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A MEANDER CUTOFF INTO A GRAVEL EXTRACTION POND, CLACKAMAS RIVER, OREGON

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Abstract

The River Island mining site is located at approximately river mile (RM) 15 on the Clackamas River, a large gravel-bed river in northwest Oregon. During major flooding in February 1996, rapid channel change occurred. The natural process of meander cutoff, slowed for several years by dike construction, was accelerated by erosion into gravel extraction ponds on the inside of a meander bend during the flood.

In a matter of hours, the river cut off a meander and began flowing through a series of gravel pits located on the inside of the meander bend. The cutoff resulted in a reduction in reach length of approximately 1,100 m. Erosion by bed lowering, knick point retreat and lateral erosion of upstream river banks occurred quickly. Within two days of the peak flow, 3.5 hectares of land and 105,500 m^3 of gravel were eroded from the river bank just above the cutoff location. Much of this gravel moved a short distance downstream into the excavation. Reach slope increased from 0.0022 to approximately 0.0035 in the cutoff reach. Between 1996 and 2003, the knick point from the meander cutoff has migrated 2,290 m upstream, resulting in increased bed load transport, incision, and local lowering of the water table. In 1993, prior to the meander cutoff, transects were surveyed in the River Island reach upstream of the cutoff location. Resurvey of these transects and aerial photo analysis indicates that 96% of the knick point migration occurred during the first winter following meander cutoff.

Connection of the flowing river to the off-channel ponds has had minimal effect on water temperatures in the mainstem Clackamas River. It is likely that this minimal change in temperature will decrease as ponds are isolated from active river flow by gravel bar deposition.

Fish net-ting in spring 2002, suggests that salmonid use of the pond in the spring is minimal. The most abundant native species netted were large-scale sucker and northern pikeminnow. The most abundant non-native species netted was brown bullhead.

Early regulation by state and federal agencies did not adequately evaluate potential impacts to the river and the floodplain; nor did it evaluate future impacts related to geomorphic processes and sediment transport. New permit evaluation methods, currently implemented by both Oregon and Washington, incorporate 1) river dynamism through historic river migration analysis; 2) stability of human structures in light of river dynamics; and 3) sediment transport and its impact on channel stability and dynamics.

The gravel pit capture at River Island highlights the potential risks of mining in an active secondary channel of a large gravel-bed river. Mining deeper than the depth of the adjacent channel, within the active migration zone, may increase off-site impacts. In locations where multiple gravel excavations are present within the meander zone, a comprehensive reclamation and restoration plan should be developed which provides long-term channel stability within the natural variability of the entire river reach.

Introduction

The River Island site provides a unique opportunity to examine the physical changes to a river channel resulting from avulsion into a gravel extraction pond. Data from before and after the meander cutoff allow evaluation of changes to river geometry, sediment transport, temperature, habitat, and channel form.

An avulsion is defined as a lateral migration or cutoff of a river. It involves the diversion of water from the primary channel into a new channel that is either created during the event or reoccupied. Avulsions may be rapid or take many years to complete (Slingerland and Smith, 2004). Meander cutoff is a specific type of avulsion where channel length and sinuosity are reduced through lateral erosion of the neck on the inside of a meander bend (Allen, 1965). Channel migration and meander cutoff are natural processes that create aquatic habitat, off-channel refuge, and rejuvenate riparian species.

Channel avulsions are more likely to occur in channels with slope, discharge, sediment load, and width which place them near the threshold between meandering and braided patterns (Gilvear, 1999; Leopold and Wolman, 1957). River reaches where meandering and cutoffs occur are typically locations where sediment supply exceeds the competence of the stream to carry sediment (Thompson, 2003).

In-stream and floodplain gravel extraction can result in increased likelihood of avulsions due to the physical alterations to the channel and floodplain that occur during mining operations (Collins and Dunne, 1990). Impacts from in-stream, floodplain, and channel migration zone (CMZ) extraction ponds can be viewed as both positive and negative. Impacts generally viewed as negative include: 1) bed lowering (incision or degradation) upstream and downstream of the extraction site and related scour adjacent to bridge supports, pipelines, or other structures; 2) changes to channel bed morphology and exposure of bedrock; 3) lowering of the water table and loss of riparian vegetation; 4) reduction of floodplain sedimentation; 5) increase in lateral erosion of river banks; and 6) flooding of ponds resulting in stranding of indigenous migratory fish species and/or release of non-native species into the river. Impacts typically viewed as positive include: 1) reduction in flood height for a given discharge due to bed lowering; 2) increase in side-channel refuge and habitat for juvenile salmonids; 3) introduction of sediment and large wood through lateral erosion; and 4) increase in overall edge habitat and channel complexity (Bayley, 1995; Bayley et al., 2001; Bell et al., 2001; Minakawa and Kraft, 1999; Peterson, 1982; Swales and Levings, 1989).

The River Island gravel extraction site has been controversial virtually since mining began. Controversial aspects of mining the site included potential downstream impacts and dike construction to protect the site from flooding which blocked secondary channels and directed the river into a single channel. In 1974, a local ordinance was struck down by the courts which would have resulted in closure of the mine site.

Mining at River Island has included both in-stream and floodplain mining. In-stream, or in-channel, mining is defined in Oregon statutes as mining within the beds and banks of the stream or river. This is typically interpreted as mining below the elevation of the ordinary high-water mark. Floodplain mining is considered "upland" extraction in Oregon and is defined as mining above the ordinary high-water mark. The term "upland" refers to mining within the 100-year floodplain, terraces adjacent to rivers, and areas not near rivers. Both in-stream and floodplain mining can result in similar geomorphic changes to the river system when floodplain mining sites become connected to the river system through avulsion.

This paper presents a unique set of data documenting impacts due to a channel avulsion into a gravel pit. These impacts are evaluated within the context of current land use and mine permitting practices for floodplain and in-stream mining sites.

Geologic Setting and Site Location

The Clackamas River has a drainage area of 243,460 hectares, and traverses three distinct physiographic provinces in its 97 km course from Timothy Lake to the Willamette River at Oregon City (Figure 1, see Appendix A). The River Island reach is located between RM 13 and 17.

The headwaters in the High Cascades provide the river with a relatively constant supply of cold, clean water throughout the year. As the river enters the Western Cascades, it encounters a deeply eroded volcanic landscape with numerous landslides and high sediment yield. Near Estacada, the river emerges from a confined canyon into a broad valley, which is part of the Willamette Valley physiographic province. As it travels, geomorphic processes are altered by human activities such as dam construction, in-stream and floodplain mining, bank protection, riparian removal, and bridge construction.

Throughout the Pleistocene, the lower Clackamas River accumulated sediment generated in the Western and High Cascades, including glacial outwash from Cascade glaciers and mass wasting processes. Dramatic climate fluctuations, advance and retreat of glacial ice in the Cascade Mountains, and changes in sediment yield from the upper Clackamas Basin have generated alternating periods of aggradation and incision in the River Island reach (Wampler, 2004). Systematic incision since the last glacial maximum has resulted in the preservation of floodplain remnants, known as terraces.

Bedrock in the vicinity of River Island is the Sandy River Mudstone (SRM) (Trimble, 1963). The SRM is a silty, volcanic mudstone that is easily eroded once exposed to fluvial processes to form flutes and potholes. The lower Clackamas River is constrained in many reaches by steep cliffs of SRM due to Holocene incision.

The lower Clackamas River exhibits a combination of channel forms including meandering, braided, and anabranching reaches. The River Island reach has historically had multiple channels and exhibited dynamic river behavior in some sub-reaches while remaining quite fixed in others (Figure 2). This pattern reflects longitudinal changes in sediment transport which are a function of channel competence. Incised straight reaches and the outside of many meander bends are confined and more competent to transport available sediment. Expansion into unconfined reaches results in decreased transport competence, sediment deposition, and increased channel migration. Channel plan form area and length have decreased systematically from 1938 to 2000 in the River Island reach (Figure 3, see Appendix A). This decrease in complexity and incision along the Clackamas River represents the combined effects of anthropogenic and natural trajectories of change. Part of the observed incision rates below River Mill Dam are a result of climate change and degradation affecting the entire watershed; and part of the incision rates at River Island meander cutoff are due to climate and dam-induced incision (Wampler, 2004).

Methods

A combination of surveying, GIS analysis of aerial photos, temperature loggers, and fish netting were used to evaluate physical and biological changes at the River Island site.

Two sets of pre-cutoff channel transect data were available for the River Island reach: Federal Emergency Management Agency (FEMA) flood study transects surveyed in 1979, and a resurvey of selected FEMA transects in 1993 (Ogden Beemon and Associates, Inc., 1994). Several of the authors, supported by volunteers and Clackamas County personnel, identified the locations of the historic transects, cleared brush, "cut line", established control points and surveyed new transects with a total station. The initial post-flood work effort took place in 1998. A total station was used in combination with control points established with a Global Positioning System (GPS) to resurvey the 1993 and 1979 transects. Gravel bar elevations and pond depths were surveyed periodically to determine transport volumes. Pond depths were determined using a combination of total station surveying and an Acoustic Doppler Profiler (ADP).

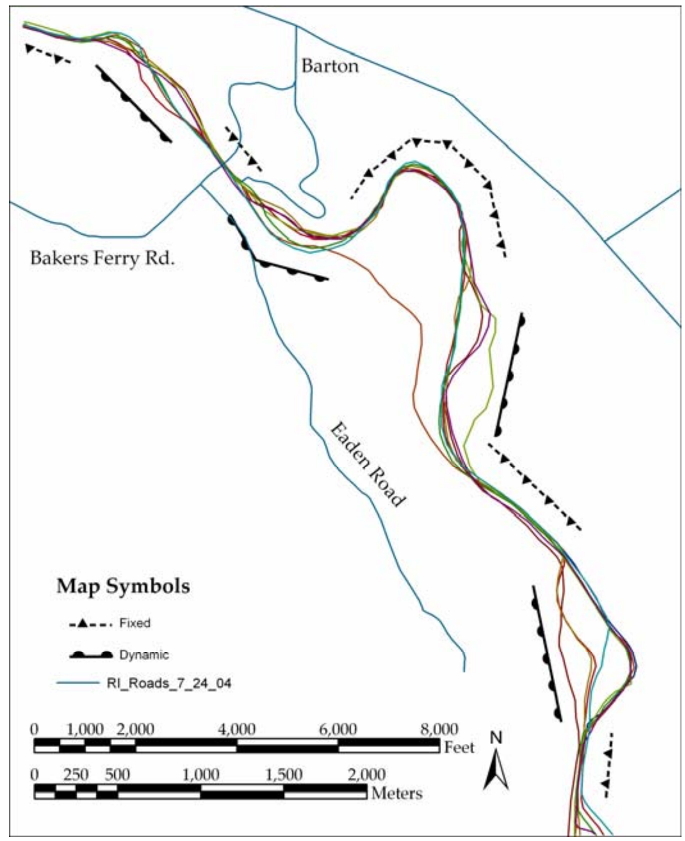

Figure 2. Center line changes at River Island 1938-2000 based on aerial photos. Fixed reaches exhibit minor lateral migration, and dynamic reaches exhibit avulsions and lateral erosion.

Fish usage was evaluated at the River Island site between March 6 and June 19, 2002. Portland General Electric (PGE) fisheries biologists set a six-foot Oneida trap net in the northern River Island excavation pond. The trap net was deployed once or twice each month for a sampling period that varied from three to five days. The net was checked every day or every other day and, the trap was removed at the end of the period. Fish captured were identified by species, their length was measured, and then they were released.

During the summer of 2000, seven HOBO temperature recorders were installed at the River Island site. In the main channel, probes were installed upstream and downstream of the meander cutoff in the active mixing zone and secured with concrete blocks. Three recorders were placed on the bottom of the southern pond. In 2001, three additional recorders were added in the northern pond.

Temperature probes were installed during the summers of 2000 and 2001, by Oregon Department of Geology and Mineral Industries (DOGAMI), to evaluate thermal changes resulting from the meander cutoff. Temperature recorders were placed upstream of the ponds (2000-2001), in the southern pond (2000), in the northern and southern ponds (2001), and downstream of ponds (2000-2001). Approximate locations of recorders are shown in Figure 4 (see Appendix A).

Duplicate probes were placed upstream and downstream of the cutoff to insure that continuous data were available in the event of a malfunction. Duplication also allowed an assessment of the variability introduced by recorder placement. The two upstream probes were in very good agreement with each other (R^2_{2000} = 0.9999; R^2_{2001}= 0.9997). However, daily average temperatures for the two downstream probes, located just 10 meters apart, differed by as much as 0.62 C in 2000 and 1.65 C in 2001 (R^2_{2000} = 0.9983; R^2_{2001}= 0.9730). This disparity creates a problem in that the observed mean change in daily average temperature between the upstream and downstream probes was only 0.32 C in 2000 and 0.36 C in 2001.

Fortunately, PGE had independently installed a probe within 100 m of the downstream location in 2001. Temperature data from the PGE probe was in good agreement with one of the two probes installed for this study.

Since the PGE probe and RI10 are in good agreement, Probes RI10 and RISG10 were used for analysis of upstream and downstream changes in water temperature. Data from RI9 and RISG9 were not used in the analysis.

Historic aerial photos and maps were georeferenced using ArcView 3.2 Image Analysis Suite and ArcMAP georeferencing tools. All aerial photos were georeferenced to a set of 2000 orthophotos provided by PGE. A minimum of 6 points were used to reference each photo. Short-term channel migration was analyzed using maps and aerial photos dating back to 1853. Photos were compared to determine erosion and channel migration rates.

Mine History at River Island

Mining on the River Island site began in the mid 1960's as an in-stream extraction site and slowly moved to floodplain terraces. Total aggregate production from the River Island site between 1967-1996 was approximately 2.7 million cubic meters (Table 1).

Table 1. Aggregate production from the River Island mining site.

Years of Activity	Mining Type	Permitting Authority	Average Annual Production (yd^3)	Average Annual Production (m^3)
1960's-1967	In-stream	None	Unknown	Unknown
1967-1972	In-stream	Division of State Lands	150,000	115,000
1972-1978	Flood-plain	Department of Geology and Mineral Industries	112,500	86,000
1979-1990	Flood-plain	Clackamas County	161,000	123,000
1991-1999	Flood-plain	Department of Geology and Mineral Industries	66,700	51,000
Total Estimated Production 1967-1996[a]			**3,500,000**	**2,676,000**

[a]Total production does not include years during which production was not known: 1973-74, 1979, and prior to 1967.

Early interactions between the mining company and the DSL were contentious, and resulted in legal action over permit requirements. In 1972, miners reported that annual in-stream gravel removal volumes were averaging 110,000 m^3 (150,000 yd^3). In 1973, an on-site evaluation by DSL determined that mining was also occurring outside of DSL jurisdiction on the adjacent floodplain, within the meander bend, and behind the dike completed in 1971.

In Oregon, zoning and conditional use of land for mining of floodplains and uplands is decided by the local land use authority, usually either the city or county planning department. In 1972, the Department of Geology and Mineral Industries (DOGAMI) became the agency responsible for reclamation of floodplain mineral extraction sites. The mine operator filed for a DOGAMI permit in 1972. However, 1972 statutes allowed the continued operation of the site as a "grandfathered" or pre-law site. None of the natural resource protection or reclamation standards contained in the 1972 legislation could be enforced through the issuance of a DOGAMI permit.

From 1979 through 1990, DOGAMI delegated regulatory authority to the Clackamas County Planning Division. In 1984, Clackamas County approved a site reclamation plan for 16 of the 160 acres within the 100-year floodplain for the creation of a 4 to 8 m deep pond (DOGAMI file #03-0051). These 16 acres, located along the south or upstream property boundary, were the only area on the floodplain subject to the standards of the state reclamation act. By 1993, floodplain mining had ceased. The operator continued to process imported material until the 1996 flood. The dike, designed to withstand a 100-year flood, ended at the upstream boundary with the Cassinelli property (Figure 5b). The Cassinelli property was acquired by the mining operator several years prior to the meander cutoff.

1996 Flood and Meander Cutoff

In January 1996, Oregon experienced unseasonably cold weather; and snow accumulations of several inches were present on the Willamette Valley floor. Snow pack for the Willamette River basin was at 112% of average. On February 6th, a warm front, referred to as a "Pineapple Express," brought several days of warm, moist air from the western Pacific Ocean. Heavy rains and warm winds melted snow pack in the mountains to generate a "rain on snow" event, resulting in the flooding of many western Oregon rivers, including the Clackamas River.

The 1964 flood, referred to as the "Christmas Day Flood," is the yardstick by which most floods are measured in Oregon. Peak discharge on the Clackamas River on December 22, 1964, was 2,461 cms (86,900 cfs) at the Estacada gage (14210000), whereas a peak discharge of 1,951 cms (68,900 cfs) was recorded on February 7, 1996, at Estacada (Figure 6). Eagle Creek enters the Clackamas River above River Island, so discharge at the site would have been higher than reported at Estacada. An aerial photo of the River Island site taken February 9, 1996, shows the extent of erosion and channel change that occurred during the peak of the 1996 flood (Figure 7, see Appendix A). The mean daily discharge at Estacada for February 9, 1996, was 1,025 cms (36,200 cfs).

No velocity measurements were made during the flood event; however standing waves, prominent in the flood photos taken February 9, 1996 (Figure 7: inset), can be used to estimate an average velocity of approximately 4.9 m/s through this portion of the reach. Based on the estimated velocity and depth, shear stress was approximately 10,000 N/m^2 in the location of the standing waves on February 9, 1996 (Wampler, 2004).

The river entered the site upstream of the dike (Figure 8). It is unclear whether flood waters entered from the Shoe Island channel or another topographic swale further west. As the water rose, a low point between the River Island site and the adjacent Cassinelli property allowed the river to flow around the upstream end of the dike and into the upstream excavation. Once the river began flowing over the 1.5H:1V slopes, it quickly eroded the unprotected farmland and captured flow from the main channel of the Clackamas River. As additional flow was captured by the "new cutoff channel", bed load from the mainstem was deposited in the historic meander, essentially sealing off this direction of flow.

During the falling limb of the hydrograph, the majority of the Clackamas River flow was captured by the new cutoff channel. Efforts to redirect the river back into its original channel were discussed but deemed infeasible due to concerns regarding funding and regulatory issues related to in-channel alterations. The entire flow of the Clackamas River remains in the newly occupied channel.

Channel Geometry and Knick Point Migration Data

Five channel transects originally surveyed by FEMA in the late 1970's were surveyed in 1993. These same transects were resurveyed in 1998 and subsequent years to document the physical channel changes (Table 2, see Appendix B; Figure 8).

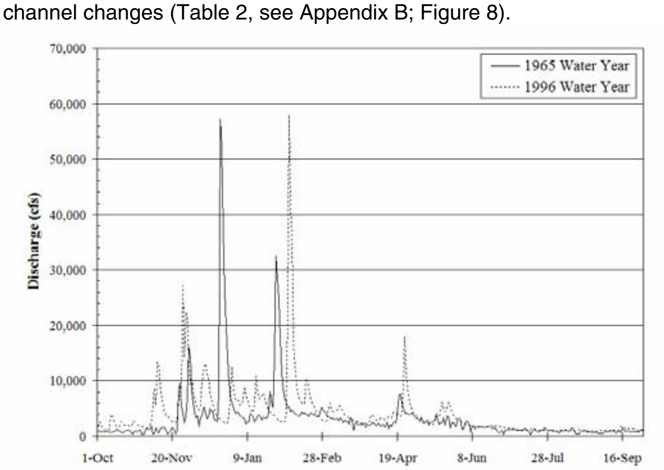

Figure 6. Hydrographs for the Estacada gage (14210000) showing mean daily flow for 1965 and 1996 water years.

From transect data it is clear that the knick point migrated upstream quite rapidly. Ninety-six percent of the upstream movement of the knick point occurred during the winter of 1997, before the first set of survey data were collected on the transects in 1998. This is reflected in elevation decreases of 1 to 2 m on all transects.

Aerial photos were used to measure knick point migration. No obvious knick point is visible in aerial photos taken February 9, 1996, just two days after the peak flow. However, the water level and turbidity were sufficiently high to make knick point identification difficult.

The 1998 transect survey shows a general bed lowering of 1 to 2 m; however, 1993 transects only extended approximately 884 m above the cutoff location. Based on aerial photo evidence, it is likely that the knick point had already migrated past all the 1993 sections prior to the 1998 survey. With the exception of the lowermost transect, thalweg elevations have been relatively static since 1998. Transect 53 near the upstream end of the cutoff channel aggraded 3 m between 2000 and 2001. This represents a bed elevation of 1.2 meters higher than was measured in 1993, prior to the meander cutoff. This localized aggradation is probably due to downstream transport and deposition of alluvium in the gravel ponds.

An aerial photo taken July 7, 1996, shows a prominent knick point 274 m upstream of the cutoff location. Upstream of the knick point, channel width increased from 46 to 82 m (Figure 9). By April 1997, following a winter with three sizable flood events, an aerial photo showed that the knick point had migrated 2,195 m upstream of the cutoff location (Figure 10). The average annual rate of knick point migration is 287 m/year although, as mentioned above, the majority of knick point migration occurred during the winter of 1997.

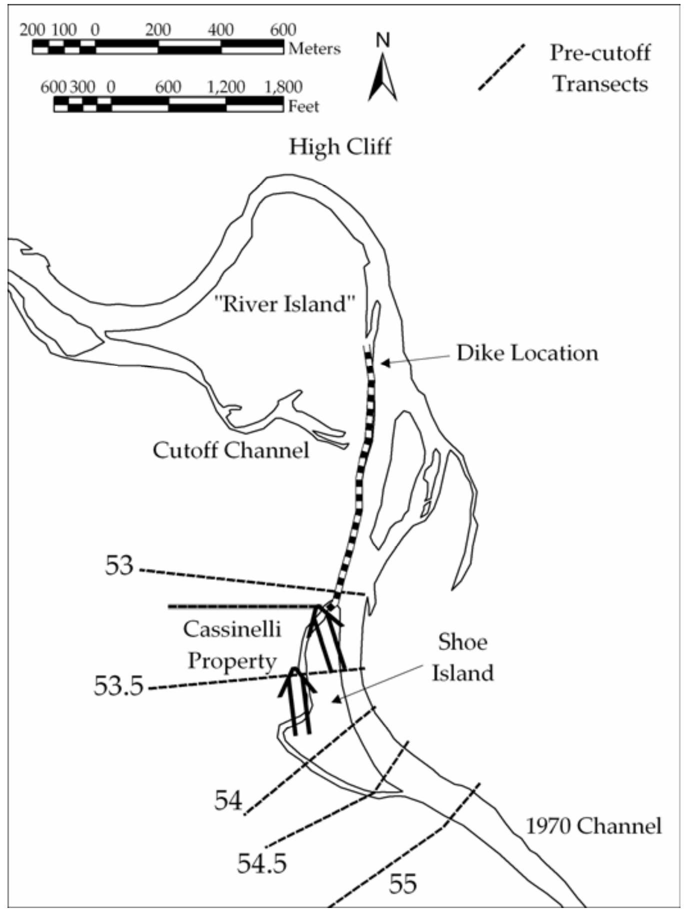

Figure 8. Flood routing map. Bold arrows indicate possible flood entry paths. Numbers refer to Section ID #'s found in Table 2.

Riparian vegetation appears to have responded to the upstream migration of the knick point. Alder trees on the north bank hundreds of feet upstream of the cutoff have died. Similar alder tree deaths were observed at other locations along the Clackamas River where rapid incision was documented.

Channel Gradient Data

Transect data from 1993 suggests that aggradation was occurring in the main channel upstream and immediately downstream of the cutoff location. Between 1979 and 1993, reach slope increased between transect 53 and 55. Between 1993 and 2000, slope increased at the cutoff location and decreased upstream of the cutoff (Figure 11).

Wetted Perimeter Data

Wetted perimeter, a measure of channel complexity, in the reach from RM 12 to RM 17 (the reach depicted in Table 2 and Figure 3) was measured using aerial photos from 1938 to 2000. The measurement of wetted perimeter includes the incorporation of new shorelines and increased riparian areas following the capture of the pits. Wetted perimeter length decreased since 1938, with static to slightly increasing length through the 1950's, 60's and 70's (Figure 12). Discharge at Estacada during the photo dates ranged from 27 to 91 cms (960 to 3,220 cfs). No attempt was made to correct for discharge differences, however the magnitude of the changes suggest the changes are real rather than attributable to discharge differences. Wetted perimeter increased slightly after 1996, due to incorporation of complex shorelines from ponds, but remained well below 1938 perimeter length.

Sediment Erosion and Deposition Data

Pond area prior to meander cutoff was approximately 28.9 hectares. After the meander cutoff, erosion occurred on the left bank upstream and in the upstream bed; and deposition of gravel occurred in the former extraction ponds, reducing the depth and surface area of ponds (Table 3; Figure 13). Volumes of erosion and deposition were calculated using surveying data, aerial photos, and observed sediment depths.

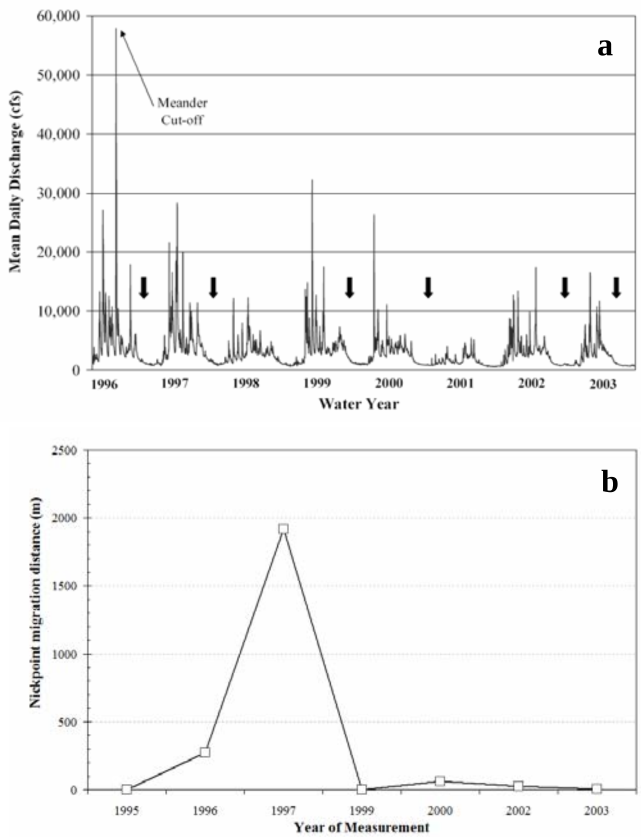

Figure 10. a. Mean daily discharge at Estacada (1421000) 1996-2003. b. Knick point migration distance measured upstream of Barton Bridge during the same time period. Arrows indicate approximate timing of knick point measurements from photos and ground survey measurements.

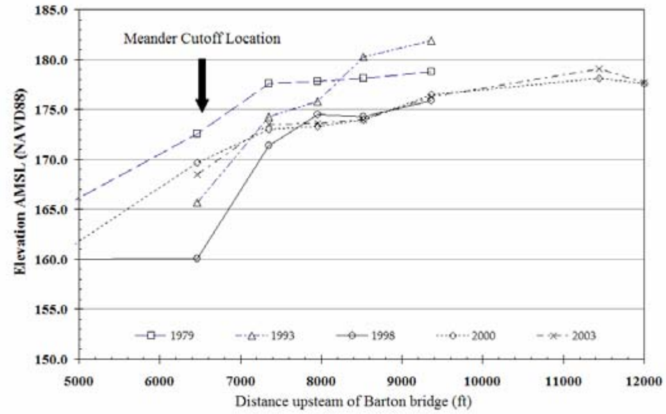

Figure 11. Changes in channel gradient 1979 to 2003 based on thalweg elevations from surveyed transects.

Figure 12. Changes in channel perimeter from RM 12 and RM 17 based on 1938 to 2000 on aerial photos. Discharge at Estacada during the photo dates ranged from 27 to 91 cms (960 to 3,220 cfs).

Table 3. Deposition and erosion volumes based on ground surveys and aerial photos.

Date of Measurement	Amount Eroded[a]		Total Volume in Gravel Bars[b]	
	Volume (ft^3)	Volume (m^3)	Volume (ft^3)	Volume (m^3)
2/9/1996	3,727,400	105,500	Unknown[c]	Unknown
7/7/1996	363,500	10,300	8,345,100	236,300
7/16/1998	2,103,300	59,600	12,029,700	340,600
10/3/2000[d]	843,800	23,900	12,909,600	365,600
TOTAL	**7,401,500**	**209,600**	**12,909,600**	**365,600**

[a]Average gravel depth was 10 feet.

[b]Bar area was mapped on aerial photos at low water. Bar volumes are cumulative.

[c]Water turbidity and levels were too high to determine deposition amounts.

[d]Bankline surveys in 2002 and 2003 showed virtually no change in bank line since 2000.

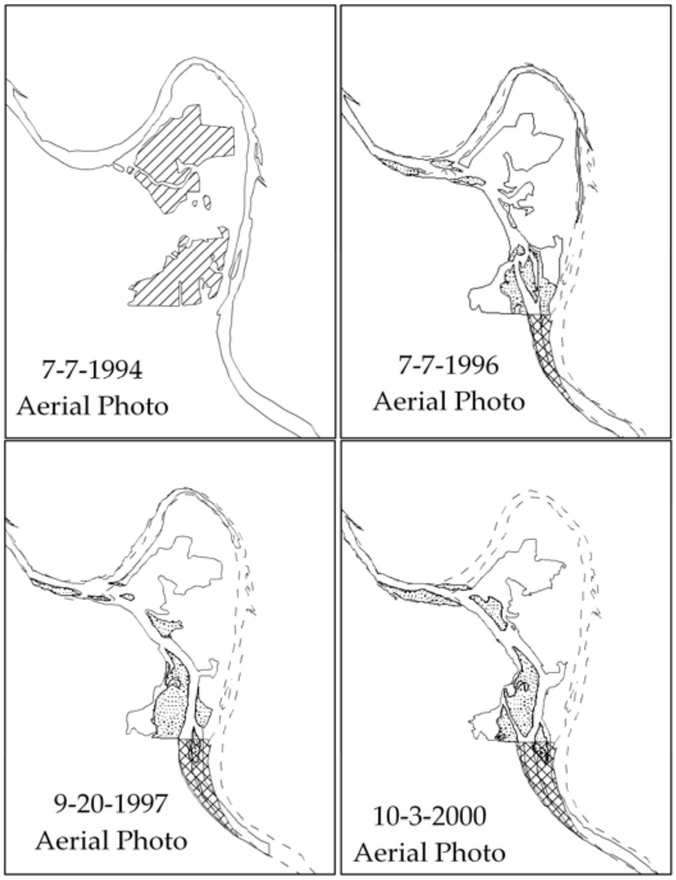

Figure 13. Erosion and deposition patterns in the River Island reach 1996-2000. The 1994 channel is shown with a dashed line for reference. Solid lines show the post-1994 channel configuration. Stippled regions are exposed gravel bars. Cross-hatched area is eroded river bank upstream of the cutoff. Hachured area represents the pre-cutoff pond area.

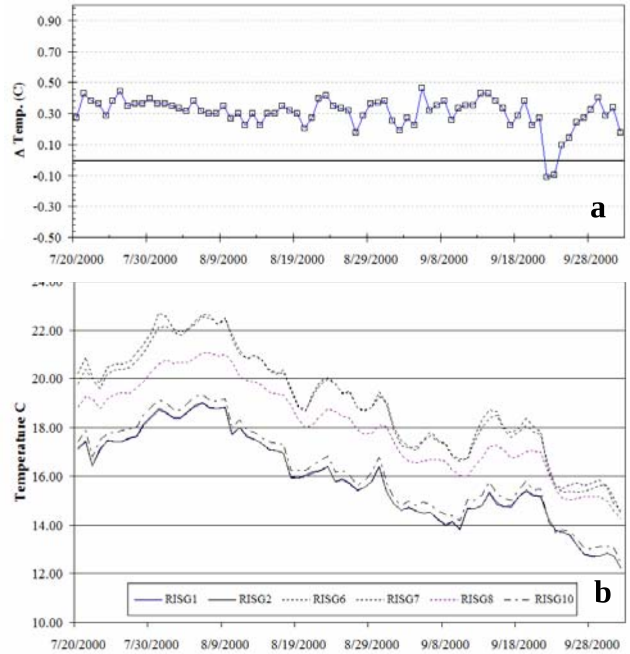

Figure 14. a. Change in temperature between the upstream and downstream probes. b. Average daily temperature data from six recorders during 2000.

Thermal and Biological Changes

Thermal and biological changes are among those often cited as off-site impacts related to gravel pit captures. Temperature probes and fish netting were used at River Island to evaluate these changes.

Probes installed above and below the ponds revealed a temperature increase between the upstream probes in the main channel and probes below the meander cutoff at Barton Bridge of 0.32 C in 2000 and 0.36 C in 2001 (Figure 14; Figure 15). This suggests that the capture of the ponds did not influence overall summer stream temperature significantly despite the fact that average temperature over the entire summer was 0.32 C to 2.76 C higher in the ponds than in the main channel upstream of the ponds. Pond temperatures were more variable than main channel temperatures. Vertical thermoclines were evident in the ponds due to local input of hyporheic (intragravel) flow and lack of water movement.

No studies were identified that evaluated the growth and survival of juvenile salmonids in the lower Clackamas River. However, high summer water temperatures, the prevalence of both native and non-native predators, and the extensive release of hatchery-reared fish have led many biologists to conclude that survival of native juvenile salmonids is low in the lower Clackamas River in the vicinity of the River Island site.

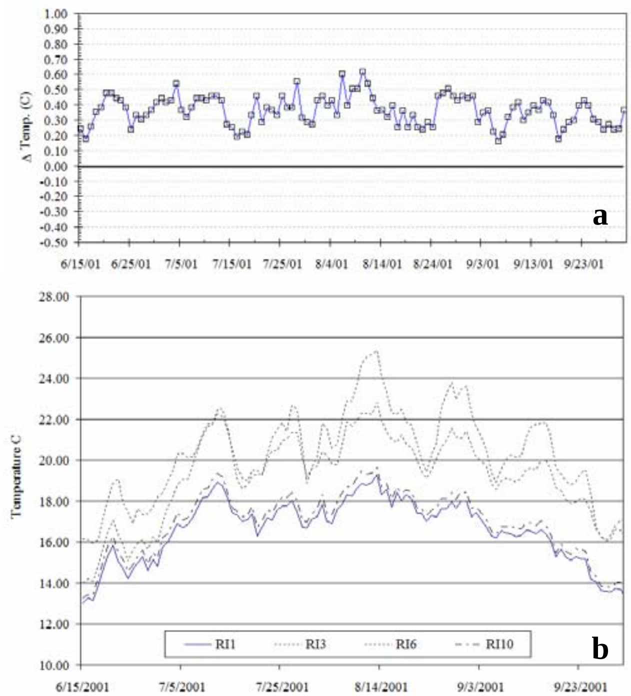

Figure 15. a. Change in temperature between the upstream and downstream probes. b. Average daily temperature data from 10 recorders in 2001.

The total number of species caught in the northern River Island pond varied widely among sampling periods (4 to 12), as did the average daily catch (6 to 114). Variation in species count and daily catch did not correspond to changes in flow or run timing during the 2002 sampling (Table 4).

Table 4. Fish netting data, 2002.

Sample Period	Average Flow (cfs)	# of Native Species	# of Non-native Species	Daily Catch (#/day)
3/5-3/7	3,273	2	2	6
3/18-3/22	3,133	7	1	46
4/1-4/4	3,033	6	2	14
4/23-4/25	3,505	9	2	114
5/29-5/31	4,816	3	2	23
6/17-6/19	2,401	8	3	89

The most numerous species caught during netting at River Island were the native large scale sucker and northern pikeminnow, and the non-native brown bullhead. A small number of salmonid smolt and fry were caught, as well as a few adult steelhead. Ten species of native fish and four species of non-native fish were caught during the six sampling periods. The four salmonid species that were caught (mountain whitefish, chinook salmon, coho salmon, and steelhead) are considered intolerant of warm water temperature. Sampling took place when the water was relatively cool and did not cause a stress to cool-water fishes. During the summer, some or all of these fish will likely leave the pond as water temperatures exceed 21.1 C (70° F).

The stomach contents of five northern pikeminnows were examined; four had salmonid smolt or fry in their stomachs. The number of salmonids in the four northern pikeminnow varied from one to ten. The small salmonids were likely consumed while they were trapped with the pikeminnow in the net and may not reflect the diet of the northern pikeminnow in general.

A summary of smolt sizes is shown in Table 5 and indicates a distinct difference in length between wild and hatchery chinook salmon. Hatchery chinook were nearly twice as long as wild chinook.

Table 5. Number and lengths of salmonid smolts.

Species	#	Mean Length (mm)	Minimum Length (mm)	Maximum Length (mm)
Chinook salmon				
Wild	6	82	42	128
Hatchery[a]	3	150	140	159
Coho salmon				
Wild	13	121	110	140
Hatchery[a]	10	144	128	155
Steelhead				
Hatchery[a]	5	202	195	210

[a]Identified by a clipped adipose fin.

Discussion

Channel adjustment at River Island was rapid, and development of a new equilibrium occurred within a few years of the meander cutoff. The meander cutoff reach is slowly reestablishing channel width as ponds fill with alluvium. Hydraulic connection between the former ponds and the river is generally decreasing as transported gravel is deposited near the opening of the ponds and near the mouth of the former main channel. In July of 1996, the summer after the meander cutoff, channel form through the extraction ponds was braided and gravel deposition was most pronounced in the excavation immediately downstream of the meander cutoff. By the year 2000, the southern pond was connected by only a small downstream outlet at low flows and the downstream mouth of the former channel was completely closed off by a gravel bar.

The Clackamas River dike construction adjacent to River Island resulted in channel simplification and may have resulted in increased bed load transport adjacent to the dike. Gravel aggradation in the main channel, as documented by the transect changes between 1979 and 1993, combined with the path of low flow resistance provided by the excavations, contributed to the relocation of the river into the meander cutoff channel.

Dike construction between 1967 and 1971 isolated the ongoing gravel extraction activities and temporarily halted the natural process of pattern shift and meander cutoff that had been occurring throughout the 1960's. The dike adjacent to the site was stable from an engineering perspective (for river stages less than the dike crest elevation), but because it did not extend onto adjacent land, it was ineffective at preventing the eventual meander cutoff. The river exploited the path of least resistance onto the adjacent land. Had the dike never been built, it is likely that the river would have cut off this meander through natural accretionary processes and eventually shifted into today's channel permanently. It appears that mining activity and the construction of the dike condensed this natural trajectory of slow change into a single flood event.

Thermal and biologic changes resulting from the meander cutoff are both positive and negative. During the summer months, very slight warming of river water temperatures (0.32 to 0.36 C) is documented. However, the magnitude of warming is not large relative to the warming trend in the entire lower Clackamas River. Salmonids clearly use the pond into the summer, but so do many predators, potentially offsetting any habitat gains through increased predation. Fish netting data from this study is insufficient to confirm or deny whether predation is more prevalent in the ponds than it is in the main river.

Off-channel ponds and alcoves, such as the River Island ponds, can provide winter refuge and feeding areas for juvenile salmonids (Bustard and Narver, 1975b; Giannico and Healy, 1998; McMahon and Hartman, 1989; Moser et al., 1991; Sommer et al., 2001; Swales and Levings, 1989). However, no netting or electro-shocking was done during the winter to evaluate the usage of the ponds as refuge. Data from other Willamette Valley gravel extraction ponds and alcoves connected to rivers, suggest that usage of side-channels may be important, especially at night when avian predators are less active (Chip Andrus, personal communication, 2000; and Bayley et al., 2001).

Implications for Mining within Secondary Channels and the Channel Migration Zone

Pit mining or excavations deeper than the thalweg in secondary channels and within or near the CMZ create unnecessary risks to channel stability and protection of adjacent natural resources. At River Island, early statutes allowed pre-law activities to continue, and consideration of river dynamism and sediment transport was not part of the permit process at the time.

Floodplain mine regulators in Washington state have adopted the concept of a CMZ (Rapp and Abbe, 2003). The size and shape of the CMZ implicitly considers the dynamism of each river through historic analysis of river migration. CMZ delineation methodology removes areas termed disconnected migration areas (DMA). DMA's are areas isolated from the CMZ by human structures built to prevent channel migration.

At River Island this methodology may have resulted in the removal of the area behind the dike from the CMZ. It is not clear whether the proposed CMZ methodology evaluates the stability of structures relative to the river slope and stream power. Such evaluation would insure that structures intended to isolate the river from meander areas could in fact do so under the full range of expected flows and sediment transport.

Current Oregon floodplain guidelines, first written in 1992 and updated several times, recognize the importance of protecting the channel migration zone and providing adequate floodplain space for future channel adjustments (unpublished DOGAMI guidelines, 2003). The Oregon guidelines assume that channel migration could occur in areas that are disconnected by revetments or other channelization structures. DOGAMI guidelines call for the evaluation of structures placed to control channel migration or avulsion.

The meander cutoff at River Island was somewhat unique in that channel transect data had been collected only a short time before the cutoff occurred. Pre-cutoff transect data extended only 880 m above the cutoff location; not far enough to record the rapid upstream progression of the knick point. In order to capture the scale of change that occurred at River Island, pre-cutoff transects would need to have extended at least 3 km, and perhaps as much as 5 km upstream of the cutoff location. Baseline data which extends far enough upstream to capture geomorphic changes of the magnitude that occurred is crucial to improving our understanding of the impacts from gravel pit avulsions.

Sediment transport modeling should be done in reaches where mining or other floodplain modifications are planned to determine if the channel is aggrading or degrading. Sediment transport modeling upstream and downstream would provide reach-scale aggradation and degradation patterns so that changes in sedimentation patterns could be identified, and the stability of engineered structures evaluated.

The mineability, set back width, flood connections and mining depths need to be addressed during the regulatory process. Should pit capture occur, mine depth in excess of the thalweg of the adjacent channel will increase the magnitude of off-site impacts. Floodplain mines should not be isolated by dikes. The dike at River Island, constructed to prevent floodwater from entering the meander cutoff, delayed an ongoing process of meander cutoff that was taking place over several decades and resulted in rapid channel change and incision. Dikes constructed on the floodplain should be designed to allow ingress and egress of floodwaters.

When existing or proposed sites are developed within the CMZ and floodplain ingress and egress for peak flows should be provided. In some cases, headcutting potential and erosion can be mitigated through sloping and reinforcing pond banks to account for differences in water surface elevation during a flood event. Floodwater ingress and egress designs should also be sensitive to stranding of indigenous migratory fish species and release of non-native species into the river during peak flows; although in many river systems the release of non-native species from excavations does not appear to be a problem.

The gravel pit capture at River Island highlights the risks of mining within active channel migration zones as well as isolating mining activities by the construction of engineered structures. It is apparent that mining activities within the active floodplain and CMZ are subject to flooding and possible connection to the river. In locations where multiple gravel excavations are present within the CMZ, a comprehensive reclamation and restoration plan should be developed which addresses long-term channel stability within the natural variability of the entire river reach.

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Appendix A

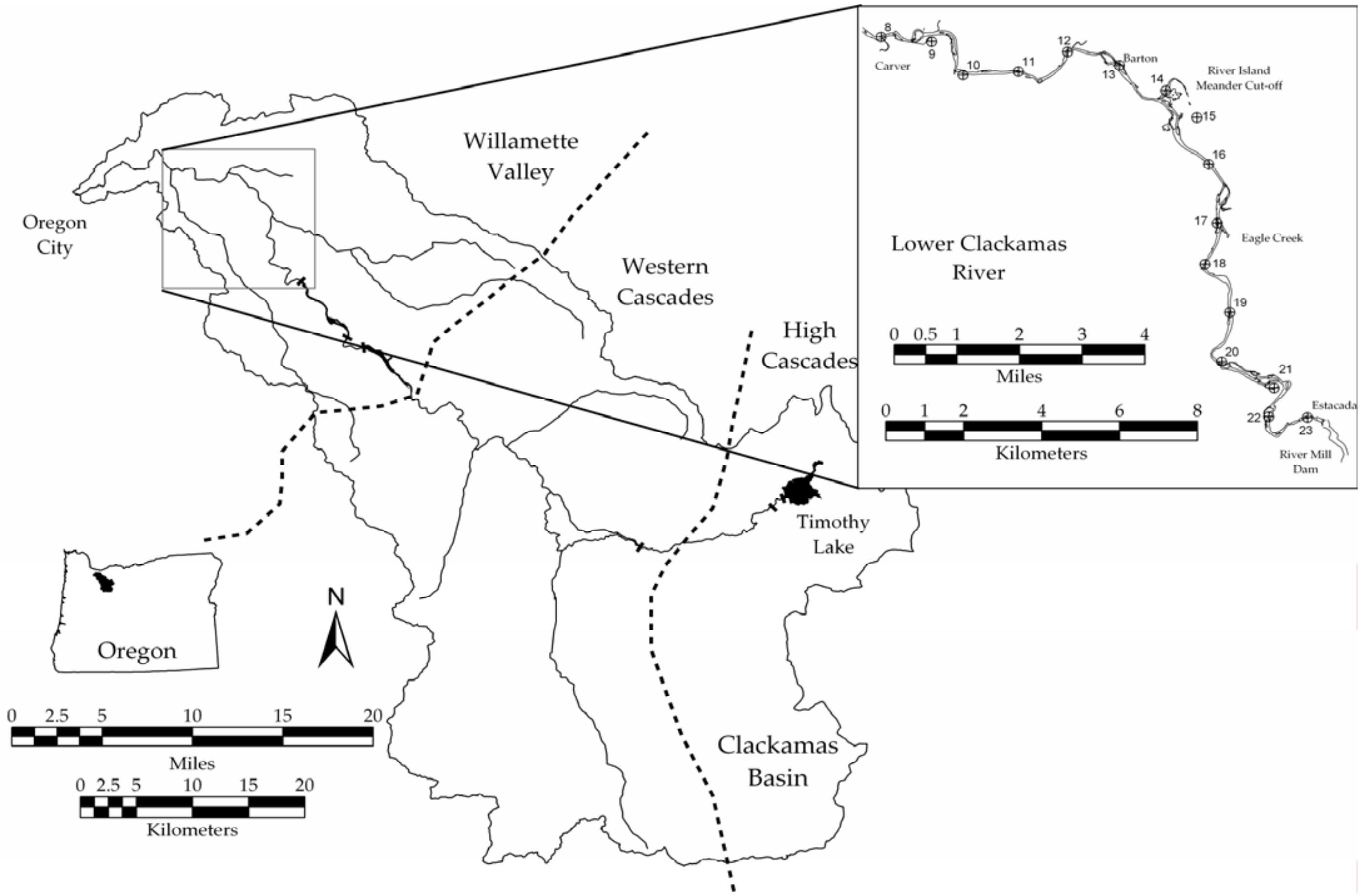


Figure 1. Location map for the Clackamas Basin and River Island meander cutoff.

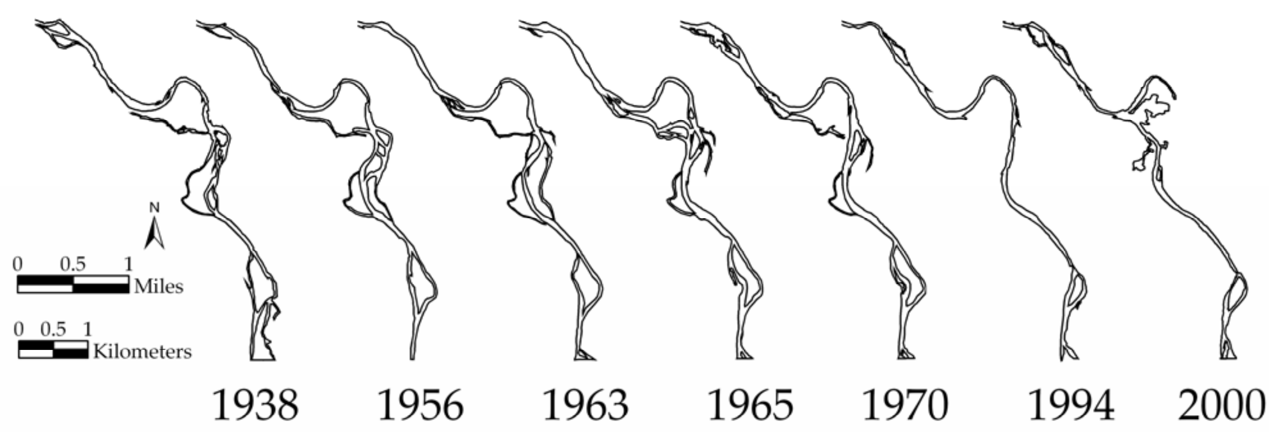
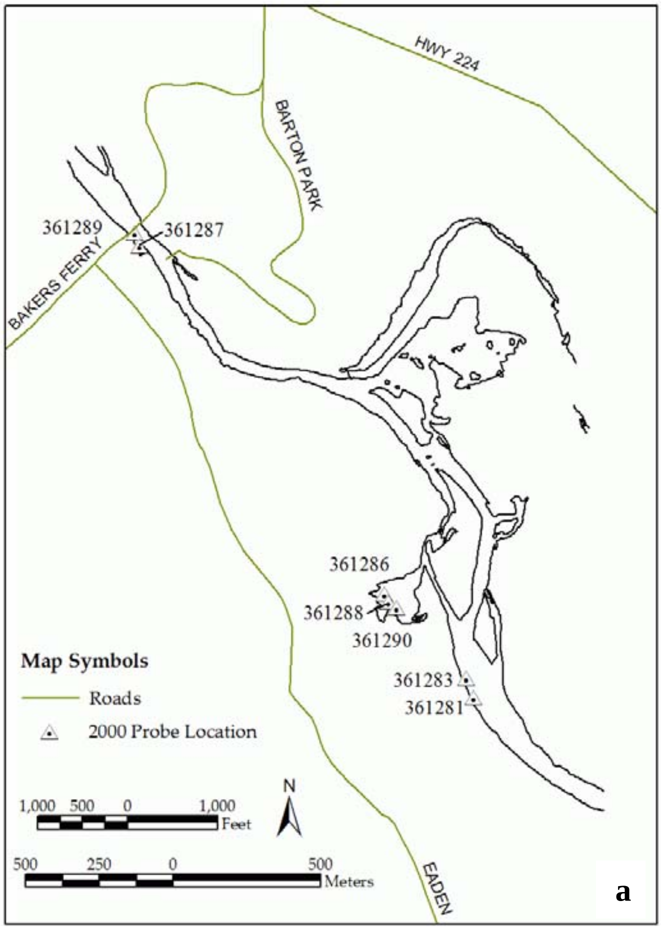


Figure 3. Historic channel plan form changes in River Island reach 1938-2000, based on aerial photos.

Appendix A (cont'd)



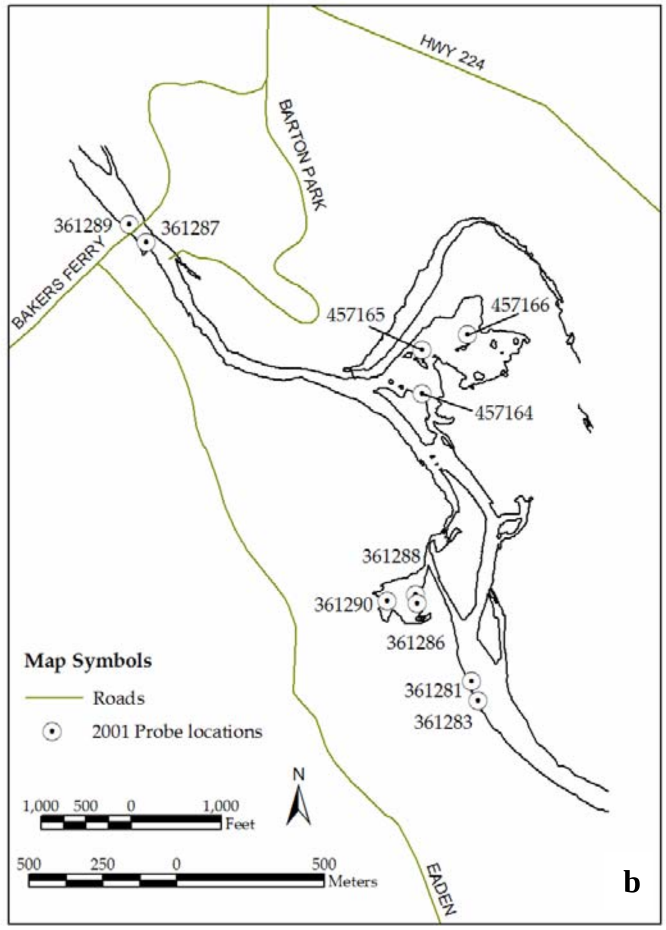


Figure 4. a. HOBO temperature recorder locations in 2000. b. in 2001.

Appendix A (cont'd)

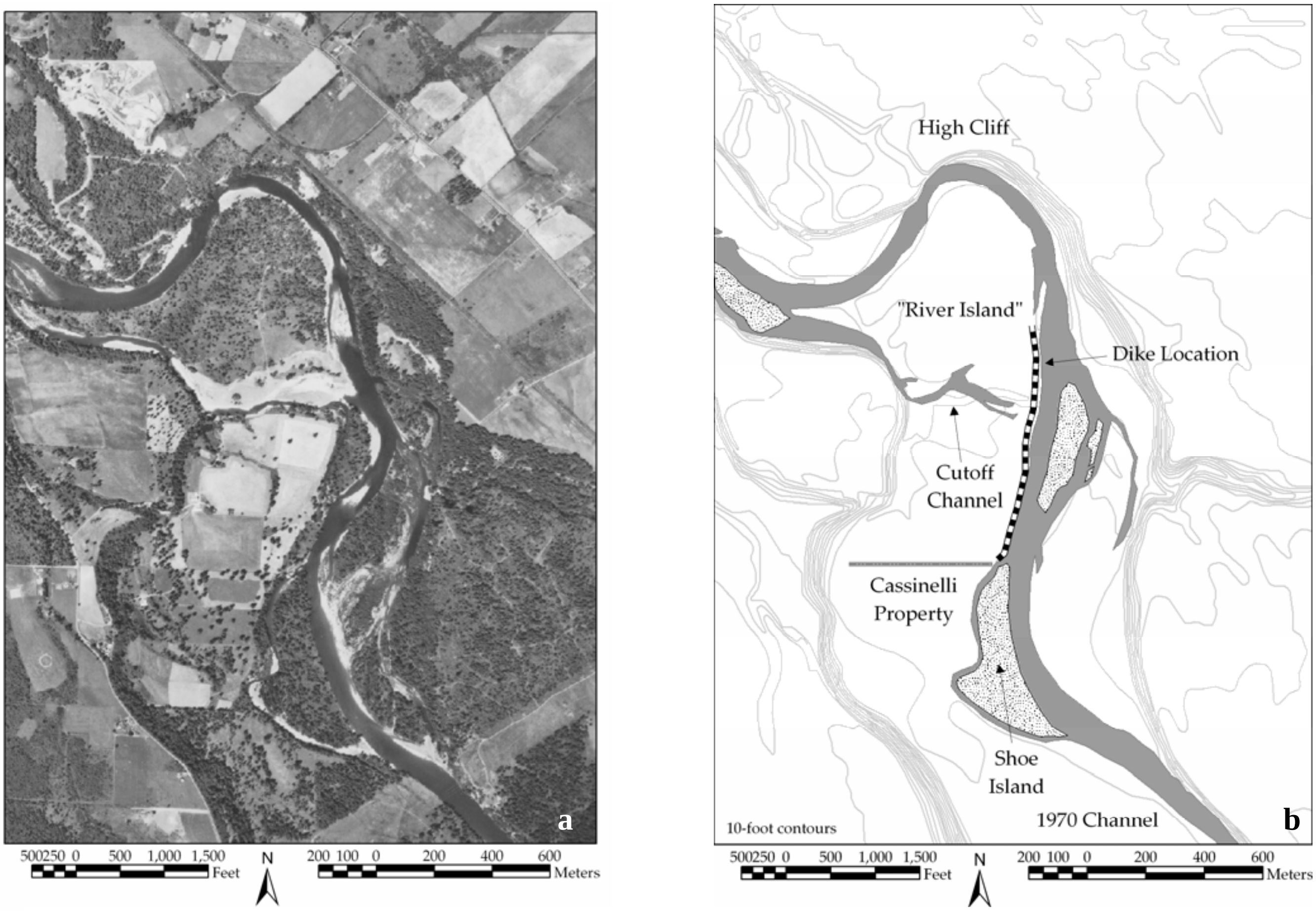


Figure 5. a. Aerial photo taken June 17, 1963. b. Detailed site map showing the configuration of the site after dike construction.

Appendix A (cont'd)

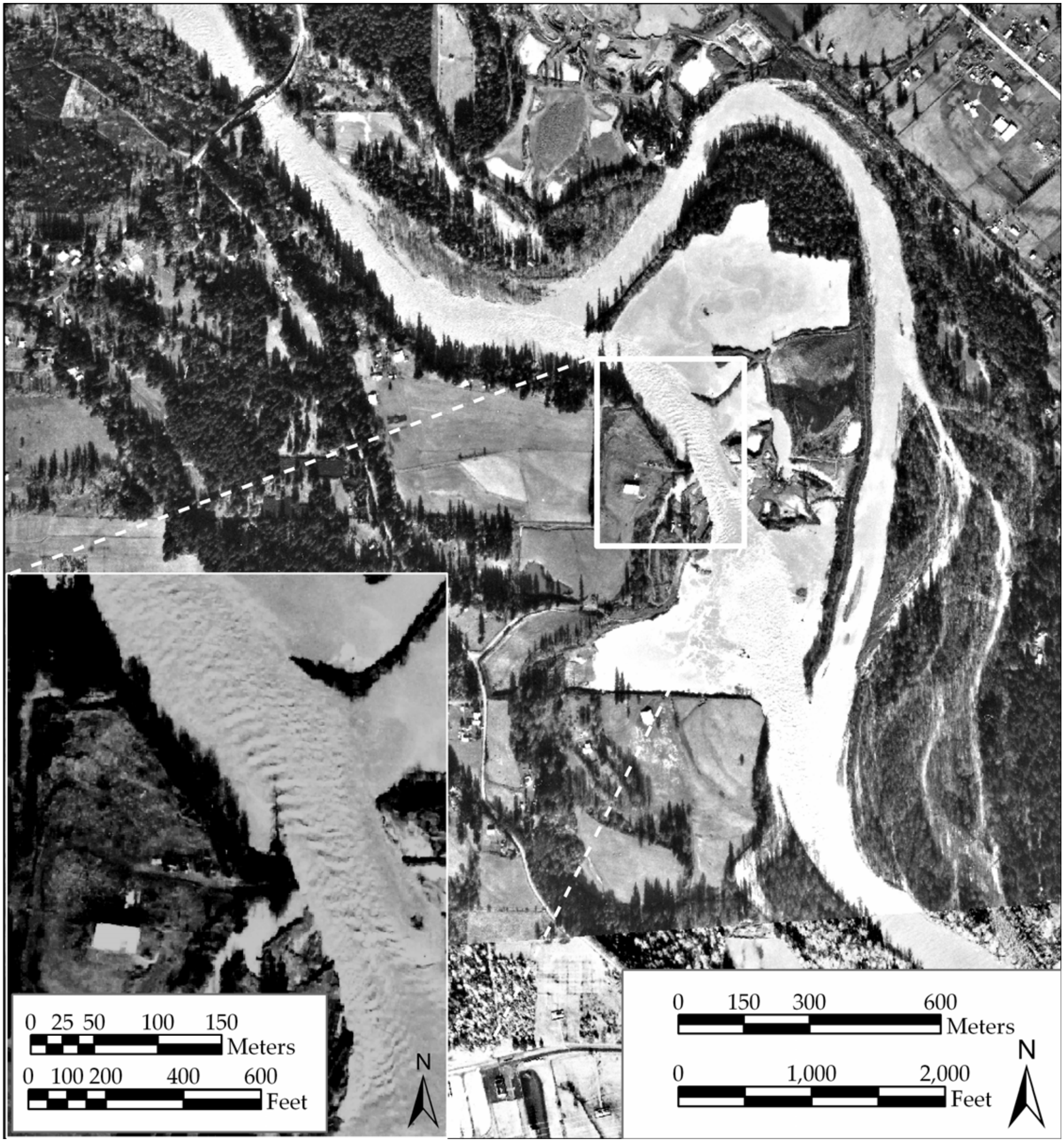


Figure 7. Aerial photo taken February 9, 1996. Mean daily discharge at Estacada was 1,025 cms (36,200 cfs). Note standing waves on inset image.

Appendix A (cont'd)

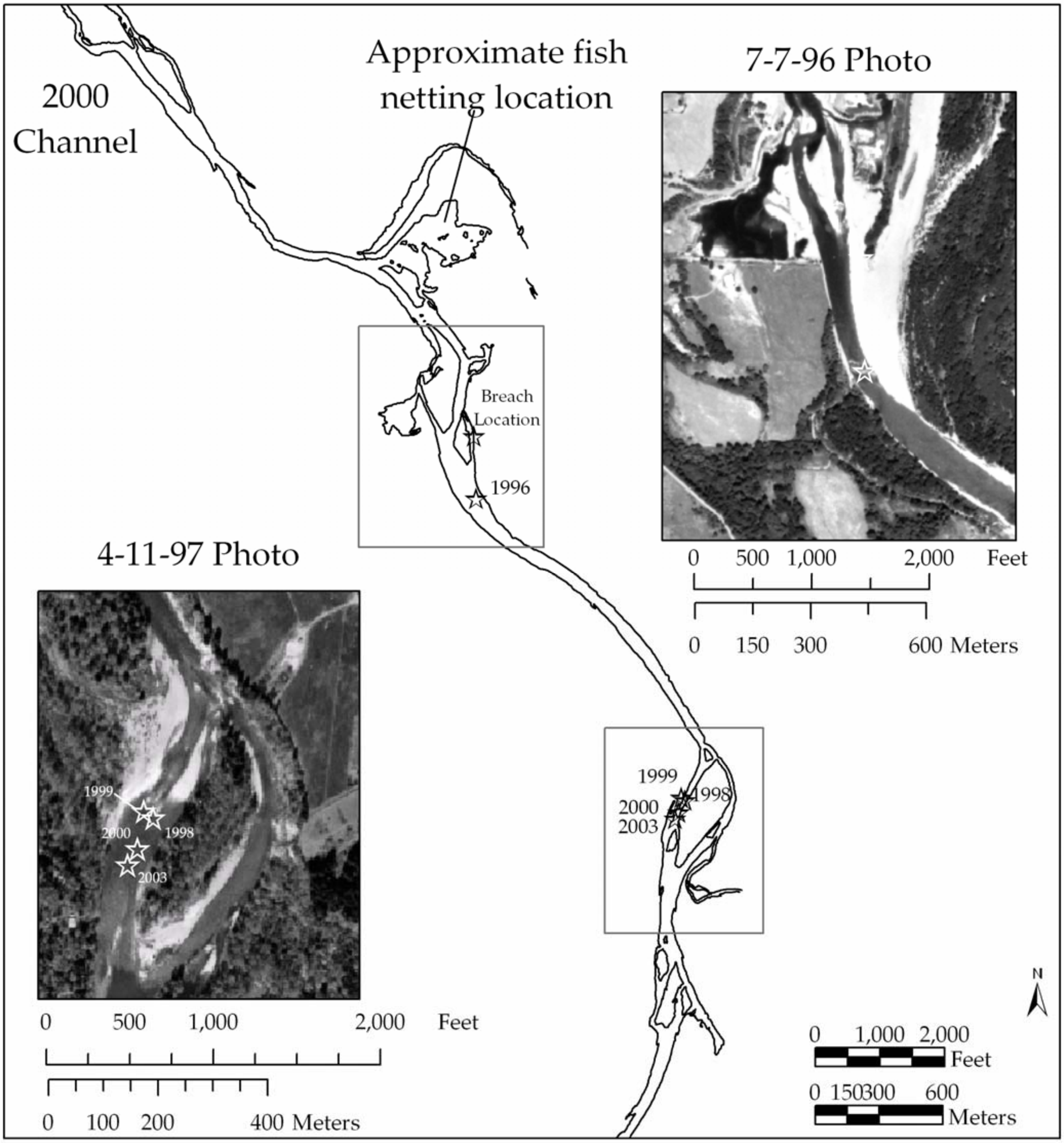


Figure 9. Knick point migration between 1996 and 2003. Note the location of fish netting in the northern pit. Stars indicate a measured knick point locations.

Appendix B

Table 2. Transect Survey data. Channel thalweg evaluations are in feet relative to the 1988 North American Vertical Datum (NAVD88).

Distance Upstream of Barton Bridte (ft) Pre-cutoff	Distance Upstream of Barton Bridge (ft) Post-cutoff	Section ID #	1970	1979[a]	1993	1998[b]	2000	2001	2002	2003
0	0	47	138.6	138.6	ND[c]	ND	ND	143.0	142.7	ND
2138	2138	48	ND	151.5	ND	151.0	ND	151.0	151.4	ND
7506	4368	49	ND	163.4	ND	160.0	ND	158.5	159.8	ND
10220	6468	53[d]	ND	172.6	165.7	160.1	160.0	169.7	168.9	168.5
10990	7354	53.5[e]	ND	ND	174.3	171.4	173.1	173.0	173.7	173.5
11745	7954	54[f]	ND	177.6	175.8	174.5	173.3	173.3	173.4	173.6
12190	8519	54.5	ND	177.8	180.3	174.3	174.2	174.0	173.6	174.0
13040	9369	55	ND	178.1	181.9	175.9	ND	176.5	176.2	176.3
15072	11441	56_Upper	ND	ND	ND	ND	ND	178.1	178.2	179.1
15603	12001	57_FEMA_BS	ND	178.8	ND	ND	ND	177.6	ND	177.7

[a]FEMA flood study transects selected nearest to transect locations. Elevation is extrapolated where needed.
[b]Surveyed in both 1998 and 1999.
[c]No data available.
[d]Center line of the channel moved laterally ~685 feet west.
[e]193 feet upstream of 1993 data and 2001 data is upstream of 1998-2000 by approximately 110 feet.
[f]77 feet dounstream from lines surveyed post-1996.