the 5-, 10-, 25-, and 100-year floods, channel and flood-plain hydraulics near the proposed mine site, and any previous stream capture events; flow paths for the 5-, 10-, 25-, and 100-year floods before and after the mining project;
- a carefully documented study of potential impacts to salmon species listed under the Endangered Species Act.

In summary, because flood-plain gravel pits are in the dynamic riverine environment, the environmental analysis should be undertaken with great care, taking into account long-term stability of the site, and include proposals for enhancing or restoring the site's fish and wildlife habitat.

ACKNOWLEDGMENTS

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Reclamation of Flood-Plain Sand and Gravel Pits as Off-Channel Salmon Habitat

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INTRODUCTION

Many permitted sand and gravel mining sites located on Washington's 100-year flood plains will require reclamation. However, even in the long term, reclamation may not restore the entire ecologic function of the flood plain (Collins, 1996, 1997; Kondolf, 1993). Nonetheless, opportunities exist in some places to develop highly productive wetlands and off-channel habitat for salmon, many species of which are struggling to maintain strong populations.

Side-channels and oxbow lakes connected to the main stem of a river are types of wallbase channels or off-channel sites that are primary overwintering habitats for juvenile coho salmon and cutthroat trout (Cederholm and Scarlett, 1981, 1991; Peterson and Reid, 1984). Enhancing areas of reclaimed habitat is most feasible in small (<5 acres), shallow gravel pit lakes (Fig. 1) where wallbase channels can be mimicked. Large, deep gravel pit lakes may not be convertible to off-channel habitat. Furthermore, the consequences to the riverine environment of either avulsion or maintaining isolation from the river with dikes are much greater at deep pits (Norman and others, this issue, p. 3) than at a small pit, which may be left unprotected.

Wallbase channels are created on flood plains where runoff is channeled through swales created by the migration of the main stem river. These channels can develop either along abandoned meanders or between the long ridges (termed scroll bars) in a large meander loop that are built at the inner edge of the low-water channel during bankfull stages. In most places, wallbase channels appear as swamps, ponds, or small tributaries and are connected to the main stem of the river. In spring and fall, juvenile salmon move out of the main river and into tributaries and side channels to spend the following season (Cederholm and Scarlett, 1981; Peterson and Reid, 1984). Off-channel habitats also provide refuge for overwintering coho (Brown, 1985), chinook, and steelhead, and chum salmon spawn in these areas (Fig. 2) (Grays Harbor College and others, 1990). Efforts to enhance some natural wallbase channels and overwintering ponds as environments for juvenile coho salmon have met with success (Cederholm and others, 1988; Cederholm and Scarlett, 1991; Peterson, 1985).

Figure 1. Sand and gravel pit lakes such as this one can be reclaimed as highly beneficial fish and wildlife habitat with riparian zones. When connected to rivers and streams, these kinds of ponds can provide essential off-channel habitat for juvenile salmon. Placing abundant large woody debris in these ponds can create the complex structures needed for salmon habitat.

The success of projects that convert gravel pit ponds to off-channel habitat generally depends on the following factors:

- good access for fish to leave and enter main river channels,
- low risk of avulsion (stream capture), flooding, or drought, and
- adequate cover, food supply, and water quality (Samuelson and others, 1997).

Fairly shallow, small ponds that have complex shapes and are in areas that are not frequently flooded or likely to be affected by avulsion are the best candidates for this type of reclamation. Only the edges of large, deep gravel pit lakes are productive habitat for salmon; the lack of cover and aquatic plants elsewhere in the water is not attractive to these fish (Norman and others, this issue, p. 3).

Carefully prepared site plans and well-executed reclamation can enhance site stability so as to maximize the longevity of the new habitat without the use of dikes. When preparing mine plans, miners should consider the location, size, shape, and depth of pits, as well as local geomorphology and hydrology, in order to preserve flood-plain and river dynamics during and after mining. Revegetation of the reclaimed riparian zone should concentrate on establishing dense growths of diverse

Figure 2. Chum salmon migrating to spawning areas. Studies of ponds such as those at the Weyco-Briscoe facility in Grays Harbor County have shown that chum spawn in gravel banks where ground water wells up. (Washington Department of Fish and Wildlife photo.)

vegetation. These plants will create a zone of soils bound by roots that will slow erosion and reduce floodwater velocities.

To begin rehabilitating the function of the riparian zone and associated wetlands, revegetation plans should take into account the potential for attracting a wide variety of aquatic and terrestrial wildlife, including amphibians and reptiles. Aquatic vegetation as cover and environments that promote insect populations for food will benefit the salmon. Approaches to creating or restoring wetlands in gravel pits are reviewed by Norman and Lingley (1992), Michalski and others (1987), Prange (1992), Norman and others (1996), and Stevens and Vanbianchi (1993).

This paper focuses on principles and techniques to be considered in establishing salmon habitat in reclaimed gravel pit lakes and describes some successful examples.

DESIGN OF RECLAIMED PONDS FOR OFF-CHANNEL SALMON HABITAT

Benefits

Gravel pit lakes can be reclaimed to imitate natural oxbows and cutoff channels, commonly already present on a flood plain, that are connected to the main channel (Collins, 1997; Norman and others, this issue, p. 3). Off-channel habitat offers numerous benefits to salmon. Juvenile salmon will migrate into wallbase channels to seek shelter from strong currents and turbid water during freshets in April and May and the first freshets in the fall. Young salmon typically feed in the shallows and hide in water deeper than 6 ft or in complexes of woody debris in these channels. A few modifications, such as adding woody debris or aquatic plants, to a reclaimed pond design will greatly increase the ponds' utility for salmon. This created habitat would be similar to natural wallbase channels.

While in these channels, salmon take advantage of the rich food supply of aquatic insects, for example, chironomid larvae, that live on the abundant aquatic and riparian vegetation and in the slow currents. They also eat copepods (small crustaceans) and oligochaetes (such as earthworms) that live on or in the pond floor. Because these juvenile salmon migrants have grown larger in these channels than their contemporaries in other environments, their chances of survival are improved.

Pond Shapes and Depths

Gravel pit lakes with a regular shape (chiefly rectangular), steep slopes (1.5 horizontal:1 vertical), and uniform depth offer little habitat complexity for fish and wildlife (Kondolf, 1993). A productive gravel pit lake connected to the main stem river can result if the mine operator constructs or reshapes ponds so that they have irregular shorelines and a variety of depths (Fig. 3).

An arrangement of gravel pits that benefits salmon is a series of connected irregular ponds that have islands and peninsulas (Fig. 4). The shoreline length is maximized, and the connections between ponds provide channels with riffles, thus increasing the dissolved oxygen content and adding complexity.

Gradually sloped, complex reclaimed shoreline margins help promote aquatic plant development. If the bottom of the pond is irregular, it will offer a range of habitats for plants, benthic fauna, and fish.

Optimal slopes in shallows intended as fish habitat are flattened to at least 5H:1. Slopes of 15H:1V (3 ft water depth at 45 ft off shore) would provide a broad rim with the potential for diverse aquatic plant growth. Where a shoreline slopes steeply, marsh conditions and space for aquatic plants are confined to a narrow band (Andrews and Kinsman, 1990).

Maintaining approximately 25 percent of the lake as benches and bars less than 2 ft deep, 25 percent as areas 2 to 6 ft deep, and half the lake more than 10 ft deep provides the complexity that enhances biotic diversity (Norman and Lingley, 1992; Norman and others, 1996). For fish and wildlife habitat, the higher the percentage of shallow areas, the better the potential for both food production and shelter in aquatic plants and woody debris that has fallen in the pond.

Some of the shallow gravel shelves along a pit lake perimeter will be places where ground-water flow is intercepted. Upwelling generally occurs along the hydrologic upgradient of ponds. This water is typically well oxygenated, and chum salmon are known to choose these ground-water-fed shallows (<2 ft deep) for spawning (Grays Harbor College Research, 1990).

Wallbase channel gravel pits should be designed to minimize chances or consequences of avulsion. This can be achieved by keeping wallbase channel ponds shallow, small (<5 acre), longer than wide, parallel to the river, and away from

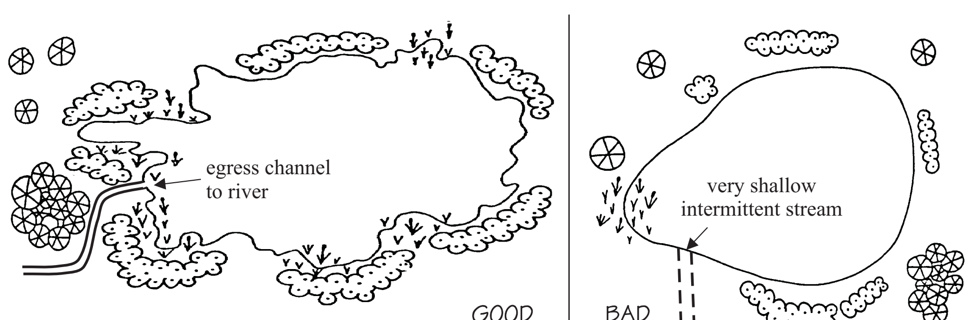

Figure 3. The shorelines of ponds used for wildlife habitat should be irregular and planted for cover with a mixture of open meadows and shrubs in the surrounding area. The shape of the pond on the left is better suited to supporting wildlife than that of the pond on the right. (Modified from Szafoni, 1982.)

actively meandering channels (Fig. 4). Habitat ponds must be connected with the river on the downstream side (Norman and others, 1996) for optimal fish access. A channel connected on the upstream end can offer a route for river avulsion.

Substrates

Off-channel habitat should be designed for a variety of uses by preserving gravel substrates that could be used as spawning areas and by placing soil to accommodate aquatic plant growth. Topsoil in shallow water facilitates revegetation and speeds re-establishment of a food chain. Soils placed in the shallows provide a mud bottom that is generally a nutrient-rich substrate for bacteria, plants, and benthic macroinvertebrates. If these food sources and sheltered areas are plentiful, young salmon have a better chance of reaching maturity.

Choice spawning substrates generally have a combination of round gravels ranging from 0.25 to 3 in. in diameter and moving water. Suitable spawning areas may also be provided by (a) springs welling from the pond bottom or sides where the ground-water table has been intercepted by the excavation or (b) those parts of the channels connecting ponds where water is moving across gravels. In addition, coarse gravels and cobbles are home to preferred salmon food sources such as immature stages of caddis flies and mayflies. Juvenile fish also hide in coarse gravel. Most of the pit lake floors and channel banks should be covered with soil, which will be the most productive substrate for vegetation and insects.

Miners are required by Washington law (RCW 78.44) to save and replace all topsoil and sediments within 4 ft of the surface and to practice segmental reclamation. Topsoil should be directly replaced from one area of a mine to another without a period of storage. Wherever possible, 12 to 18 in. of the "A horizon" topsoil should be placed on banks and islands and in all shallow areas of the new pond to the depth that light penetrates through the water.

Aquatic Vegetation

A network of aquatic plants shelters fish from predators. The soil placed on the lake shore or in shallow water promotes growth of sedges, reeds, lily pads, and other aquatic vegetation.

Plants also are essential to insect populations. The surface area of plants may be many times greater than that of the pond or lake bed; hence plants may considerably increase the amount of surface area that insects can colonize. Many insect species lay their eggs on plants. Dead and decaying plants are also a food resource for insects (Andrews and Kinsman, 1990).

Juvenile coho salmon feed on insects of the family Chironomidae (non-biting midges) as the young insects emerge through the shallow water column (Peterson, 1982a,b). Chironomid species colonize every type of freshwater substrate. However, population densities in *sand* are generally very low, and *gravel and rock* usually support high densities only where well covered with algae. By contrast, organic sediment and plant surfaces can support high chironomid population densities.

Aquatic plants can help slow or prevent erosion on a shoreline that is subject to wave erosion by absorbing moderate wave energy. Exotic plant varieties rarely provide the same benefits as natives. Aggressive native species, such as common cattail and Douglas' spiraea, should be used cautiously or avoided completely because they tend to become a virtual monoculture.

If there are wetland areas within the site before gravel pit excavation starts, then the aquatic plants and muck soil layer should be carefully protected and moved into the pond during the reclamation process. Many aquatic plants grow and propagate themselves vigorously. The initial introduction need not be vast, and early-planted material may be thinned for planting during later reclamation stages. Planting times will vary, depending on the requirements for successful establishment of each species.

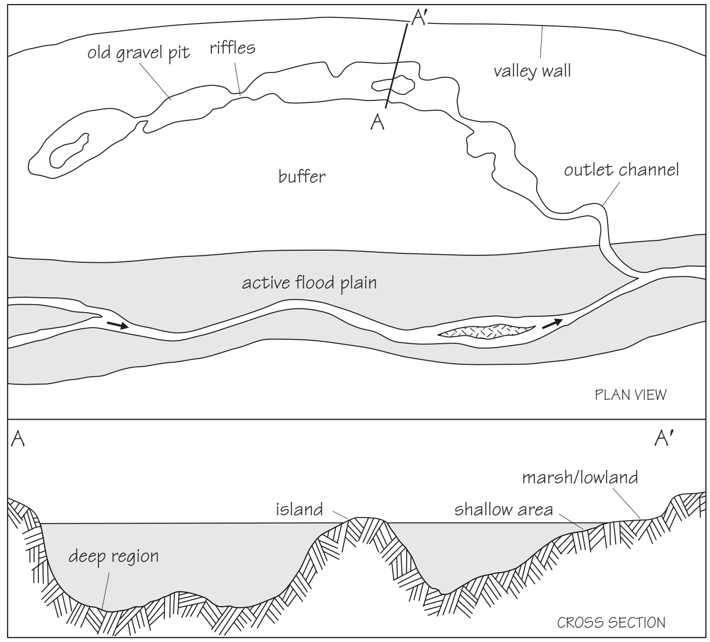

Figure 4. Plan view and cross section of a reclaimed gravel pit with a pond shape that mimics a natural river system. Not to scale. (Modified from Woodward-Clyde, 1980.)

Upland Vegetation

Planting riparian areas with native tree species (for example, cottonwood, poplar, alder, willow, fir, spruce, cedar, pine, maple) and native grasses, sedges, legumes, and forbs can accelerate the process of providing productive habitat, create diversity, and help stabilize the site. Deciduous trees and shrubs, especially willow and alder, are valuable sources of food for insects because their submerged, fallen leaves rapidly degrade and develop a microfauna of bacteria, fungi, and protozoa (Andrews and Kinsman, 1990).

Native plants should always be used for this kind of revegetation, preferably those species that grow close to the site. Planting willow, osier dogwood, poplar, and cottonwood cuttings is an effective and fairly quick method of building a root matrix that can slow erosion. Planting should take place in the spring or fall, preferably while plants are in the dormant stage (Norman and others, 1996).

Buffers

To reclaim a mine site as off-channel habitat, miners should plan and maintain areas of undisturbed riparian vegetation as setbacks from rivers. Wide buffers delay a river's entry into a pit by giving the river room to migrate and to disperse floods. Buffers of well-rooted vegetation on banks and in the riparian zone slow erosion and will extend the time that the gravel pit off-channel habitat exists. Highly vegetated buffers can be seed sources of plants, which will speed the revegetation process.

Calculating an appropriate buffer width may be difficult. In general, the width selected should be based on stream and valley morphology and the rate at which the river migrates. Buffer widths should be adequate to protect or restore full function to both the river and the pits. The Washington Department of Fish and Wildlife (WADFW) recommends that the riparian habitat area be at least as wide as the 100-year flood plain or 250 ft, whichever is greater (Knutson and Naef, 1997).

When designing buffer revegetation, miners should consider the orientation of the area relative to the sun. For instance, a north-facing slope receives less sun than a south-facing slope and is likely to be easier to revegetate because it dries more slowly and remains cooler.

Livestock should be excluded from the reclaimed ponds and riparian areas because they can trample and overgraze vegetation and adversely change the water quality.

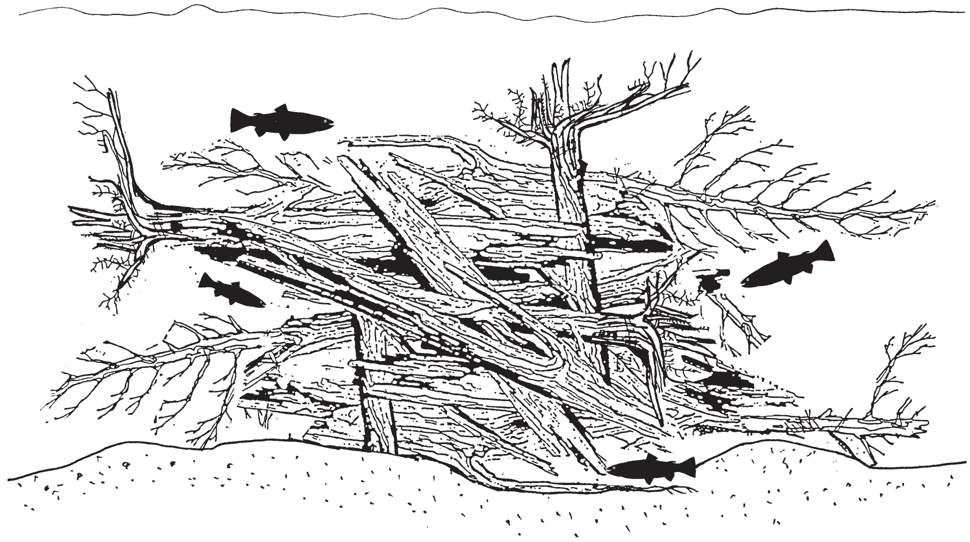

Figure 5. Logs with roots and crowns attached can be lashed together and placed in deep (≅20 ft) water. They can be held in place by dumping overburden, rocks, or sand bags on top to form reef habitat for fish and aquatic insects. Reefs like this are better constructed of conifers than of deciduous trees, which may rot too quickly.

Coarse Woody Debris and Shelter

Overwintering success for juvenile salmon in off-channel areas can be greatly enhanced by adding large woody debris, which provides cover. Side channels that contain such debris had more coho than channels with no woody debris (Sedell and others, 1984; Tschaplinski and Hartman, 1983). Trees need not completely surround a flood-plain pond or completely line a channel, but the more enclosed the reclaimed lake, the better the habitat. Eventually, large woody vegetation along the shoreline will fall into the pond and provide further habitat for fish. If none is present, woody debris should be placed on the shore and at a variety of depths.

Logs and stumps can be lashed together to form debris jams in the wallbase gravel pits ponds. They may be anchored by rocks, overburden, or soils. In water 20 ft deep, logs and stumps form reef habitat (Fig. 5) for fish and aquatic insects. Stumps with their intricate masses of rootlets still attached (root wads) provide cover and can be easily and cheaply added to ponds. Large boulders can also be used to build reefs (Norman and Lingley, 1992; Norman and others, 1996).

Submerged and anchored tree crowns provide excellent cover along steep banks (Norman and others, 1996). Trees most suitable for aquatic habitat restoration of this kind are cedar and fir. Alder can be used if no other trees are available; however, deciduous trees generally decompose too quickly.

Connection to the River

If the reclaimed flood-plain mine is near the active river channel, not deeper than the deepest part of the adjacent river, not subject to drying up, and not susceptible to flooding, ponds can be connected to the river at the downstream end. These outlet connections (ingress/egress channels) allow fish to enter and leave the off-channel ponds. Where feasible, connections to a river should be made by way of natural wallbase channels or sloughs that enter the main river and flow near the ponds. Other natural features that mimic the natural riverine system, such as side channels along gravel bars, can be effective connections if the bar is stable. Connections to rivers should not be straight or constructed where a stream is depositing sediment.

For fish, the ideal entrance to a pond is located adjacent to a main stem channel irregularity that creates a large to moderate eddy; fish can recognize the plume of clear water flowing from the pond into the main river. Connection gradients should be gentle (0–1%). Logs can be laid in the connection channel to provide "steps" to lower the gradient and create pools in which fish can rest.

Riffles or fast water areas are less desirable outlet sites because fish do not spend much time there and may not find the outlet. Very shallow outlets may be left high and dry during low water. The designed ingress/egress channel should be deep enough to maintain year-round flow. Connecting the ponds to the river on the upstream section of the mine should be avoided because this may encourage the river to avulse into the pit at an accelerated rate.

Miners need to obtain a Hydraulic Project Approval issued by the Washington Department of Fish and Wildlife if mining plans involve a constructed connection to a river or smaller stream.

EXAMPLES OF OFF-CHANNEL HABITAT CREATED BY RECLAMATION

Weyco-Briscoe Ponds on the Wynoochee River

Many gravel pits are located along the Wynoochee River, which drains the Olympic Mountains (Fig. 6).The Weyco-Briscoe ponds, in sec. 22, T19N, R8W, river mile 17, are examples of small ponds excavated for gravel that have been converted to off-channel habitat (Fig. 7). Using natural pond characteristics identified by Peterson (1985) as a guide, the company constructed ponds that provide shallow areas for food production, deep water for cover, and few perching areas for predatory birds. Because of the location, size, shape, and depth of the ponds, avulsion or stream capture is not likely to cause drastic environmental changes to the river (Collins, 1997).

Six ponds were created over a period of seven years during the 1980s. All are generally less than 20 ft deep, approximately

0.5 to 1.5 acres in area, and connected to each other (Partee and Samuelson, 1993). On the downstream end, the ponds join the river to allow fish passage.

The ponds have been monitored since 1989 by Grays Harbor College to determine the extent of chum salmon spawning and use by other salmonid juveniles for overwintering. Monitoring of the site in 1990 indicated that the average immigrant coho fingerling was 49.6 mm long and weighed 1.20 g and the average immigrant chinook was 66.52 mm long and weighed 2.36 g. In contrast, the average Wynoochee River coho fingerling was 30.38 mm long and weighed 0.38 g, while the average chinook was 41.25 mm long and weighed 1.30 g. Immigrants into the ponds in 1990 included 1,249 coho and 146 chinook. Only 2 chum were recorded immigrating into the ponds in 1990. However, there were 73 juvenile chum emigrants that had spawned in the Weyco-Briscoe ponds (Grays Harbor College and others, 1990).

Initially, minor amounts of woody debris were placed in the ponds; however, Don Samuelson of Grays Harbor College considered this sparse cover to be a factor that limited use by and survival of salmon (Samuelson and Willis, 1995). In 1995, tons of woody debris were hauled to the site and placed in the ponds (Fig. 8). The ponds are being monitored to determine the results. From November through December of 1997, 31 chum adults and 66 coho juveniles immigrated into the ponds. Only 8 juveniles emigrated during this time period. Seven steelhead juveniles immigrated, and none left. Fish biologists also counted the carcasses of 69 adult chum in the ponds (Samuelson and others, 1997).

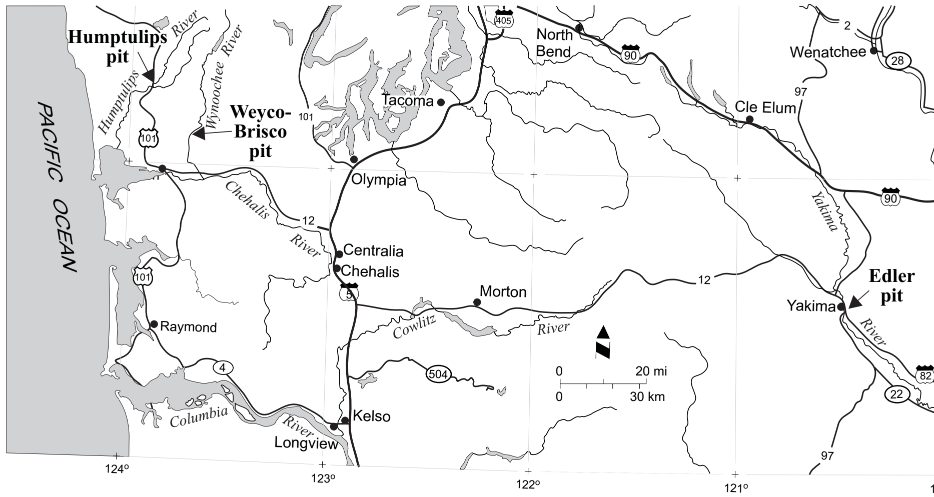

Figure 6. Location of gravel pits near rivers discussed in this article that have established off-channel fish habitat.

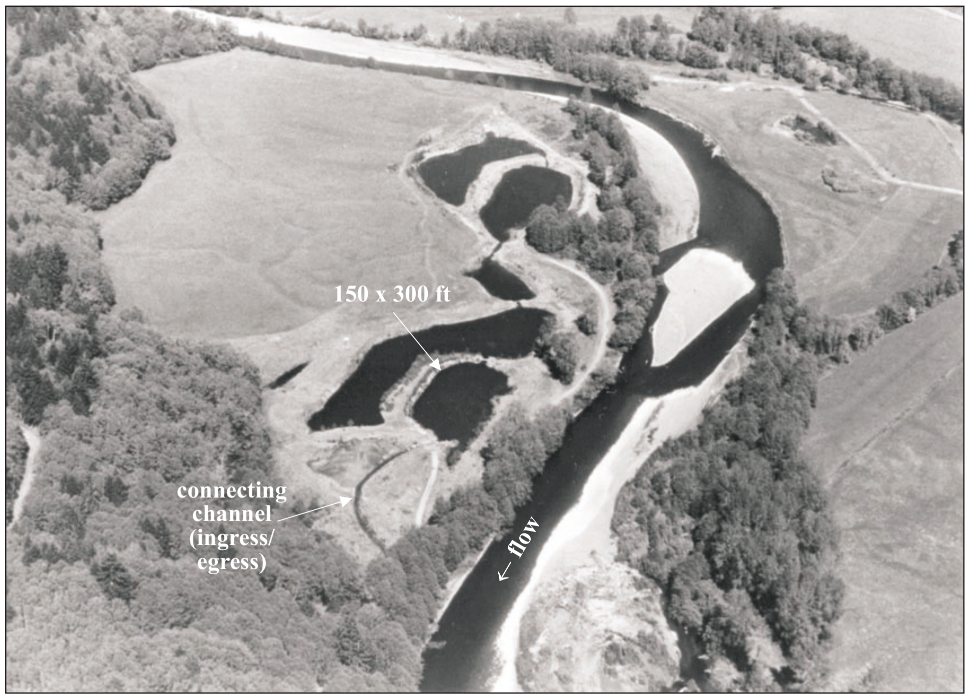

Figure 7. The Weyco-Briscoe ponds on the Wynoochee River (Fig. 6) in 1994. Mining and reclamation were designed to enhance off-channel habitat. An existing creek (at arrow) connects the ponds to the river. Avulsion is likely in the near future because the river has shifted closer to the ponds. Stream capture will not have major environmental consequences because the river channel and pond depths and widths are similar.

Gravel Pits on the Humptulips River

During the 1980s and early 1990s, gravel mining took place along the Humptulips River, which drains the Olympic Mountains (secs. 8 and 17, T20N, R10W), about 1/4 mi upstream of the U.S. Highway 101 bridge (Fig. 6). The gravel pits are no deeper than 30 ft and consist of about 20 acres of ponds (Fig. 9). Connections to the river were created by the mining company after mining had ceased. No woody debris was placed in the ponds, so there is minimal cover. The ingress/egress channel to one of the ponds dries up in summer. However, a well-vegetated riparian zone is now established along much of the ponds' perimeter, and salmon usage is generally high during the winter. No further reclamation is planned.

A local salmon club now uses one of the ponds for a rearing pen. The other ponds are unmanaged and left open for salmon spawning and off-channel habitat. No quantitative monitoring of the site has been done, but Jack Ljestfield (WADFW, oral commun., 1994) believes the ponds support both salmon spawning and off-channel habitat for juveniles. Adult salmon are readily observed in the ingress/egress channels.

Yakima River at Union Gap

The Edler gravel ponds operated by Len Sali of Columbia Ready Mix, Inc., near the town of Union Gap are currently being mined with the intent of providing fish and wildlife habitat as a subsequent use. The ponds are located approximately 500 ft west of the Yakima River (Fig. 10). The reclamation plan is to finish mining with four ponds no deeper than 25 ft and covering an approximate total of 30 acres. Individual ponds will be connected to each other by sinuous channels as mining is completed, mimicking natural conditions. The first pond that was mined has been reclaimed (Fig. 10) and is no deeper than 18 ft. The southernmost pond, the last to be excavated, will be connected at final reclamation to the Yakima River by a channel that will provide fish access to the pond system.

All the ponds will be excavated to final slopes of 5:1 at the water edge. Where natural vegetation (trees and brush) exists adjacent to the excavation, Sali has selectively trenched to construct islands with established vegetation, which provides a seed source and increases the speed of final reclamation. There is deeper water in predator trenches developed around islands. Slopes above water will be no steeper than 3:1 and have the topsoil respread and grasses and native plants re-established. Topsoil stripped from the second pond area was replaced around the first pond mined, as required in the segmental reclamation plan. All four ponds will ultimately have irregular shorelines and varied depths. Approximately 25 percent of the ponds' complex shoreline has water 2 ft deep, following the recommendations of regulatory agencies (Norman and Lingley, 1992; Norman and others, 1996).

Avulsion occurred in 1971 at gravel pits immediately downstream of the Edler site (Dunne and others, 1981; Dunne and Leopold, 1978). If avulsion or stream capture occurs at the Edler pits, the off-channel habitat would be lost, but the mining company and regulatory agencies anticipate few negative impacts on the Yakima River because the pit lakes emulate abandoned channels and are not overly wide or deep relative to the river.

While the Washington Department of Fish and Wildlife specialists expect that fish and wildlife use of the ponds will be high, the agency has no plans at this time to monitor the effectiveness of the reclamation or the plan that is being implemented.

Figure 8. Rootwads, treetops, and slash supplied by Weyerhauser Company in a Weyco-Briscoe pond. Grays Harbor College received funds through the Watershed Restoration Project from Washington Departments of Natural Resources and Fish and Wildlife for the project. Dan Brock and his crew from Northwest Upland Restoration used an excavator to place large logs in the ponds. Wood pieces less than 10 in. in diameter were bundled, towed with a small motor boat or by hand, submerged, and held in place by rocks and sandbags. This debris provides complex macro- and microhabitats for cover, feeding, and shade. (Photo by Don Samuelson, Grays Harbor College.)

Figure 9. Mining operations in the late 1980s along the Humptulips River. Gravel removal operations have now ceased. Flow is toward the top of the photo. Turbid water (the white reflection in the photo) is seeping though coarse gravels from the active mining pond into a downstream pond. In some ponds upwelling spring water (arrow) provides oxygen, which creates favorable spawning areas along gravel banks. (Photo by Jack Ljestfield, WADFW.)

RECOMMENDATIONS

Digging more ponds for off-channel habitat may be counterproductive in some reaches, and the ponds are not likely to outperform the natural system. Creation of off-channel habitat for salmon should be firmly coupled with plans for long-term monitoring to determine its effectiveness. Currently, the only gravel pit lakes that are monitored for off-channel habitat are the Weyco-Briscoe ponds. Department of Natural Resources reclamation specialists recommend that government agencies, tribes, academia, and industry collaborate in monitoring existing and future sites. Sites should be evaluated by a multidisciplinary team to determine the success of planned habitat and thereby improve future efforts.

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Figure 10. A pond in a part of the Edler sand and gravel pit near Union Gap south of Yakima shortly after reclamation and planting with native species (chiefly willows and cottonwood). The island in the background is in the center of the lake. Trees in the far background are on a reclaimed shoreline and are part of an undisturbed riparian zone. Shoreline slopes are less than 5:1. The 2- to 5-acre pits at this site were designed with islands and shallow shorelines to enhance fish and wildlife habitat. The miner replaced topsoil in and around the ponds to promote revegetation. The last pond to be mined will be connected to the Yakima River by a 20-ft-wide channel.

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BOOK REVIEW: Collecting the Natural World—Legal requirements and personal liability for collecting plants, animals, rocks, minerals, and fossils

by Donald Wolbery and Patsy Reinard
Geoscience Press, Inc.
PO Box 42948, Tucson, AZ 85733
1997. $24.00

This book presents summaries of federal and state laws regarding collecting archaeological, botanical, biological, and geological items. Few entries are more than a page long, but the essence of each regulation is set forth. Federal land ownership and management are briefly described. The authors evidently recommend cautious use of their book. The disclaimer in small print on the back of the title page states

"This book is an interpretation of relevant state and federal statutes, a subject which is a constantly moving target. Therefore, it is entirely possible that a particular law has been missed or misinterpreted or has changed...the reader is directed to contact the agencies listed for more detailed information."

Several appendices take up more than half of this 330-page book. These cover state symbols, fossils, flora, and fauna; addresses for various agencies; lists of national parks and monuments and when they were established; and the texts of the Antiquities Act of 1906, Historic Sites Act of 1935, Archaeological Resource Protection Act of 1979, and Federal Endangered Species Act of 1973 (with list of species). One of the appendices is titled "Using basic instruments [tools], maps, and leases". In this section, the authors provide a sample lease form that might be used to arrange access to private lands. But they also recommend getting thorough legal advice about leases to avoid situations similar to what followed discovery of the infamous "Sue" tyrannosaurus. Paleontologists should be aware that at least 13 acts now affect collecting on federal lands, and other legislation is pending.

When contacted in July 1998, state offices had a somewhat different message for persons interested in collecting:

- Washington's State Archaeologist Rob Whitlam encourages potential collectors to go to the Internet for current regulations and contacts. The office urges a conservation and preservation ethic: Take only photos and try not to leave footprints.
- In Washington state, no permits are required at this time for fossil or mineral collecting on lands managed by the Department of Natural Resources (DNR), but as a courtesy, contact Ellis Vonheeder at DNR's Resource Planning and Asset Management Division, Materials Management Section (360-902-1618).
- The Washington Department of Fish and Wildlife requires a permit for collecting on land it administers.
- Washington law (RCW 79.01.748) states: "Every person who willfully commits any trespass upon public lands of the state and...digs, quarries, mines, takes, or removes therefrom any earth, soil, stone, mineral, clay, sand, gravel, or any valuable materials, shall be guilty of larceny."

A general rule then is: To avoid trespassing, get permission and up-to-date information about regulations from the landowner (federal, state, or private) before you set out. The legal complexities and case law call for keeping current.

Despite the fact that this is a 1997 book, readers should be aware that there are typos and slips. Further, addresses given in the appendices may be out of date. For example, Washington's Historic Preservation Officer can now be reached at PO Box 48343, Olympia, WA 98504-8343; the office is in Lacey, Wash. There is no longer a DNR Division of Lands and Minerals. It has become the Resource Planning and Asset Management Division, PO Box 47014, Olympia, WA 98504-7014. Look in your local phone book for information about locations of federal or local government offices as well.

This book is only an introduction to the fuzzy world of legalities in collecting. It might be a useful (though flawed) reference book for libraries, but it is not a comprehensive guide. The disclaimer says it all. Caveat emptor.

Kitty Reed