SUMMARY OF SEDIMENT TRENDS

Lower White River: RM 4.44 to RM 10.60

Prepared for

King County
River and Floodplain Management Section
Department of Natural Resources and Parks

February 2010

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Prepared for

King County
River and Floodplain Management Section
Department of Natural Resources and Parks
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February 10, 2010

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Executive Summary

King County River and Flood Management Section ('King County') retained Herrera Environmental Consultants ('Herrera') to evaluate historical trends in sediment aggradation and degradation in the Lower White River, Washington from approximately river mile (RM) 4.44 to RM 10.60. The study area overlies a significant geomorphic feature of the Lower White River, where it transitions between a confined canyon and an alluvial fan formed upon the Puget Lowland.

King County undertook this study to determine the historical trends in sedimentation throughout the study area and understand how these trends relate to geologic and geomorphic conditions, historical flood control measures and other anthropogenic projects implemented within the study area. The purpose of this study is also to describe the current conditions of the study area in the spectrum of these trends and how these trends may influence study area conditions in the future. The information in this report will be used in the planning and design of future capital improvement projects within the study area.

During the early- to mid-twentieth century, the study area was permanently altered by flood control and channel modification projects including dam building, water diversion, channel excavation, gravel removal, and levee and revetment construction. Prior to channel modifications, the river historically occupied two separate channel alignments downstream of the canyon near Auburn. The main branch of the White River flowed to the northeast and into the present-day Green River. A secondary branch split from the White River at approximately RM 8.0 to form the Stuck River, which flowed south to join the Puyallup River. After a large flood event in 1906, permanent measures were taken to re-align the entire White River into the Stuck River to then join the Puyallup River at Sumner. Construction of the Auburn Wall in 1915 made diversion of the river into the Puyallup River drainage basin permanent.

Levee and bank protection measures implemented in the early to mid-twentieth century progressively narrowed the active channel and further isolated the river from the prehistoric floodplain and alluvial fan. Due to this channel confinement, the White River no longer migrates across the prehistoric alluvial fan, but instead deposits sediment and conveys almost all flood flows within the constructed channel. Throughout most of the twentieth century, large volumes of gravel have been removed from the study area and downstream reaches to address the loss of flow conveyance resulting from ongoing aggradation. The removal of gravel from the Lower White River study area ceased in 1987. Comparison of surveyed cross-sections of the river from different time periods indicates a pattern of aggradation downstream of the R Street Bridge since the cessation of gravel removal. Changes in bed elevation upstream of the R Street Bridge are more variable and have been influenced by channel confinement, limited channel complexity, and direct and indirect responses to gravel removal.

For the purposes of this sediment study, the Lower White River study area was divided into five study reaches based on existing geomorphic and channel conditions. Cross-section survey collected at a total of 58 locations throughout the study area between 1969 and 2009 were used to determine changes in bed elevation and cross-sectional area at each cross-section. Based on

these data, this analysis calculated: (1) Bed elevation changes, (2) Average annual rates of bed elevation change, (3) Net changes in sediment volume, and (4) Average annual rates of change in sediment volume. Channel gradients and longitudinal profiles were also constructed with survey channel data from each survey period.

Basin sediment production, the location of the study area at the transition to an alluvial fan, historical channel modifications, channel confinement due to levees and revetments, and a history of considerable gravel removal are the most significant conditions influencing historical and current sediment trends in the study area. The analysis of cross-section data documents net aggradation throughout the entire study area over four of the five historical survey intervals, with the exception being the interval from 1974 to 1984, when high rates of gravel removal are documented.

All information gathered for this study, from historical to present-day data, suggests the following trends for the overall study area:

- The downstream end of the study area (downstream of about RM 7.30) is on the White River alluvial fan and is aggradational. Since the cessation of gravel removal activities, the study area has experienced net aggradation of 45,500 yds^3/year, with a large percentage of this aggradation (85 percent) occurring downstream of the R Street Bridge. Average increases in bed elevation of 0.23 feet/year, and 0.44 feet/year are documented between the 8th Street Bridge (RM 4.99) and the A Street Bridge (RM 6.33) for the periods between 2001 and 2007, and 2007 and 2009, respectively.

- The study area between the canyon and the alluvial fan (approximately RM 8.82 to RM 7.30) shows transitional characteristics with consistently minor channel changes. Trends in this reach over the last 25 years show ongoing, albeit slow rates of channel degradation, and it is likely that absent increases in channel width and roughness, these trends will continue.

- The upstream end of the study area within the White River canyon (from RM 10.60 to about RM 8.82) shows variable aggradation and degradation, with braided channel conditions and some lateral channel migration. Rapid localized increases in bed elevation were associated with increased channel widths resulting from lateral channel migration and erosion of the TransCanada levee in the vicinity of RM 9.50 at the upstream end of the study area. This response indicates that continued erosion of the TransCanada levee could decrease the delivery of sediment to downstream reaches, and that levee setback projects in this vicinity could result in local aggradation that could increase the frequency of floodplain connectivity.

Documented rates of aggradation since the cessation of gravel removal activities, and earlier rates of gravel removal, are consistent with new calculations of basin sediment yield which include estimates of annual bedload yield ranging from 55,000 to 110,000 yds^3/year. The current trends in aggradation observed downstream of RM 7.30 are expected to continue in the absence of gravel removal, other measures affecting channel confinement, or changes in basin-scale factors. Maintenance of the current profile would require gravel removal to resume at historical rates to match the bedload supply rate.

Introduction

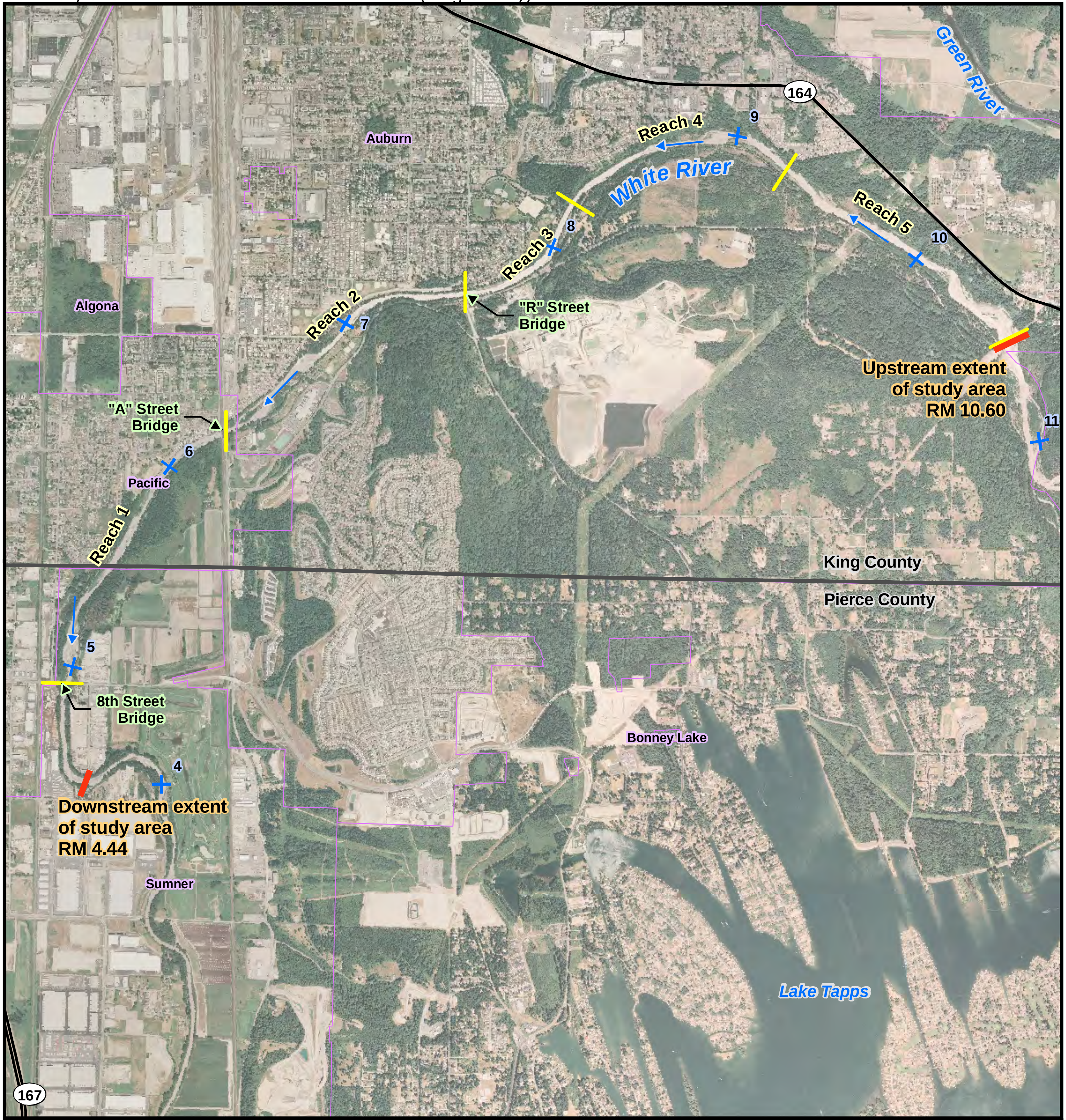
King County River and Flood Management Section (King County) retained Herrera Environmental Consultants (Herrera) to evaluate historical trends in sediment aggradation and degradation in the Lower White River, Washington from approximately river mile (RM) 4.44 to RM 10.60 (Figure 1). The study area lies at the geomorphic transition between the confined canyon of the White River and the alluvial fan constructed upon the Puget Lowland by sediment deposition during the Holocene (Collins and Sheikh 2004a).

During the early- to mid-twentieth century, the study area was permanently altered by flood control and channel modification projects, including dam building, channel excavation, and levee and revetment construction. Within the alluvial fan reach of the study area, the river historically occupied two separate channel alignments. The main branch of the White River flowed to the northeast and into the present-day Green River. A secondary branch split from the White River at approximately RM 8.0 to form the Stuck River, which flowed south to join the Puyallup River. After a large flood event in 1906, permanent measures were taken to re-align the entire White River into the Stuck River to then join the Puyallup River at Sumner. Construction of the Auburn Wall in 1915 made diversion of the river into the Puyallup River drainage basin permanent.

Levee and bank protection measures implemented in the early to mid-twentieth century progressively narrowed the active channel and further isolated the river from the prehistoric floodplain and alluvial fan. Because the river has been channelized and its banks have been reveted with rock and concrete slabs, the White River no longer migrates across the prehistoric alluvial fan, but instead deposits sediment and conveys almost all flood flows within the constructed channel. Throughout most of the twentieth century, this ongoing aggradation has been managed by gravel removal, most consistently between the 8th Street and R Street bridges. Historical cross-section surveys of the river bed indicate ongoing aggradation downstream of the R Street Bridge since the cessation of gravel removal in 1987. An evaluation of sediment trends based on the results of historical survey analysis as presented in this report will provide guidance for future planning efforts and capital improvement projects along the Lower White River.

Purpose and Scope

The purpose of this study is to describe the historical and present-day trends in aggradation or degradation throughout the study area and understand how these trends relate to or were affected by historical flood control measures and other historical projects implemented within the study area. In addition, the information in this report will be used in the planning and design of future capital improvement projects within the study area. The scope of this study included review of previous studies and historical information, geomorphic field reconnaissance of the study area, analysis of historical cross-section surveys to evaluate temporal and spatial trends in sediment aggradation and degradation, and to assess current conditions with respect to these trends and relationships.



Legend

- Study area
- Reach break
- River mile
- Highway
- County
- City

Figure 1. Lower White River Summary of Sediment Trends study area vicinity map.

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Aerial photograph: USDA, 2006

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Geomorphic Setting

The White River originates at the terminus of the Emmons Glacier on the northern slope of Mt. Rainier and flows west through the Cascade Range before joining the Puyallup River in the Puget Lowland (Figure 2). Elevations in the watershed range from 14,410 feet on Mount Rainier to approximately 30 feet at the confluence with the Puyallup River in Sumner. The headwaters of the White River are located predominantly within Mount Rainier National Park and U.S. Forest Service and private timberlands. The White River drains an area of approximately 464 mi^2 at Auburn (RM 6.3).

At the upstream extent of the study area, the Lower White River flows within a 100- to 250-foot-deep canyon formed by the incision of late Quaternary glacial sediments and Holocene lahar deposits (Collins and Sheikh 2004a). Glacial sediments were deposited between 18,000 and 14,000 years ago by the advance retreat of the Puget lobe of the Cordilleran ice sheet (Booth 1987).

Lahar deposits of the Osceola mudflow filled the canyon of the White River approximately 5,600 years ago following the collapse of the northeast side of Mount Rainier (Crandall 1972). At that time, the White River flowed through the South Prairie Creek Valley. As a result of the Osceola mudflow, the White River was forced to abandon its southerly course and cut a new path northward toward the present day location of Auburn (King County 1988). The mudflow traveled down the upper White River, filled the Lower White River valley with a poorly sorted mixture of silt- to boulder-sized sediment, and then spread out across the Puget Sound Lowland between Enumclaw and Kent (Collins and Sheikh 2004a). Subsequent erosion of the canyon, channel migration and mass wasting, and sediment aggradation below the canyon outlet near Auburn (RM 8.2) formed the White River delta and filled the former marine trough of Puget Sound between Kent and Elliot Bay (Collins and Sheikh 2004b). Figure 3 shows the decreasing gradient of the channel through the study area on a longitudinal profile of the White River from RM 27.16 to 3.53.

Climate and Hydrology

Flow within the White River is fed by glacial melt-waters from Mount Rainier, spring snow melt in the upper basin, groundwater recharge, and storm-driven precipitation. Annual precipitation within the watershed ranges from 48 inches at Buckley to 130 inches in the upper basin (Herrera 2005). White River flood flows are regulated by the U. S. Army Corps of Engineers at the Mud Mountain Dam. Minimum instream flows have been affected by the Buckley diversion dam. Two significant tributaries below Mud Mountain Dam contribute to flow into the study area: Red Creek (RM 26.8) and Boise Creek (RM 22.6). The reach of the White River from the Buckley dam diversion (RM 24.25) to the Dierenger Powerhouse return (RM 3.50) is historically known as the *bypass reach* because flows were diverted from the mainstem White River to Lake Tapps

Figure 2. Map of the White River watershed in King and Pierce Counties, Washington.

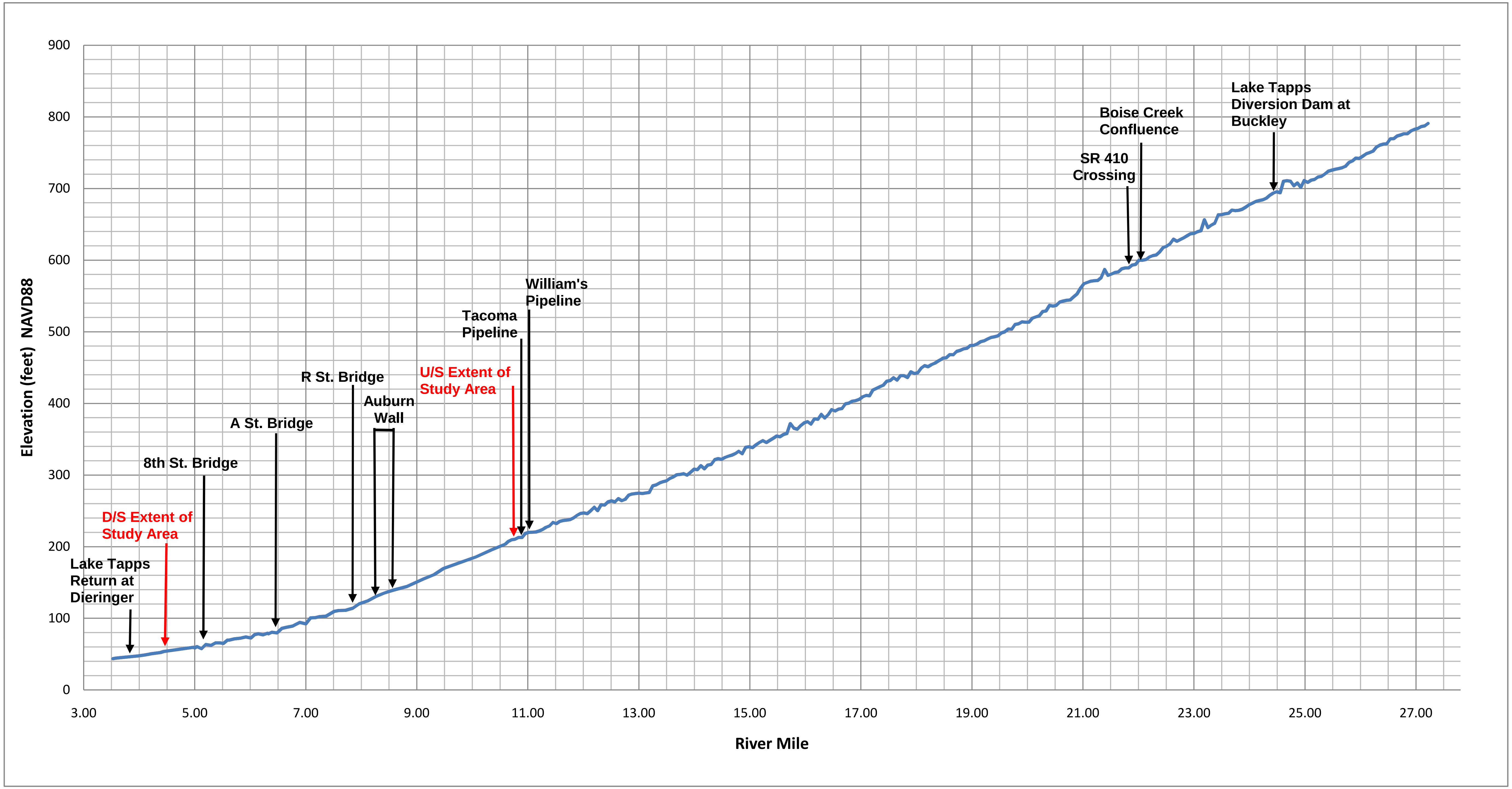

Figure 3. Longitudinal profile of the White River from RM 27.2 to 3.5 (adapted from Herrera 2005, Collins 2009, and King County 2009b).

in support of hydropower operations, thus bypassing a long segment of the White River through the Cities of Auburn and Pacific.

Northwest Hydraulic Consultants (NHC) constructed a 54-year record of peak flood flow data from the Sumner and Auburn gauges, and supplemented it with calculated flows based on Mud Mountain Dam releases and scaled Boise Creek flow data from USGS gauges at the White River Canal near Buckley (#12099000), Boise Creek at Buckley (#12099600), and the White River near Buckley (#12098500) (NHC 2004). A data gap exists for the period 1973 to 1976 due to the lack of local inflow data for water years 1974-1976: estimates of peak flow at Auburn/Sumner were not made for these years (NHC 2004).

Flood Frequency Analysis

Flood frequencies were developed for the Lower White River for other sediment and flood studies using flow records from flow gauges near Sumner, Auburn, and Buckley (FEMA 1987; Prych 1988). However, the conclusion of hydropower operations at the Lake Tapps diversion in January 2004 meant that the historical regulated flow record was no longer a reliable indicator of the magnitude and frequency distribution of anticipated future peak flow events (NHC 2004). The historical record was adjusted to reflect current operations at Mud Mountain Dam and diversions, including: capping dam releases at 12,000 cfs and eliminating diversions from the White River below Mud Mountain Dam (NHC 2008). An updated flood frequency analysis by NHC augments the 54-year peak flow record with 2005 and 2006 flood events (NHC 2008). The results of NHC's 2008 flood frequency analysis are listed below (Table 1).

Table 1. White River flood frequency flows through the study area (NHC 2008).

Recurrence Interval (Year)	Flood Flow (cfs)
10	14,100
50	15,400
100	15,600
500	19,100

Extreme flooding occurred in Washington in early January 2009. This flooding was caused by heavy precipitation that fell on January 6th and 7th and warm temperatures that melted snow still on the ground from December 2008 storms. Rain totals in King County for January 7 ranged from approximately 1.5 to 2.0 inches in western King County, and approximately 3.0 to 5.0 inches in eastern King County. Streamflow in both western and eastern Washington was high, with many rivers reaching flood stage or above. The White River at Auburn peaked at 12,300 cfs on January 9 (USGS 2009a). Water surface elevations observed along the Lower White River during the January 2009 event by NHC were much higher than previously observed events of similar or greater peak discharge, and inundated portions of the floodplain on either bank of the river (NHC 2009). The apparent cause of the increased flooding was a substantial change in the river channel capacity resulting from channel aggradation (USACE 2009a).

Historical Conditions

Timber harvest practices, agriculture, and extensive urban development outside the national park boundary have substantially altered the White River watershed from its prehistoric conditions. Early accounts of the Lower White River by settlers and government surveyors describe the formation of large logjams and the constant shifting of the river around these obstructions (Chittenden 1907; Wolff 1916). Interaction between the river and riparian forests created and sustained a series of side channels, floodplain sloughs, forested islands, and extensive wetlands and ponds (Collins and Sheikh 2004b). Land use practices have channelized or locally isolated the river from much of the prehistoric floodplain habitats.

River engineering projects constructed on the White River during the twentieth century have altered natural geomorphic processes throughout the study area as well as in the entire watershed. These projects have included both in-channel and floodplain structures that have impacted river hydrology and sediment transport throughout the study area.

White River Diversion and Channel Modifications

The historical Lower White River corridor has been altered by several flood control projects in the early to mid-1900s and are described below in detail (some of which are shown in Figure 4). These projects altered the natural flow regimes of the river, which in turn affected the natural hydrology, flooding, and sediment regimes. Levee and bank protection measures implemented in the mid-twentieth century in the vicinity of Auburn progressively narrowed the active channel and isolated the river from the prehistoric floodplain and alluvial fan. Historically, White River flows split on the alluvial fan, with most of the flow draining north to the Green River and Duwamish River system, and secondary flow draining to the south via the Stuck River alignment to the Puyallup River (Collins and Sheikh 2004b).

Similar to other lowland Puget Sound Rivers, large log jams were documented during the earliest known surveys in the White River basin. Early accounts of the Lower White River by settlers and government surveyors describe the formation of large logjams and log drifts and constant shifting of the river around these obstructions (Chittenden 1907; Wolff 1916). Settlers along the White River frequently dynamited such logjams and bluffs in order to divert flows from eroding their property (Collins and Sheikh 2004a). Removal of drift in the early 1900s used donkey engines to stack and burn more than 100,000 cords of drift wood, trees, logs, and stumps along the Lower White River (Roberts 1920). Sources of this drift included natural wood as well as saw logs and smaller debris (Chittenden 1907). Because of the large volumes of wood reaching Auburn, the Inter County River Improvement (ICRI) built a valley-spanning drift barrier in 1915 at RM 12.4 (upstream of the study area) to collect wood drift and debris and alleviate further accumulations of wood downstream (Wolff 1916). The drift barrier consisted of horizontal steel cables strung between 27 concrete piers. According to Wolff (1916), the structure was designed to span the entire floodplain and eliminate the need for continual wood removal. Although the steel cables are no longer present, the concrete piers remain within the active channel and floodplain.

In 1898, farmers dynamited key bluffs near RM 8.0, and diverted part of the White River flows southward into the Stuck River channel (the present day alignment of the White River) to the Puyallup River. A large logjam formed during a 1906 flood (flow approximated at 19,200 cfs) that diverted all of the White River flow into the Stuck River channel (Roberts 1920). In 1915, the ICRI made the diversion permanent with construction of a concrete diversion, known as the Auburn Wall. The Auburn Wall is reinforced concrete structure that is 1,600 feet long and approximately 10 feet high (Roberts 1920) that is still in place today. The Auburn Wall (RM 8.0) permanently cut-off the White River from the Green and Duwamish Rivers and directed flow to the Puyallup River via the historical Stuck River alignment.

A 1907 map produced as part of the flood control and channel modification planning efforts associated with the diversion of the White River into the Stuck River alignment illustrates the longitudinal profile of both the historical White River alignment (to the Green River) and the historical Stuck River alignment (Kielland 1907). Based on the reported bed elevations, the gradient of the historical White River alignment to the Green River was 0.0038, or 0.38 percent, and the river dropped 20 feet per mile over the 4.26-mile alignment between the position of the present-day Auburn Wall and the former White and Green River confluence. The profile of the historical Stuck River dropped approximately 37 feet per mile (a gradient of 0.0069, or 0.69 percent) for the 2.18 miles immediately downstream of the present day Auburn Wall. Beyond this point the gradient decreased substantially to 0.0011, or 0.11 percent, which represents a drop of approximately 6 feet per mile for the 5.25 miles to the confluence with the Puyallup River. The contours presented in a plan view of the area where the White River split into two alignments to the Green and Puyallup Rivers also illustrate the abrupt transition along the historical Stuck River alignment and a gentler, concave profile along the more frequently occupied alignment to the Green River. Based on historical information from the ICRI (Appendix A, King County 2009a), the channel of the historical Stuck River alignment was dredged approximately 4 feet below its natural grade to provide adequate conveyance capacity to accommodate river flows in this new alignment.

Numerous levees and revetments exist along both banks within the study area (Figure 4). One of the more significant levees, the TransCanada, was constructed in the 1960’s along the left bank from approximately RM 8.6 to RM 10.6. The levee artificially reduced the width of the available channel area by more than half in most locations and confined the channel against the eroding northern bank. By 1974 (based on bracketing by aerial photographs), the river had breached the levee upstream of RM 10.6 in the vicinity of the Williams pipeline crossing and destroyed approximately 3,700 feet of levee, thereby reclaiming previously isolated floodplain (Herrera 2005).

Lake Tapps (Buckley) Diversion

Lake Tapps was created in 1911 for water storage to support power generation by the Puget Sound Power and Light Company (PSPLC) at the Dieringer Powerhouse. Lake Tapps was formed by constructing levees and merging four small lakes on the plateau above the White River. For nearly a century, water and sediment from the White River were diverted at the

Buckley diversion dam (RM 24.25) and routed through a series of flumes and settling basins before flowing into Lake Tapps. Most of the coarse bedload sediment was returned (via rock chutes along the flume) to the river immediately downstream of the diversion dam, whereas fine sediment was collected in a series of settling basins and mined by a commercial aggregate distributor.

Water is returned to the White River below the Dierenger Powerhouse at RM 3.5. Historical flow diversion from the bypass reach varied considerably in accordance with hydropower demand and the desire to maintain target water levels in Lake Tapps. In general, flow diversion was greatest during summer low-flow conditions, when diversion was required to maintain lake levels for hydropower generation and recreational purposes. The original water rights for the hydropower project allowed PSPLC (now known as Puget Sound Energy or PSE) to divert up to 2,000 cfs; however, flow diversions as high as 2,340 cfs have been measured in the canal (Herrera 2005). During such diversions, the minimum required in-stream flow through the bypass channel was 30 cfs prior to 1986. Subsequently, upon an agreement between PSE and the Muckleshoot Indian Tribe, minimum in-stream flows were increased to 130 cfs. Under more recent agreements, in-stream flows have been further increased to as much as 875 cfs depending on the time of year. Powerhouse operations ceased in January 2004, and withdrawals from the White River were reduced.

Since PSE ceased power plant operations, water is diverted from the White River to maintain Lake Tapp's water quality and recreational uses. PSE is in the process of transferring its water rights and project facilities to the Cascade Water Alliance for purposes of developing a regional water supply (Ecology 1996). This existing water right will be replaced with a new water right that will be issued by Ecology in 2010 (Loranger 2010). The amount of this water right is still in the process of being determined, and will be less than the original claim granted to PSE for power generation (Loranger 2010).

Tacoma Water Pipeline Crossing

The City of Tacoma's water supply pipeline extends from its source at the Green River (Tacoma Water Diversion Dam at Green River RM 61.0) to Tacoma. Construction of the original pipeline was completed in 1912. The pipeline crosses under the White River near RM 23.3, approximately 1 mile downstream of the Buckley diversion dam. A concrete grade-control structure was built in the 1920s to protect the pipeline from scour (R2 Resource Consultants 2005). The placement of the structure caused the channel to aggrade four to five feet upstream of the pipeline crossing, creating an anadromous fish passage barrier (R2 Resource Consultants 2005).

In 2003, the pipeline was reburied at a greater depth, and the concrete grade control structure that provided scour protection was removed. Based on the post-construction monitoring by R2 Resource Consultants (2005), the channel morphology has changed as a result of the removal of the scour protection structure. At the construction site, a head cut developed that was observed as a steep riffle immediately upstream of the construction site (R2 Resource Consultants 2005).

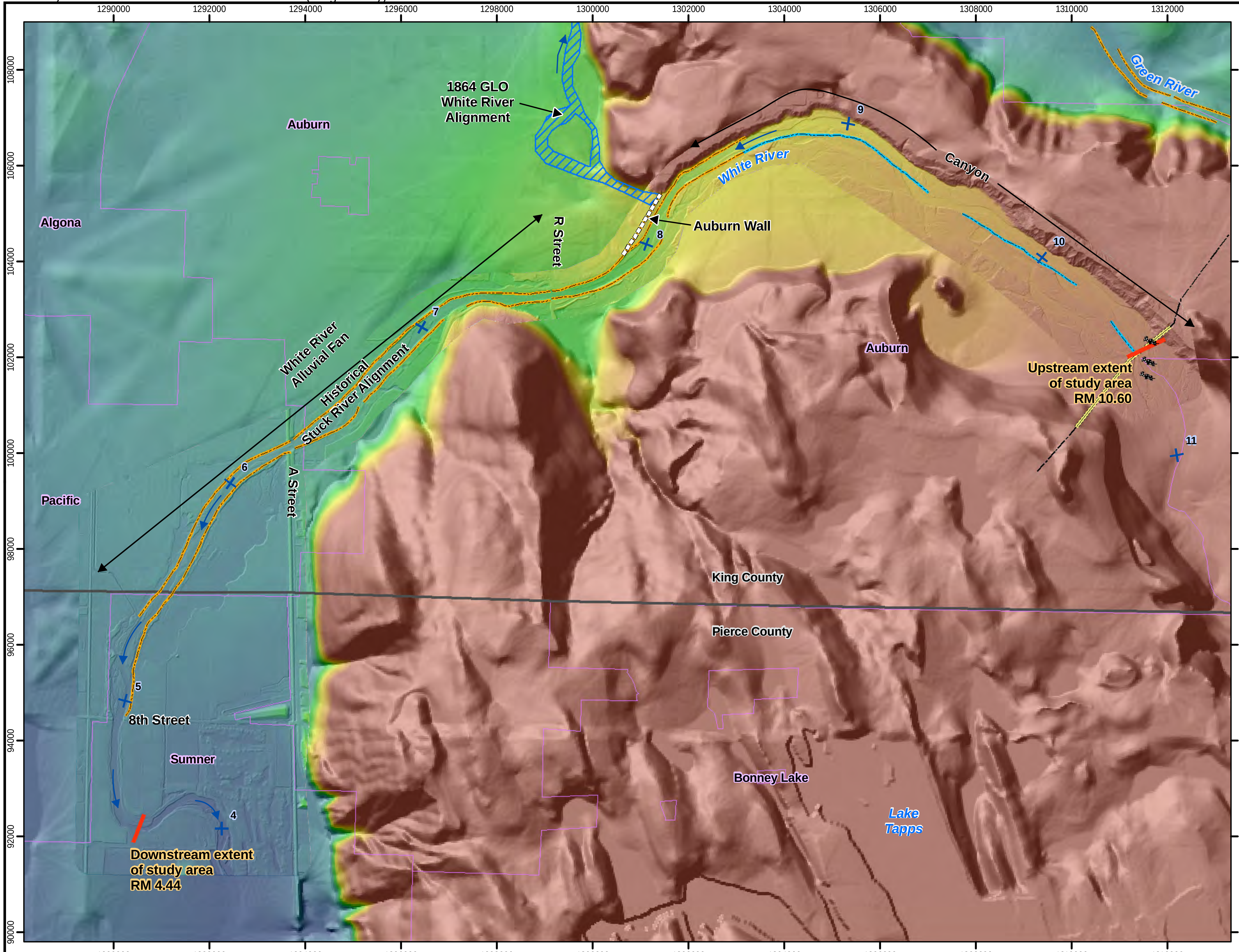

Figure 4.
Channel modifications and historical river alignments in the Lower White River Summary of Sediment Trends study area.

Legend
- Auburn Wall
- Existing engineered log structure
- Levee or revetment (per King County records)
- TransCanada Levee
- Historic White River channel (1864) (General Land Office)
- Study area
- Williams Pipeline crossing
- River mile
- County
- City

Elevation (feet)
High : 220
Low : 50

Note: Existing Pierce County levees or revetments are not represented on this map.

N
0 1,000 2,000 4,000 Feet

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Coordinates: NAD83 Washington StatePlane North (feet)

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According to the results of the 2005 monitoring study, the channel bed of the White River and mouth of Boise Creek have degraded three to four feet as a result of scour since the removal of the scour protection structure (R2 Resource Consultants 2005).

Mud Mountain Dam

Mud Mountain Dam, operated by the U.S. Army Corps of Engineers, is located near Buckley, Washington at RM 29.6. Flooding occurred nearly annually on the Lower White River before construction of Mud Mountain Dam in 1948. The dam is constructed of an earth core and rock fill and is 425 feet high and 700 feet long. Two tunnels, 9 feet and 23 feet in diameter, pass the river flow with a concrete spillway available to manage floodwaters under emergency conditions of very rare storm events.

Mud Mountain Dam is a single-purpose flood control project that is federally authorized to target flow reductions along the leveed and lowermost portion of the Puyallup River (NHC 2009). Mud Mountain Dam does not typically impound water except during flood storage or maintenance operations (Herrera 2005) During such events, the dam can impound water upstream (as backwater) to near the confluence of the Clearwater River (RM 35.5). The dam is regulated to a maximum release of 17,600 cfs under flood control operations, except in cases of extreme emergency. In September 2004, the Mud Mountain Dam Water Control Manual was revised to allow for flow releases to be controlled to 12,000 cfs when feasible (Pierce County 2009).

Williams Pipeline

The Williams Company owns and maintains a natural gas pipeline at RM 10.60 located at the upstream extent of the study area. In 2005, three engineered log jams (ELJs) were built to enhance aquatic habitat and fulfill a mitigation requirement for impacts associated with the Williams White River Replacement Project. The replacement project consisted of the removal of 26-inch and 30-inch natural gas pipelines and their replacement with a 30-inch pipeline that was installed by directional drilling 60 to 80 feet below the existing channel bed. The initial 26-inch pipeline was originally constructed in 1956 and was likely abandoned in the early 1970s when the pipeline was exposed from ongoing river scour at the site (Golder 2003). When constructed in 1956, the pipeline may have only been buried approximately 5 feet below the channel bed (Golder 2003). In addition, the removal of a rock and wood fill structure (a.k.a., North Bank Structure) that had been placed to protect the pipeline along the right bank, and the removal of 150 lineal feet of sheet pile that had been placed along the left bank to limit channel bank erosion and lateral channel migration, also occurred as part of the replacement project. Prior to removal of the abandoned pipeline, an approximately 5-foot drop in bed elevation developed on the downstream side of the exposed pipeline (Golder 2003).

The placement of the left bank erosion control measure in the channel limited channel migration to the south. In the vicinity of the pipeline crossing, flood flows inundate the adjacent floodplain areas along the left bank. Actions and measures implemented by Williams to impede this channel migration have limited the interaction of the river flows to the floodplain and the development of

functional side channels. Based on previous FEMA flood hazard mapping, the river flooded the left bank floodplain in this area during the 100-year event (NHC 2008). The lowering of the pipeline below the river bed and most of the adjacent floodplain has reduced most of the need for in-channel measures to limit lateral migration. However, if the river channel were to move where the pipeline is at a shallow depth, additional measures may be needed to protect the pipeline.

Gravel Removal

A description of historical gravel removal activities on the Lower White River by King County (2009a) summarizes the gravel extraction that occurred in the study area for most of the 20th Century (Appendix A). Based on the County's findings, gravel extraction in the early 1900s was carried out by the ICRI as part of the river management techniques to control flooding throughout the lower reaches of the river from its confluence with the Puyallup River to RM 10.5 (Muckleshoot Reservation). Also, the ICRI dredged and channelized the Puyallup River downstream of the confluence with the White River.

The ICRI issued annual reports; however, details on gravel extraction volumes, locations, or dates were not generally included in these reports. These annual reports suggest that gravel extraction occurred almost annually and occurred from the County Line (RM 5.5) upstream to the Muckleshoot Reservation. Prych (1988) documented a total of 780,000 yds^3 of material removed from the White River from 1974 to 1985 by the ICRI (Table 2). Some of the sediment removed during these years is from the Greenwater River, a tributary to the White River upstream of the Mud Mountain dam at RM 45.8 (Prych 1988).

Table 2. Volume of sediment removed from the White River by Pierce County and Inter-County River Improvement in the years 1974 to 1985 (Prych 1988).

Year	Volumes in Cubic Yards (yds^3)
1974	70,780
1975	50,890
1976	246,690
1977	56,050
1978	152,680
1979	40,000
1980	560
1981	1,350
1982	27,940
1983	55,240
1984	66,730
1985	11,890
Total	780,800

Information from all available historic ICRI documents and annual reports, the study by Prych (1988), and anecdotal information suggest a history of gravel removal on the Lower White River as follows. There is enough quantitative information from the first two decades of ICRI operations (circa 1914 to 1932) to indicate that upwards of 2 million yds^3 of gravel were excavated in the initial river engineering that altered the course of the Lower White River. Then a subsequent lack of information on any large specific gravel removal operation suggests a period of time from about the mid 1930s to the early 1970s when a routine level of maintenance of gravel removal occurred throughout the Lower White River. From 1974 through 1985, a more aggressive approach was taken to gravel removal; it is suggested that this effort coincided with the tenure of a chief engineer who favored gravel removal. Unpublished ICRI reports more specifically document the amount of gravel removed only from the Lower White River during this period as 766,000 cubic yards (Appendix A, King County 2009a). The difference between this volume and the total from Prych (1988) is that Table 2 also includes gravel removed from the Greenwater River. Not long after 1985, ICRI annual reports state that it became more difficult to obtain permits for gravel removal. Individuals who worked for Pierce County state by direct experience that there were no gravel removal operations on the Lower White River upstream of the 8th Street Bridge in 1987 or thereafter (Appendix A, King County 2009a). Based on discussion with personnel working on the White River in the early 1990's and Hydraulic Permit Application records compiled by the Washington Department of Fish and Wildlife, gravel removal did occur downstream of cross-section 4.44 in the mid-1990s (Appendix A, King County 2009a).

It should be noted that this suggested history applies primarily to gravel removal by ICRI crews and programs. There is ample evidence that there also was much gravel removal by private contractors on the Lower White River. However, the general impression from available documents and anecdotal sources still is that the mid-1970s to mid-1980s was a period of major extraction and that no gravel removal occurred after about 1987 in the study area upstream of 8th Street Bridge.

Sediment Yield and Transport

The high rates of sediment yield within the White River basin are largely driven by glacial and volcanic processes associated with Mt. Rainier. The rapidly eroding volcanic terrain of Mt. Rainier, moraine deposits, the Osceola mudflow, and underlying glacial drift provide ample sources of sediment for delivery to the White River, through various erosional and mass wasting mechanisms and subsequent downstream transport.

The timing and magnitude of historical sediment delivery to the Lower White River has been strongly influenced by upstream infrastructure, specifically Mud Mountain Dam (RM 29.6) and the Lake Tapps Diversion Dam at Buckley (RM 24.25). When Mud Mountain Dam is not providing flood storage, the majority of sediment in suspended and bed load are routed through the dam. During flood events, however, when the dam is operated to reduce peak flood discharge, a portion of the sediment load from the upper basin may also be trapped in the

reservoir. This trapped sediment is then released or sluiced from Mud Mountain Lake during the receding limb of the flood event (Dunne 1986). This process results in flows during the receding limb of flood events that have higher concentrations of sediment than would occur in absence of the dam. Intake works improvements completed to the dam in 1995 improved the routing of sediment through the reservoir, thereby reducing the occurrence of sediment accumulation in the reservoir and eliminating the practice of intentionally enhanced summer releases intended to clear the reservoir of accumulated sediment (USACE 2009b).

Although an explicit sediment budget has not been determined for the White River basin, various researchers have constructed estimates of sediment yield to Mud Mountain Dam and the Lower White River (Nelson 1979; Dunne 1986; Sikonia 1990; Collins and Dunne 1990). Nelson (1979) conducted suspended and bedload sediment sampling upstream of Mud Mountain Dam between June 1974 and June 1976. By constructing seasonal suspended sediment rating curves, Nelson used daily flow records to compute suspended sediment loads for the years from June 1974 to June 1975 and June 1975 to June 1976. Nelson concluded that during the first year of his study, when the annual runoff was 104 percent of the long-term average, the suspended sediment yield at the sampling station was 430,000 tons (250,000 yds^3). During year two of the study, annual flow was 124 percent of the long-term average and the White River was calculated to have transported 1,400,000 tons (820,000 yds^3) of suspended sediment. Dunne (1986) extended these computations of annual suspended sediment transport using the discharge record at the White River near Buckley Gauge from the period 1966 to 1973. Using this method, Dunne (1986) calculated that the average annual suspended sediment yield for the 10-year period from 1966 to 1976 was 500,000 tons/year (300,000 yds^3/year), with a range of 146,000 tons/year (86,000 yds^3/year) in 1973 to 1,400,000 tons/year (820,000 yds^3/year) in 1976. Recent studies on the Skagit River have questioned how well suspended sediment data represent long-term sediment loading (Mastin et al. 2008). An alternative calculation of basin sediment yield for this study is presented in the Estimates of Basin Sediment Yield section later in this report.

Bedload measurements completed by Nelson upstream of Mud Mountain Dam during the same time period determined that bedload constituted up to 10 percent of the total load at low discharges, approximately 4 percent of the total load at higher flows, and approximately 4 percent of the total sediment yield on an annual basis. Based on these proportions, the annual bedload yield to Mud Mountain Dam is calculated to average 20,000 tons/year (12,000 yds^3/year) over the period from 1966 to 1976, with annual totals ranging from 6,000 to 56,000 tons/year (3,500 to 33,000 yds^3/year). Dunne estimated that of the 20,000 tons/year (12,000 yds^3/year), no more than half (10,000 tons or 6,000 yds^3) would consist of gravel, cobbles, and boulders.

Although some fraction of the total bedload sediment yield upstream of Mud Mountain Dam may persist in moderate to longer-term storage as a sediment wedge within the reservoir, much of it is likely routed to the White River below the dam. Dunne (1986), in agreement with Mullineaux (1970), argues that the bedload yield above Mud Mountain Dam, however, is only a fraction of the total yield downstream, as Holocene and Pleistocene glacial deposits and Osceola mudflow deposits downstream of the dam are the dominant sources of coarse alluvium to downstream reaches, including the study area.

Downstream of Mud Mountain Dam, the Lake Tapps Flow Diversion at Buckley captured sediment with the flow diverted to Lake Tapps. Diversion largely ended in 2004, but for nearly a century before, an estimated 200,000 tons/year (120,000 yds^3/year), or approximately 40 percent of the total sediment yield estimated at Mud Mountain Dam was removed from the White River by this mechanism (Dunne 1986). Coarse sediment was largely returned to the river downstream of the diversion. Since diversion ended in 2004, this flux of material has been retained within the White River.

Collins and Dunne (1990) applied estimates of channel degradation and aggradation based on channel capacity surveys completed in 1974/1977 and 1984 with records of gravel extraction between 1975 and 1985 (Table 1 and Appendix A). They assert that changes in bed elevation between the survey periods show a general trend of aggradation downstream of RM 5 and the lower extent of extraction activities and degradation upstream. Calculations of sediment accumulation associated with the changes in bed elevation downstream of RM 5.0 indicate an average deposition rate of 73,000 tons/year (43,000 yds^3/year) during the 10-year period. Upstream of RM 5, the apparent degradation may be related to the high extraction rates that occurred during the survey period, estimated to average 133,000 tons/year (78,000 yds^3/year) annually over the same 10-year period. A minimum rate of coarse sediment yield to the Lower White River of 206,000 tons/year (121,000 yds^3/year) may be derived by aggregating these values. This may be considered a minimum value as additional bed material is transported downstream to the Puyallup River and because gravel extraction records are incomplete (Collins and Dunne 1990).

Methods

This section describes the methods used to analyze sediment aggradation and degradation trends throughout the study area. Field data collected includes post-2009 flood season channel cross-section and channel bathymetry surveys collected in the spring of 2009, as well as field reconnaissance of most of the established surveyed cross-sections. In addition, large wood was documented throughout the study area and its effect on sedimentation was evaluated qualitatively. Also, sediment yield of the White River basin was estimated.

Cross-section Surveys

White River cross-section survey data from as early as 1969 is considered in this study. These White River cross-sections were established to conduct earlier flood studies, or to measure channel aggradation, or both. Additional cross-sections have been added since 1969.

Cross-section station and elevation data and subsequent volume and elevation analyses were provided by King County (King County2009b). There are 58 historical cross-sections from approximately RM 4.44 to RM 10.60, located at approximately 400 to 600 foot spacing along the river. Years of survey include 1969, 1974, 1978, 1984, 1986, 2001, 2007 and 2009, though not every cross-section was surveyed every year. Cross-section data sources vary by year (see Table 3). All survey elevations are referenced to the NAVD 88 vertical datum in this report. Survey elevations referenced to the NAVD 29 vertical datum were converted to NAVD 88 by adding 3.53 feet to the NAVD 29 elevation. The river mileage system identified by NHC (2009) is used in this report.

The absolute locations of channel cross sections, and therefore the accuracy of reoccupation, was less controlled in decades past. More recent surveys have cross-section endpoints with well established horizontal and vertical control. All study cross-sections are included in Appendix B. Available cross-section raw data (table format) are included in Appendix C.

King County Analysis of City of Auburn Cross-sections

The City of Auburn established 13 cross-sections between the A Street and R Street Bridges in Auburn (Reach 2) and has surveyed these almost annually since 1996. A complete summary report prepared by King County (2009c) is included as Appendix D.

Cross-section Analyses

Annual aggradation or degradation was visually analyzed at each cross-section in order to establish a preliminary understanding of sedimentation trends between years. The visual analysis

consisted of comparing cross-sectional areas between survey years, and recording whether aggradation or degradation was the predominant change, if any (Appendix C). The earliest available cross-section is a baseline for judging aggradation in this and subsequent analyses. In judging whether net aggradation had occurred, the baseline data was compared with that of the most recent data (i.e., 2009 in almost all cases).

Table 3. White River cross-section survey years and sources (King County 2009b).

Year	Source
1969	Referenced as King County cross sections in Jordan/Avent (1974)
1974	US Army Corps of Engineers (uncertain)
1977, 1984, 1986	US Geological Survey (uncertain)
1994	David Evans and Associates (DEA) for Pierce County (at one cross-section)
1996-2000	City of Auburn
2001	King County; City of Auburn
2002, 2003	City of Auburn
2006	City of Auburn
2007	Minister Glaeser Surveyors Inc. , for White River flood study
2008	Northwest Hydraulic Consultants; City of Auburn, DEA
2009	Various sources for King County or in collaboration with King County, including: ▪ True North Land Surveying ▪ NW Hydro Inc. ▪ City of Auburn ▪ Watershed Sciences (Feb 2009 LiDAR)

Thalweg elevations (the lowest point of the active channel) were identified in river-station cross-section data (King County 2009b) for each year. Thalweg data were used to create profiles of the study area channel bed for each surveyed time period.

The 2009 study area thalweg data (King County 2009b) was combined with 2005 channel data (Herrera 2005) downstream of RM 10.60 to RM 3.25 and 2004 thalweg data (Collins 2009) upstream of RM 10.60 to RM 27.2, to create a longitudinal profile of the Lower White River channel (Figure 3). Extending the thalweg upstream and downstream helps to identify how changes in gradient through the study area coincide with larger scale trends on the White River.

King County calculated changes in sediment volumes between the 58 cross-sections for the survey interval years 1969 to 1974, 1974/77 to 1984, 1984 to 2001, 2001 to 2007/2008, and 2007/2008 to 2009 (King County 2009b). The change in volume between cross-sections for each time period was calculated from the average change in cross-sectional area at two sequential cross-sections multiplied by the distance between the two cross-sections. Aggradation and degradation rates were calculated by dividing the inter-cross-sectional volumes by the time between surveys.

Changes in average cross-section channel elevations were calculated at each of the 58 cross-sections between 1974/77 to 1984, 1984 to 2001, 2001 to 2007/2008, and 2007/2008 to 2009 (King County 2009b). Changes in cross-sectional area were calculated generally from the toe of

the left bank to the toe of the right bank. The change in average channel elevation at each cross-section over a given survey interval was calculated by dividing the change in channel cross-sectional area by the channel width, where channel width was defined as the distance between the toe of bank on each side of the channel.

An exception to the methods described here was made for the calculation of elevation changes between 1969 and 1974. Cross-section survey data is not available from 1969 for comparison with 1974. Instead, elevation changes were calculated from volume data compiled by Jordan and Avent (1974) for the Lower White River during this time period. Jordan and Avent (1974) calculated changes in sediment volumes using similar techniques as those outlined above, but did not publish their cross-section data. Therefore, sums of the volumes reported by Jordan and Avent were used to describe volumetric changes for each reach, and changes in bed elevation were calculated by dividing the reported volumes by the planimetric areas of each reach (Appendix C). Planimetric areas were calculated from channel widths multiplied by channel lengths between cross-sections. Channel widths for this calculation were primarily taken from 2001 cross-section data, but where cross-sections were unavailable in Reach 5, 1974 channel width data was used. The variability of the channel width sources and the coarser, reach scale, calculation of changes in bed elevation, may have introduced uncertainty in the 1969 to 1974 data set that is not in the other data sets.

Net changes in volume were calculated for each of the five study reaches. Changes in elevations were averaged for the five study reaches. Cross-section 9.477 was the only Reach 5 cross-section surveyed in 2001, meaning that the time periods 1984 to 2001 and 2001 to 2007 do not have enough cross-sections surveyed to represent volumetric changes throughout Reach 5 from cross-section 9.311 to cross-section 10.596. Therefore, Reach 5 volumetric changes are not tabulated, but the changes in cross sectional area are described in the text for those two time intervals. Channel averaged changes in bed elevation are reported for cross-section 9.477, though it is noted that such a change may not necessarily be representative of aggradation or degradation throughout Reach 5.

An additional exception to the methods described herein for calculating changes in sediment volumes and elevations was made for the cross-section at 9.477. Channel width typically varies only slightly between time periods through most of the study area, however, a left bank levee failure near RM 9.477 between 2001 and 2007 locally doubled the channel width, from 286 to 500 feet. A second failure on the left bank between 2007 and 2009 further widened the cross-section by 92 feet. Using the standard methods previously described to interpolate changes in sediment volumes and elevations between cross-section 9.477 and its nearest downstream cross-section misrepresents changes in channel bed elevation and sediment volumes. Instead, the cross-sectional change in area was differentiated between in-channel and overbank areas for the periods between 2001 and 2007, and 2007 and 2009. In-channel volumes and elevations were then interpolated using the standard method to the next cross-section downstream. The overbank volume and elevation changes were calculated separately, by multiplying the overbank cross-sectional areas by the lengths of the left bank failures delineated from 2007 and 2009 aerial photographs. These volumes were then divided by 2 in order to more accurately describe the roughly triangular shapes of the left bank erosional wedges.

Lidar and Aerial Photos

The most recent aerial photos of the entire study area were taken in February 2009 by King County. Lidar (Light Image Detection and Ranging) data of the study area was also collected in February 2009.

Field Reconnaissance

Field reconnaissance of the entire study area was conducted in the summer of 2009 by Herrera and King County staff. Herrera documented existing geomorphic conditions throughout the study area (RM 4.44 to RM 10.60) on June 25, June 30, July 1, July 30, and August 17, 2009.

Existing channel conditions were documented with photos and a handheld global positioning system (GPS) device. During field reconnaissance, bank conditions, riparian conditions, channel substrate, pebble counts, occurrence of wood, and bank armoring were documented throughout the study area. The study area is dominated by a plane-bed channel below the Auburn Wall, and a mostly riffle dominated channel upstream. Minimal pools were noted throughout the study area. Evidence of scour pools at the large accumulations of large wood was observed. Based on both conditions noted in the field and cross-section information, five sub-reaches (identified as Reaches 1 through 5) were identified. The sub-reaches are described in detail in the Delineation or Study Reaches below.

Herrera staff conducted a site reconnaissance of 41 of the study area cross-sections. At most of these cross-section locations, channel conditions were documented on individual field data forms (Appendix E). Data gathered during this reconnaissance was used to determine the reach boundaries within the study area for the sediment trends analysis.

Pebble Counts

Surface and subsurface pebble counts were collected throughout the study area at selected bar locations. Pebble counts followed the Wolman pebble count procedure. The intermediate axis of randomly selected gravels was measured using a gravelometer in a selected sample area. Sample sites were selected along exposed river bars. Nine surface and eight subsurface pebble counts were collected throughout the study area to document existing substrate conditions. At each sampling location, the seven largest apparently mobile surface clasts were also measured. Following field collection, the pebble count data were plotted to determine a distribution to determine a D_{50} pebble count size. Gravel bars throughout the study area were delineated by King County and are presented in Appendix F.

Large Wood Analysis

The large wood analysis consisted of (1) documenting large wood accumulations in 2007 and 2009, (2) identifying the stable wood accumulations present between 2007 and 2009, and

(3) comparing the large wood in the Lower White River to large wood found in other western Washington river systems. In addition, Herrera qualitatively documented the depositional features associated with the stable wood accumulations observed during the field reconnaissance.

Stable wood was identified as accumulations that occupied a minimum plan view area of at least 300 ft^2 between the two photo sets (2007 and 2009). The stable wood accumulations were qualitatively delineated during the summer 2009 field reconnaissance. Aerial photographs were subsequently used to confirm that the wood identified as stable in the field was present in 2007, and therefore persisted for at least 2 years in its original location. All wood accumulations were delineated from the 2007 and 2009 aerial photographs using GIS. The smallest identified stable wood accumulation in GIS was 300 ft^2 (in plan view area). Based on the aerial photo interpretation and field verification, the wood volume (derived from the area of the wood accumulation) and an estimate of the number of key pieces were made throughout the study area. Sediment accumulations associated with the stable wood accumulations were also qualitatively documented during the summer 2009 field reconnaissance.

The results of the large wood inventory were compared to the results of a study completed by Fox and Bolton (2007) of western Washington rivers, and with large wood data collected on the South Fork Nooksack River by the Lummi Nation (2009). This comparison was made to provide context as to how large wood on the Lower White River compares to large wood on other western Washington river systems. Fox and Bolton (2007) evaluated the distribution of large woody debris for three different regions in the Pacific Northwest and stream bankfull width classes. For each bankfull width class, parameters evaluated included number of pieces, wood volume, and number of key pieces per 100 meters of channel width.

At the Williams Pipeline site, at approximate RM 10.60, three engineered log structures were constructed in 2005 as part of a mitigation project for the re-burial of the pipeline at the White River crossing. These ELJs were omitted from the wood volume and key piece analysis because of their constructed and engineered origin.

Estimates of Basin Sediment Yield

Total sediment flux through the Lower White River was estimated using a method that calculates general sediment input from unmonitored basins (Syvitski et al. 2005), hereafter referred to as the Syvitski model. The Syvitski model has been shown to be appropriate for temperate basins in the northern hemisphere, such as the Lower White River basin. The model is purely empirical and therefore does preserve unit dimensions. The governing equation of the model is the following:

$$Q_s = 6.15 \times 10^{-5} A^{0.55} R^{1.12} e^{0.07T} \qquad (1)$$

Where: Q_s is the long-term average sediment input (kilograms per second)

A is the basin area (square kilometers), approximately equal to 1,184 km^2

R is the maximum relief in the basin (meters), approximately equal to 4,363 m

e is the base of the natural logarithm, approximately equal to 2.718

T is the *calculated* average annual temperature (degrees Celsius)

The average annual temperature *T* is frequently not known for a basin, and therefore must be estimated from an elevation based equation (Syvitski et al. 2003):

$$T = T_0 - LH \qquad (2)$$

Where: *L* is the lapse rate of the atmosphere (i.e., the decrease in temperature with elevation above sea level [calculated to be 7.42°C/km for the White River])

T_0 is the measured average annual temperature, for the purposes of this analysis, the average annual temperature a NOAA's Cooperative Observer Program (COOP) weather station in Buckley, Washington (station # 450945) was used as the average annual temperature, which is 10.33°C (WRCC 2009)

H is the average basin elevation (kilometers), approximately equal to 1.112 km

Geographic information system (GIS) spatial analyst tools were applied to the U.S. Geological Survey 10-meter digital elevation model to delineate the basin area, relief, and average elevation draining to the study area. It is important to mention that the Syvitski model was designed to predict sediment input to the ocean, therefore it may be in error if the area of interest is not close to the coast. Because of the close proximity of the project area to Puget Sound in terms of both location and elevation above sea level, errors due to this assumption should be within the precision of the model. Furthermore, the elevation at the study area (23 feet above sea level) was subtracted from the maximum basin elevation (14,411 feet) to compute the maximum relief in the basin (R).

Delineation of Study Reaches

The sediment trends study area extends from River Mile 4.44 (below the 8th Street Bridge) to River Mile 10.60 located at the Williams Pipeline crossing upstream of the City of Auburn on the Muckleshoot Indian Tribe Reservation (Figures 5, 6, and 7). The study area includes the downstream end of the White River canyon, the transition to the alluvial fan just upstream of the R Street Bridge, and the course of the river across the White River alluvial fan itself. Based on information gathered in the field, geomorphic features such as channel width, gradient and confinement, infrastructure such as bridges, and results of the sediment analysis, five separate reaches (1 through 5) were identified for the purposes of sediment trends analysis and reporting. Because the most downstream surveyed cross section, 4.440, is located approximately 2,500 feet downstream of the nearest cross-section at RM 4.978, this cross-section has been omitted from the most downstream reach, Reach 1. However, this cross-section location defines the most downstream extent of study area.

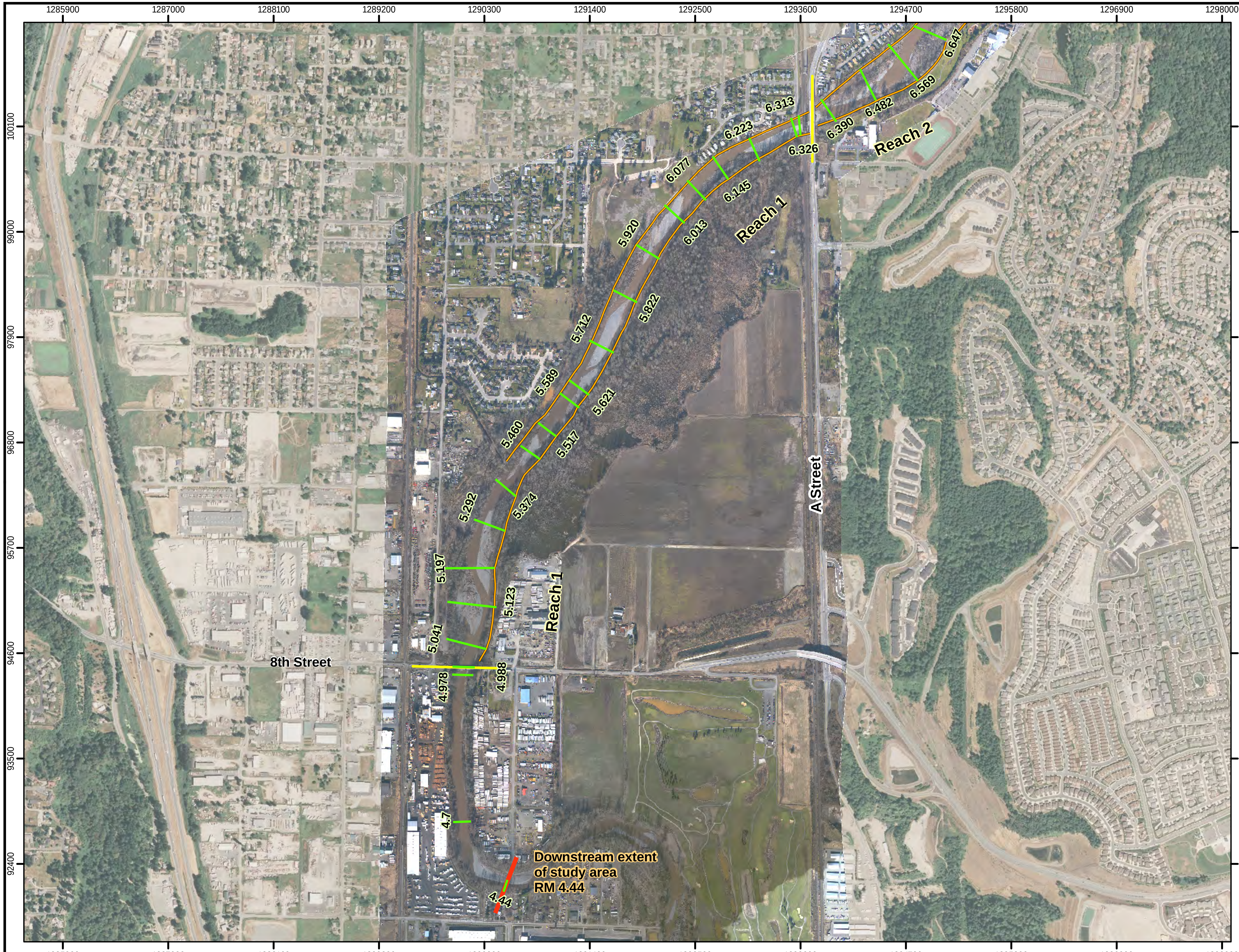

Figure 5.
Lower White River Summary of Sediment Trends
Reach 1

Legend

- 5.123 Cross section ID
- Levee or revetment (per King County records)
- Study area
- Reach break

Note: Existing Pierce County levees or revetments are not represented on this map.

N

0 500 1,000 2,000 Feet

HERRERA ENVIRONMENTAL CONSULTANTS

Coordinates: NAD83 Washington StatePlane North (feet)
Aerial Photo: King County (2009)

Produced By: GIS (rdr)
Project: K:\Projects\08-04059-013\Project\reach_cross_section.mxd

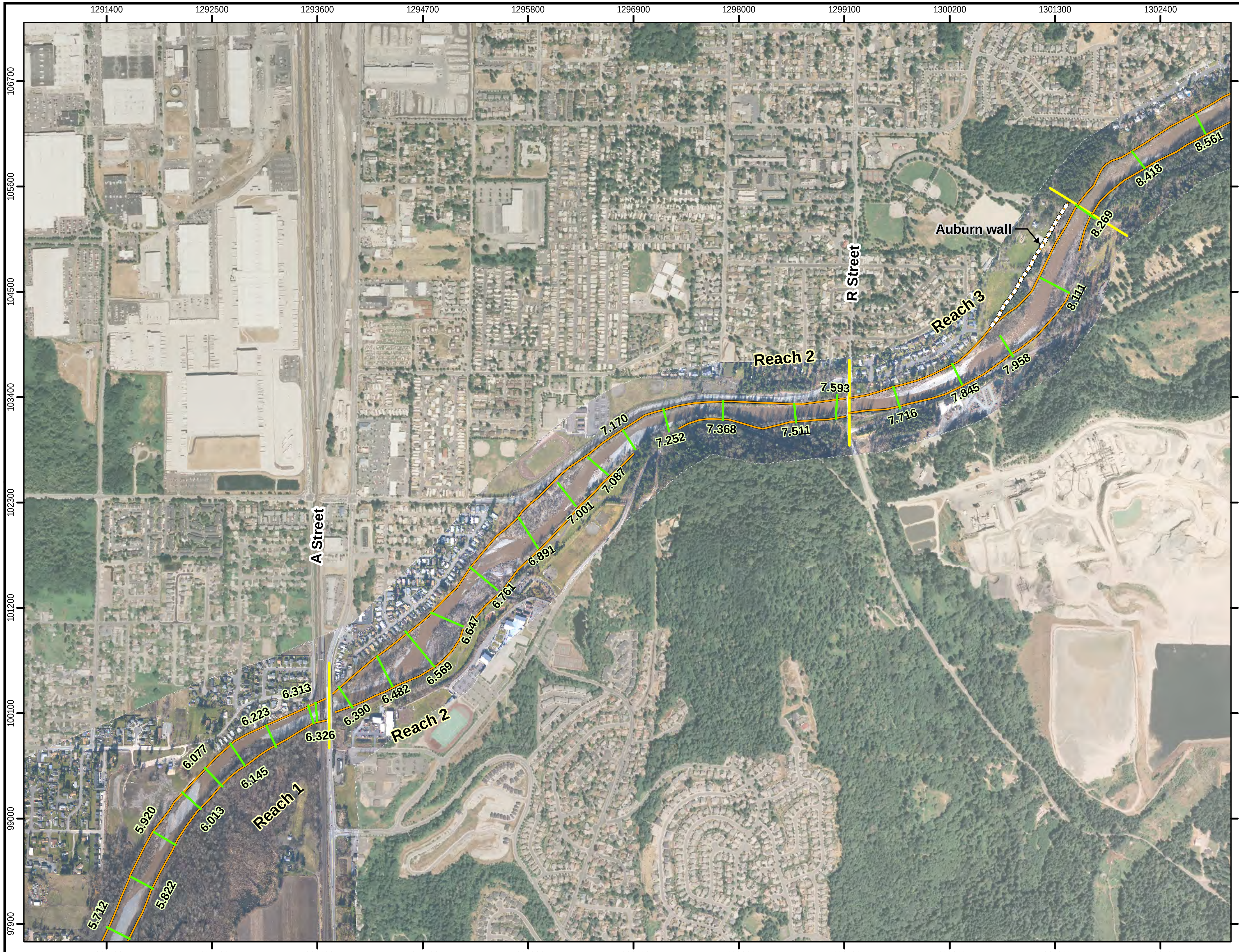

Figure 6.
Lower White River Summary of Sediment Trends
Reaches 2 and 3

Legend

- 5.123 Cross section ID
- Levee or revetment (per King County records)
- Study area
- Reach break
- Auburn Wall

Note: Existing Pierce County levees or revetments are not represented on this map.

N

0 500 1,000 2,000 Feet

HERRERA ENVIRONMENTAL CONSULTANTS

Coordinates: NAD83 Washington StatePlane North (feet)
Aerial Photo: King County (2009)

Produced By: GIS (rdr)
Project: K:\Projects\08-04059-013\Project\reach_cross_section.mxd

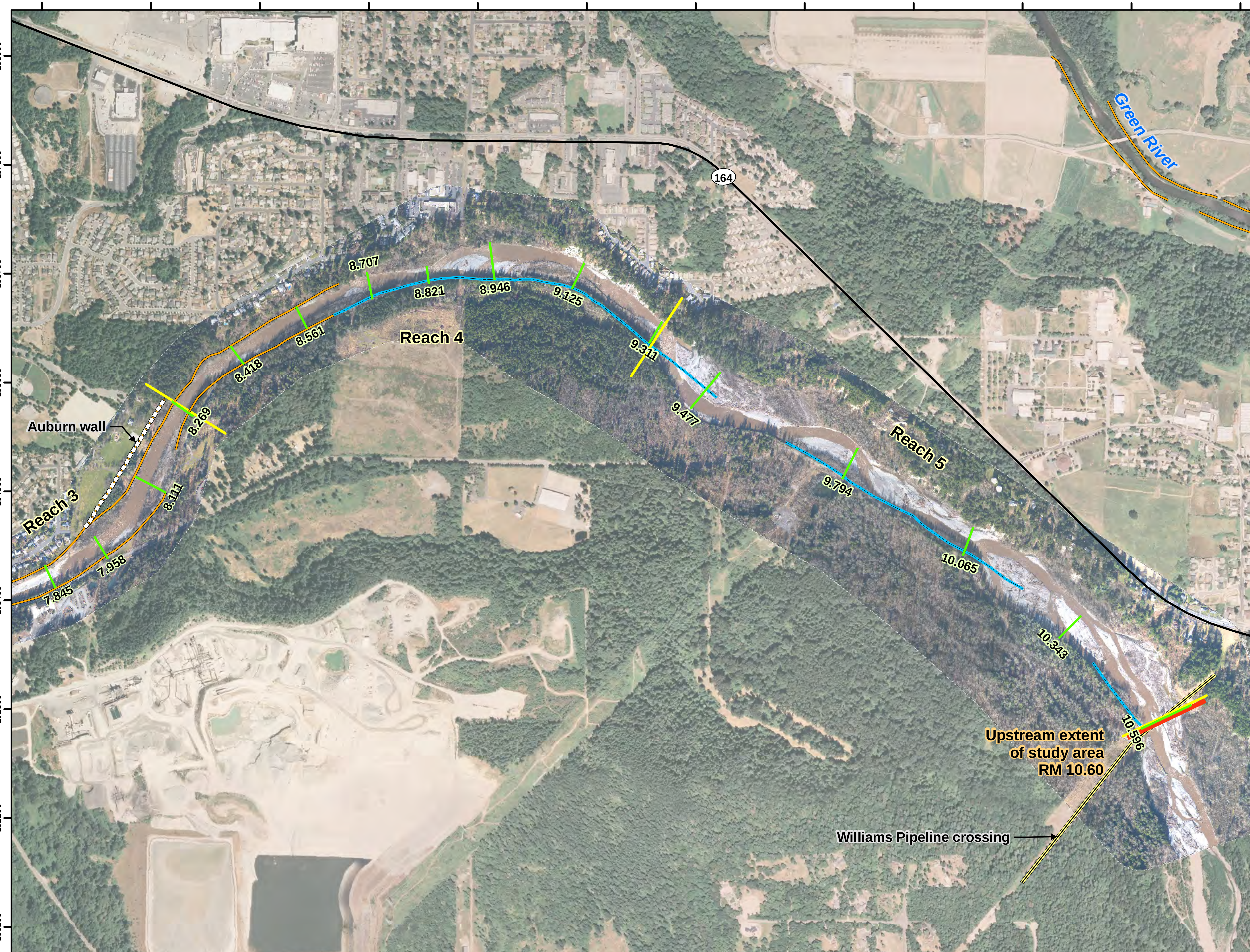

Figure 7.
Lower White River Summary of Sediment Trends
Reaches 4 and 5

Legend

- 5.123 Cross section ID
- Levee or revetment (per King County records)
- TransCanada Levee
- Study area
- Reach break
- Auburn Wall
- Williams Pipeline crossing
- Highway

Note: Existing Pierce County levees or revetments are not represented on this map.

N

0 500 1,000 2,000 Feet

HERRERA ENVIRONMENTAL CONSULTANTS

Coordinates: NAD83 Washington StatePlane North (feet)
Aerial Photo: King County (2009)

Produced By: GIS (rdr)
Project: K:\Projects\08-04059-013\Project\reach_cross_section.mxd

Within the study area, the channel transitions a predominately pool-riffle morphology in the upstream reaches to a confined prismatic (e.g., trapezoidal) channel in the downstream reaches. Upstream in Reach 5, the channel is wider and less confined and is dominated by riffles with limited occurrence of pools. As the channel transitions to the more confined system downstream (due to the levees and bridge constrictions) with a lower gradient, the channel becomes a well-defined prismatic channel where sand deposits have formed. These deposits found in the lower reaches play a role in the sediment transport dynamics in the downstream reaches as they add roughness to the channel and affect the sediment transport rate through the lower portion of the study area.

Reach 1: River Mile 4.99 (8th Street Bridge) to River Mile 6.33 (A Street Bridge)

Reach 1 is a mostly narrow, plane-bed channel that is constricted along both banks by levees and revetments (Figure 5). Two bridge crossings are included in this reach: the 8th Street Bridge and the A Street Bridge, the latter defining the most upstream reach extent. This reach is the longest of the five defined project reaches, with a length of 7,050 feet (1.3 miles). The floodplain width within the levees and revetments ranges from approximately 150 feet to 500 feet. During the time of the field reconnaissance on July 30, 2009, the wetted width ranged from 55 feet to 170 feet. Based on the USGS provisional data for the gauge in Auburn (# 12100496), the mean flow on the day of the field reconnaissance was 1,200 cfs (USGS 2009b). The gradient throughout this reach is low, 0.002, the lowest in the study area. Historically, gravel extraction in this reach has been significant.

There are about six lateral gravel bars in this reach. Minimal quantities of large woody debris (LWD) are found within this reach with the exception of a large natural log jam located on the right bank just upstream of the 8th Street Bridge at the head of a lateral bar. A small side channel network flows between the gravel bar and the right bank levee; this is in the location of the old Butte pit.

Reach 2: River Mile 6.39 (A Street Bridge) to River Mile 7.59 (R Street Bridge)

Upstream of RM 7.17, Reach 2 is a narrow, incised channel that is bound along both banks by levees built for flood control. Downstream of RM 7.17 the channel is wider with more gravel bars (Figure 6). The upper part of this reach is dominated by plane-bed channel morphology. The gradient throughout the 6,639-foot (1.26 miles) reach is 0.005. The floodplain width within the revetments ranges from approximately 170 to 425 feet. During the field reconnaissance on July 1, 2009, the wetted channel width ranged from 66 feet to 171 feet. Based on the USGS provisional data for the gauge in Auburn (# 12100496), the mean flow on the day of the field reconnaissance was 1,510 cfs (USGS 2009b). This reach has been surveyed almost annually by the City of Auburn since 1996 (except 2004 and 2005) in order to monitor changes.

A few large wood accumulations were documentedon gravel bars in the lower half of Reach 2 (downstream of RM 7.17). The vegetated right bank gravel bar located just upstream of the A Street Bridge has a perennial side channel along the right bank between the bar and the right

bank. A large log jam is at the head of this gravel bar. Four significant large wood accumulations were noted throughout the reach during the field reconnaissance.

Reach 3: River Mile 7.72 (R Street Bridge) to River Mile 8.27

Reach 3 extends upstream from the R Street Bridge to the upstream extent of the Auburn Wall (Cross-section 8.269) (Figure 6). This reach is the transition zone between the upstream canyon and the White River alluvial fan downstream. This reach includes the upper portion of the alluvial fan that formed where the White River flows out of the canyon and spreads out across the low-lying valley. The gradient throughout this reach 0.006. Reach 3 is the shortest of all the five delineated reaches with a length of 4,566 feet (0.86 miles).

Three lateral gravel bars are located in this reach. The approximate floodplain width within revetments ranges from 165 to 360 feet. During the field reconnaissance on June 30, 2009, the wetted channel width ranged from 110 feet to 165 feet. Based on the USGS provisional data for the gauge in Auburn (# 12100496), the mean flow on the day of the field reconnaissance was 1,550 cfs (USGS 2009b). The channel is mostly a plane-bed channel with one large riffle located adjacent to a gravel bar near RM 7.96. Throughout the reach levees and revetments extend along both banks. No large wood accumulations were documented in this reach. Upstream of RM 8.27, the right bank is no longer confined by a levee as the steep canyon wall extends along the right bank upstream to close to the Williams pipeline crossing at RM 10.60.

Reach 4: River Mile 8.27 to River Mile 9.31

This reach is characterized by the high canyon wall along the right bank and a levee along the left bank. The reach is 5,543 feet (1.1 miles) in length (Figure 7). The floodplain width between the left bank revetment and the right bank bluff throughout the reach ranges from approximately 165 feet to 360 feet. The gradient throughout the reach is 0.005. During the field reconnaissance on June 30, 2009, the wetted channel width ranged from approximately 75 feet to 345 feet. Based on the USGS provisional data for the gauge in Auburn (# 12100496), the mean flow on the day of the field reconnaissance was 1,550 cfs (USGS 2009b).

The unvegetated channel and floodplain widens in the mid-part of the reach near RM 8.95. The channel in the upstream part of this reach is characterized by a wide, braided channel with riffles between the lateral and mid-channel bars. Stable large wood accumulations were lacking in this reach during summer 2009 fieldwork. Individual pieces of large wood have been deposited on the bars, but most are not stable and do not influence sediment aggradation. Based on the cross-section data collected throughout this reach, the thalweg has shifted laterally across the channel since 1977.

Reach 5: River Mile 9.31 to RM 10.60 (Williams Pipeline Crossing)

Reach 5 extends from the Williams Pipeline downstream to the left bank area where the TransCanada levee has failed (just upstream of cross-section 9.311) (Figure 7). The floodplain

width within revetments in this reach ranges from approximately 175 feet to 630 feet. The wetted channel width varied from 100 to 150 feet throughout this reach during the field reconnaissance on June 25, 2009. Based on the USGS provisional data for the gauge in Auburn (# 12100496), the mean flow on the day of the field reconnaissance was 1,760 cfs (USGS 2009b). This reach is characterized as having a braided channel. The gradient throughout this reach is the steepest of all the reaches at 0.007.

Three ELJs were constructed in 2005 at the Williams Pipeline crossing site at the upstream extent of the reach at RM 10.60. These ELJs are still intact and provide hydraulic complexity in the channel and are accumulating large wood with sediment deposition occurring in the lee of the structures. The most upstream ELJ which is located along the left bank of the wetted channel is engaged in mainstem river flow. This ELJ is located along the right-side of a large left bank lateral bar located at the very upstream extent of the study reach (Figure 8). The other two ELJs are located downstream on a right bank lateral bar. These structures are not engaged with the mainstem channel; side channels, however, intersect the lateral bar where these structures are located. Wood accumulation has occurred on the large right bank bar where the two downstream ELJs are located.

At cross-section 9.477 and immediately downstream to approximately cross-section 9.311, the left bank levee breached between the 2001 and 2007 cross-section surveys. The channel has eroded laterally approximately 350 feet into the left bank at this location expanding the un-vegetated channel width.

Due to the highly dynamic nature of the channel in Reach 5, the thalweg has shifted laterally through time at most cross-section locations. Such shifting is a typical characteristic of a braided channel. As the thalweg shifts laterally across the channel, the areas of aggradation and degradation across the section shift as the bars migrate.

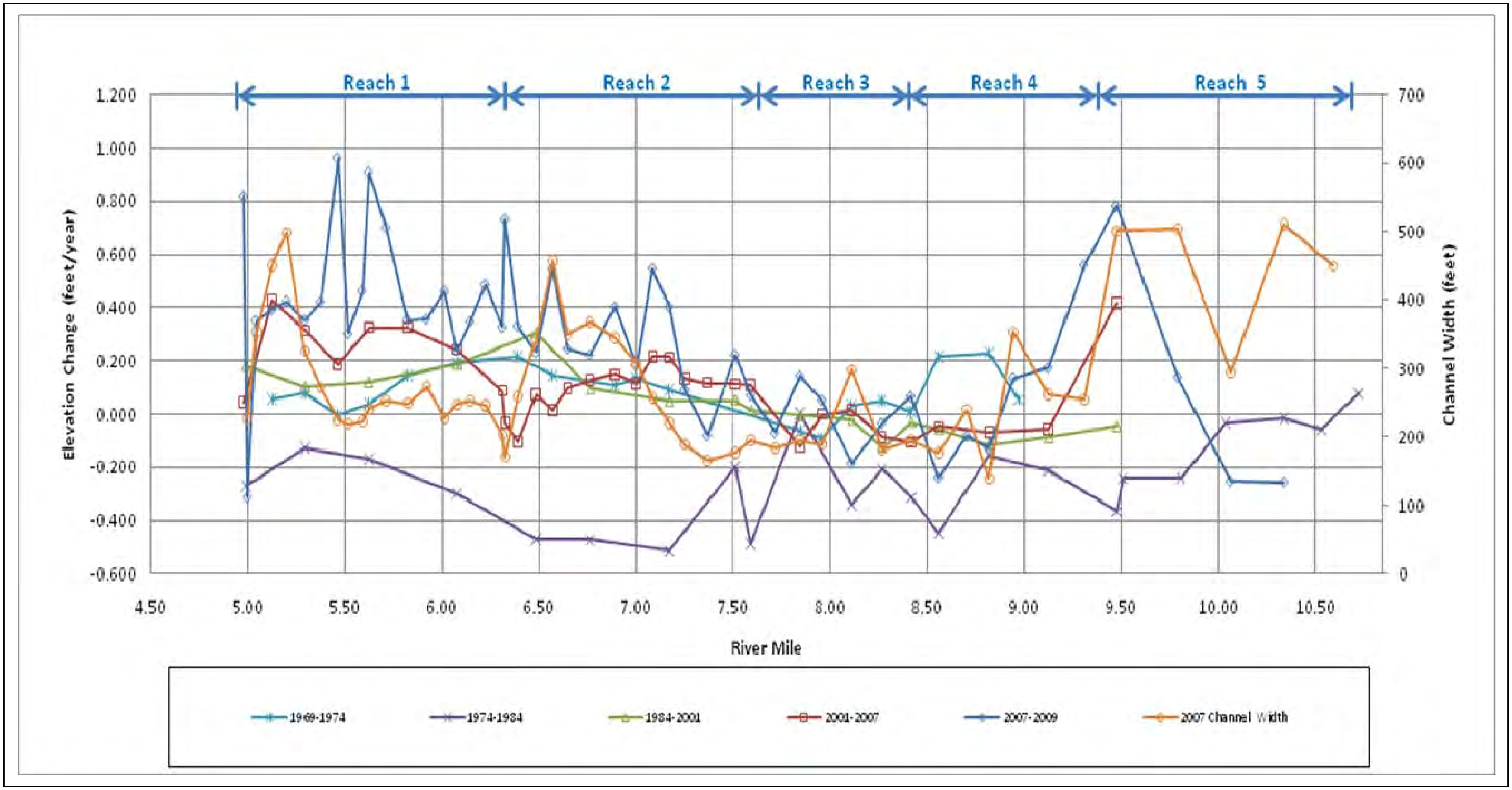

Figure 8. Longitudinal profile of average annual rates of bed elevation change (adapted from data provided by King County 2009b).

Results

This section presents the results of the cross-section analyses, substrate characterization, evaluation of the influence of large woody debris on sediment trends, and an estimate of basin sediment yield.

Channel cross-sectional data has been evaluated using a range of analytical techniques to describe the spatial and temporal dynamics of bed elevation and sediment storage in the Lower White River. Channel cross-sections from the different survey years used in this study are provided in Appendix B. Tables with the calculated changes in bed elevation and sediment storage for each cross-section over the various survey intervals are presented in Appendix C. A summary of the results of the cross-section analysis are provided in the following sections.

Channel Width

Channel width was defined as the distance between the toe of bank on each side of the channel. Average, minimum, and maximum channel widths for each reach from the 1969, 1974/1977, 1984, 2001, and 2007 surveys are presented in Table 4. Variability between surveys for a given reach is partly explained by the varying number and locations of cross-sections surveyed within a given reach in a given survey effort. The channel widths for each cross-section used in the change in channel bed elevation analysis are presented in Appendix C.

Table 4. Average, minimum, and maximum channel widths for each reach in 1974/1977, 1984, 2001, and 2007 (adapted from data provided by King County 2009b).

	Channel Width (feet)											
	1974/77			1984			2001			2007		
Reach	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
1	190	218	262	190	221	261	157	235	429	171	272	498
2	160	241	358	149	235	343	131	254	425	166	280	458
3	170	228	314	160	207	293	160	209	314	181	209	298
4	187	228	261	127	198	256	109	187	257	139	231	353
5	272	351	560	275	275	275	286	286	286	294	452	511

Channel Bed Elevation

Changes in average bed elevation and average rates of bed elevation change at every cross-section are provided in Appendix C. Reach-averaged results of changes in bed elevation and rates of bed elevation change are summarized by reach in Tables 5 and 6. The rates of bed elevation change are also illustrated in Figure 8.

Table 5. Reach-averaged bed elevation changes (adapted from data provided by King County 2009b).

		Reach Averaged Net Bed Elevation Change (feet)				
	Reach	1969-1974	1974-1984	1984-2001	2001-2007	2007-2009
1	X-S 4.988 to X-S 6.326	0.59	-1.99	2.31	1.40	0.87
2	X-S 6.390 to X-S 7.593	0.58	-4.29	1.74	0.63	0.52
3	X-S 7.716 to X-S 8.269	-0.03	-1.82	-0.86	-0.29	-0.11
4	X-S 8.269 to X-S 9.311	0.43	-2.82	-1.23	-0.42	0.58
5	X-S 9.311 to X-S 10.596	-0.96	-1.26	-0.80	2.50	0.13

Table 6. Average annual rates of bed elevation change (adapted from data provided by King County 2009b).

		Reach Averaged Annual Average Rates of Bed Elevation Change (feet/year)				
	Reach	1969-1974	1974-1984	1984-2001	2001-2007	2007-2009
1	X-S 4.988 to X-S 6.326	0.12	-0.20	0.14	0.23	0.44
2	X-S 6.390 to X-S 7.593	0.12	-0.43	0.10	0.11	0.26
3	X-S 7.716 to X-S 8.269	-0.01	-0.18	-0.05	-0.05	-0.06
4	X-S 8.269 to X-S 9.311	0.09	-0.28	-0.07	-0.07	0.29
5	X-S 9.311 to X-S 10.596	-0.19	-0.13	-0.05	0.42	0.07

Sediment transport and deposition and changes in channel form are typically highly variable over time. Although the data in Table 5 document the change in bed elevation averaged over each reach based on the bed elevation values at the beginning and ending of each survey interval, the data may not reflect the maximum increase (or decrease) in bed elevations that occurred over that time period. Similarly, the average annual rate of change reflects the total change apportioned over the duration of the survey interval; actual rates of change in bed elevation within a single survey interval may vary widely from year to year. As noted in the Methods section, the results for Reach 5 contain analysis only at cross-section 9.477 during the intervals 1984 to 2001 and 2001 to 2007 because that was the only Reach 5 cross surveyed in 2001. This affects results in both Tables 5 and 6.

Understanding that rates of vertical channel change may vary considerably from year to year, a review of the data reveals a general pattern in bed elevation change through the study reach over the duration of the study period. Except for 1974 to 1984, bed elevations in Reaches 1 and 2 are observed to be generally increasing.

In Reach 3, bed elevations are observed to decrease over every survey interval. Reaches 4 and 5 shows both increases and decreases in bed elevation over the different survey intervals with both having a net increase over the most recent time period from 2007 to 2009. Maximum rates of increased channel elevation for Reaches 1, 2, and 4 occur in the most recent survey interval from 2007 to 2009. The rate of increase within Reach 1 over this interval, 0.44 feet/year, represents

the maximum rate of increase present in the data. The maximum rate of decreased bed elevation for each reach is observed to have occurred between 1974 and 1984.

These results are consistent with trends identified in an analysis of cross-section data collected nearly annually between 1996 and 2009 at the 13 cross-sections in Reach 2 (Appendix A, King County 2009a). Results of that analysis are presented in Appendix D, and show that the bed elevation increased by 1.5 feet in Reach 2 from 1996 through 2009, at an average rate of 0.12 feet/year.

A longitudinal plot of the average annual rate of bed elevation change at each cross-section location shows that although the rates of bed elevation change are highly variable from section to section, a pattern of downstream increases in the rate of bed elevation change is evident (Figure 8). The survey interval from 1974 to 1984 is an unmistakable exception to this pattern. The rates of bed elevation change over this interval are negative in almost all cases, and are also the lowest throughout the study reach for almost all cross-sections when compared to rates over the other intervals. These values are most striking downstream of RM 7.8, where the trend over other intervals is predominately aggradational.

Another notable feature in Figure 8 is the high rate of increased bed elevation change at RM 9.48 from 2001 to 2007 and 2007 to 2009, which appears to be associated with the increased channel width due to erosion of the of the TransCanada Levee that borders the left bank of the White River along this part of the river. The high rates of increased bed elevation change at RM 9.31 likely result from channel infilling caused by the significant sediment production associated with the upstream lateral expansion.

Comparing the rates of bed elevation changes to channel widths from 2007 illustrates that the areas with the lowest rates of increase in channel elevation or with decreasing trends in channel elevation, i.e., the upper part of Reach 2, all of Reach 3, and the lower part of Reach 4, are coincident with the lowest channel widths. The portion of the study area showing the greatest trend in increased bed elevations, Reach 1 and the downstream part of Reach 2, are generally coincident with an abrupt increase in channel widths at the downstream end of Reach 2.

Longitudinal Profiles and Channel Gradient

Longitudinal profiles and channel gradients were derived from thalweg data points from each survey. Longitudinal profiles constructed from the thalweg points of each cross-section illustrate the relative vertical position of the bed over the study period (Figure 9). Channel gradients calculated from reach boundary thalweg elevations for each reach and survey show a decreasing gradient through the study reach from upstream to downstream over the study period (Table 7).

The longitudinal profiles clearly illustrate the extent and magnitude of bed degradation between 1974/77 and 1984 and the patterns of bed elevation change since that interval. Degradation from 1974/77 to 1984 is most evident in the upstream part of Reach 2 and in Reach 3. That degradation is not evident from 1974/77 to 1984 in the lower part of Reach 2 likely results from

the relative timing of survey and gravel removal; significant gravel removal occurred in 1975 and 1976 but survey was not conducted until 1977.

Table 7. Channel gradients calculated from reach boundary thalweg elevations (adapted from data provided by King County 2009b).

Reach		Average Channel Gradient by Reach				
		1974-77	1984	2001	2007	2009
1	X-S 4.988 to X-S 6.326	0.0035	0.0027	0.0037	0.0027	0.0020
2	X-S 6.390 to X-S 7.593	0.0059	0.0039	0.0046	0.0054	0.0049
3	X-S 7.716 to X-S 8.269	0.0059	0.0056	0.0060	0.0056	0.0055
4	X-S 8.269 to X-S 9.311	0.0048	0.0062	0.0054	0.0050	0.0054
5	X-S 9.311 to X-S 10.596	0.0067	0.0079	NA	0.0056	0.0066

The longitudinal profiles illustrate both the continued aggradational trend in Reach 1 and the lower portion of Reach 2 since 1984, and the relatively static (though slowly degrading) character of Reach 3. The zone of transition between these conditions is largely coincident with an increase in channel widths that occurs between RM 7.3 and RM 7.1. Reach 4 and Reach 5 show greater patterns of variability in bed elevation. These patterns are evident both between cross-sections during a single survey and also between survey intervals. The longitudinal variability observed during a single survey may be due to the generally greater distance between sections in these reaches than in those downstream.

Cross-Section Comparisons

Cross-section surveys at RM 5.621 and RM 8.821 (Figures 10 and 11) illustrate representative patterns and morphologic processes observed throughout other cross-section data. Differences in cross-sectional geometry at RM 5.621 illustrate typical patterns in channel and bar elevation change observed within Reach 1 (Figure 10), with bar aggradation from 1974 to 1977 and subsequent degradation from 1977 to 1984, bar growth from 1984 to 1986, lateral migration of the main stem channel from the left bank to the right from 1986 to 2001. Significant lateral bar growth and infilling of the main channel are evident in the periods from 2001 to 2007, and 2007 to 2009. From 1974 to 2009, the thalweg elevation at cross-section 5.621 increased from 65.6 feet (NAVD 88 vertical datum) to 69.6 feet with a minimum of 62.8 in 1984. Lateral bar growth and main stem channel infilling are evident in many sections in Reaches 1 and 2 between 2001 and 2009, and represent the channel features that account for the majority of sediment storage over this time period.

Changes in cross-section geometry for much of Reaches 3, 4, and 5 are illustrated by cross-section 8.821 (Figure 11). Evident in this cross-section is confinement by the left bank levee and the right bank hillslope, and relative stability of right bank floodplain surface. Deepening of the main channel, potentially related to gravel extraction activities, is apparent from 1977 to 1984.

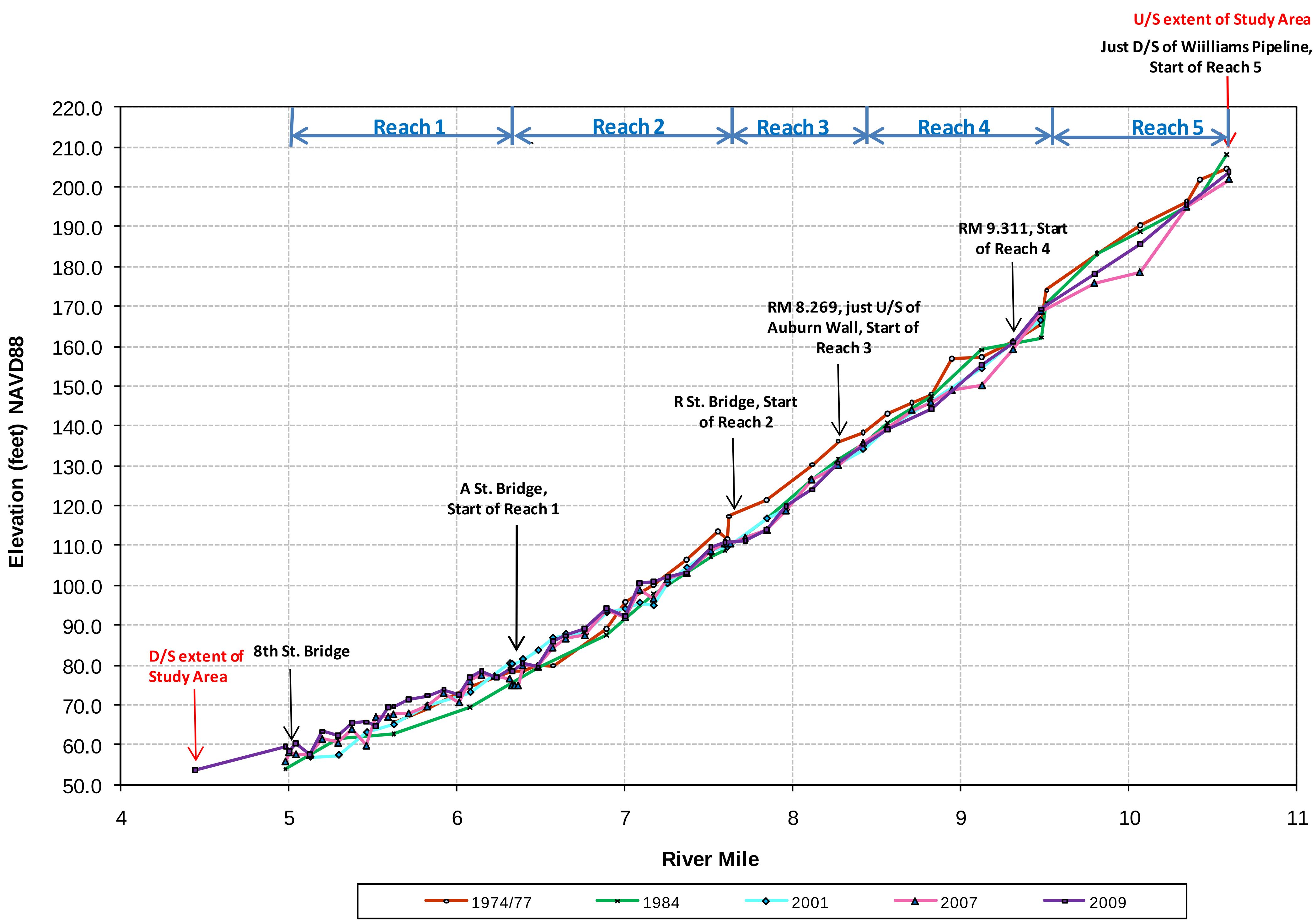

Figure 9. A comparison of thalweg elevation profiles of the Lower White River for the years 1974/77, 1984/86, 2001, 2007, and 2009 (adapted from King County 2009c).

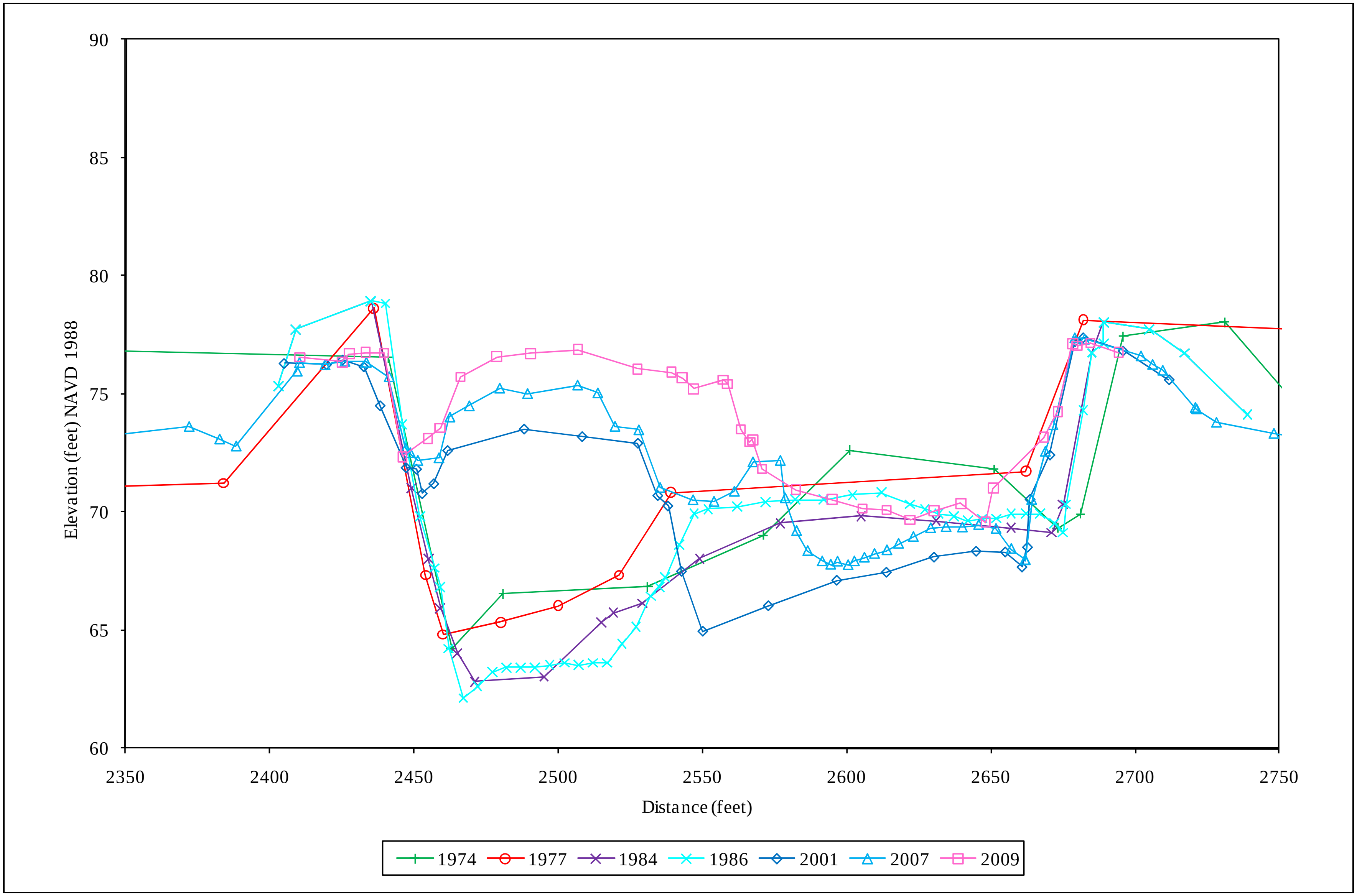

Figure 10. Cross-section surveys at RM 5.621.

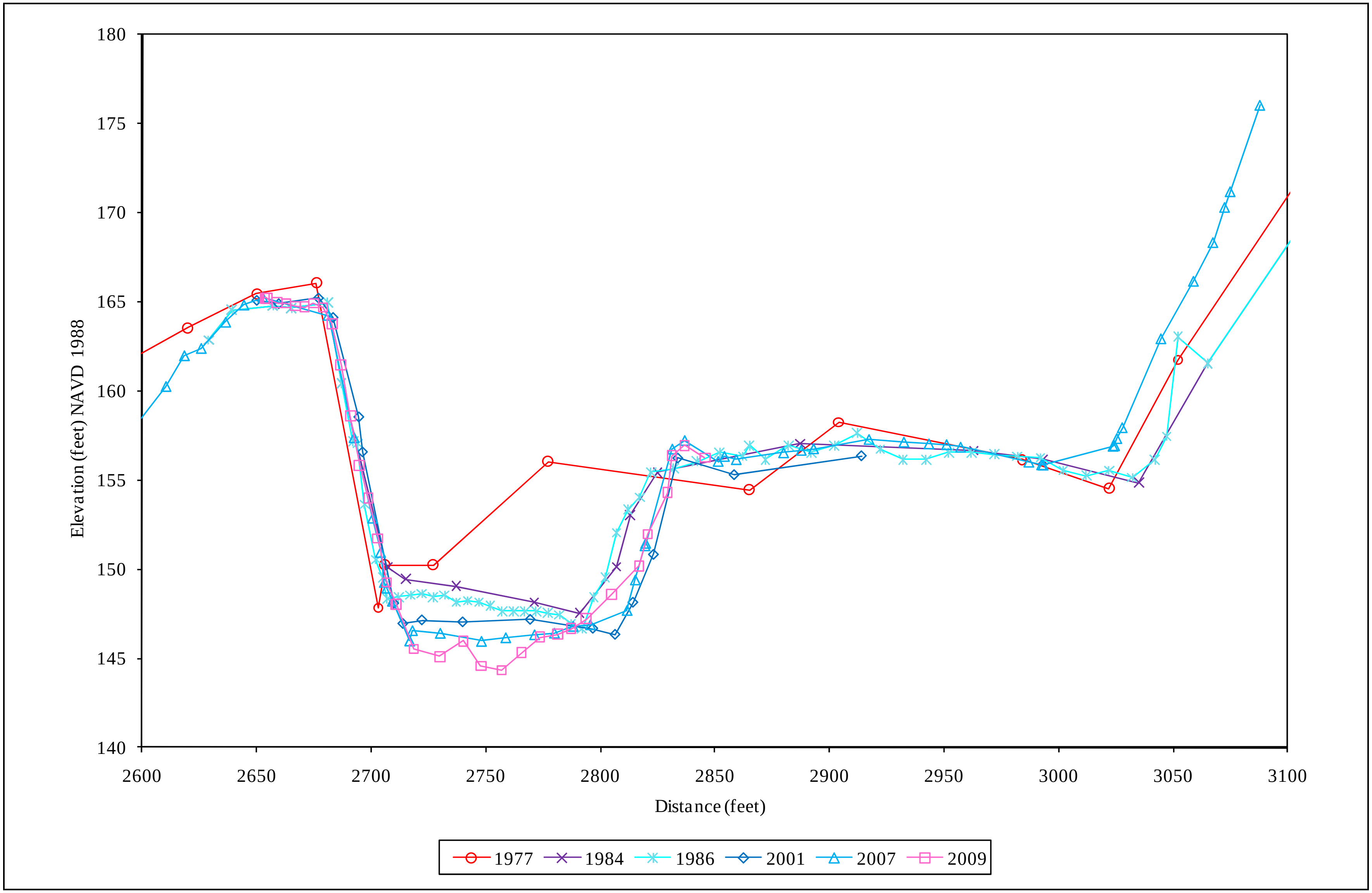

Figure 11. Cross-section surveys at RM 8.821.

Progressive channel incision is clear from 1984 to 1986, 1986 to 2001, 2001 to 2007, and 2007 to 2009. From 1974 to 2009, the thalweg elevation at cross-section 8.821 decreased by 3.5 feet.

Channel Aggradation and Degradation

Changes in sediment storage, including total and average annual change in storage volume for each reach for each survey interval, were calculated within the study area as a function of the difference in cross-sectional area at a given section between survey intervals, and the distance between cross-sections. Changes in sediment storage by cross-section are provided in Appendix C; reach summaries of these data are presented in Tables 8 and 9. Note that a positive value reflects an increase in sediment storage or net aggradation and a negative value represents a decrease in sediment storage or net degradation. Reach scale-results are not reported in Reach 5 for 1984 to 2001 or 2001 to 2007 because only one Reach 5 cross section was surveyed in 2001, which would not adequately represent the full study reach with regard to sediment volumes or rates of change in sediment volumes.

Table 8. Reach averaged net change in sediment volume for each survey interval (adapted from data provided by King County 2009b).

		Net Change in Sediment Volume (yds^3)				
Reach		1969-1974	1974-1984	1984-2001	2001-2007	2007-2009
1	X-S 4.988 to X-S 6.326	38,400	-85,100	101,600	110,100	65,000
2	X-S 6.390 to X-S 7.593	35,500	-334,100	189,800	39,000	40,300
3	X-S 7.716 to X-S 8.269	-700	-70,800	-9,700	-2,300	-2,000
4	X-S 8.269 to X-S 9.311	16,600	-99,600	-41,200	-11,700	7,600
5	X-S 9.311 to X-S 10.596	-82,200	-183,800	NA	NA	25,800
	Total	**7,600**	**-773,400**	**240,500**	**135,100**	**136,700**

Table 9. Reach averaged annual average rate of change in sediment volume for each survey interval (adapted from data provided by King County 2009b).

		Average Rate of Change in Sediment Volume (yd^3/year)				
Reach		1969-1974	1974-1984	1984-2001	2001-2007	2007-2009
1	X-S 4.988 to X-S 6.326	7,700	-8,500	6,000	18,400	32,500
2	X-S 6.390 to X-S 7.593	7,100	-33,400	11,200	6,500	20,200
3	X-S 7.716 to X-S 8.269	-100	-7,100	-600	-400	-1,000
4	X-S 8.269 to X-S 9.311	3,300	-10,000	-2,400	-2,000	3,800
5	X-S 9.311 to X-S 10.596	-16,400	-18,400	NA	NA	12,900
	Total	**1,600**	**-77,400**	**14,200**	**22,500**	**68,400**

These data show that there has been net aggradation within the study area over four of the five survey intervals, with the greatest rate of accumulation (68,400 yds^3/year) occurring between

2007 and 2009. Net degradation within the study area was documented only for the period from 1974 and 1984, when the average rate of degradation was 77,400 yds^3/year. These data also show that the average rate of aggradation in the study area represented by the two survey intervals that were not directly influenced by gravel removal activities, 2001 to 2007 and 2007 to 2009, is approximately 45,500 yds^3/year.

The cross-section comparison analysis documents aggradation in Reach 1 and Reach 2 over all survey intervals, except the period from 1974 to 1984. The highest rates of aggradation in these reaches occurred between 2007 and 2009. Reach 3 shows degradation over all survey intervals; excluding the period from 1974 to 1984, the magnitude of degradation, particularly when viewed as an average annual rate, is negligible when compared to rates of change in other reaches. Reach 4 and Reach 5 show both aggradation and degradation over the study period. For both of these reaches, calculated rates of degradation are highest between 1974 and 1984. The highest rate of aggradation in Reach 4 occurred from 1969 to 1974; the highest rate of aggradation in Reach 5 occurred from 2007 to 2009.

It is possible to use the calculated change in sediment volume and the documented gravel removal volume for the period of 1974 to 1984 to estimate the net volume of deposition or erosion in that same period. Table 10 shows both the net change in sediment volume for the period from 1974 to 1984 (from Table 8) and the documented volume extracted over the same time period for each reach (modified from Table 6, Appendix A). These values are integrated to estimate the net sediment deposition or erosion for each reach. The estimated net sediment erosion over the time period is 140,400 yds^3 of degradation. This estimated value of net deposition or erosion also constitutes the minimum net flux of sediment into the study area. They are a minimum influx because there likely was also undocumented extraction by private operators during this period not included in Table 10 plus there is some part of the influx that continues to be transported downstream of this study area.

Table 10. Net sediment deposition or erosion per reach for the period from 1974 to 1984 based on calculated net change in sediment volume and documented gravel removal.

	Reach	Calculated Change in Volume (yds^3)	Documented Gravel Removal (yds^3)	Net Sediment Deposition or Erosion (yds^3)
1	X-S 4.988 to X-S 6.326	-85,100	320,000	234,900
2	X-S 6.390 to X-S 7.593	-334,100	127,000	-207,100
3	X-S 7.716 to X-S 8.269	-70,800	71,000	200
4	X-S 8.269 to X-S 9.311	-99,600	115,000	15,400
5	X-S 9.477 to X-S 10.596	-183,800	0	-183,800
	Total	**-773,400**	**633,000**	**-140,400**

Summary of Cross-section Analysis Results

A summary of key findings from the cross-section analysis is provided below for each reach in the study area.

Reach 1

The cross-section comparison documents aggradation in Reach 1 in all survey periods except from 1974 to 1984. Reach 1 has the greatest increases in channel bed elevation and aggradation of the reaches in the study. From 1969 to 1974, the channel bed elevation increased an average of 0.12 feet/year and aggraded an average of 7,700 yds^3/year. Between 1974 and 1984, the cross-section comparison indicates an average decrease in the channel bed elevation of 0.20 feet/year and net degradation of 85,100 yds^3. From 1984 to 2001, sedimentation in Reach 1 continued, with an average increase in channel bed elevation of 0.14 feet/year and net aggradation of 101,600 yds^3, or 6,000 yds^3/year.

From 2001 to 2007 the rate of sedimentation in Reach 1 increased, with an average increase in channel bed elevation of 0.23 feet/year and net aggradation of 110,100 yds^3, or 18,400 yds^3/year. Between 2007 and 2009 the rate of sedimentation in Reach 1 increased further, with an average increase in channel bed elevation of 0.44 feet/year and net aggradation of 65,000 yds^3, or 32,500 yds^3/year. The rate of sedimentation in Reach 1 between 2007 and 2009 is the highest rate documented in this study.

Reach 2

Similar to Reach 1, the comparison of cross-sections in Reach 2 documents aggradation and increases in bed elevation over the full study period, with the exception of the period from 1974 to 1984. Aggradation within the reach is highest downstream of an increase in channel width that begins between RM 7.368 and RM 7.170. Small increases in bed elevation are documented upstream of this transition during most survey intervals, however, the rate of increases in channel bed elevation and in aggradation are notably higher downstream.

From 1969 to 1974, the channel bed elevation increased an average of 0.12 feet/year and aggraded an average of 7,100 yds^3/year. Between 1974 to 1984, the cross-section comparison indicates an average decrease in the channel bed elevation of 0.43 feet/year and net degradation of 334,100 yds^3, equivalent to an average rate of degradation of 33,400 yds^3/year. From 1984 to 2001, bed elevations in Reach 2 increased an average of 0.1 feet/year, although downstream of RM 7.368, this increase was 0.15 feet/year. Change in sediment storage over this time period was equivalent to aggradation of almost 190,000 yds^3, or 11,200 yds^3/year. Aggradation continued in Reach 2 from 2001 to 2007 and 2007 to 2009.

From 2001 to 2007, channel bed elevation in Reach 2 increased at a rate of 0.11 feet/year, associated with net aggradation of 39,000 yds^3, or 6,500 yds^3/year. Between 2007 and 2009, channel bed elevation increased 0.26 feet/year along with aggradation of 40,300 yds^3, or

20,200 yds^3/year. The rates of sedimentation in Reach 2 between 2007 and 2009 are the second highest in the study (to Reach 1 during the same survey interval).

Reach 3

The cross-section comparison documents decreases in channel bed elevation and degradation in Reach 3 over all survey intervals in the study period. From 1969 to 1974, bed elevations decreased at a rate of 0.01 feet/year. Degradation of 700 yds^3 (or 100 yds^3/year) was documented over this time period. The greatest rates of degradation documented in Reach 3 occurred between 1974 and 1984. During this interval, bed elevation decreased at a rate of 0.18 feet/year associated with net degradation of 70,800 yds^3, or 7,100 yds^3/year.

Patterns in bed elevation change and sedimentation are consistent between 1984 and 2009. From 1984 to 2001, bed elevation decreased an average of 0.05 feet/year, associated with degradation of 9,700 yds^3, or 600 yds^3/year. From 2001 to 2007, bed elevation again decreased at an average of 0.05 feet/year, associated with degradation of 2,300 yds^3, or 400 yds^3/year. Between 2007 and 2009, bed elevation decreased an average of 0.06 feet/year, associated with degradation of 2,000 yds^3, or 1,000 yds^3/year.

Reach 4

The cross-section comparison of Reach 4 shows more variability than the other reaches in the study area, and documents both increases and decreases in bed elevation, and related aggradation and degradation, over the course of the study period. From 1969 to 1974, bed elevations increased at a rate of 0.09 feet/year. Aggradation of 16,600 yds^3 (or 3,300 yds^3/year) was documented over this time period.

Between 1974 and 1984, the cross-section comparison for Reach 4 documents a decrease in average channel bed elevation of 0.28 feet/year. Over this same time period, the cross-section comparison calculates degradation of 99,600 yds^3, or 10,000 yds^3/year. From 1984 to 2001, Reach 4 degraded, with an average decrease in average channel bed elevation of 0.07 feet/year and net degradation of 41,200 yds^3, or 2,400 yds^3/year. From 2001 to 2007, Reach 4 continued to degrade, with an average decrease in channel bed elevation of 0.07 feet/year and net degradation of 11,700 yds^3, or 2,000 yds^3/year. Between 2007 and 2009, however, the cross section comparison illustrates aggradation in Reach 4, with an increase in average channel bed elevation of 0.29 feet/year, and net aggradation of 7,600 yds^3, or 3,800 yds^3/year.

Reach 5

The cross-section comparison documents both increases and decreases in channel bed elevation, and net aggradation and degradation, in Reach 5 over the study period. Between 1969 to 1974, the cross-section comparison for Reach 5 documents a decrease in average channel bed elevation of 0.19 feet/year, and net degradation of 82,200 yds^3 or 16,400 yds^3/year. From 1974 to 1984, bed elevations decreased at a rate of 0.13 feet/year, associated with degradation of almost 184,000 yds^3 (or 18,400 yds^3/year).

For the cross section comparison for 1984 to 2001, and 2001 to 2007, data for Reach 5 was available from only cross section, RM 9.477 and so are not reported in Tables 8 and 9. Changes in bed elevation at RM 9.477 decreased by an average of 0.05 feet/year from 1984 to 2001. Change in sediment storage over this time period, calculated from RM 9.125 to 9.477 within the channel only, was equivalent to degradation of almost 21,000 yds^3, or 1,200 yds^3/year. From 2001 to 2007 bed elevation increased at RM 9.477 by 0.42 feet/year. Aggradation of 21,800 yds^3 (or 3,600 yds^3/year) occurred within the channel from RM 9.311 to RM 9.477 over this time period. Over this same period the channel width at RM 9.477 increased from 286 to 500 feet. The lateral migration driving this change in channel width also resulted in significant erosion of the left bank floodplain. This erosional process generated and estimated 40,000 yds^3 of sediment between 2001 and 2007 and 23,000 yds^3 between 2007 and 2009.

From 2007 to 2009, Reach 5 continued to aggrade. The average channel bed elevation increased 0.07 feet/year, associated with aggradation of 25,800 yds^3 (or 12,900 yds^3/year). In contrast to the time periods from 1984 to 2001, and from 2001 to 2007, the figures reported from 2007 to 2009 include cross section comparisons at six cross-sections and are therefore representative of reach-scale trends. For comparison to these earlier time periods, the channel width at RM 9.477 increased from 500 to 608 feet from 2007 to 2009 and the bed elevation increased 0.78 feet/year.

Grain–Size Distribution of Surface and Subsurface Sediment

Throughout the study reach, White River alluvium ranges in size from sand (0.063 to 2 mm) to cobbles (64 to 256 mm), with the majority of sediment consisting of course gravel (4 to 64 mm) to cobbles (64 to 256 mm). Surface pebble counts yield a median grain size (D_{50}) of 31 to 120 mm (Table 11). Subsurface pebble counts yield a D_{50} ranging from 13 to 26 mm. The smaller D_{50} measured for the subsurface indicates that the bed surface is armored at all sample locations. Local armoring indicates winnowing of fine material from the bed surface following bedload transport events. Patches of sand overlying coarse grained depositional features within the channel suggest high rates of sand yield from upstream.

D_{50} varies along the study reach beginning upstream, in Reach 5. In Reach 5, sediment sizes are larger, then drop off dramatically to their lowest values in Reach 4 (Figure 12). Sediment sizes increase in Reach 3, peak in Reach 2, then decline again in Reach 1. It appears the size difference between the surface and subsurface samples (for the same grain size category) was greatest for the sites with the largest surface pebble count sizes, indicating greater channel armoring at these locations.

The specific locations of certain sediment samples may have influenced the results from those locations and subsequent comparison to upstream and downstream samples. The sample at RM 6.761 was taken upstream of a mid-channel log jam. This feature encourages deposition during high magnitude flow events and the proximity of the sample location may explain the coarse nature of the resulting grain-size distribution. At RM 8.00, the sample was collected on a small bar in the lee of a large forested gravel bar. The position of the sample location in a low energy position in the lee of an upstream feature may is a likely cause of the relatively fine

Table 11. Surface and subsurface pebble count results.

Reach		RM	Surface (mm)			Subsurface (mm)			Average of 7 Largest Clasts (mm)
			Surface D_{10}	Surface D_{50}	Surface D_{90}	Subsurface D_{10}	Subsurface D_{50}	Subsurface D_{90}	
No.	Downstream of X-S 4.988		24	65	114	5	15	59	172
1	X-S 4.988 to X-S 6.326	5.292	18	64	110	8	26	64	140
1	X-S 4.988 to X-S 6.326	6.013	40	98	167	6	14	52	219
2	X-S 6.390 to X-S 7.593	6.761	38	120	214	Subsurface data not collected at this location [a]			224
2	X-S 6.390 to X-S 7.593	7.170	45	87	173	5	17	47	207
3	X-S 7.716 to X-S 8.269	8.000	26	55	87	6	22	43	214
4	X-S 8.269 to X-S 9.311	9.311	10	31	72	6	16	32	191
5	X-S 9.477 to X-S 10.596	9.794	55	113	195	6	28	64	252
5	X-S 9.477 to X-S 10.596	10.343	7	50	158	5	13	56	244

[a] Subsurface data not collected at this location due to coarse surface layer.

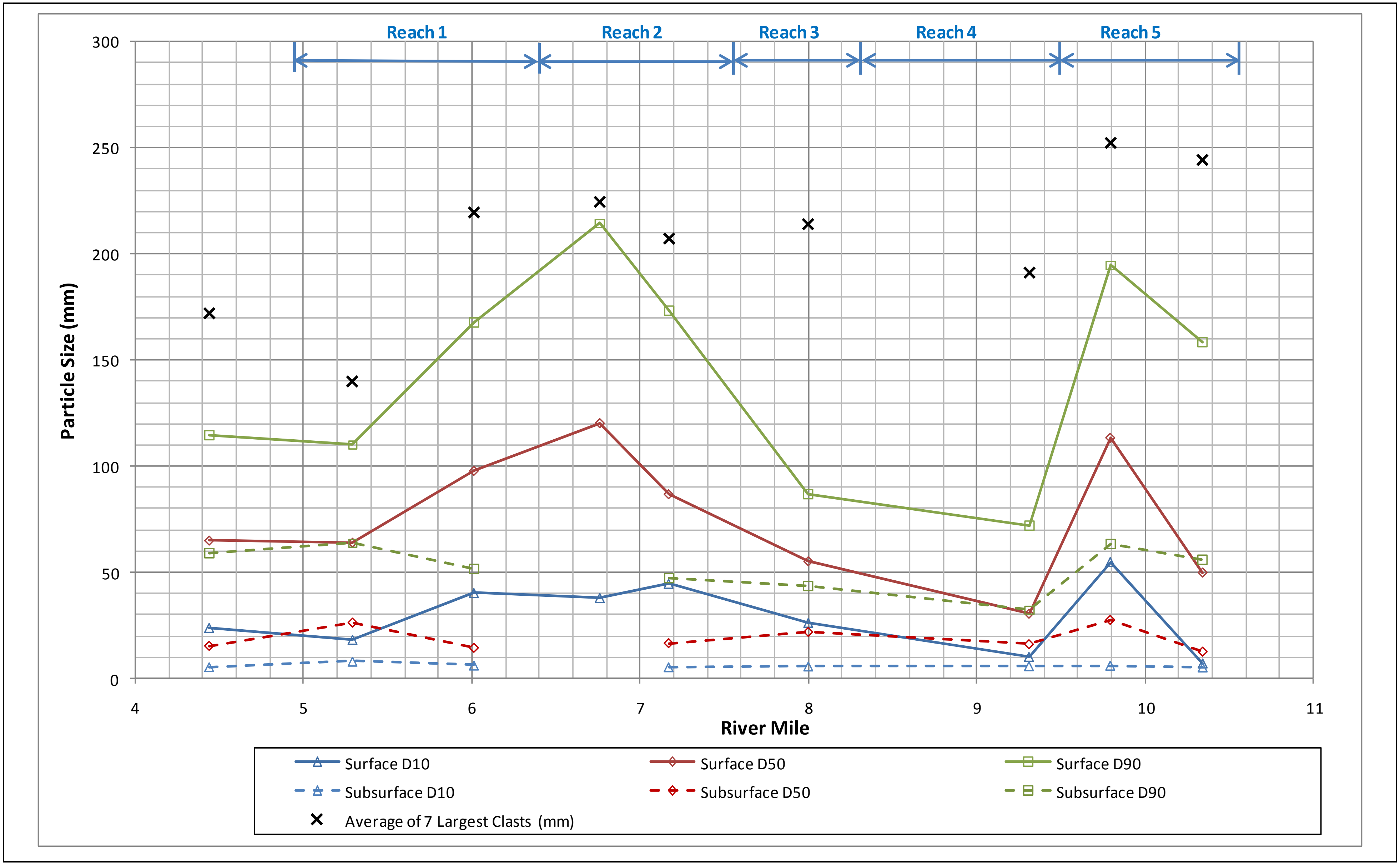

Figure 12. Surface and subsurface pebble counts.

grain-size distribution. Similarly, the sample at RM 9.311 was taken approximately midway down the bar; this location may help explain the fine nature of the grain size distribution at this sample site.

The average of the seven largest apparently mobile sediment clasts ranges in size from large cobbles to small boulders, and follows similar trends as that of the surface and subsurface sediment sizes. The largest clasts were observed in Reach 5, at the upstream extent of the study area and the smallest average clast size found in Reach 1.

Grain-size distribution graphics are included as Appendix G. The pebble count results for each of the five reaches are listed in Table 11 and Figure 12.

A comparison with an analysis conducted in 1986 reveals similar estimates of mean sediment size and sediment trends along the study reach (Dunne 1986). Mean sediment sizes collected in 2009 are at the most 32 percent larger and 10 percent smaller than those collected in 1986. Similar trends in longitudinal sediment sizes are visible in 1986, where particle diameters peak in Reaches 2 and 5, and decrease in Reaches 3 and 1.

Large Wood Occurrence in Study Area

The results of the Fox and Bolton (2007) study for wood volume and key piece frequency are presented in Table 12 for the 25th percentile, median and 75th percentile. Their results are based on data collected in unmanaged, forested basins in western Washington. Using the wood data gathered throughout the study area, a comparison to the volume per 100 meters of channel length and the number of key pieces per 100 meters of channel length were made.

Table 12. Distribution of large Woody Debris (volume per 100 m of channel) and key pieces by bankfull width for western Washington rivers (per Fox and Bolton [2007]).

Fox and Bolton (2007) [a]	Volume (m^3 per 100 m)	Number of Key Pieces (per 100 m)
25th Percentile	<44	<1
Median	93	1.3
75th Percentile	>317	>4

[a] Western Washington percentile numbers for rivers >30 to 100 meters in bankfull width in unmanaged forest basins.

The target percentile recommended by Fox and Bolton (2007) is the 75th percentile for river restoration, which targets >4 key pieces per 100 meters of channel length. The results for the Lower White River wood inventory show that the key piece count, estimated at 0.32 per 100 meters of channel, is well below the 25th percentile found by Fox and Bolton (2007) (Table 13) for an unmanaged, forested basin. However, the results of the key piece inventory are

close to the results for the South Fork Nooksack River where the key piece inventory resulted in an average of 0.21 pieces per 100 meters of channel length. The South Fork Nooksack River basin land use consists of a mix of agricultural lands in the lower basin and managed forest lands in the upper basin (Appendix H).

Table 13. Distribution of volume of wood and key pieces in the Lower White River and the South Fork Nooksack River as compared to the Fox and Bolton (2007) study results for unmanaged forested basins.

Large Wood Attribute	South Fork Nooksack River	Lower White River	Fox and Bolton (2007) 75th Percentile
Key Pieces (per 100 m)	0.21	0.32 [c]	>4
Wood Volume (m^3 per 100 m)	135 [a]	100 (2007) [b] 324 (2009) [b]	>317

[a] South Fork Nooksack wood volume determined from interpretation of the occurrence of natural log jams from 2001 air photos. Log jam wood volume determined from area delineation of log jam at a 50 porosity and a height of 2 feet (Soicher et al. 2006).

[b] Lower White River wood volume determined from the 2007 and 2009 air photo interpretation. Wood volume determined from area delineation of log jams and a 50 percent porosity and a height of 2 feet.

[c] Lower White River Key Piece Determination. Analysis assumed two key pieces per *stable* wood accumulation (n=16) as determined from air photo interpretation and field verification. Key piece analysis assumes no key pieces were identified outside of stable wood accumulations (Appendix H).

The results of the Lower White River wood volume analysis varied greatly between the two years, 2007 and 2009, within the study area. The 75th percentile found by Fox and Bolton (2007) for rivers >30 to 100 meters in bankfull width is >317 m3 per 100 meters of channel length. The results for the White River varied dramatically between 2007 and 2009 (Table 13). Based on the air photo interpretation for 2007, the number of pieces found per 100 meters of channel length was 100. Based on the air photo and field verification for 2009 the volume of wood found throughout the project reach was much higher at 324 per 100 meters of channel length. The 2009 air photo was flown in February, approximately one month after the large January flood event. The flood deposited a large amount of loose wood in the upstream reaches of the study area, as is evident on the 2009 air photo and documented during the summer 2009 field reconnaissance.

Basin Sediment Yield

The Syvitski model estimates an annual sediment flux of 41.3 kg/s, or 1,434,300 tons/year of sediment produced by the White River basin at the upstream extent of study area. Bedload sediment is thought to generally constitutes approximately 5 to 10 percent of the total sediment transported through the channel network (Hicks and Gomez 2003). Therefore, average annual bedload flux into the Lower White River study area is estimated as a range from approximately 55,200 to 110,300 yds^3/year.

Discussion

The following sections discuss the observed trends in sedimentation and channel evolution, the primary natural and anthropomorphic factors influencing these trends, the current state of the study area channel within the spectrum of historical trends, and how the channel may continue to evolve in the future.

Sediment Trends

The trends in aggradation and degradation documented in the study area are generally consistent with the study area's location at the transition between the White River canyon and alluvial fan. The results of the cross-section analysis alone do not fully describe these trends, and must be considered in the context of significant and long-term gravel removal that continued until 1987. Overall, four of the five historical survey intervals document net aggradation throughout the entire study area (Table 8). The one exception documenting net degradation includes the interval from 1974 to 1984. The volume of degradation computed from the cross-section analysis during this interval roughly corresponds to the documented volume of sediment removed during this same period. If sediment removal had not occurred between 1974 and 1984, all five survey intervals might show net aggradation through the study reach. A synthesis of the observed trends in each reach, with an emphasis on the importance of historical gravel removal, follows.

Reach 1, at the downstream end of the study area, and positioned on the historical and present alluvial fan, shows the greatest increases in channel bed elevation and aggradation of all the reaches in the study area. In addition to showing the greatest rates of aggradation (Table 9), the documented historical rates of gravel removal in Reach 1 are also the greatest of all of the study reaches (Table 10). A comparison of cross-sectional analysis results with gravel removal data illustrates some uncertainty in the results of the cross-section analysis when isolated from the gravel removal data and also the importance of the gravel removal data to understanding the magnitude of aggradation in the reach. For example, the timing of gravel removal in 1969 relative to the timing of the cross-section surveying is not known. If the gravel removal occurred following the survey, the actual aggradation over the 1969-1974 survey interval could be more than twice the amount reported. Between 1974 and 1984, the cross-section comparison indicates the bed elevation in Reach 1 decreased an average of 0.20 feet/year, with net degradation of 85,000 yds^3 over the entire reach. Over this same period, ICRI records document removal of no less than 320,000 yds^3 of gravel from the reach. Based on these values, at least 235,000 yds^3 of sediment, or 23,500 yds^3/year must have accumulated within the reach during the survey interval to offset the removal volume. Rates of sedimentation in Reach 1 increased from 1984 to 2009. The rate of sedimentation in Reach 1 between 2007 and 2009 is the highest rate documented in this study.

Similar to Reach 1, the comparison of cross-sections in Reach 2 shows aggradation and increases in bed elevation over the duration of the study period, with the exception of the period from 1974

to 1984. The estimated gravel removal in Reach 2 during the 1960s was an order of magnitude lower than in Reach 1 and does not significantly affect estimates of channel aggradation (King County 2009a). Between 1974 and 1984, however, the cross-section comparison indicates net degradation of 334,000 yds^3, whereas ICRI records document removal of only 127,000 yds^3 (King County 2009a). Two possible explanations may account for the approximately 200,000 yds^3 discrepancy. One is that the actual volume of sediment removal was in fact greater than the extraction volume reported by ICRI. This is a plausible explanation because anecdotal information indicates that there was a large private commercial gravel removal business operating in Reach 2 during this time interval that appeared to have removed gravel volumes in excess of what the river supplied (Appendix A, King County 2009a). The second explanation is that significant gravel removal in Reach 1 and the downstream end of Reach 2 in 1974, 1975, and 1976, promoted the formation of a knickpoint in the channel profile that propagated through Reach 2 between 1974 and 1984 and transported a considerable volume of sediment downstream and out of the reach. Some combination of these two mechanisms may also have occurred.

Because the cross section survey in the downstream portion of Reach 2 occurred in 1977, the longitudinal profile labeled “1974/1977” in Figure 9 illustrates the removal of gravel from the downstream portion of Reach 2 in 1974, 1975, and 1976. The 1974/77 profile, therefore, effectively illustrates the knickpoint generated due to the gravel removal that may have propagated through the reach before 1984. The profiles of Reach 2 in Figure 9 also illustrate that the reduced bed surface, resulting either from gravel removal, knickpoint propagation, or a combination of these mechanisms, has remained largely unchanged upstream of RM 7.4 since 1984.

Reach 3 is the most static reach observed in the study area and functions largely as a transport reach for sediment delivered from upstream. Most survey intervals indicate relatively moderate degradation; however, anomalously high degradation rates of 70,800 yds^3, or 7,080 yds^3/year were documented by the cross-section analysis between 1974 and 1984. Records of gravel removal indicate that approximately 71,000 yds^3 of gravel were removed from Reach 3 between 1974 and 1984. As Table 10 suggests, gravel extraction appears to have approximately matched the calculated change in sediment volume in Reach 3, resulting in essentially no net deposition or erosion during this period absent gravel removal. It is also possible that channel modifications associated with the construction of the R Street Bridge at the downstream end of Reach 3 in 1967 reduced the channel roughness and decreased the probability of deposition in the reach. The longitudinal profiles of Reach 3 in Figure 9 show that since bed elevations were reduced between 1974 and 1984, they remained relatively unchanged at the lower elevation to the present day. This indicates that Reach 3 has been functioning largely as a transport reach since 1984, and suggests that existing channel confinement and relatively low roughness has prevented a rebound in bed elevations since the late 1980s.

The cross-section comparison of Reach 4 shows more temporal variability in bed elevation and related aggradation and degradation than the other study reaches. The 1960, 1967 and 1969 estimated volumes of gravel removal from the ICRI Muckleshoot River Section (which includes both Reach 4 and Reach 5) total approximately 158,000 yds^3 and appear to have been associated

with construction of a new levee in that area (Appendix A, King County 2009a). Gravel removal continued in Reach 4 between 1974 and 1984. ICRI records document removal of no less than 115,000 yds^3 of gravel from the reach, with approximately 40,000 yds^3 of gravel removed during 1974. Because the reach was surveyed in 1977, the cross-section comparison does not capture the sediment that was removed in 1974. Considering the additional 75,000 yds^3 that were removed in 1977, 1978, and 1984 with the degradation documented by the cross section comparison, the net sediment deposition in the reach over the survey interval was closer to 47,500 yds^3. Since 1984, most channel and gravel bar surfaces in Reach 4 have not aggraded to the 1974/77 elevations.

The cross-section comparison of Reach 5 shows both increases and decreases in channel bed elevation, and net aggradation and degradation, over the study period. Documented degradation between 1969 and 1974 may be related to gravel removal associated with new levee construction, similar to Reach 4, or from knickpoint migration resulting from downstream gravel removal. Continued degradation is documented from 1974 to 1984, although ICRI records indicate no gravel removal in the reach over that time period. This degradation may also be related to downstream gravel removal during the period, and subsequent upstream knickpoint propagation. The steep channel gradient seen in 1974/77 and 1984 in Reach 5 (Table 7) would favor such upstream knickpoint migration. Since 1984, most channel and gravel bar surfaces in Reach 5 have not returned to the 1974/77 elevations, however, where lateral channel migration has increased channelwidth, increases in sediment storage and bed elevation are observed.

The historical measurements of gravel removal (and estimates based on assumed unit costs) provide a minimum estimate of bedload flux to the study area, and a reasonable proxy for future sediment aggradation now that gravel removal is no longer conducted. With the cessation of gravel removal in 1987, the study area has aggraded an average of approximately 45,500 yds^3/year, 85 percent of which has occurred in Reaches 1 and 2. This value closely corresponds to calculated estimates of basin sediment yield and estimates of bedload flux of approximately 55,000 to 110,000 yds^3/year into the study reach.

All information gathered for this study, from historical to present-day data, suggests the following trends for the overall study area:

- The upstream end of the study area within the White River canyon (all of Reach 5 and Reach 4 down to about RM 8.82) shows variable aggradation/ degradation with braided channel conditions and some lateral channel migration. Aggradational and degradational tendencies are apparently related to channel width. Since 1984, the channel and gravel bar surfaces have not returned to elevations evident in the 1974/77 channels.

- The study area between the canyon and the alluvial fan (approximate RM 8.82 to RM 7.30) shows transitional characteristics with consistently minor channel changes through all periods, including 1974 to 1985 and since that period.

- The downstream end of the study area on the White River alluvial fan (all of Reach 1 and Reach 2 up to about RM 7.30) is aggradational. In all time periods since 1984 and the

cessation of gravel removal, the channel and gravel bar surfaces have increased in elevation to the 1974/77 levels and higher.

- There was a significant lowering of gravel bar and river bed elevations from 1974/77 to 1984 throughout the study area. In the downstream reaches, these decreased elevations likely were caused directly by extraction of gravel over that same period; bed elevations have since aggraded. In upstream reaches where gravel extraction did not occur or was not explicitly documented, degradation appears to have resulted from the upstream propagation of channel knickpoints following the cessation of downstream gravel removal.

Conditions Influencing Sediment Trends

This subsection describes conditions influencing the observed sediment trends, presented generally in decreasing order of significance. The descriptions of these influencing conditions also recognize their origins, whether natural or anthropogenic, and identify their timeframe of the influence over the last century.

A fundamentally significant condition influencing sediment trends in the overall study area is its location at the downstream end of a sediment-rich basin. Observed rates of aggradation correspond to estimates of basin sediment yield calculated in this study. Earlier studies integrating comparisons of channel cross-sectional geometry and gravel removal have yielded similar results to this study, however previous estimates of basin sediment yield may have under-predicted coarse sediment yield. Recent rates of aggradation reported here represent 85 percent to 42 percent of bedload production rates estimated using the Syvitski model. The difference between estimated production and observed aggradation represents the bedload fraction that is routed downstream of the study area, to be deposited in lower reaches of the White River or transported to the Puyallup River.

Variations in sediment trends within the study area can be traced to the physical parameters of channel gradient and channel width, largely because sediment transport capacity is primarily a function of channel gradient and flow depth (the latter of which is strongly influenced by channel width or channel confinement). Even in its natural state, the channel was steeper and more confined at the upstream end of this study area, within the White River canyon, than the flatter and less confined channel that exited the canyon and flowed across its alluvial fan. The ongoing aggradation reported in Reach 1 and Reach 2 results from their position along the decreasing gradient of the alluvial fan of the White River, an area of natural deposition.

Large scale reengineering occurred in the early 1900s, rerouting the White River, creating the current river alignment, and establishing conditions that influence sediment trends to this day. Dredging of the channel to create adequate flow conveyance established a channel bed at elevations lower than naturally created by the ongoing processes of sediment delivery and transport. This effectively created a depositional environment within the channel, particularly in the County Line section, where gravel removal associated with the original excavation of the

Lower White River was no less than 280,000 yd^3 and the channel expresses a decrease in gradient as described above.

In addition to conditions thus established, the channel constriction created by the system of levees and revetments confines the channel and increases sediment transport capacity over what it would be if the channel were well connected with the adjacent floodplain. In the downstream part of the study area, the increase in sediment transport capacity due to constriction is not enough to overcome the decrease in sediment transport capacity that results from a 70 percent decrease in channel gradient over this depositional landform. Furthermore, without access to the adjacent floodplain and the ability to migrate laterally, sediment accumulating in the alluvial fan is restricted to the confined channel. Due to the constriction of the channel, the head of the current depositional fan (RM 7.40 and RM 7.20) is now located at the first significant channel widening downstream of the historical fan apex at RM 8.30.

In the upstream part of the study area, the influence of channel width on depositional patterns is also illustrated at locations where increases in width were observed over the study period. Lateral channel migration through the TransCanada levee and into the left bank floodplain, in Reach 5 in the vicinity of RM 9.50, significantly increased channel widths from 2001 to 2007 and 2007 to 2009. The sediment produced by bank erosion likely contributed to the rates of aggradation at nearby downstream cross-sections, however increases in bed elevation and aggradation were also documented from 2001 to 2007 and 2007 to 2009 at RM 9.477. This immediate response in bed profile following expansion of the channel width is an indication that channel confinement has likely contributed to decreases in bed elevation in Reach 4 and 5 observed over the study duration.

Gravel removal played a significant role in maintaining channel conveyance from the time the current river alignment was constructed in the early 1900s until gravel removal was stopped in 1987. The response of certain reaches in the study area to the cessation of gravel removal is now one of the most significant influences on observed sediment trends. Following the original channelization of the White River, gravel removal was continued as necessary, and kept pace with sedimentation rates to maintain adequate channel conveyance and a nearly static bed elevation. Information available to determine the magnitude of gravel removal activities between the 1930s and 1960s is limited; however, excerpts from ICRI annual reports acknowledge ongoing sedimentation within the study area, and the repeated gravel removal efforts that were conducted following flood events. The reconstructed gravel removal estimates from the 1960s are considerable, and the record of sediment removal from 1974 to 1985, even if incomplete, documents excavation that is nearly equivalent to the original magnitude of sediment removal that channelized the river for the expected flow conveyance almost 100 years ago.

Since cessation of gravel removal, the variation of sediment trends within the study area have been mainly influenced by the combined effects of channel gradient and channel width (or confinement):

- In the upstream area within the canyon, a steep channel gradient combined with channel confinement maintains adequate sediment transport capacity to favor degradation. Where

channel confinement is removed and channel width increases there is a tendency toward local deposition.

- In the transition area between the canyon and the alluvial fan, the gradient is adequate to maintain transport and the channel width (confinement) has been constant for several decades, resulting in static channel conditions through the full study period.

- In the downstream area, decreasing channel gradient down the alluvial fan decreases sediment transport capacity. In this downstream area, channel confinement limits aggradation to the active channel by preventing flood access and deposition in overbank areas. Since the cessation of gravel removal in 1987, Reach 1 and much of Reach 2 have aggraded to elevations near or above those from 1974/77.

The following influencing conditions are of lesser significance than those discussed above.

In addition to anthropogenic channel modifications in the lower White River, the study area has been influenced by upstream infrastructure and flow and sediment management practices at Mud Mountain Dam and the Lake Tapps Diversion at Buckley. Mud Mountain Dam historically limited and retarded the delivery of sediment to the study reach; the present influence of the dam, however, is limited to a reduction in total fine sediment delivery when suspended sediments are deposited in the reservoir during high magnitude flood events.

Before diversions for power production ended in 2004, the Lake Tapps Diversion at Buckley significantly altered the character of sediment delivery to the study reach, particularly the fine fraction of the sediment load. Since 2004, the flux of material previously removed at the diversion has been retained within the White River, and has likely increased the sediment yield to the study reach. Because the character of sediment removed from the White River by the Lake Tapps Diversion was largely suspended load, the material now retained as part of the sediment flux will largely pass through the gravel dominated study area in suspension during peak flow events. Sand deposits observed during field reconnaissance may represent deposits resulting from increased sand delivery to the reach. More significant impacts from this flux of material may occur downstream of this study area where depositional features are sand dominated.

Other channel modifications, such as the installation and removal of grade control structures (i.e., Williams pipeline at the upstream end of the study area and the Tacoma Power Utility weir near Boise Creek), may have significant local influence on channel gradient and bed elevations, but impart little influence over patterns of sedimentation in the study area.

Stable wood accumulations can force the formation of gravel bars by creating hydraulic roughness and blockages that physically block sediment transport or cause flow divergence that results in a significant reduction in sediment transport capacity (Montgomery et al. 2003). Sediment deposition forced by large wood can be significant, and in channel systems with high wood loads, sediment storage associated with woody debris can act as a sediment capacitor and

dampen the variability associated with sediment transport rates (Massong and Montgomery 2000, Lancaster et al. 2001).

Whereas field observations confirm that stable wood accumulations locally influence patterns of sediment storage, the low rate and relatively small sizes of woody debris supplied to the Lower White River appear to limit its influence on sediment storage and bed surface elevations at a reach scale. Therefore, large wood is not a primary factor in influencing channel aggradation throughout the study area. The confined and disconnected nature of much of the lower White River will continue to limit recruitment of woody debris; however, increased wood loading from natural mass wasting processes, repaired channel migration processes, or engineered structures could encourage increased sediment storage.

Status of Study Area in Spectrum of Spatial and Temporal Sediment Trends

The current trends in aggradation observed in Reach 1 and the downstream part of Reach 2 are expected to continue in the absence of gravel removal, other measures affecting channel confinement, or changes in basin-scale factors. Maintenance of the current profile would require gravel removal to resume at historical rates to match the bedload supply rate.

The trends observed in Reach 3 have been consistent over the last 25 years, when conditions in other reaches have varied both in pattern and magnitude. It is likely that absent increases in channel width and roughness, ongoing, albeit slow rates of channel degradation will continue.

Patterns in bed elevation and sedimentation in the downstream end of Reach 4 have been relatively consistent with those in Reach 3. Future changes in the observed patterns are unlikely absent increases in channel width and roughness.

Where lateral migration has eroded the TransCanada levee and increased channel width, parts of Reach 5 have responded with rapid local aggradation. Ongoing erosion or removal of additional portions of the levee would contribute to future localized increases in bed elevation. Increases in roughness, whether from naturally occurring or constructed features, would contribute to this channel response of localized increased sediment deposition in Reach 5.

Summary of Findings

This technical report documents an assessment of the historical trends in aggradation and degradation throughout the study area of the lower White River from RM 4.44 to RM 10.60. The purpose of the study was to characterize the physical processes, historical flood control measures, and other anthropogenic modifications to the White River that are the most significant influences on these trends and describe where the study area is in the spectrum of these trends. The scope of this study included review of existing information including previous studies and historical information, geomorphic field reconnaissance of the study area, analysis of historical cross-section surveys to evaluate temporal and spatial trends in sediment aggradation and degradation, integration of these analyses with technical appendices provided by King County and assessment of the current conditions in the study area with respect to these trends and relationships. Key findings presented in this report include:

1. Gravel removal of at least 1,200,000 yds^3, and potentially as much as 4,800,000 yds^3, occurred from 1914 to 1919 during the original construction of the current lower White River alignment through Auburn and Pacific to the current confluence with the Puyallup River. An estimated 280,000 yds^3 were removed from Reach 1 during this time period.

2. Until 1987, gravel removal was conducted as necessary to maintain channel conveyance. ICRI annual reports document the ongoing sedimentation within the study area, and the repeated gravel removal efforts that were conducted following flood events.

3. The magnitude of gravel removal between 1974 and 1985, including 320,000 yds^3 in Reach 1, and nearly 800,000 yds^3 between RM 3.70 and RM 8.80 was comparable to the efforts required to originally establish conveyance along the lower White River alignment.

4. Since the cessation of gravel removal activities, the study area has experienced net aggradation of 45,500 yds^3/year, 85 percent of which has occurred in Reaches 1 and 2.

5. Documented rates of aggradation since the cessation of gravel removal activities, and earlier rates of gravel removal, are consistent with new calculations of basin sediment yield which include estimates of annual bedload yield ranging from 55,000 to 110,000 yds^3/year.

6. The current trends in aggradation observed in Reach 1 and Reach 2 are expected to continue in the absence of gravel removal, other measures affecting channel confinement, or changes in basin-scale factors. Maintenance of the current profile would require gravel removal to resume at historical rates to match the bedload supply rate.

7. Large wood is not a significant influence on vertical changes in bed elevation. The volume of large wood in the study area varies through time (based on evaluation of two time periods). Increase occurrences of stable large woody debris would increase channel roughness and local aggradation, and limit channel degradation by functioning as bed grade control.

8. In the absence of changes in channel width and roughness, Reach 3 is expected to remain relatively static, albeit with slow rates of continued channel degradation.

9. Rapid localized responses of increased bed elevation in Reach 5 are associated with increased channel widths resulting from lateral channel migration and erosion of the TransCanada levee. These trends indicate that continued erosion of the levee, or levee setback projects, could result in localized aggradation in Reach 5 that could both increase the frequency of floodplain connectivity in Reach 5 and decrease the delivery of sediment to downstream reaches.

10. Basin sediment production, the location of the study area at the transition to an alluvial fan setting, historical and existing channel modifications, and a history of considerable gravel removal are the most significant conditions influencing historical and current sediment trends in the study area.

Recommendations for further study include:

1. More precise and accurate estimates of bed evolution would require a more comprehensive investigation of sediment transport and deposition within the study area, such as a calibrated sediment transport model.

2. Continued cross-section monitoring is recommended to document future trends in bed evolution.

3. Develop and implement a large wood monitoring plan to study a representative set of existing natural and engineered log structures in the study area. The purpose of the monitoring plan would be to refine the understanding of the influence of large wood accumulations on wood and sediment flux and changes in channel bed elevation in various reaches of the study area.

4. A basin-scale sediment budget that includes characterization of the contributions of different sediment sources and fractions, and the effect of Mud Mountain Dam on sediment yield to the lower White River Basin.

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APPENDIX A

Historical Gravel Removal on the Lower White River (King County 2009a)

DT: January 4, 2010
TO: Jeanne Stypula, Supervising Engineer
FR: Terry Butler, Geologist
RE: Historical gravel removal on the Lower White River

Purpose, background

The purpose of this memorandum is to assemble information on historical gravel removal activities in the Lower White River and to document dates, areas and volumes of extraction to the extent possible. This information on past gravel extraction should allow a better understanding of the past and present-day conditions in the Lower White River.

The King County River and Floodplain Management Section in the Dept of Natural Resources and Parks monitors sediment levels and its effects on flood hazards in certain river channels. The Lower White River (previously the Stuck River) from approximately River Mile (RM) 4.4 to RM 10.6 is one such channel. The study area for this memo is the lower 11 miles of the White River.

Inter County River Improvement (ICRI) is an agreement executed in 1914 and implemented jointly by King County and Pierce County for river management and flood control purposes along the Lower White and Puyallup Rivers. ICRI carried out extensive re-engineering of the Stuck River and Lower White River in the early 1900s, including permanent diversion of the Lower White River into the Stuck River channel and channelization of the Lower White River. These major channel changes are not described in detail here, but should be recognized as a significant factor affecting river dynamics, sediment transport and deposition, and ensuing gravel removal activities. The re-engineering of the Lower White River and the subsequent maintenance gravel removal operations were carried out by ICRI crews or by contractors hired by ICRI.

Only gravel removal conducted by ICRI crews or contactors hired by ICRI is addressed here. Extraction dates, areas and volumes of private or commercial operators, which may have been considerable, are not estimated quantitatively in this memo.

The primary sources of information consulted and assembled for this memo include published reports, ICRI annual reports and other ICRI documents, and anecdotal information.

Findings

<u>*General information from ICRI*</u>

Review of available information indicates that there has been extensive and voluminous gravel removal in the Lower White River since the formation of ICRI in the early 1900s, both for initial channel re-engineering and for ongoing maintenance. It is also apparent that records are incomplete on specific locations, dates and volumes of gravel removal.

The information source that most consistently covers the study period from 1914 to the late 1980s is the ICRI annual reports. ICRI annual reports summarize the activities, accomplishments and costs for a given year and were available and reviewed for 1931 through 1937, 1939 through 1949, 1960, 1963, 1967, 1969 and 1974 through 1988.

ICRI annual reports and other documents identify eight different named River Sections, which today might be called river reaches, from the mouth of the Puyallup River up the White River to about RM 11 in the Muckleshoot Reservation. To the extent that locations of gravel removal are identified in ICRI records, they typically are keyed to these ICRI White River Sections. The downstream four sections cover the Puyallup River and about the downstream 0.7 miles of the White River. The upstream four ICRI River Sections are most relevant to this memo, so their approximate lengths and boundaries are summarized in **Table 1**. All eight of the ICRI River Sections are shown in a map from the 1967 ICRI annual report **(Figure 1)**.

Table 1: Four ICRI River Sections on Lower White River; boundaries and lengths

ICRI White River Section	Boundaries	Approx length (river miles)
Dieringer Section	Sumner Bridge (*) to 8th Street E. Bridge	3.9
County Line Section	8th Street E. Bridge to A Street Bridge	1.3
Auburn Section	A Street Br to Auburn Wall	2.0
Muckleshoot Section	Auburn Wall to drift barrier	3.0

(*): This bridge is described as "highway bridge over the river entering Sumner" in various ICRI annual reports, which is assumed to be the Pacific Avenue Bridge in Sumner at approximate White River RM 0.7.

Most ICRI annual reports describe the river section in which ICRI maintenance crews carried out gravel removal activities and list the associated costs but few of the annual reports identify specific gravel removal volumes. There is a passing reference in the 1934 annual report text to the recent excavation of 200,000 cubic yards from the County Line Section, without further detail. Annual reports covering years 1934 through 1969 do not list any excavation volume, but the lack of specific excavation volumes does not mean that no gravel was removed that year, only that no volume was reported in the ICRI annual report. It would be possible to estimate excavated volumes based on reported costs, but it appears that the cost of gravel removal varied considerably through time and based on specific conditions such as haul distances and market conditions.

However qualitative they were, the ICRI annual reports suggest that gravel removal was an almost annual activity, with more gravel removal activity in the summer following winters with larger flood events and more deposition. There are descriptions in ICRI annual reports that much of the gravel removal occurred in the County Line Section, attributing the large deposition to the decreasing channel slope in that area, but it is also clear that gravel removal was conducted throughout the four ICRI White River Sections.

Information from ICRI documents and others sources on gravel removal is provided in the following sections in general chronological order, starting with the inception of the ICRI activities in 1914.

1914 to mid-1930s

An ICRI plan drawing, assumed to be dated circa 1914, shows a typical cross section at the County Line area (**Figure 2**), including both the existing conditions before excavation and the proposed conditions after excavation and armoring of the re-engineered channel. The change in cross sectional area between existing and proposed conditions depicted in **Figure 2** is 1040 square feet. With a channel width of 245 feet at the excavation, an average excavation depth would have been 4.2 feet. The excavation indicated by this typical cross section would have lowered the thalweg by about 6 feet at this location. If the excavation proposed at this typical cross section was representative of actual excavation through the full 1.3 river miles of the County Line section, then approximately 270,000 cubic yards was excavated from the 8th Street E. Bridge to the A Street Bridge for channelization of the White River. These calculations and rounded results are summarized in **Table 2**.

Table 2: Measurements and calculations from Typical Cross Section in Figure 3

Measurement	Value	Units
Approx excavated cross sectional area	1040	Sq ft
River length between A Street and 8th Street E Bridges	1.3	Miles
River length between A Street and 8th Street E Bridges	6900	Feet
Approx excavated volume between bridges	7,180,000	Cubic feet
Approx excavated volume between bridges	270,000	Cubic yards
Channel width, Typical Cross Section, at excavation	245	Feet
Average depth of excavation at Typical Cross Section	4.2	Feet
Existing (Pre Project) thalweg elevation	55	Feet
Proposed (Post Project) thalweg elevation	49	Feet
Change in thalweg elevation	-6	Feet

W.J. Roberts, Chief Engineer of ICRI in this period, provided a summary report of the activities, accomplishments and expenses of the first six years of ICRI (Roberts 1920). The same report documents the excavation of 282,000 cubic yards in the County Line Section during 1914 and 1915, which is a similar value to the estimated volume in **Table 2**. Because Roberts (1920) identifies no further excavation through 1919 in the County Line Section, it is assumed that 282,000 cubic yards was the total excavation to channelize that particular river reach.

There is no specific volume of excavation for the rest of the Lower White River within ICRI evident elsewhere in the same report. However, Roberts (1920) identifies the excavation of 2.2 million cubic yards to enlarge the capacity of the Puyallup River and put in place several cutoffs to straighten that river. And in a summary of all ICRI expenditures through its first six years, the total cost for all gravel removal activities,

including the Puyallup straightening and the County Line Section, was $511,235 (in 1914 to 1919 dollars). The cost of gravel removal and disposal varies widely in subsequent reports, but for the six year period addressed by Roberts (1920), extraction and disposal costs appear to range from 7.3 to 15 cents per cubic yard. Based on this available information, the estimated volume excavated to channelize the Lower White River, including the County Line Section, ranges from about 1.2 million to 4.6 million cubic yards (**Table 3**).

Table 3: Gravel removal within ICRI in its first six years (1914 through 1919), based on information from Roberts (1920)

Area of Excavation	Excavated volume at $0.15/cu yd (cubic yards)	Excavated volume at $0.073/cu yd (cubic yards)
Total for all of ICRI in first six years (at a cost of $511,235)	3,400,000	7,000,000
Puyallup River straightening	2,200,000	2,200,000
All of Lower White River within ICRI, including ~280,000 cu yds in the County Line Section	1,200,000	4,800,000

Even if these calculated volumes are disregarded as inferring more accuracy than is appropriate, there is sufficient information available to suggest that the original excavation of the Lower White River within ICRI exceeded 1 million cubic yards and may well have included much more than that amount.

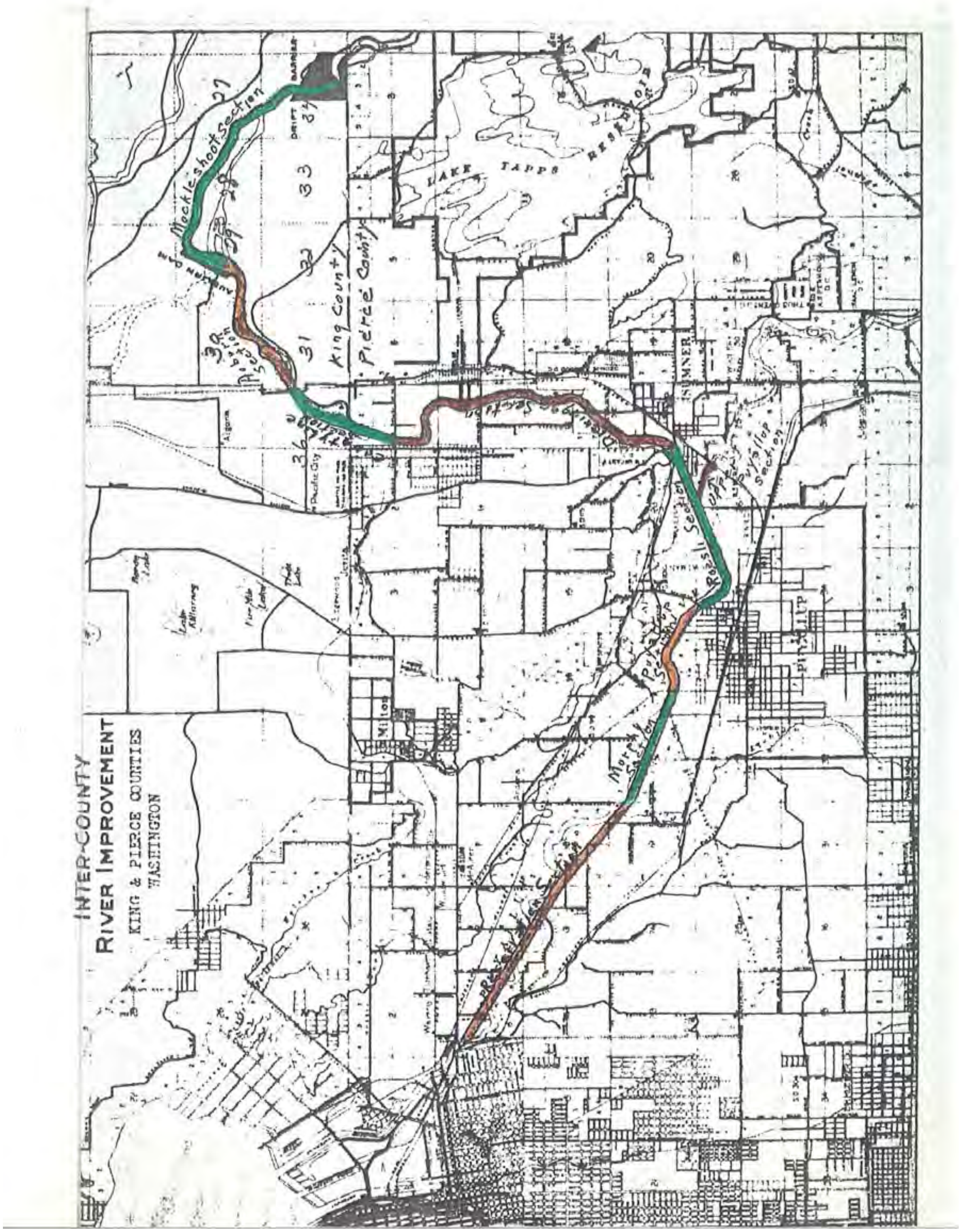

Figure 1: White River Sections identified by Inter County River Improvement

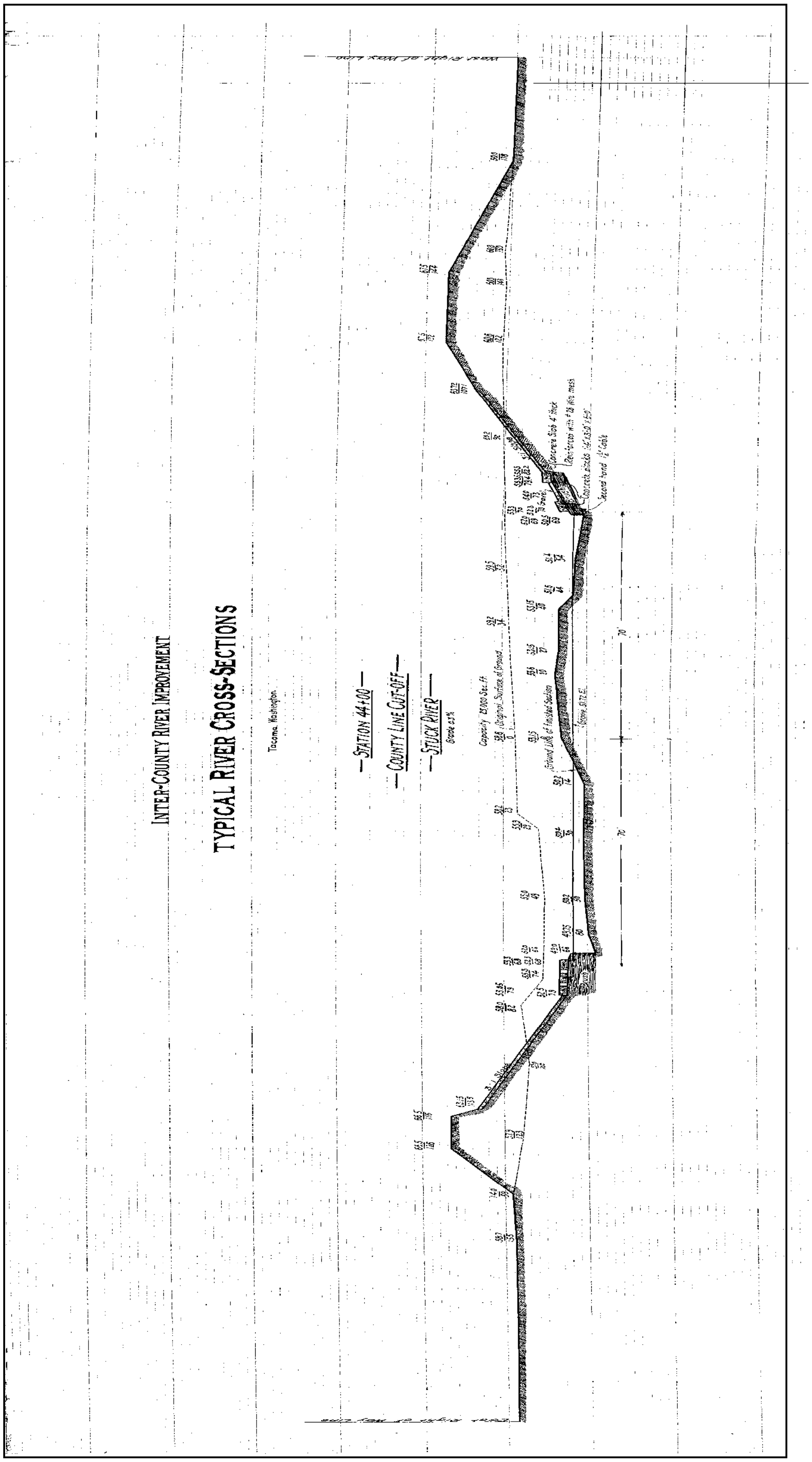

Figure 2: Typical cross section from an Inter County River Improvement plan sheet of circa 1914 showing existing conditions and proposed channel excavation at the County Line area of the Stuck River. Note that the scale is no longer 1:1.

The changes in channel geometry suggested by these large excavation volumes and the channel dimensions shown in **Figure 2** would have had a significant effect on flow hydraulics, velocities and shear stresses at any given location in the Lower White River. If such excavation did occur over most of the length of the Lower White River, there also would have been associated significant effects on reach-scale channel gradient and sediment transport capacity throughout the Lower White River.

Excerpts from ICRI annual reports during this period:
1934:

- Dredging at County Line Section: "Dredging of the river with the slack line has been concentrated at one place rather than stretched over a long distance. While a mountain of almost 200,000 yards of material has been raised on the bank of the river, the two great floods within the last year have almost completely filled the holes dredged out. As the point of dredging is at the break in gradient where the slope of the river drops from about 40 feet to the mile down to 4 feet to the mile, it is evident that the material filling up the dredged hole is brought down from the stream above, and is accomplishing in that stretch above the dredge the removal of sand and gravel the same as if the dredge were working throughout the length of the stretch."

1936:
A January 1936 ICRI annual report summarizes the work and study of the previous three years, 1933 through 1935, but also considers all of the ICRI work to date. It was authored by B.P. Thomas, Chief Engineer of ICRI, and R.H. Thomson, Consulting Engineer, the latter having been a consulting engineer on the report by Roberts (1920). The report describes "The Gravel Problem" in some detail, starting with the previous year:

"During the past year [1935] the Improvement has spend about $7,000.00 in dredging the County Line Section. As has been amply explained in previous reports, dredging is now concentrated at one location. The operation is necessary because the river deposits its burden of sand gravel at this point due to a sharp break in gradient. Some little headway has been gained during the past year against the continuous action of the river. This, however, was a year without floods and it is not to be anticipated that any great margin of headway can be maintained in the long run" (Thomas and Thomson 1936).

Thomas and Thomson (1936) believe that there was a greater quantity of gravel being carried by the river in 1936 than prior to 1914, due primarily to the changes in channel geometry of the Stuck River from a braided distributary system to a single thread river (increasing transport capacity) plus the increased volume of water flow and gravel diverted from the previous White River into the Stuck River channel. They also assert that two then-recent channel modifications had a significant effect on channel gradient, the first of which was a result of the 1906 flood and shift of the White River to the Stuck River channel.

"In order to make the channel change into the Stuck Valley, it was necessary to scour the bed of the White very deeply opposite the point at which it had heretofore turned north.

This channel deepening increased the drop of the river at that point, and therefore increased the rate of grade and erosive power of the river, and nature ever since has been busy trying to erode and carry out enough sand and gravel from the river bed upstream, so that the grade would be drawn with fair uniformity to the bottom of that drop or scour."

The second channel change that Thomas and Thomson (1936) believed affected channel gradient was the straightening of the Puyallup River, which shortened it from six and a quarter miles to five miles. Thomas and Thomson (1936) describe the combined effect of these two changes and assert that the Lower White River will never adjust itself to grade so as to cease erosion.

"As a result of these two drops causing grade changes the river with a broken but steepened profile, will continue wearing down its bed and carrying its sand and gravel down with every high flood, the quantity being just slightly diminished year by year as the grade is adjusted, to as nearly a uniform gradient as possible, but will never cease its erosive action while flood flows continue, and at all times the smooth concrete banks will continue to increase velocity alongside and thus cause their own undoing."

The conclusions of Thomas and Thomson (1936) include:

- "Channel Scour: It is evident from studies of channel cross sections that the river is continuously cutting deeper in practically the full length of that part of it under the jurisdiction of this Improvement. The one outstanding exception to this rule is the County Line section where the river drops its burden of sand and gravel, and fills the channel rather than scouring it."
- "Drift: The drift barrier constructed about four miles above the Auburn Wall has proved ineffective and was abandoned several years ago as a practical structure."
- "Gravel in County Line Section: The removal by dredging from this section will be an eternal problem unless the retarding dam at Mud Mountain is constructed to hold the crests of floods which carry great quantities of sand and gravel during the flood peaks."

Late-1930s to early 1970s

The main source of information on gravel removal activities for this period is the ICRI annual reports, as in the following excerpts.

1937

- "The dredging in the Auburn section on the left bank immediately above the Northern Pacific Bridge was continued throughout the month [May], being interfered with occasionally by water too high to permit economical operation."

1946:

- Controlling weather conditions and especially the accumulated blanket of snow throughout the western slopes of the Cascades in this state were such as to provide

the prerequisite for a most disastrous flood during the second week of December 1946.

- "Throughout the Auburn and County Line sections a vastly increased amount of silt, sand, gravel and boulders have been deposited as a result of the recent flood. These two areas have been the perpetual dumping ground for a major portion of this river borne material which is primarily traceable to the reduced gradient in the channel floor which changes abruptly from 40 feet per mile to approximately 4 feet per mile."
- "During the initial construction period of this project, channel rectification and dredging was performed on an extensive scale, and since that time… that area known as the County Line Section has been repeatedly dredged resulting in but temporary relief from this river borne material which persists in filling up the channel. We are therefore confronted with a serious problem, i.e., the removal of this river borne material which constantly builds up the floor of the channel and reduces its capacity during flood periods."

Both 1960 and 1974 annual reports included this text:

- "This [County Line] section receives an unusually heavy amount of river borne gravel. One of the chief reasons that most of the channel dredging is done in the Muckleshoot, Auburn and County Line Sections is because in these areas there is land available upon which to dispose of the gravel. This prevents the gravel from washing down where there is no disposal room."

Annual reports from 1960, 1967 and 1969 document the actual costs of gravel removal but do not identify the resulting extraction volumes. Extraction volumes are estimated in **Table 4** using an assumed the cost rate for gravel removal of $0.15/ cu yd, which was a high end estimate from circa 1914 to 1919 (Roberts 1920) and also was reported as an actual cost rate for gravel removal in the 1974 ICRI annual report. The accuracy of the estimated extraction volumes is only as good as this assumed cost rate of extraction. What can be claimed with certainty is that the vast majority of extraction in these three years occurred in the Muckleshoot and County Line Sections, with similar amounts extracted from each of the two river sections. The larger amount of 1967 gravel removal in the Muckleshoot section was associated with construction of a new levee.

Table 4: Lower White River actual ICRI gravel removal cost from 1960, 1967 and 1969 with estimated extraction volumes assuming $0.15/cu yd

ICRI River Section	Actual costs of gravel removal				Estimated volumes @ $0.15/ cu yd		
	1960 costs ($)	1967 costs ($)	1969 costs ($)		1960 vol (cu yd)	1967 vol (cu yd)	1969 vol (cu yd)
Dieringer	$ 878	$ 0	$ 295		5,850	0	1,970
County Line	$ 5,683	$ 6,830	$ 7,290		37,890	45,530	48,600
Auburn	$ 951	$ 509	$ 873		6,340	3,390	5,820
Muckleshoot	$ 7,067	$10,749	$ 5,844		47,110	71,660	38,960

The general impression from ICRI reports in this period is that gravel extraction became a routine maintenance activity for ICRI crews, with more extraction occurring following

winters with larger floods and greater deposition or as necessary for a specific purpose such as levee construction. The repeated reference in ICRI annual reports to extraction from the County Line Section continues the theme established in earlier annual reports that the focus of gravel removal activities by ICRI was in the County Line Section, but extraction occurred in other ICRI River Sections as well (**Table 4)**.

There is also information suggesting that there were other priorities than gravel removal and varying levels of interest in implementation of ICRI activities through the decades from the 1930s to the 1970s, e.g., waning interest in the 1930s after the initial construction of much of the ICRI infrastructure by the 1920s and World War II and the construction of Mud Mountain Dam in the 1940s (King County 1988). Also in the 1940s, there was litigation between the counties as King County attempted to terminate the ICRI agreement and Pierce County successfully prevented that termination (King County 1988). After the litigation there was little interaction between the counties during the 1950s and 1960s, as evidenced by annual reports that simply summarized expenses and did not elaborate on activities or accomplishments (King County 1988). Gravel removal appears not to have been a high priority for ICRI during from the late 1930s to the early 1970s.

1974 through 1985

Quantitative information on extraction volumes and extraction dates for the period of 1974 to 1985 in the Lower White River is provided by Prych (1988), who summarized extraction volumes by Pierce County and by the ICRI in the White River and other rivers in the Puyallup River system (**Table 5**). About 780,000 cubic yards of gravel was extracted from the White River in this 11-year period, which includes extraction from the Lower White River and the Greenwater River.

Collins and Dunne (1990) included the Lower White River as a case study in their guidance document on gravel removal. They appear to have reviewed the extraction volumes and the evidence of increases in channel sediment elevations downstream of about the 8th Street Bridge and general decreases in channel sediment elevations around the County Line and upstream of R Street Bridge for 1974 to 1985 using the information from by Prych (1988). Recognizing the limitations of partial extraction records, Collins and Dunne (1990) hypothesize that the observed changes in channel elevations “are consistent with an interpretation of long term aggradation in the lower fan reach and degradation in the upper canyon reach, with local degradation related to gravel removal operations.”

Table 5: Summary of sediment removed from the Puyallup, White, and Carbon Rivers, 1974 to 1985, from Prych (1988)

TABLE 1.--Volumes[a] of sediment removed from the Puyallup, White, and Carbon Rivers by Pierce County and Inter-County River Improvement in the years 1974 to 1985

[Values in cubic yards]

	Stream			
	Puyallup	White	Carbon	Total
1974	127,960	70,780	137,130	335,870
1975	87,740	50,890	56,670	195,300
1976	133,860	246,690	31,110	411,660
1977	81,040	56,050	18,150	155,240
1978	41,900	152,680	18,850	213,430
1979	123,080	[b]40,000	28,240	191,320
1980	35,400	[b]560	94,700	130,660
1981	0	[b]1,350	0	1,350
1982	6,770	27,940	23,100	57,810
1983	23,220	55,240	41,910	120,370
1984	64,950	[b]66,730	[c]32,320	164,000
1985	[d]107,710	11,890	0	119,600
Total	[d]833,630	[b]780,800	[c]482,180	2,096,610

[a]Volumes computed from data supplied by Mr. David E. Lewis, Pierce County and Inter-County River Improvement, 1986.

[b]Some of this material removed from the Greenwater River, a tributary to the White River upstream of Mud Mountain Dam.

[c]32,320 cubic yards removed from near Fairfax, upstream of study area.

[d]17,760 cubic yards removed from reach 0.5 mile upstream of study area.

Locations along the Lower White River within the four ICRI River Sections are further specified in ICRI records by River Stations that were established at 1000 foot increments (e.g., ICRI annual report of 1974). Information from unpublished ICRI documents provide gravel excavation volumes keyed to Lower White River Stations (and in some cases the river bank and gravel bar) such that the spatial distribution of gravel removal can be characterized for the period of 1974 through 1985 (**Table 6** and **Figures 3** and **4**). The ICRI River Stations were referenced to the present day river mileage system (of Northwest Hydraulic Consultants 2009) by measuring from landmarks at the ICRI River Section boundaries.

Table 6: Spatial distribution of Lower White River gravel removal volumes, 1974 thru 1985

TABLE 6: SPATIAL DISTRIBUTION OF LOWER WHITE RIVER GRAVEL REMOVAL VOLUMES BY ICRI, from 1974 through 1985

ICRI River Section	ICRI River Stations	Approx Present Day River Mile	Present Day Study Reach	GRAVEL VOLUME REMOVED (CUBIC YARDS) BY YEAR AND RIVER LOCATIONS												Rounded Totals by ICRI River Section	Rounded Totals by Present Day Study Reach
				1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985		
Dierenger	57	3.672	N/A														
Dierenger	58	3.862	N/A										11,049				
Dierenger	59	4.051	N/A										11,049				
Dierenger	60	4.240	N/A				15,953					4,657					
Dierenger	61	4.430	N/A				17,682	20,776				4,657					
Dierenger	62	4.619	N/A			12,740		2,995				4,657		7,430			
Dierenger	63	4.809	N/A			12,740											
Dierenger	64	4.998	N/A											6,067			
8th (Stewart) Bridge																132,000	
County Line	65	5.187	1					15,092	16,500			4,657		6,067			
County Line	66	5.377	1			67,925		15,092	16,500			4,657	11,049	6,067			
County Line	67	5.566	1			25,379						4,657	11,049	6,067			
County Line	68	5.756	1	15,333	14,222								11,049				
County Line	69	5.945	1	7,667		9,472		5,080						6,067			
County Line	70	6.134	1	8,888										6,067			
County Line	71	6.324	1		8,888			10,389						6,067			
A Street Bridge																320,000	320,000
Auburn	72	6.513	2		22,222												
Auburn	73	6.703	2			99,653											
Auburn	74	6.892	2		5,555												
Auburn	75	7.081	2														
Auburn	76	7.271	2														
Auburn	77	7.460	2														127,000
Auburn	78	7.650	3											2,127			
Auburn	79	7.839	3											2,127			
Auburn	80	8.028	3			18,783								2,127	5,945		
Auburn	81	8.218	3				11,203	20,816						2,127	5,945		
Approx Auburn Wall																199,000	71,000
Muckleshoot	82	8.407	4				11,203	20,816						2,127			
Muckleshoot	83	8.596	4	19,444				20,816									
Muckleshoot	84	8.786	4	19,444				20,816									
Muckleshoot	85	8.975	4													115,000	115,000
				70,776	50,887	246,692	56,041	152,688	33,000	0	0	27,942	55,245	60,534	11,890	766,000	633,000
Percent of Grand Total:				9%	7%	32%	7%	20%	4%	0%	0%	4%	7%	8%	2%	Grand	Present Day
Cumulative percent of Grand Total:				9%	16%	48%	55%	75%	80%	80%	80%	83%	91%	98%	100%	Total	Study Area Total

Note: ICRI documents identify no extraction by ICRI downstream of ICRI River Station 58 or upstream of ICRI River Station 84 in this time period.

Shade means that a volume that was reported in ICRI documents as a single cumulative total at a number of ICRI river stations has been divided between those river stations in this table.

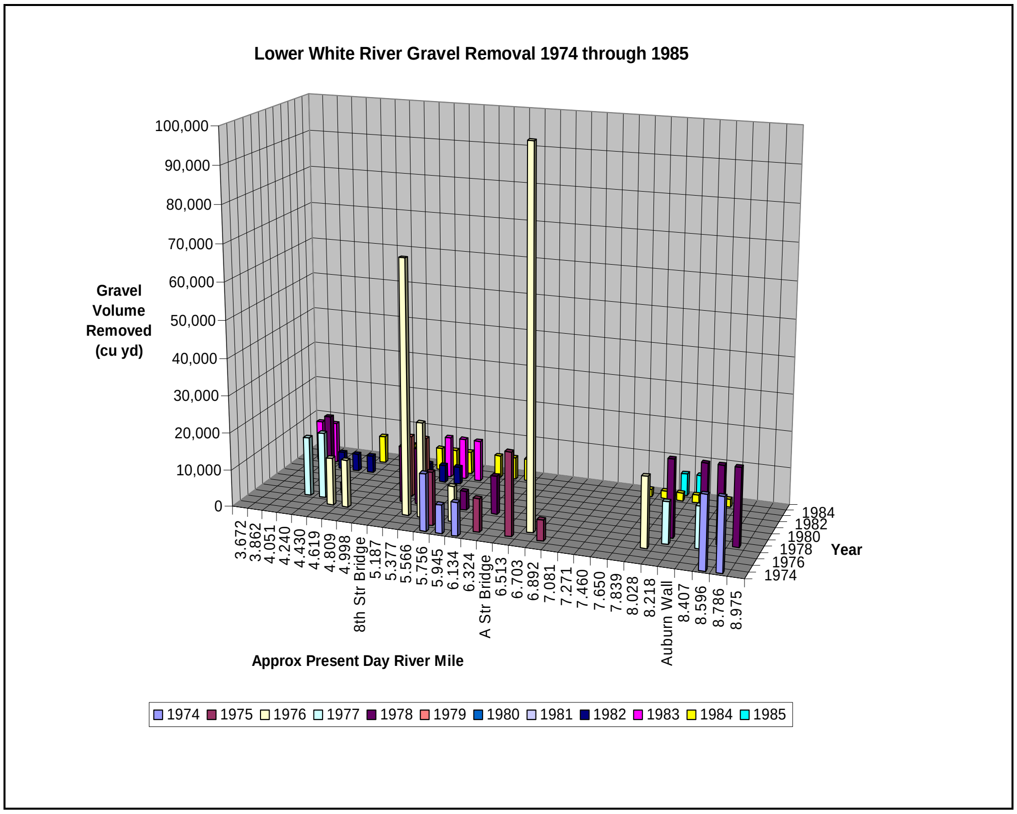

Figure 3: Lower White River Gravel Removal 1974 through 1985

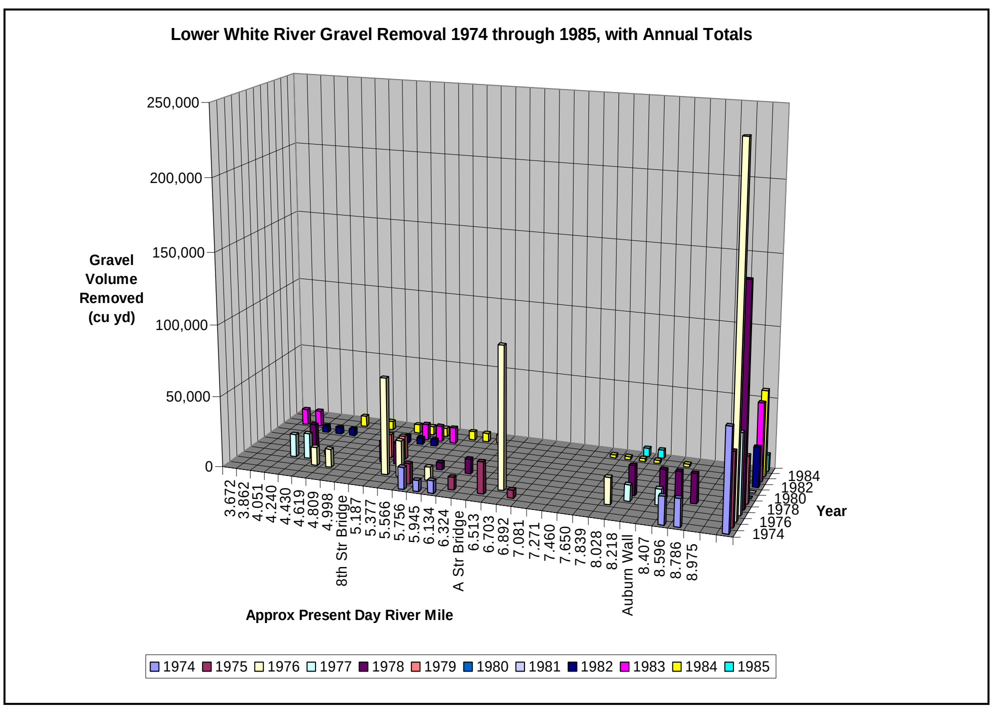

Figure 4: Lower White River Gravel Removal 1974 through 1985, with annual totals. Note different vertical scale than in the previous figure.

The volumes of gravel summarized in **Table 6** were excavated only from the Lower White River, as specified in unpublished ICRI records. These ICRI records are keyed to the White River Stations and should represent all the excavation that was done by ICRI crews throughout the Lower White River in this 11-year period. Note that **Table 6** lists only those locations in the Lower White River at which ICRI gravel extraction was reported, for purposes of minimizing the size of this table. The Dieringer Section goes further downstream and the Muckleshoot Section goes further upstream than listed in **Table 6**, but there were no extractions by ICRI reported in those areas.

The numbers in **Table 6** are identical to those in **Table 5** (Prych 1988) where the extraction occurred on the Lower White River; some of the excavation in **Table 5** occurred on the Greenwater River upstream of Mud Mountain Dam (as per its footnote b). The grand total volume of excavation in the Lower White River during this 11-year period was about 766,000 cubic yards. About a third (32%) of all of the gravel excavation in this 11-year period occurred in 1976 alone, and more than half of the total extraction occurred from 1974 through 1977. There was no extraction by ICRI reported anywhere in the Lower White River during 1980 or 1981. More than half (59%) of the total excavation in 1974 through 1985 occurred from the A Street Bridge downstream, although about 13% of the total (almost 100,000 cubic yards) was taken off of one gravel bar upstream of the A Street Bridge in 1976 alone.

Information in **Table 6** summarizes extensive gravel removal by ICRI from 1974 to 1985. Additional extraction by private commercial operators is likely to have occurred as well, but the volumes are not well documented. In such cases, anecdotal information from people who worked on the Lower White River in the 1980s and 1990s can be useful. Dave Lewis worked at Pierce County as River Systems Manager from the 1970s to 1988. Tony Fantello has worked at Pierce County as Surface Water Management Maintenance and Operations Manager from 1990 to present. Both Mr. Lewis and Mr. Fantello describe a commercial operation that removed large quantities of gravel from the White River between A Street and R Street Bridges in this time period. The extracted material may have been used in construction of a nearby residential development and was not associated with ICRI operations (Dave Lewis personal communication, October 2009; Tony Fantello personal communication, October 2009) and therefore is not quantified in **Table 6**. No documentation of volumes extracted by this commercial operation has been found, but extracted volumes appeared to have been in excess of what the White River could supply (Dave Lewis personal communication, October 2009).

Excerpts from ICRI annual reports during this period:

1974:

- Muckleshoot Section: “The river borne material is an ever present factor which cannot be neglected, for its occurrence in the channel, if not periodically removed, will result in over topping the levees in peak flood periods.”

1975:

- "The aerial photos in this report point out the excessive gravel build up caused by the last high water [Dec 1975]. This gravel must be removed to prevent future flooding."

1976:

- The majority of the activity in 1976 was to correct the flood damage caused by the high water of December 1975.
- This year private contractors have been awarded more bids to remove gravel bars on the White River.

1977:

- High water and flooding occurred on the rivers on December 2, 1977.
- The gravel removal program of letting private parties bid to removal gravel bars is continuing successfully.

1986 to present

No published reports that address gravel removal on the Lower White River in this study area for this most recent period were found. There are ICRI annual reports for the years 1985 through 1988 and the information from them on ICRI gravel removal is summarized in **Table 7**. There appears to have been minor amounts of gravel removed in 1986, based on the costs incurred, and no gravel removal reported for 1988 within the Lower White River. About 11,000 cubic yards were excavated in the Dieringer Section in 1987. There appears to have been no excavation by ICRI upstream of the 8th Street E. Bridge since 1986.

Table 7: ICRI information on gravel removal in the Lower White River, 1986 -1988

White River Section	Gravel excavation costs and volumes, 1986 through 1988					
	1986 cost ($)	**1986 volume (cy)**	**1987 cost ($)**	**1987 volume (cy)**	**1988 cost ($)**	**1988 volume (cy)**
Dieringer Section	$1533		$18,258	11,060		
County Line Section						
Auburn Section	$354					
Muckleshoot Section						
Totals	$1887		$18,258	11,060		

Anecdotal information also is available for this period. Don Nauer is a Washington Dept of Fish and Wildlife (WDFW) Biologist who worked on the White River from 1994 to 1999 and whose duties would have included issuance of Hydraulic Permit Application (HPA) permits for gravel removal during that period. The summary of HPAs described

here includes those issued to both ICRI and private parties. Mr. Nauer stated that there were no HPA permits issued for gravel removal and no gravel was removed on the Lower White River within King County during the six-year period of 1994 to 1999, nor any since 1999. Downstream of the King/ Pierce County boundary line during 1994 to 1997, there was one HPA issued for gravel removal in 1994 on a White River right bank gravel bar from RM 5.0 to 5.2 (probably the “Butte Pit” area upstream of the 8th Street E. Bridge), but the permitted gravel removal project was not conducted (Don Nauer, personal communication, August 2009).

Further downstream on the Lower White River, an HPA was issued in each of 1997, 1998, and 1999 for gravel removal on the left bank gravel bar at RM 4.44 (sometimes referred to as the RCI bar) and the permitted gravel removal probably occurred. Between 1994 and 1997, there were five HPAs issued for gravel removal on the White River downstream of RM 4.4, and the permitted gravel removal probably occurred. For context, in the same six-year period of 1994 through 1999, there were HPAs issued for gravel removal on approximately 45 gravel bars in the Puyallup River and approximately 15 gravel bars on the Carbon River. By comparison, gravel removal on the Lower White River in this period was not significant. Mr. Nauer said that reports of the extraction volumes were not required to be provided as part of an HPA in those days. Mr. Nauer cautioned that HPA issuance for gravel removal did not necessarily mean that the gravel removal actually occurred, so HPA issuance probably should not be used as a definite indication of gravel removal (Don Nauer, personal communication, August 2009).

Dave Lewis and Tony Fantello worked at Pierce County at different times over the past few decades and have direct experience with gravel removal from the White River because Pierce County crews conducted the river management activities of ICRI operations. Both Mr. Lewis and Mr. Fantello have stated they believe that no gravel removal was conducted by ICRI on the Lower White River since the mid- to late-1980s (Dave Lewis personal communication, October 2009; Tony Fantello personal communication, October 2009). That timeframe is consistent with the 1988 ICRI annual report (**Table 7**) and with the information provided by Don Nauer. From all available information, it appears that 1986 was the last year in which gravel removal occurred upstream of the 8th Street E. Bridge and 1987 was the last year in which gravel removal was conducted by ICRI crews on the Lower White River (i.e. in the Dieringer Section, **Table 7**).

Recap of ICRI gravel removal activity from 1914 to present

It is possible to piece together a general description of gravel removal by ICRI in the Lower White River from 1914 to present based on all available information. Quantitative estimates from Roberts (1920) indicate that upwards of 1 million cubic yards, and possibly much more, were excavated in the initial river engineering that altered the course of the Lower White River. By the mid-1930s, it appears that the ICRI strategy was to focus gravel removal efforts in the County Line Section (Thomas and Thomson 1936), where, although localized, large volumes of gravel appear to have been extracted on a regular basis. Information from ICRI annual reports suggests a period of time from

about the late-1930s to the early-1970s when gravel removal appeared to be a relatively lower priority, routine maintenance activity throughout the Lower White River, albeit with repeated reference to extraction focused in the County Line Section.

Well-documented extraction of large volumes of gravel occurred in the Lower White River from 1974 through 1985 (Prych 1988; ICRI unpublished data). It is suggested that this effort coincided with the tenure of an ICRI Chief Engineer who favored gravel removal for flood control purposes (Dave Lewis, personal communication, October 2009). In the mid-1980s, ICRI annual reports indicate that it became more difficult to obtain permits for gravel removal and extractions diminished. There has been no gravel removal by any entity (public or private) on the Lower White River upstream of the 8th Street E. Bridge since 1986 (ICRI annual reports; Dave Lewis, Tony Fantello, Don Nauer, personal communication).

Summary:

Available information in the form of published reports, ICRI annual reports and documents, as well as anecdotal information, allow gravel removal in the Lower White River by ICRI crews to be estimated since the inception of ICRI. Gravel extraction by private or commercial operators, though possibly extensive and voluminous, was not quantified in this memo.

Voluminous excavation occurred to channelize the Lower White River in about the first decade after 1914. An estimated 280,000 cubic yards of gravel was excavated from the 1.3 mile County Line Section of the Lower White River, from A Street Bridge to 8th Street E. Bridge. Available information indicates excavation in excess of 1 million cubic yards occurred during the channelization of the Lower White River in the early 1900s, including the County Line Section.

Specific records of extraction volumes are scant, although those that do exist are informative. Annual reports of the Inter County River Improvement suggest that gravel removal was an almost annual activity, with more gravel removal activity in the summer following winters with larger flood events and more deposition. There are descriptions in ICRI annual reports that much of the gravel removal occurred in the County Line Section, attributing the large deposition to the decreasing channel slope in that area, but it is also clear that gravel removal was conducted throughout the Lower White River.

Quantitative information on gravel removal was provided by Prych (1988) who estimated an extraction volume of about 780,000 cubic yards from the White River, including the Greenwater River, for the period of 1974 through 1985. Unpublished ICRI records refine that estimate to 766,000 cubic yards extracted from the Lower White River in the area of interest for this memo during the same 11-year period. More than half of the total extraction occurred from 1974 through 1977 and more than half of the total extraction occurred in the County Line and Dierenger River Sections (i.e., from A Street Bridge at RM 6.3 downstream to about RM 3.9).

ICRI annual reports and information from people who worked on the White River in the 1980s and 1990s indicates that the last year in which gravel removal occurred on the Lower White River upstream of the 8th Street E. Bridge was 1986.

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Thomas, B.P. and R.H. Thomson. 1936. Annual report of the engineers. Inter County River Improvement. January 1936.

APPENDIX B

White River Cross-sections
(Cross-section 4.44 to Cross-section 10.596)
(King County 2009b)

Table B-1. White River cross-section survey sources by year and cross-section (King County 2009b).

Previous River Mile	Reference Section 2007/2009	King County 1969[1]	USACE 1974[2]	USACE USGS[3] 1977	USGS 1984	USGS 1986	DEA[4] 1994	City of Auburn 1996	City of Auburn 1997	City of Auburn 1998	City of Auburn 1999	City of Auburn 2000	King County 2001	City of Auburn or DEA 2002	City of Auburn or DEA 2003	City of Auburn or DEA 2006	MGS[5] 2007 / NHC[6] 2008	Various Sources 2009	Location or Comment
4.44	N/A		**X**	**X**	**X**	**X**							**X**					**X**	
4.56	N/A		**X?**	**X?**									**X**						
4.7																		**X**	new in 2009
4.90	4.978												**X**				**X**	**X**	Old USGS gage
4.92				**X**	**X**	**X**							**X**						**d/s face**
																			8th St Br
	4.998																**X**	**X**	**u/s face**
	5.041																**X**	**X**	d/s of bar
5.00	5.123	**X**	**X?**				**X**						**X**				**X**	**X**	
	5.197																**X**	**X**	
5.20	5.292	**X**	**X**	**X**	**X**	**X**							**X**				**X**	**X**	
	5.374																**X**	**X**	
5.36	5.460	**X**	**X?**	**X?**									**X**				**X**	**X**	
	5.517																**X**	**X**	
	5.589																**X**	**X**	~County Line
5.52	5.621	**X**	**X**	**X**	**X**	**X**							**X**				**X**	**X**	
	5.712																**X**	**X**	
5.70	5.822	**X**	**X**										**X**				**X**	**X**	
	5.920																**X**	**X**	
	6.013																**X**	**X**	
5.97	6.077	**X**	**X?**		**X**	**X**							**X**				**X**	**X**	
	6.145																**X**	**X**	
	6.223																**X**	**X**	

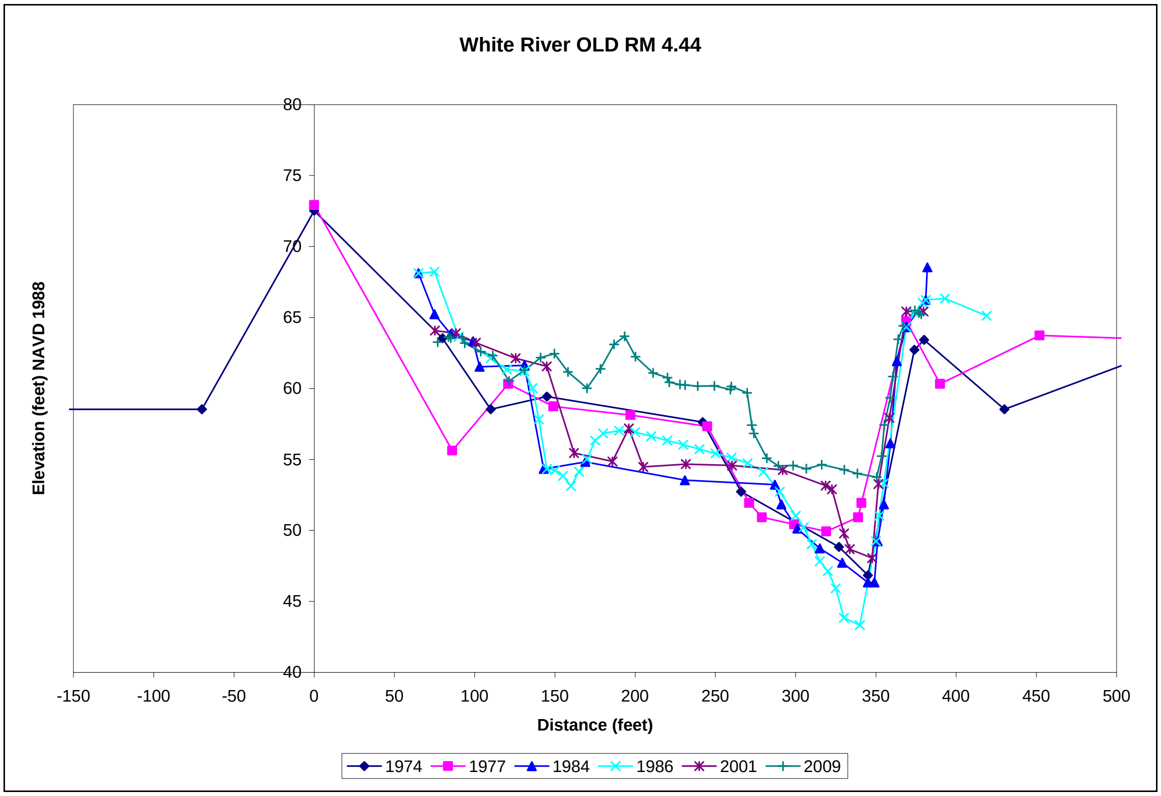
Table B-1 (continued). White River cross-section survey sources by year and cross-section (King County 2009b).

Previous River Mile	Reference Section 2007/2009	King County 1969[1]	USACE 1974[2]	USACE USGS[3] 1977	USGS		DEA[4]	City of Auburn					King County 2001	City of Auburn or DEA			MGS[5] 2007 / NHC[6] 2008	Various Sources 2009	Location or Comment
					1984	1986	1994	1996	1997	1998	1999	2000		2002	2003	2006			
USGS	6.313												X				X	X	USGS gage
6.21	6.326	X	X										X				X	X	d/s side A Str
																			A Str Br
	6.390							X	X	X	X	X	X	X	X	X	X	X	Auburn #1
6.33	6.482	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	Auburn #2
6.52	6.569	X	X					X	X	X	X	X	X	X	X	X	X	X	Auburn #3
	6.647							X	X	X	X	X	X	X	X	X	X	X	Auburn #4
6.73	6.761	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	Auburn #5
	6.891							X	X	X	X	X	X	X	X	X	X	X	Auburn #6
6.96	7.001	X	X					X	X	X	X	X	X	X	X	X	X	X	Auburn #7
	7.087	X	X					X	X	X	X	X	X	X	X	X	X	X	Auburn #8
7.09	7.170	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	Auburn #13
	7.252	X	X					X	X	X	X	X	X	X	X	X	X	X	Auburn #9
	7.368	X	X					X	X	X	X	X	X	X	X	X	X	X	Auburn #10
7.40	7.511	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	Auburn #11
7.51	7.593		X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	Auburn #12
																			R Str Br
	7.716																X	X	
7.74	7.845	X	X	X	X	X							X				X	X	
7.87	7.958	X	X?										X				X	X	
8.03	8.111	X	X	X	X	X							X				X	X	

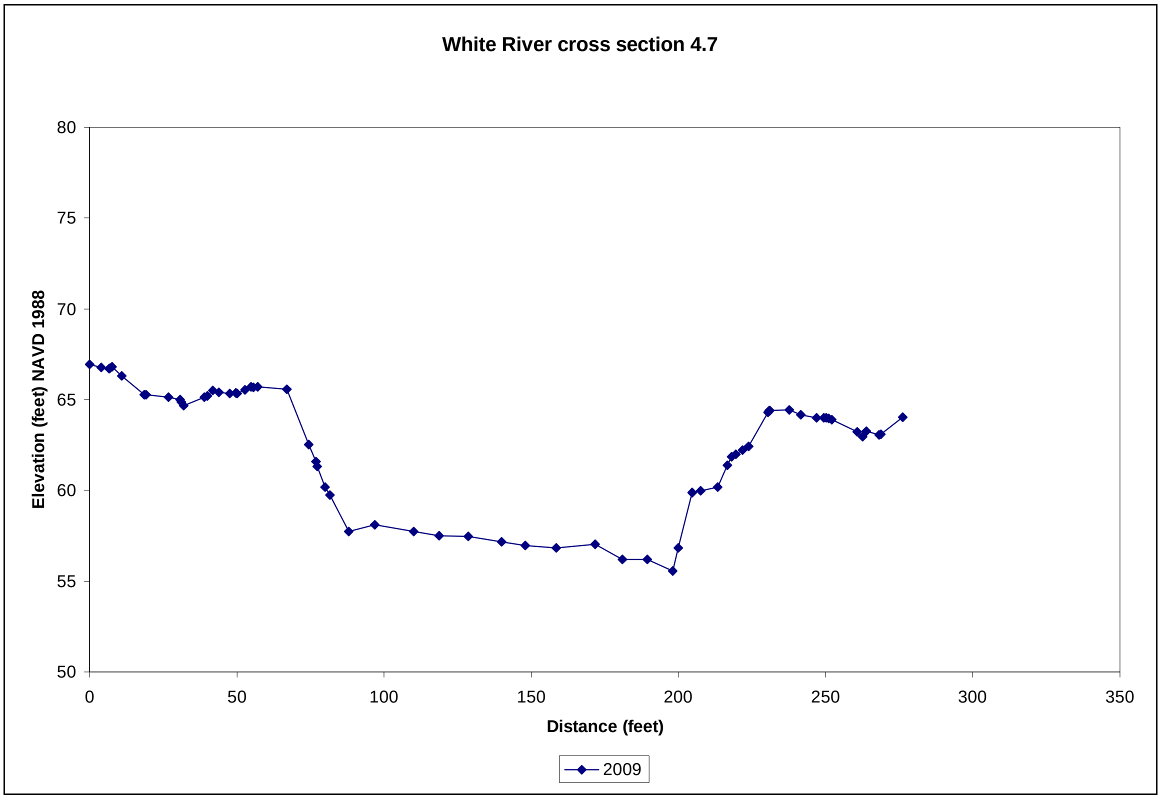
Table B-1 (continued). White River cross-section survey sources by year and cross-section (King County 2009b).

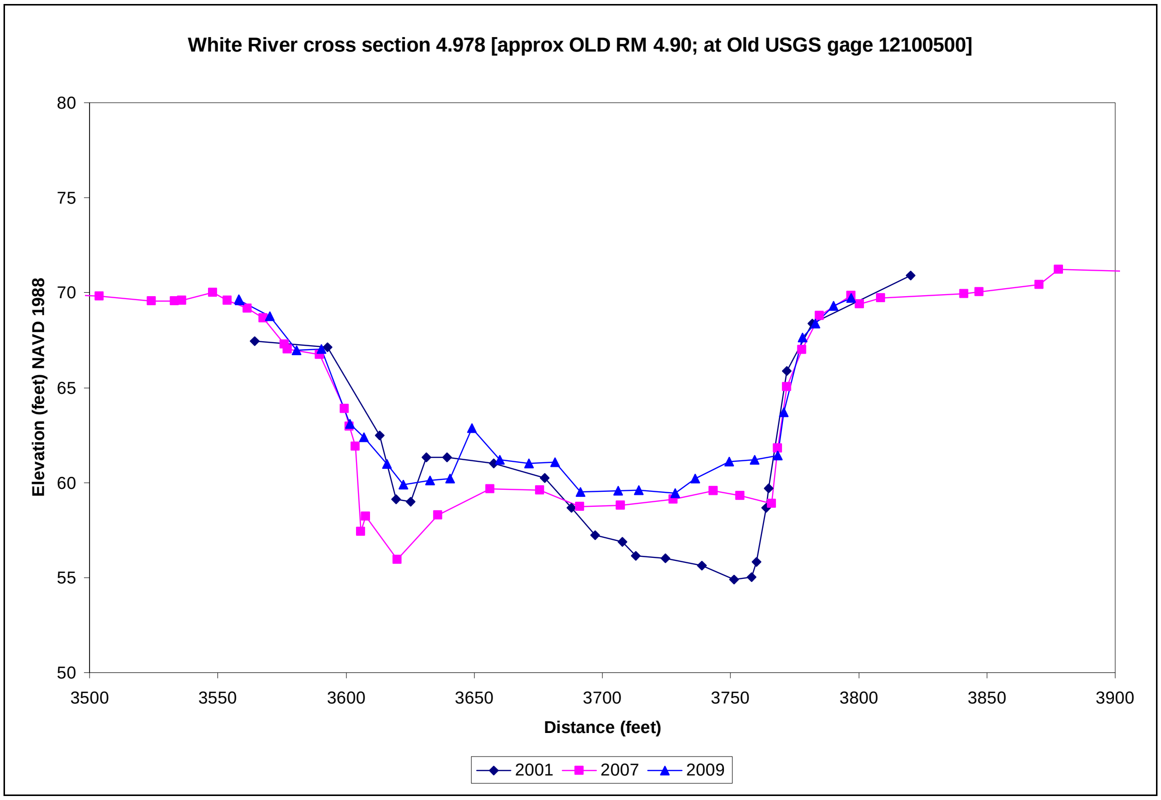
Previous River Mile	Reference Section 2007/2009	King County 1969[1]	USACE 1974[2]	USACE USGS[3] 1977	USGS		DEA[4]	City of Auburn					King County 2001	City of Auburn or DEA			MGS[5] 2007 / NHC[6] 2008	Various Sources 2009	Location or Comment
					1984	1986	1994	1996	1997	1998	1999	2000		2002	2003	2006			
8.19	8.269	X	X	X	X	X							X				X	X	
8.33	8.418	X	X	X	X	X							X				X	X	
8.46	8.561	X	X	X	X	X							X				X	X	
8.60	8.707	X	X	X	X	X											X	X	
8.73	8.821	X	X	X	X	X							X				X	X	
8.89	8.946	X	X	X	X	X											X	X	
9.02	9.125	X	X	X	X	X							X				X	X	
9.18	9.311	X	X	X	X	X											X	X	
9.33	9.477	X	X	X	X	X							X				X	X	
9.51		X	X	X	X	X													
	9.794																X	X	
9.81		X	X	X	X	X													
	10.065	X	X														X	X	
10.04		X	X	X	X	X													
10.25	10.343	X	X	X	X	X											X	X	
10.42		X	X	X	X	X													
	10.596																X	X	
10.58		X	X	X	X	X													

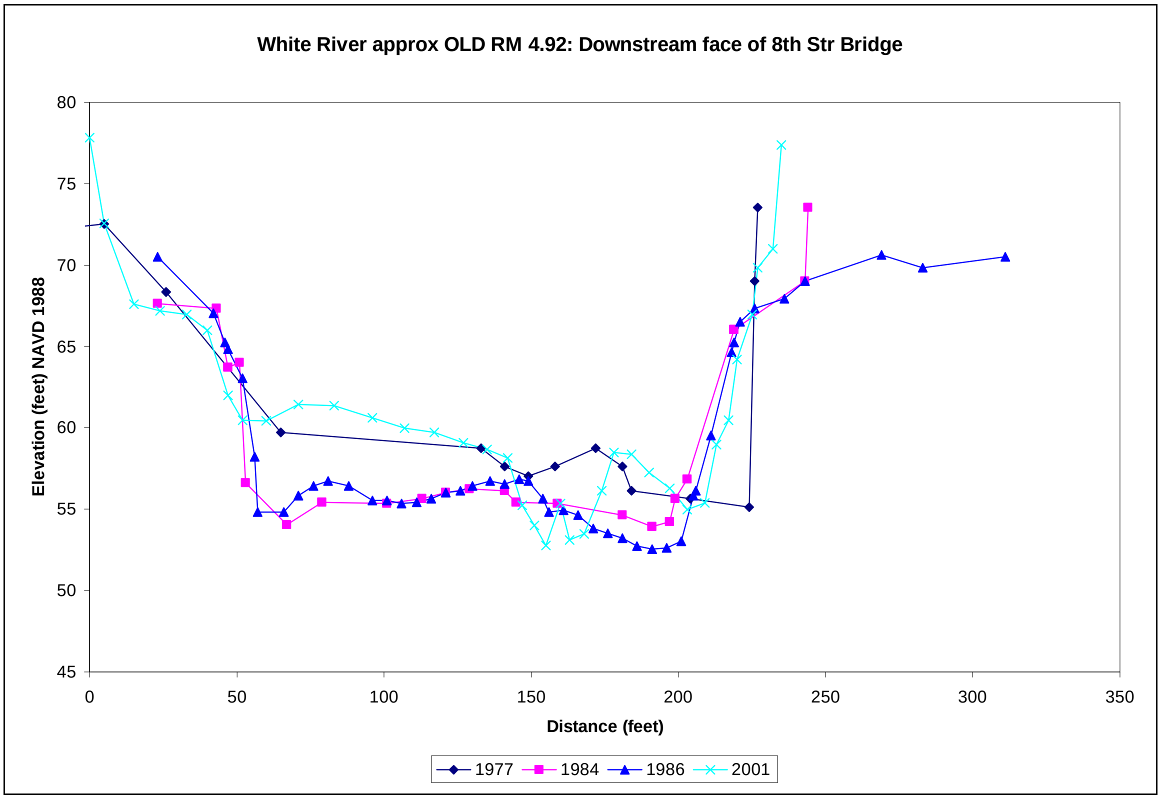
X Indicates a cross-section was surveyed at a particular river mile during a one of the time periods listed in the column.
? Indicates uncertainty of fit of older cross-section to 2007/2009 cross-section.
1 Net changes in volume from 1969 to 1974 come from Jordan/Avent (1975) Table J-1. Cross-sections from 1969 are not available for comparison with later periods.
2 Net changes in volume from 1969 to 1974 come from Jordan/Avent (1975) Table J-1. Few cross-sections from 1974 are available for comparison with later periods.
3 Cross-sections surveyed by the United States Geological Survey (USGS)
4 Cross-sections surveyed by David Evans and Associates (DEA)
5 Cross-sections surveyed by Minister Glaeser Surveyors Inc. (MGS)
6 Cross-sections surveyed by Northwest Hydraulic Consultants (NHC)

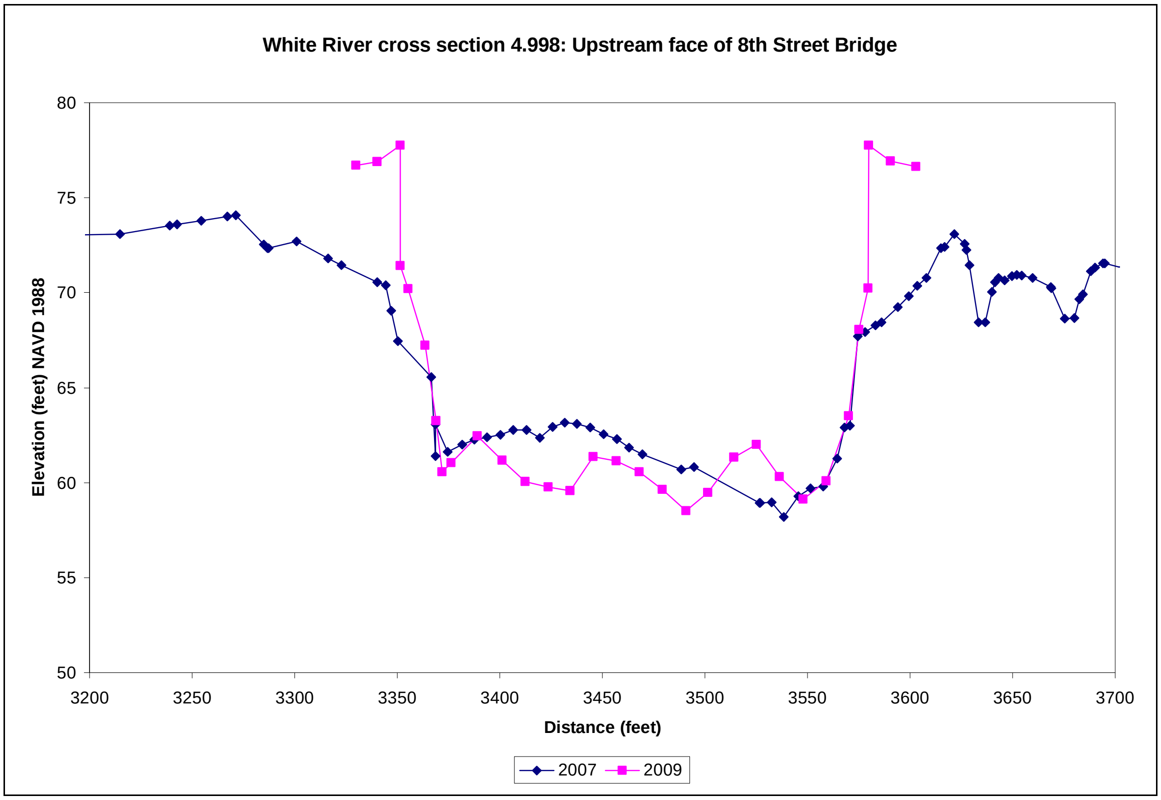

White River OLD RM 4.44
Elevation (feet) NAVD 1988
80
75
70
65
60
55
50
45
40
-150
-100
-50
0
50
100
150
200
250
300
350
400
450
500
Distance (feet)
1974
1977
1984
1986
2001
2009

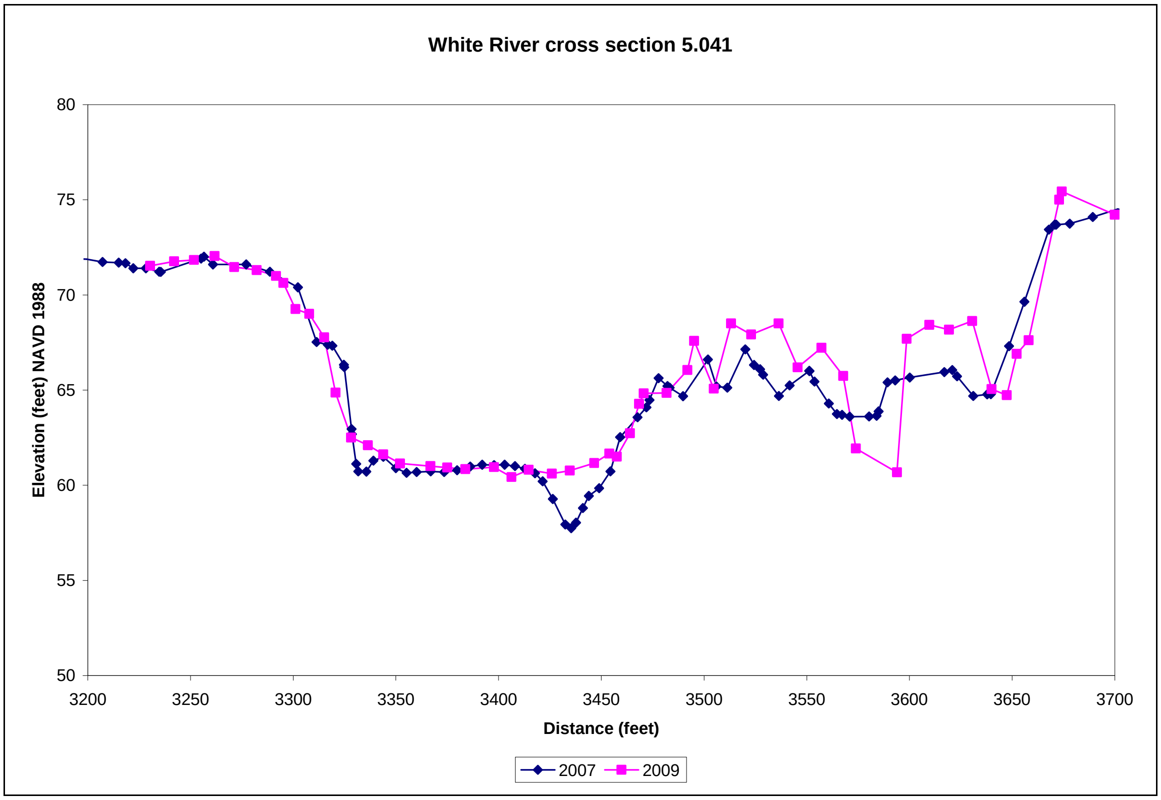

White River OLD RM 4.56
Elevation (feet) NAVD 1988
80
75
70
65
60
55
50
0
50
100
150
200
250
300
350
Distance (feet)
1974?
1977?
2001


White River cross section 4.7
Elevation (feet) NAVD 1988
80
75
70
65
60
55
50
0
50
100
150
200
250
300
350
Distance (feet)
2009

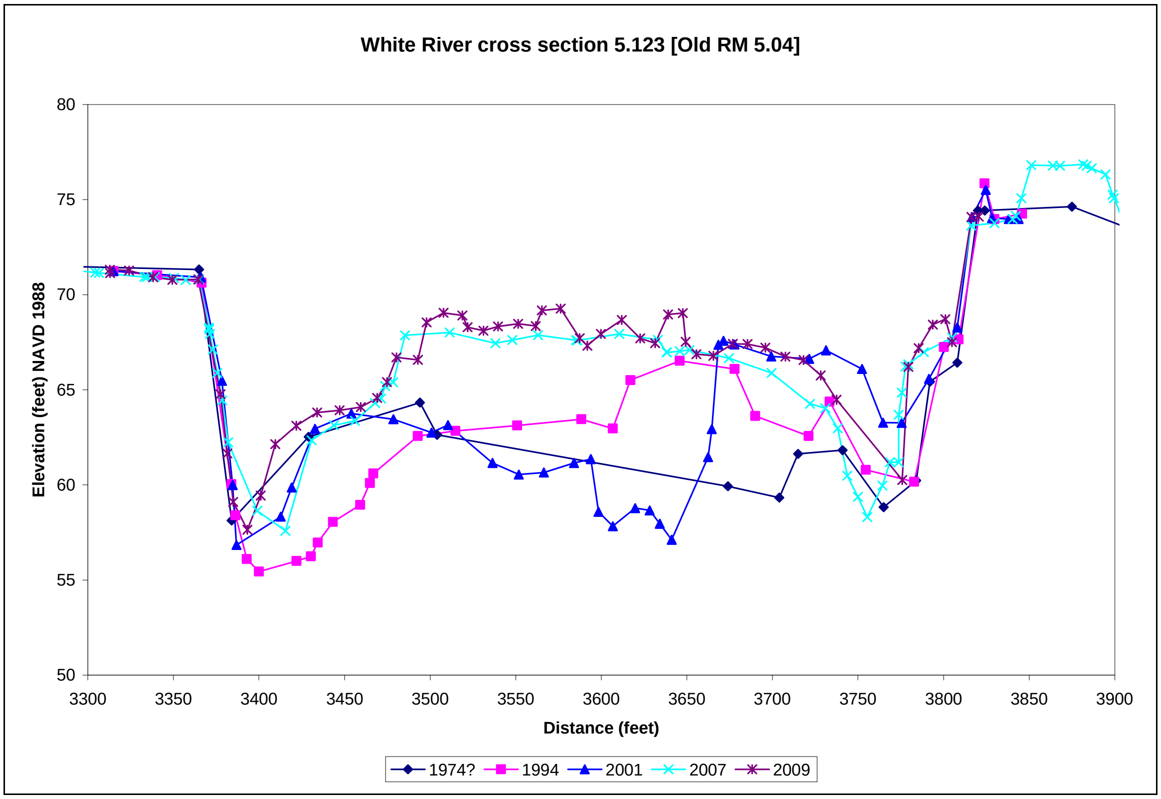

White River cross section 4.978 [approx OLD RM 4.90; at Old USGS gage 12100500]
Elevation (feet) NAVD 1988
80
75
70
65
60
55
50
3500
3550
3600
3650
3700
3750
3800
3850
3900
Distance (feet)
2001
2007
2009


White River approx OLD RM 4.92: Downstream face of 8th Str Bridge
Elevation (feet) NAVD 1988
80
75
70
65
60
55
50
45
0
50
100
150
200
250
300
350
Distance (feet)
1977
1984
1986
2001

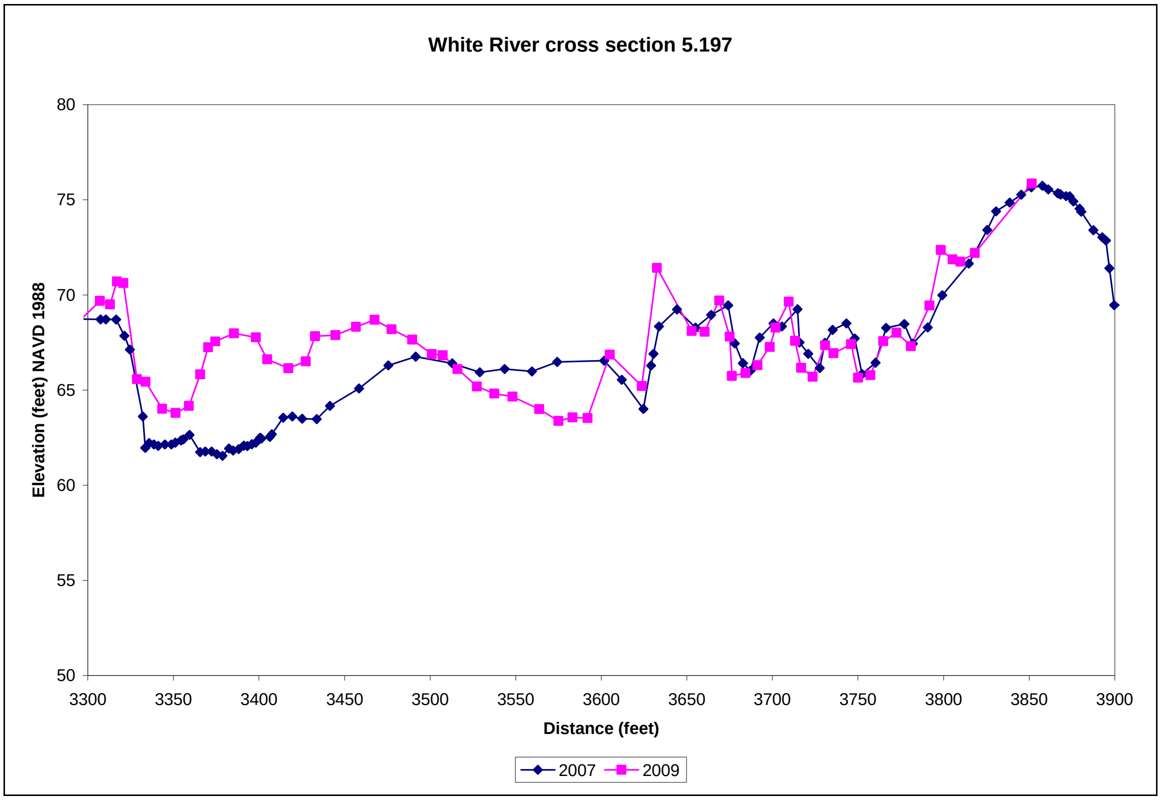

White River cross section 4.998: Upstream face of 8th Street Bridge
Elevation (feet) NAVD 1988
80
75
70
65
60
55
50
3200
3250
3300
3350
3400
3450
3500
3550
3600
3650
3700
Distance (feet)
2007
2009

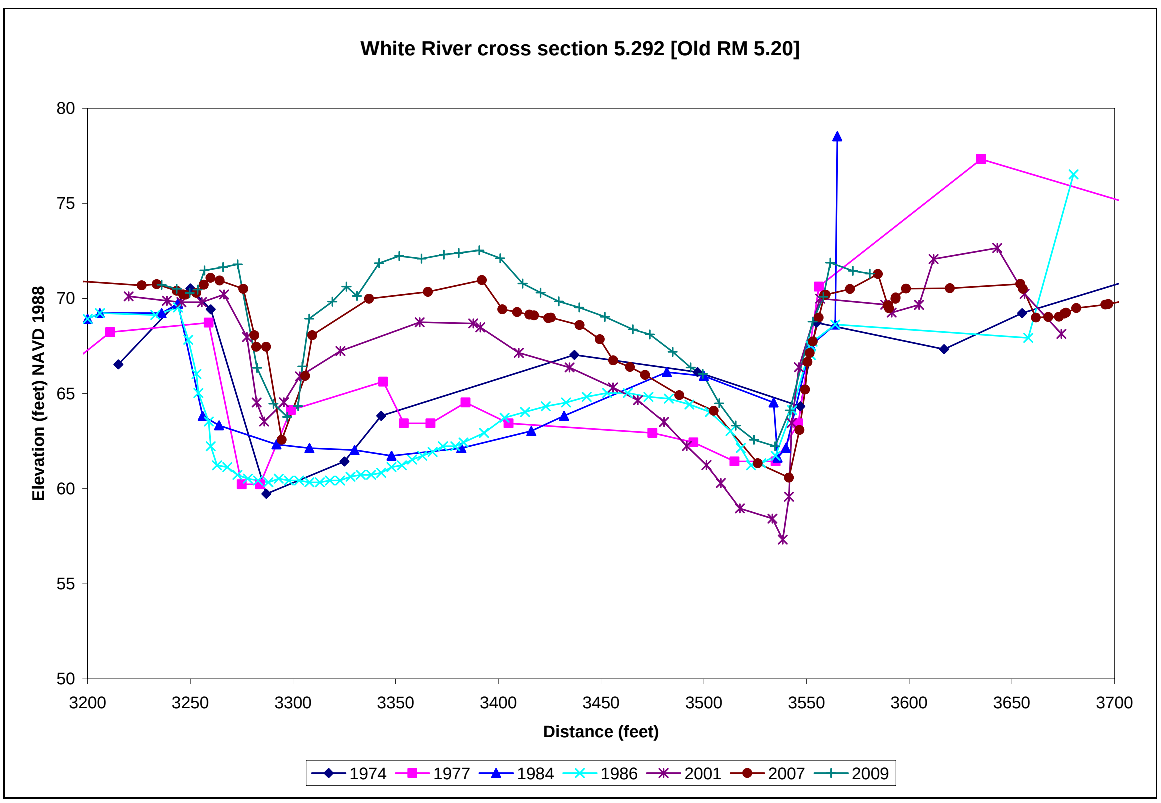


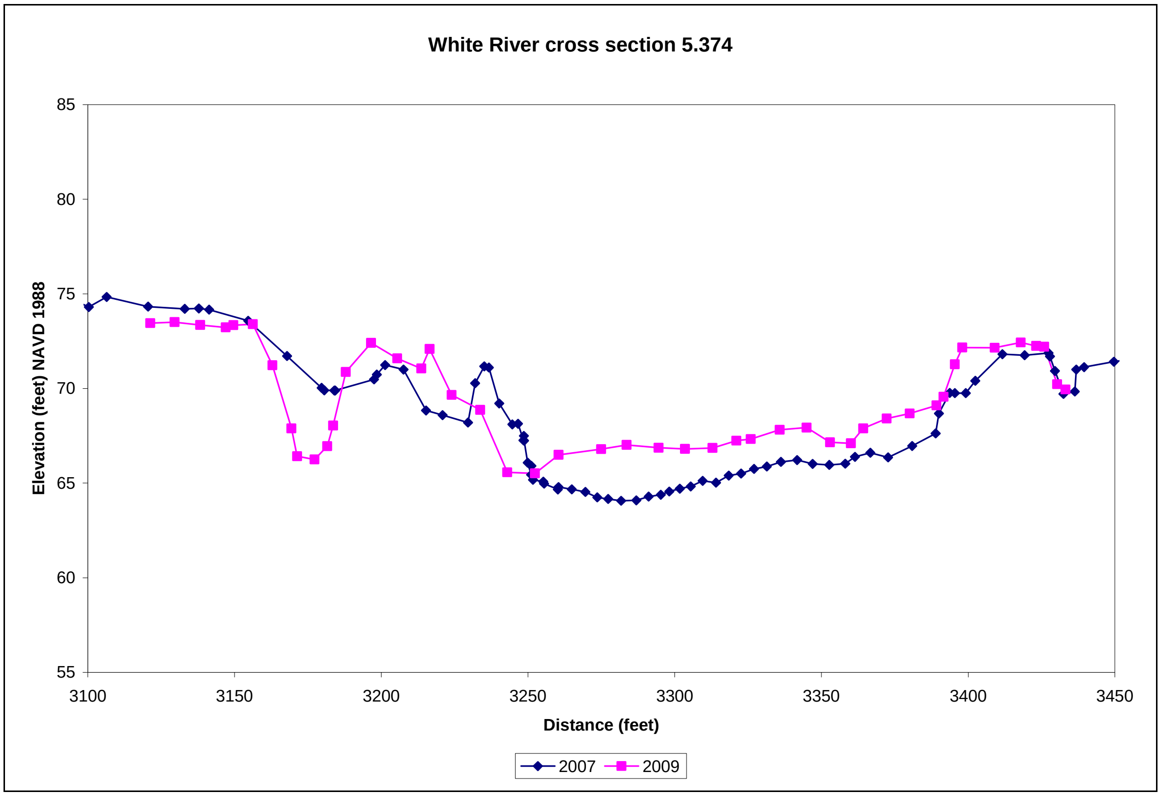
White River cross section 5.041
Elevation (feet) NAVD 1988
80
75
70
65
60
55
50
3200
3250
3300
3350
3400
3450
3500
3550
3600
3650
3700
Distance (feet)
2007
2009



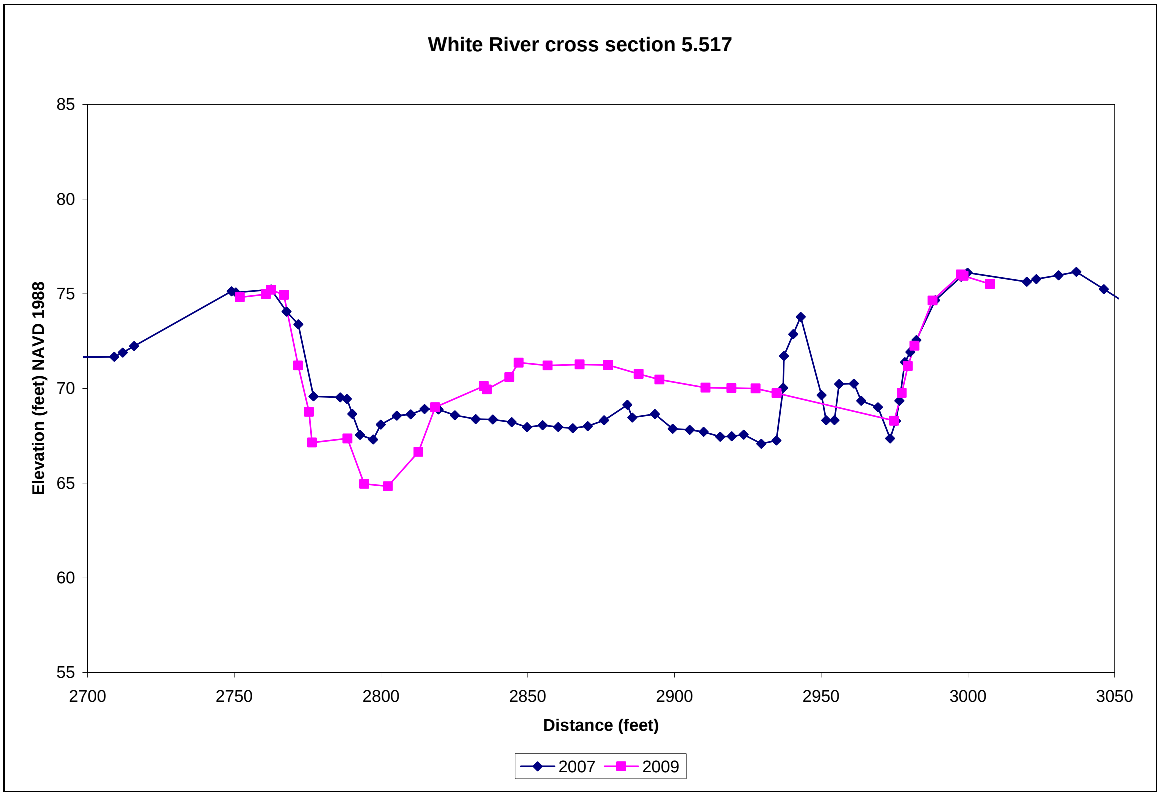
White River cross section 5.123 [Old RM 5.04]
Elevation (feet) NAVD 1988
80
75
70
65
60
55
50
3300
3350
3400
3450
3500
3550
3600
3650
3700
3750
3800
3850
3900
Distance (feet)
1974?
1994
2001
2007
2009

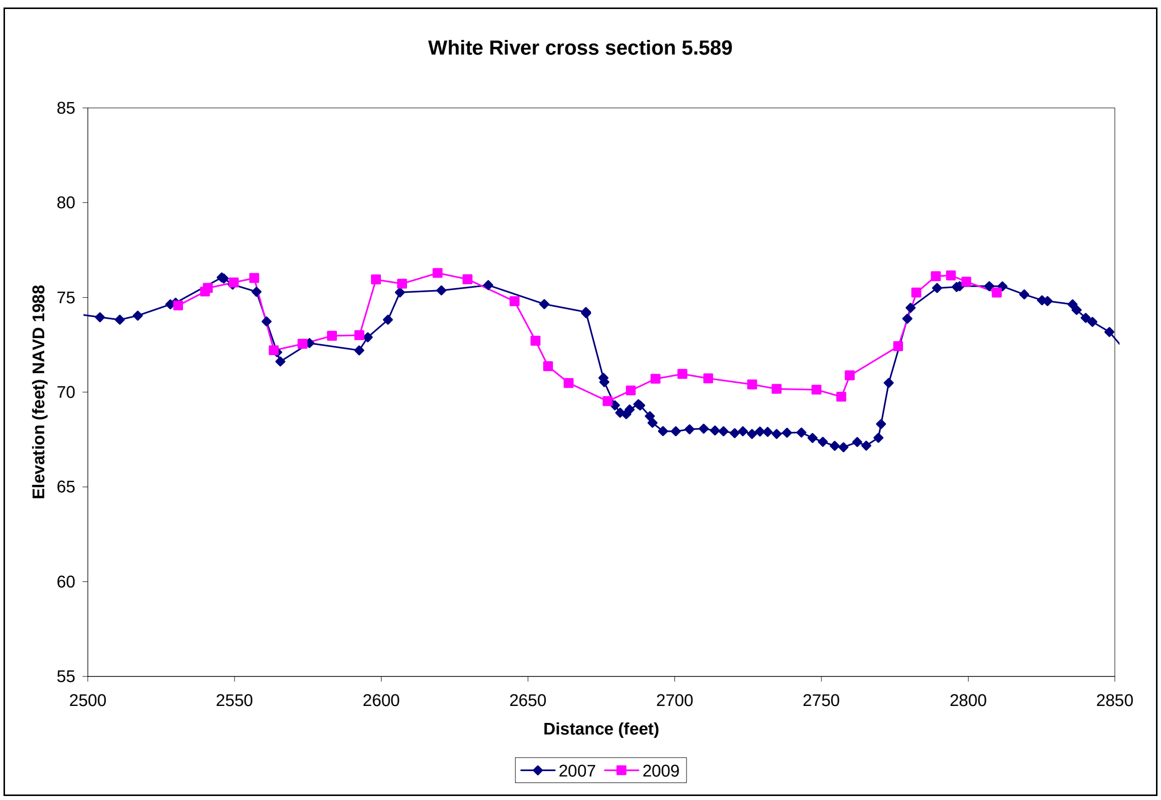

White River cross section 5.197
Elevation (feet) NAVD 1988
80
75
70
65
60
55
50
3300
3350
3400
3450
3500
3550
3600
3650
3700
3750
3800
3850
3900
Distance (feet)
2007
2009

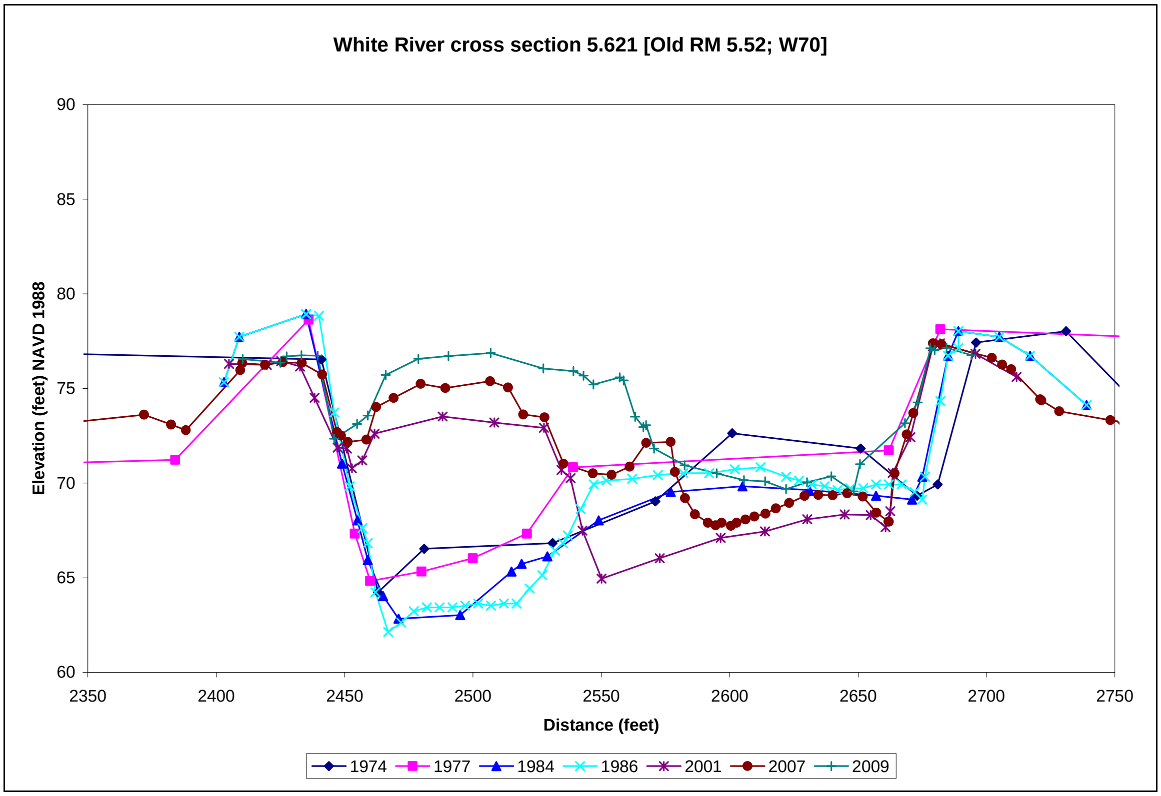

White River cross section 5.292 [Old RM 5.20]
Elevation (feet) NAVD 1988
80
75
70
65
60
55
50
3200
3250
3300
3350
3400
3450
3500
3550
3600
3650
3700
Distance (feet)
1974
1977
1984
1986
2001
2007
2009

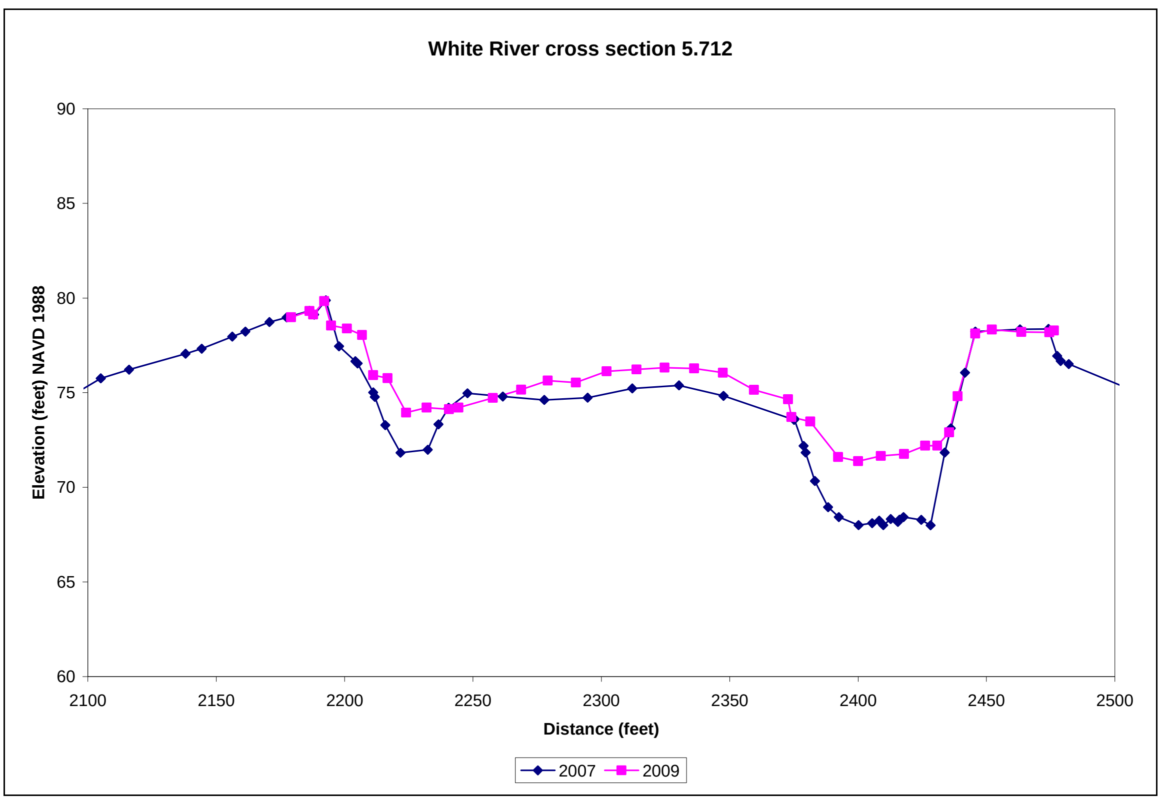

White River cross section 5.374
Elevation (feet) NAVD 1988
85
80
75
70
65
60
55
3100
3150
3200
3250
3300
3350
3400
3450
Distance (feet)
2007
2009

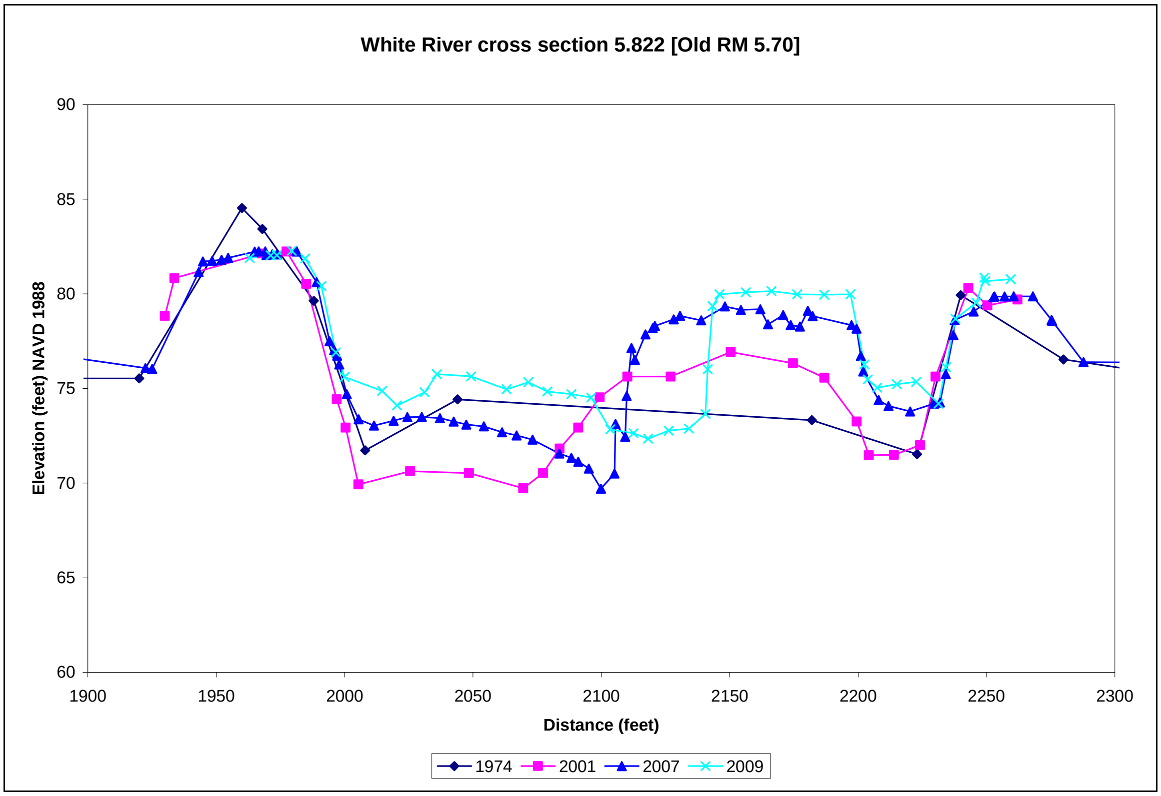

White River cross section 5.460 [Old RM 5.36]
Elevation (feet) NAVD 1988
85
80
75
70
65
60
55
2850
2900
2950
3000
3050
3100
3150
3200
3250
Distance (feet)
1974?
1977?
2001
2007
2009

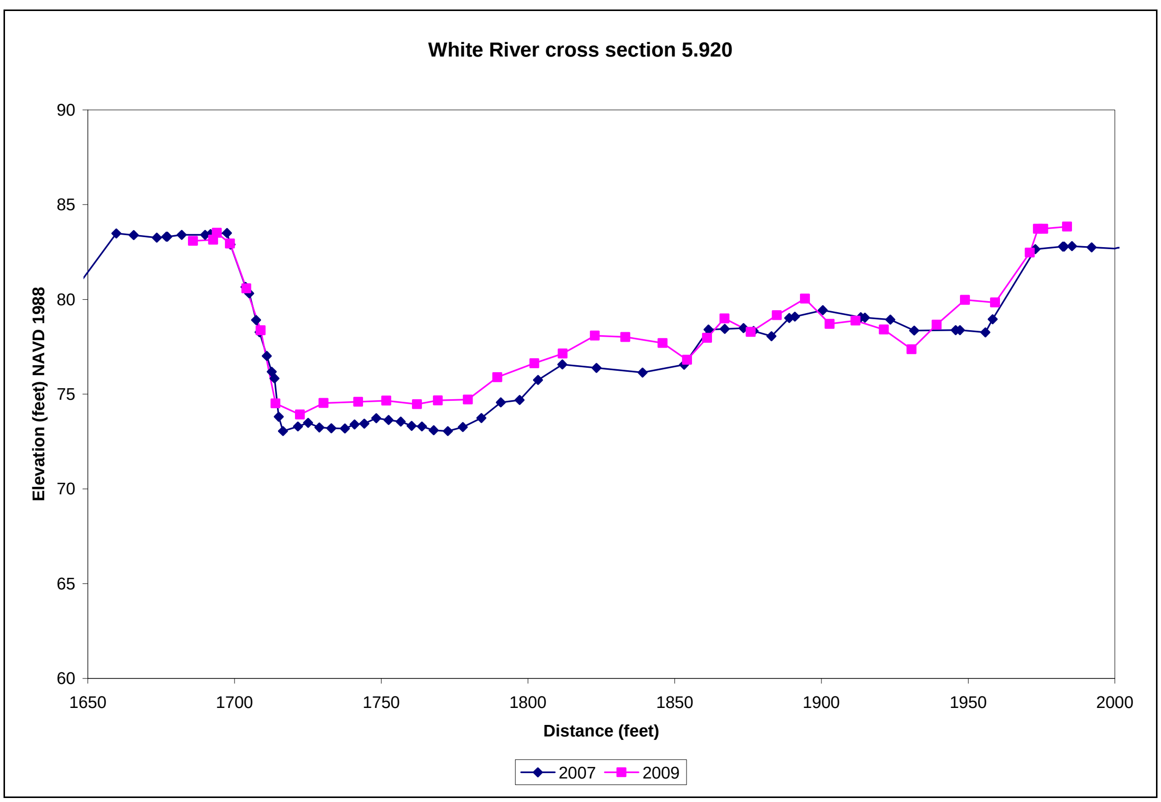

White River cross section 5.517
85
80
75
70
65
60
55
Elevation (feet) NAVD 1988
2700
2750
2800
2850
2900
2950
3000
3050
Distance (feet)
2007
2009

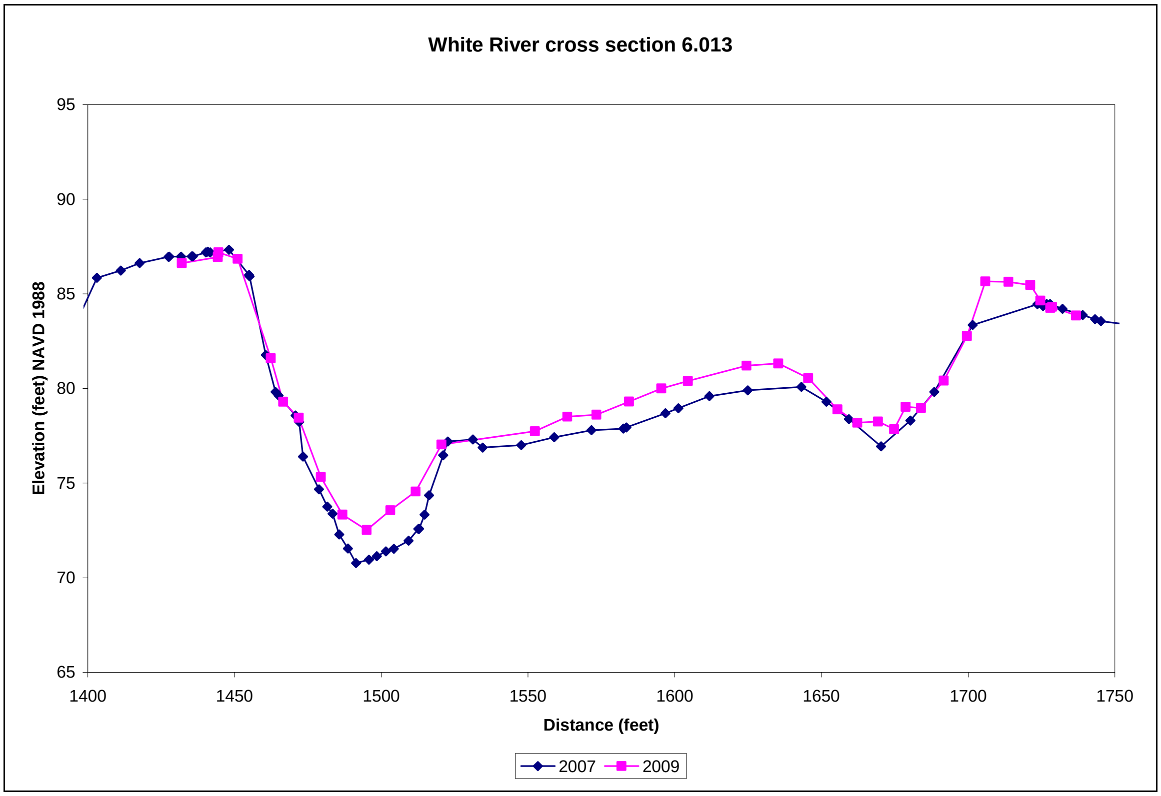

White River cross section 5.589
85
80
75
70
65
60
55
Elevation (feet) NAVD 1988
2500
2550
2600
2650
2700
2750
2800
2850
Distance (feet)
2007
2009


White River cross section 5.621 [Old RM 5.52; W70]
Elevation (feet) NAVD 1988
90
85
80
75
70
65
60
2350
2400
2450
2500
2550
2600
2650
2700
2750
Distance (feet)
1974
1977
1984
1986
2001
2007
2009

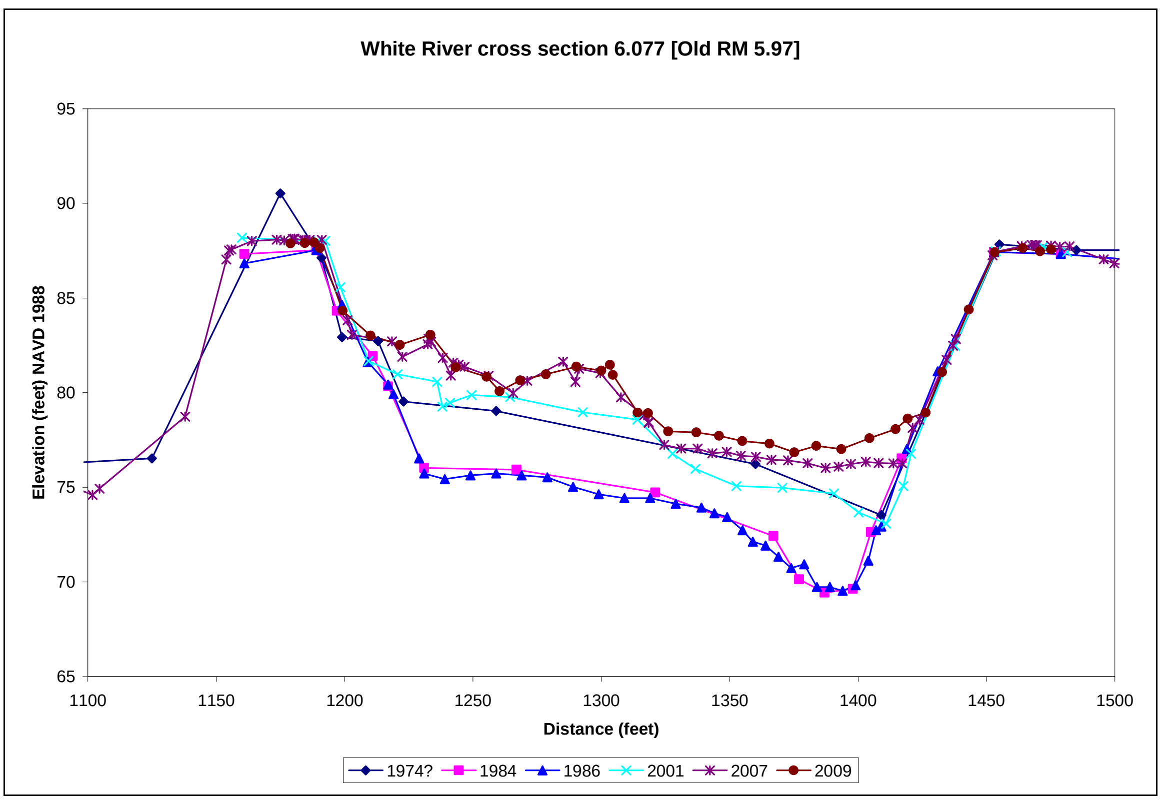

White River cross section 5.712
Elevation (feet) NAVD 1988
90
85
80
75
70
65
60
2100
2150
2200
2250
2300
2350
2400
2450
2500
Distance (feet)
2007
2009


White River cross section 5.822 [Old RM 5.70]
Elevation (feet) NAVD 1988
90
85
80
75
70
65
60
1900
1950
2000
2050
2100
2150
2200
2250
2300
Distance (feet)
1974
2001
2007
2009

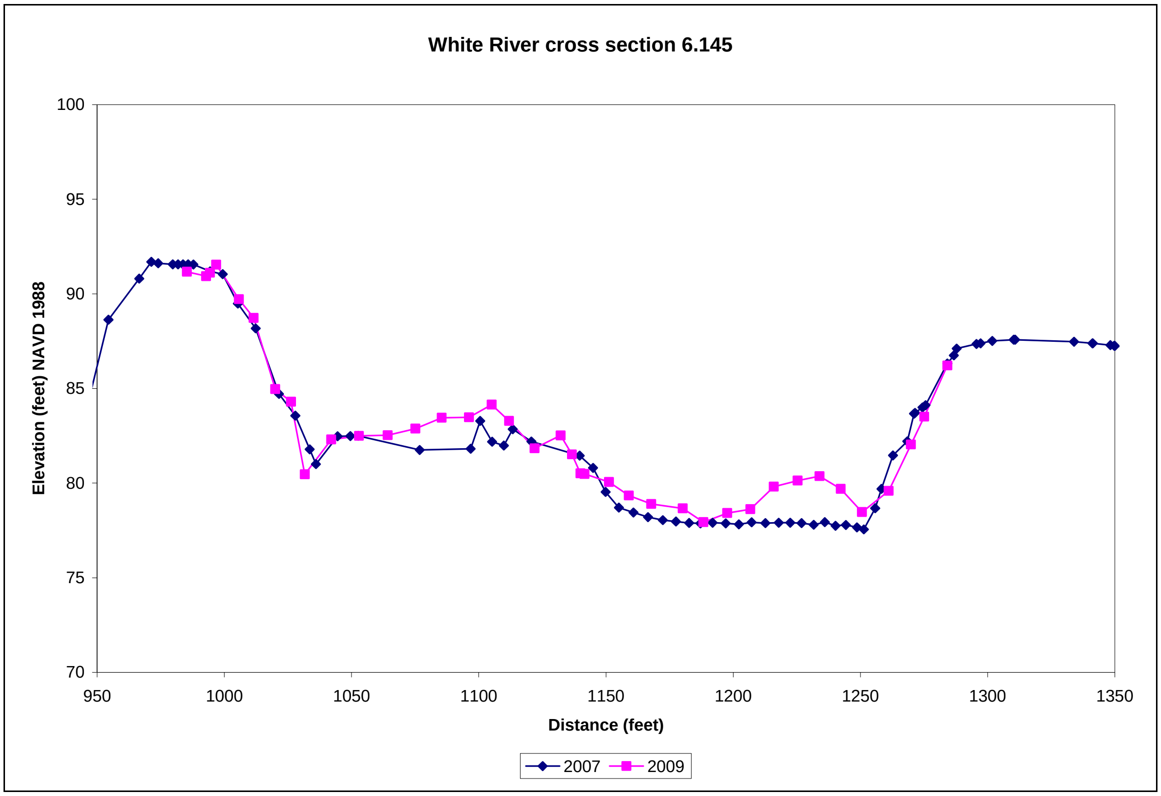

White River cross section 5.920
Elevation (feet) NAVD 1988
90
85
80
75
70
65
60
1650
1700
1750
1800
1850
1900
1950
2000
Distance (feet)
2007
2009

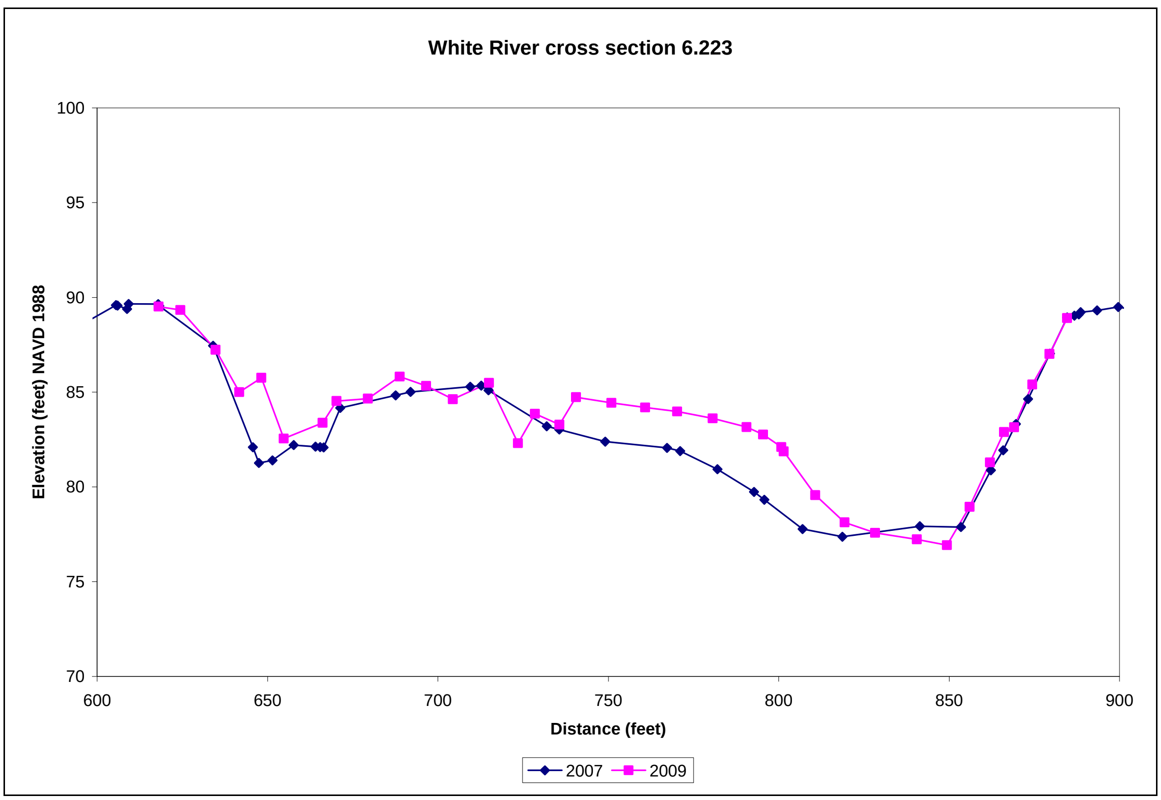


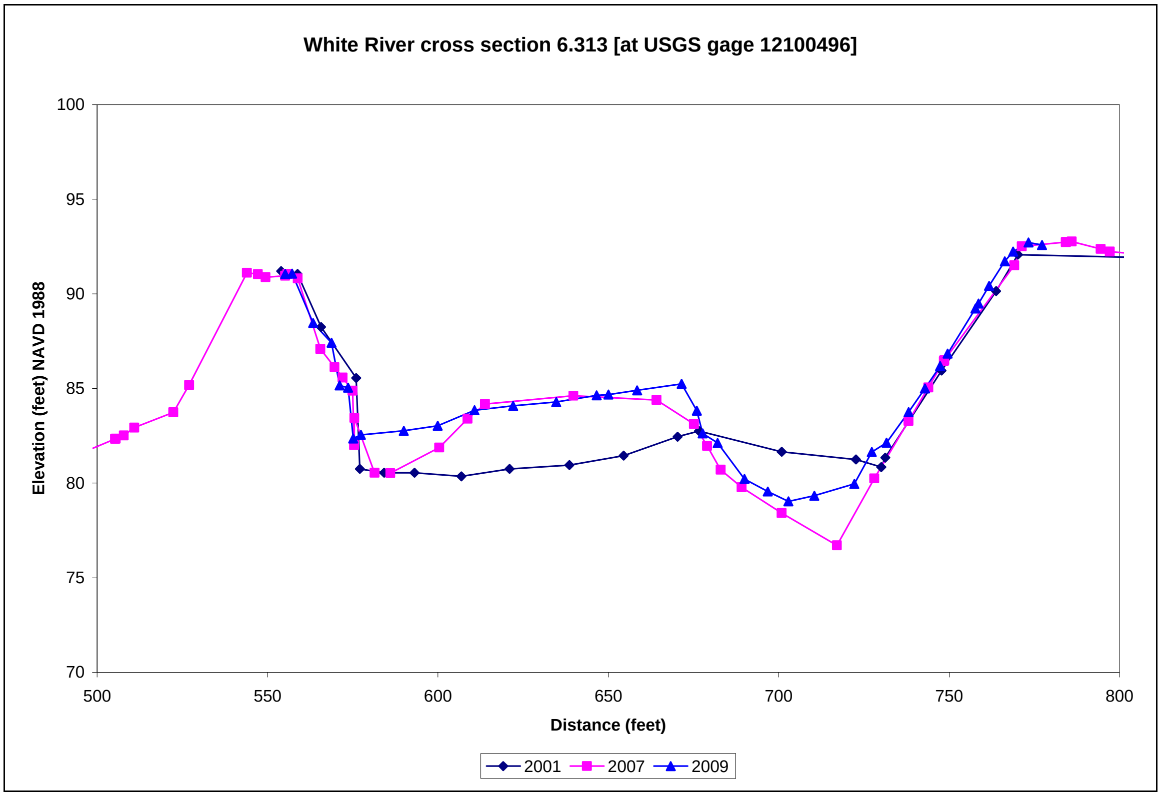
White River cross section 6.013
Elevation (feet) NAVD 1988
95
90
85
80
75
70
65
1400
1450
1500
1550
1600
1650
1700
1750
Distance (feet)
2007
2009



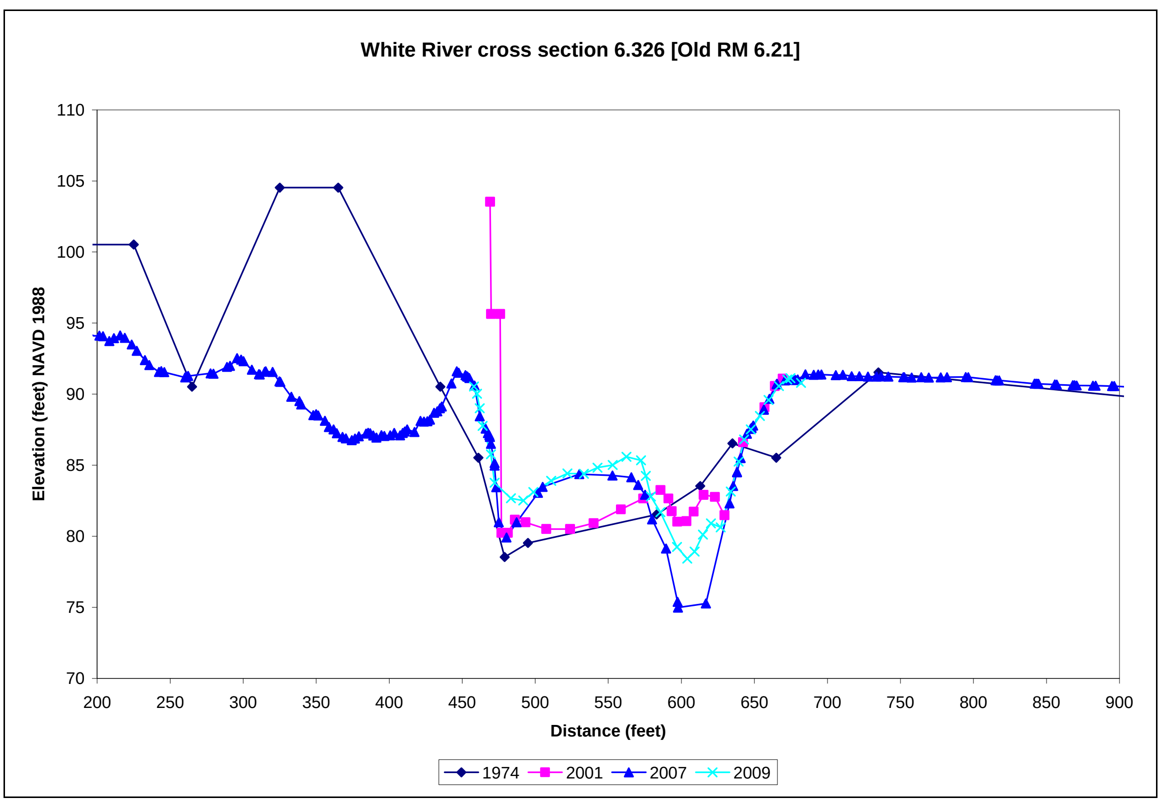
White River cross section 6.077 [Old RM 5.97]
Elevation (feet) NAVD 1988
95
90
85
80
75
70
65
1100
1150
1200
1250
1300
1350
1400
1450
1500
Distance (feet)
1974?
1984
1986
2001
2007
2009


White River cross section 6.145
Elevation (feet) NAVD 1988
100
95
90
85
80
75
70
950
1000
1050
1100
1150
1200
1250
1300
1350
Distance (feet)
2007
2009

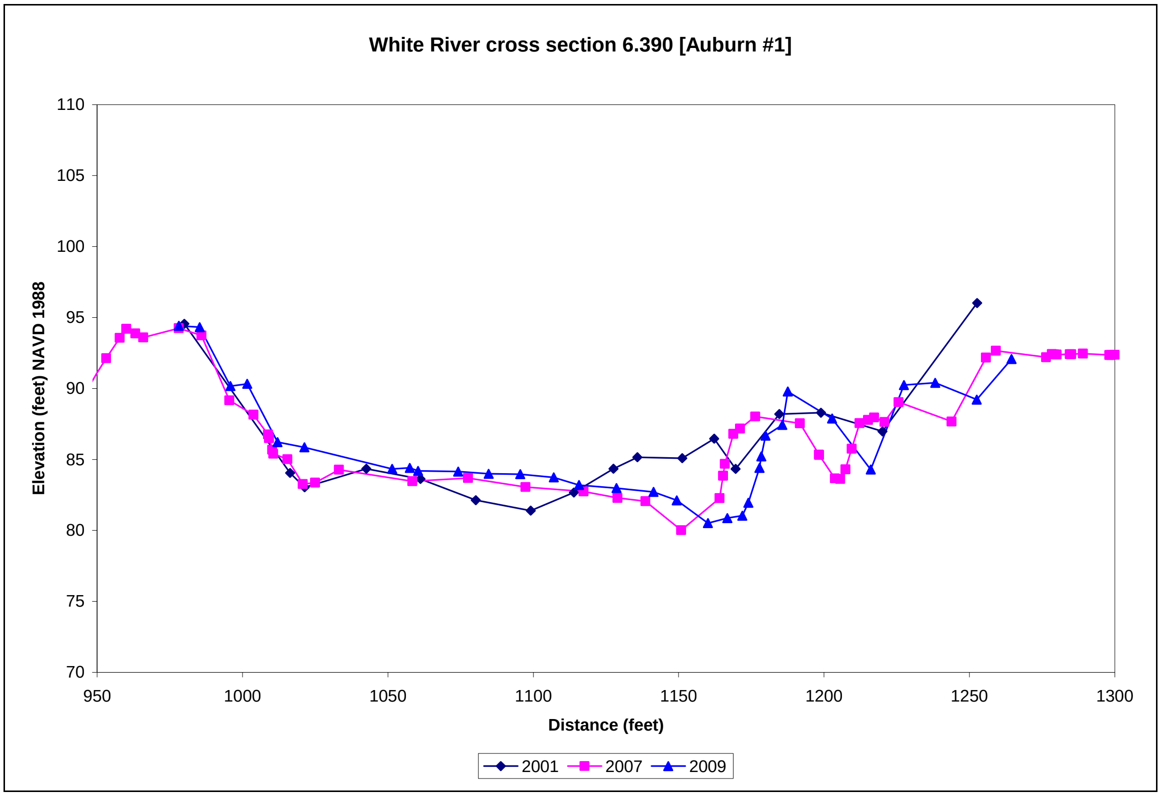

White River cross section 6.223
Elevation (feet) NAVD 1988
100
95
90
85
80
75
70
600
650
700
750
800
850
900
Distance (feet)
2007
2009

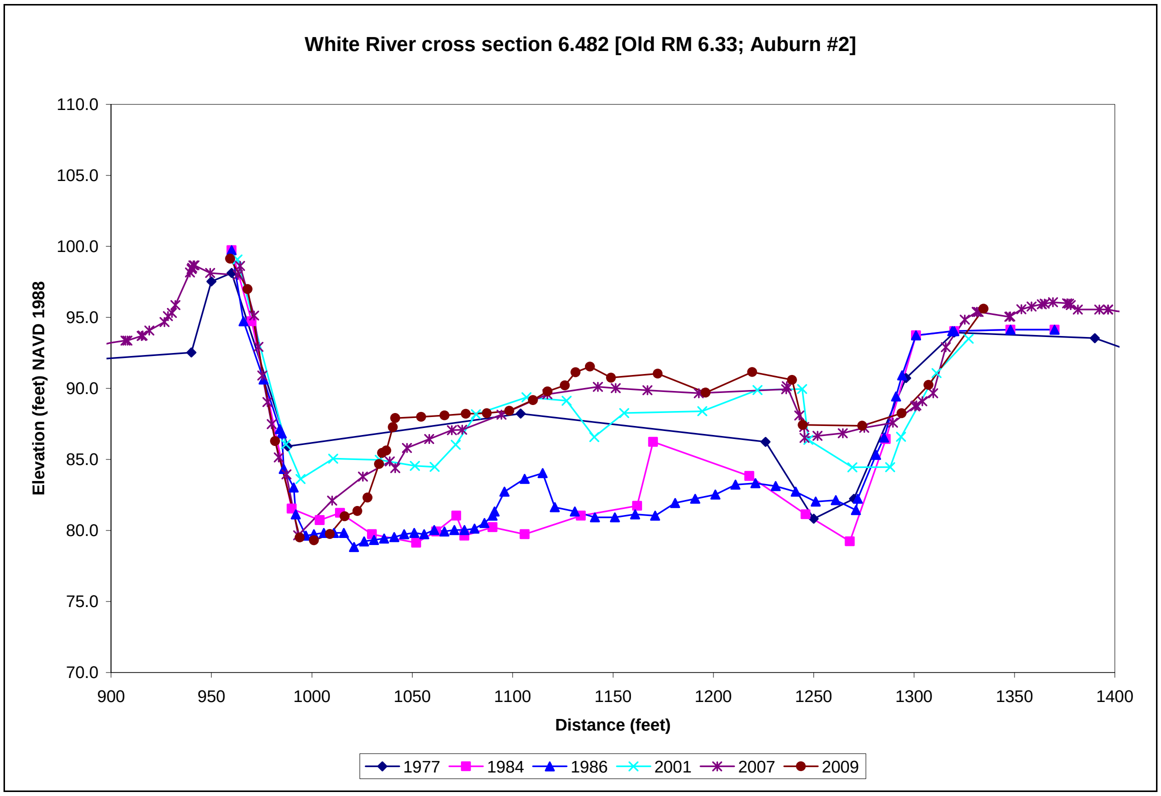


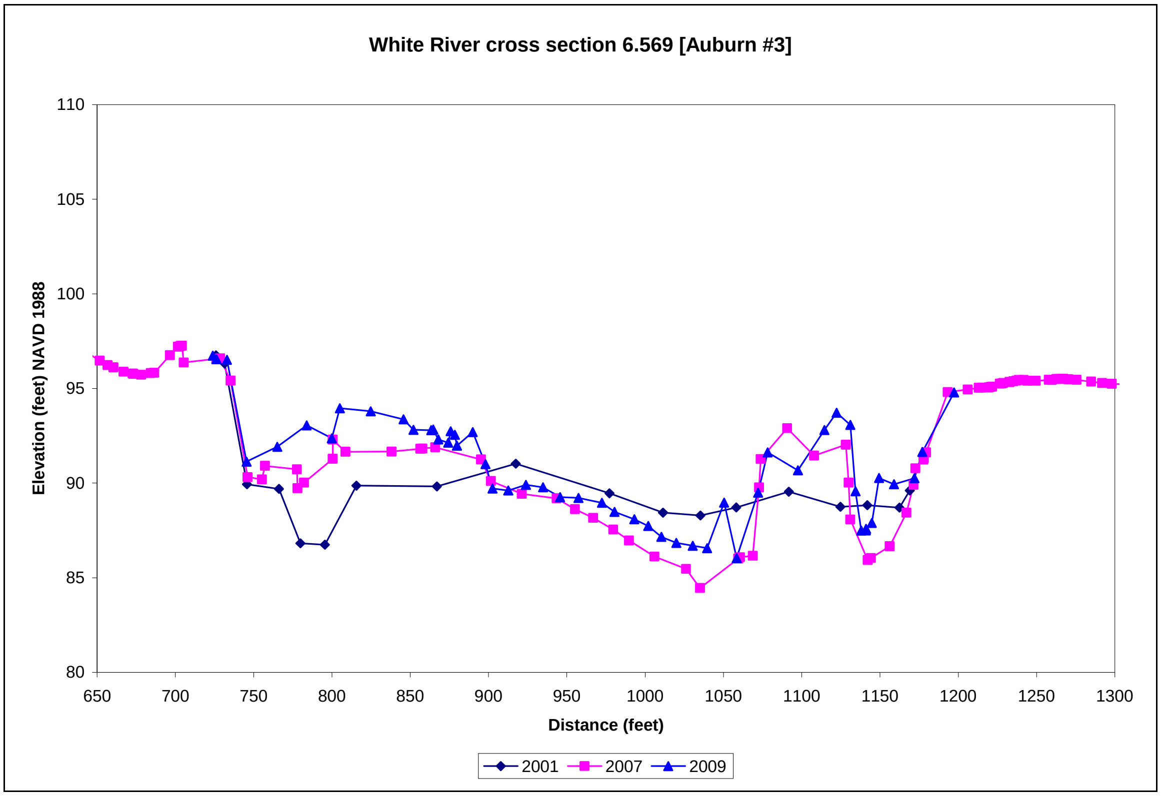
White River cross section 6.313 [at USGS gage 12100496]
Elevation (feet) NAVD 1988
Distance (feet)
100
95
90
85
80
75
70
500
550
600
650
700
750
800
2001
2007
2009

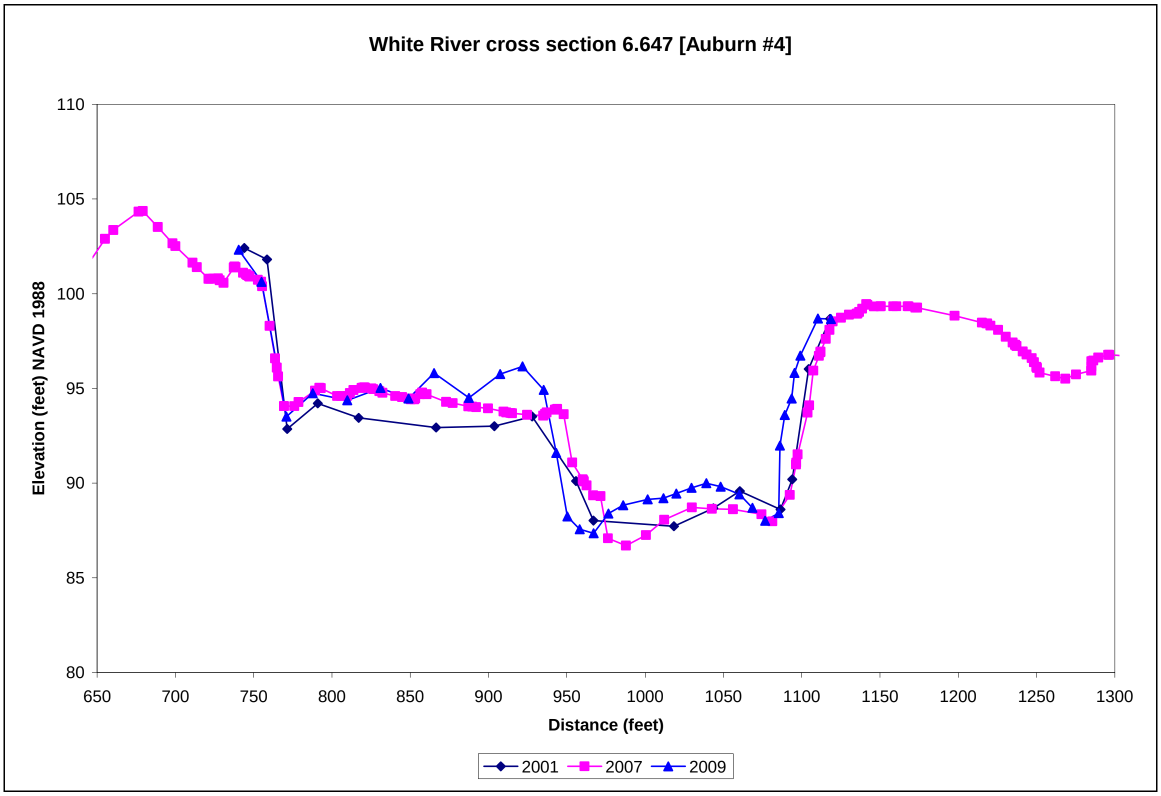


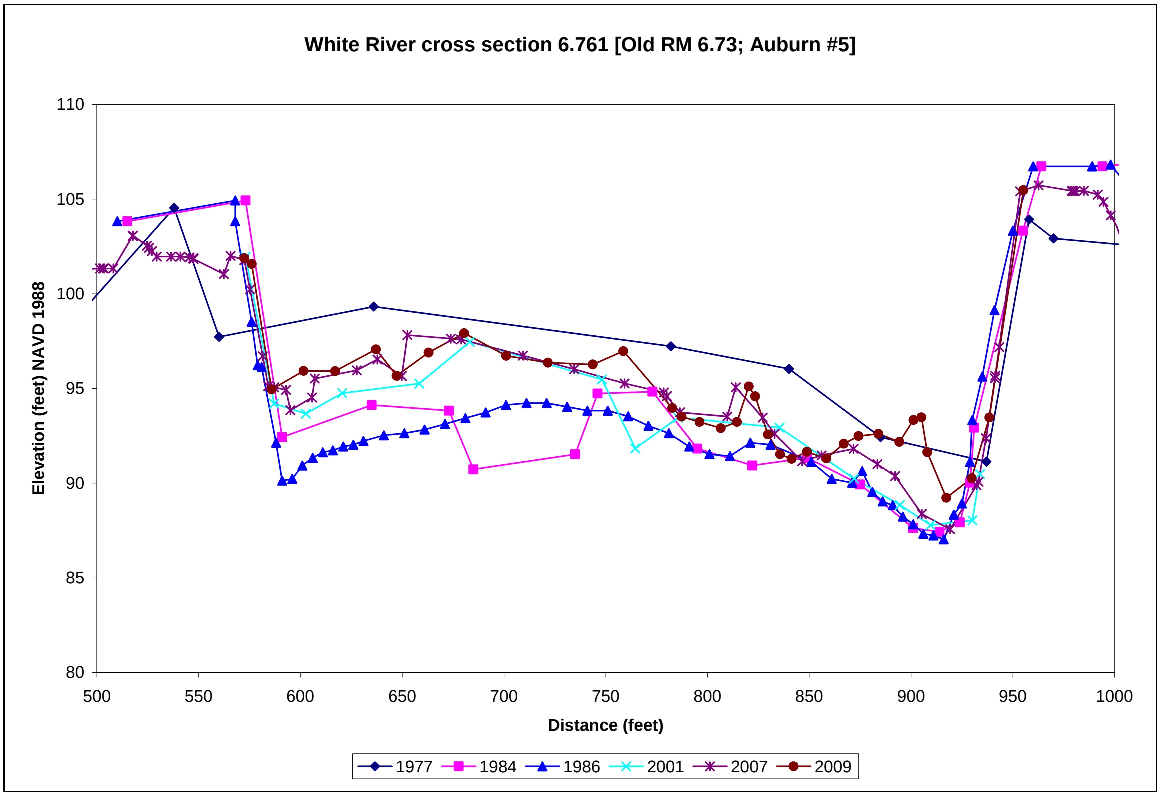
White River cross section 6.326 [Old RM 6.21]
Elevation (feet) NAVD 1988
Distance (feet)
110
105
100
95
90
85
80
75
70
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
1974
2001
2007
2009

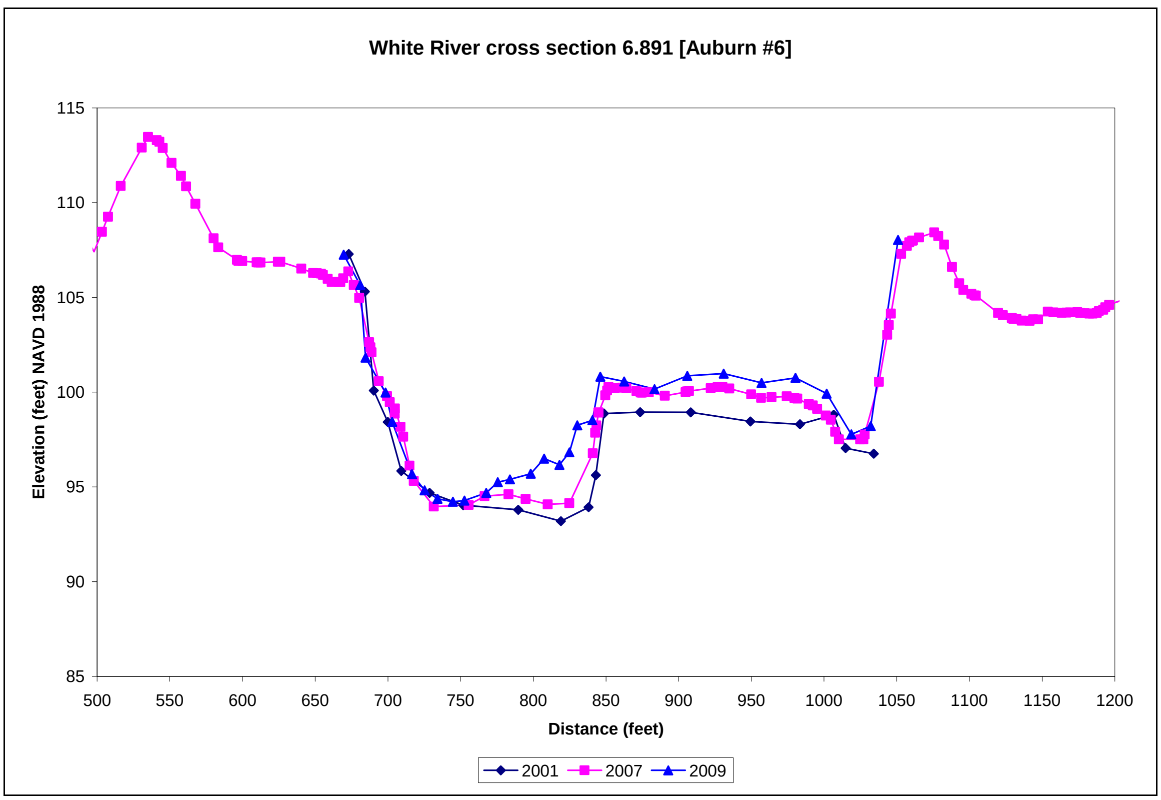

White River cross section 6.390 [Auburn #1]
Elevation (feet) NAVD 1988
110
105
100
95
90
85
80
75
70
950
1000
1050
1100
1150
1200
1250
1300
Distance (feet)
2001
2007
2009

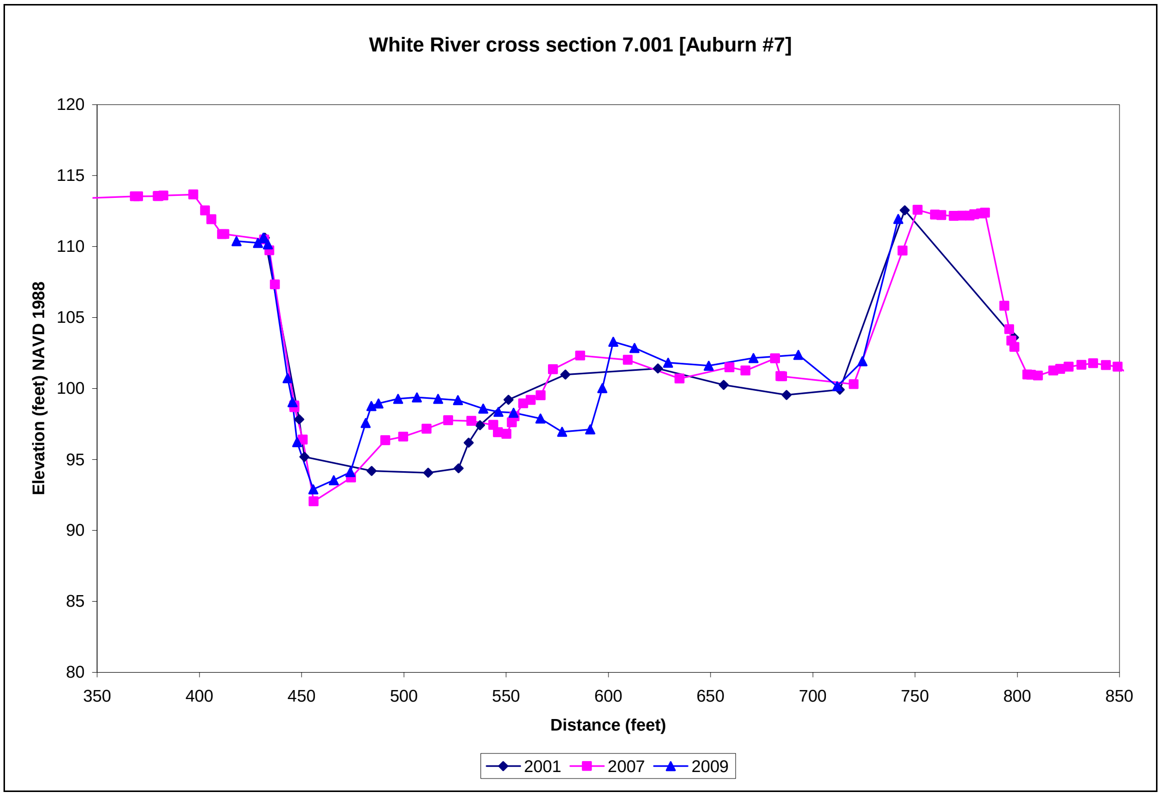

White River cross section 6.482 [Old RM 6.33; Auburn #2]
Elevation (feet) NAVD 1988
110.0
105.0
100.0
95.0
90.0
85.0
80.0
75.0
70.0
900
950
1000
1050
1100
1150
1200
1250
1300
1350
1400
Distance (feet)
1977
1984
1986
2001
2007
2009

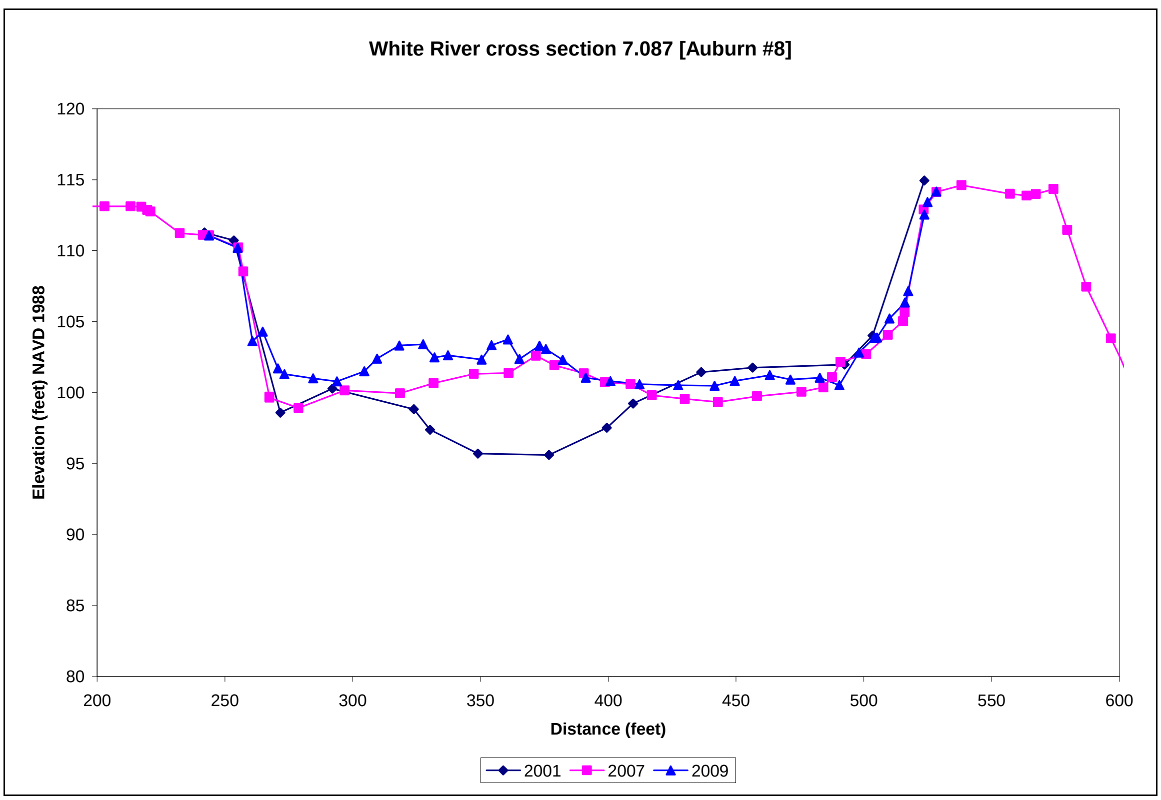

White River cross section 6.569 [Auburn #3]
Elevation (feet) NAVD 1988
110
105
100
95
90
85
80
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
Distance (feet)
2001
2007
2009

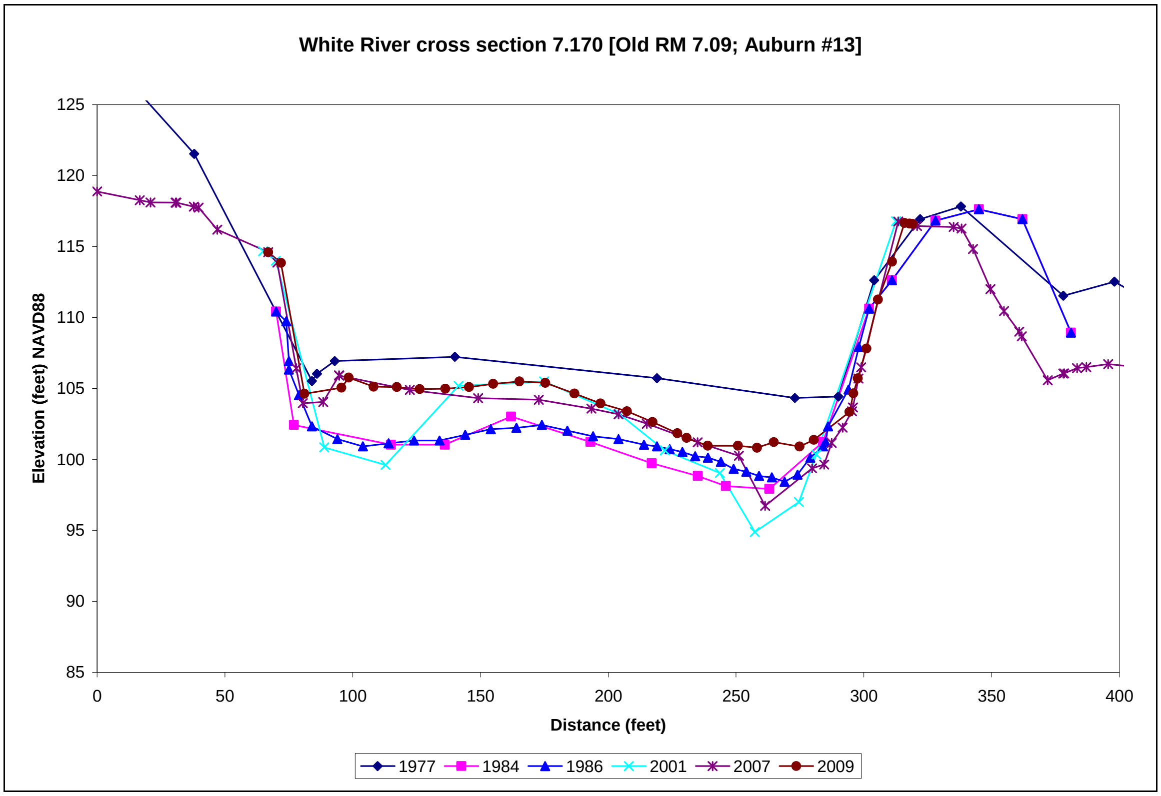

White River cross section 6.647 [Auburn #4]
Elevation (feet) NAVD 1988
110
105
100
95
90
85
80
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
Distance (feet)
2001
2007
2009

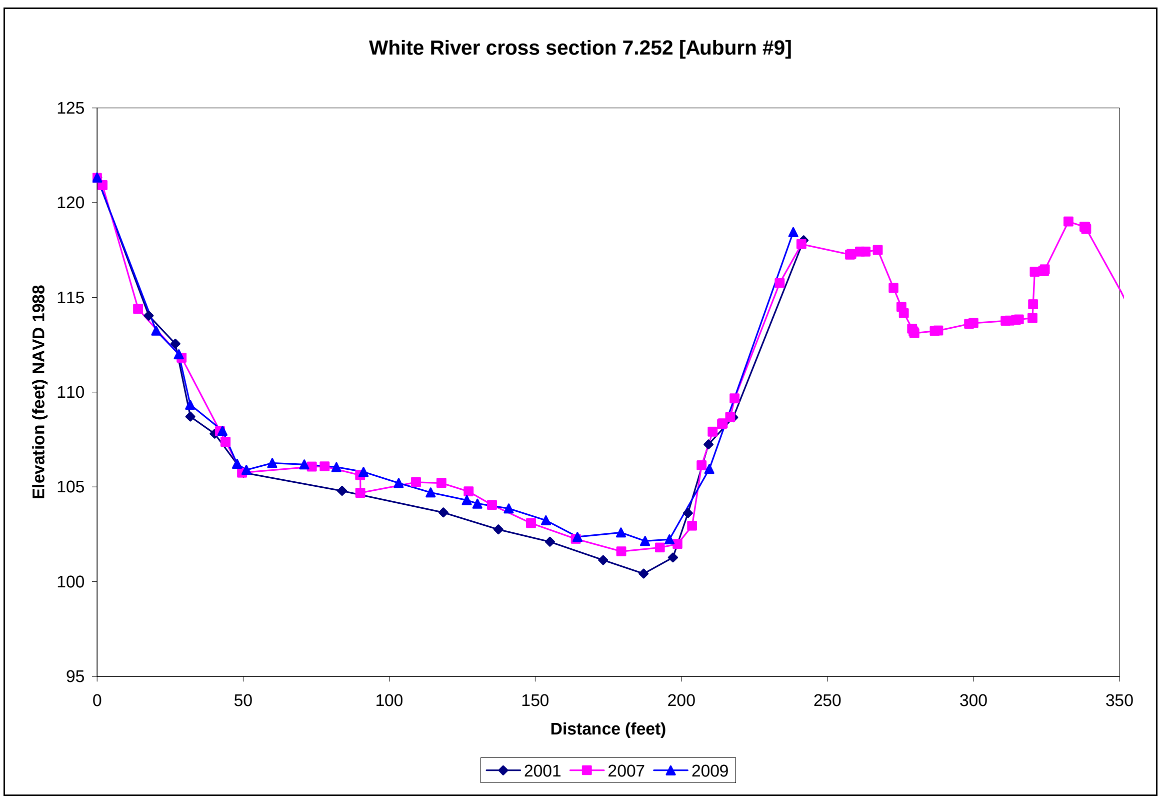

White River cross section 6.761 [Old RM 6.73; Auburn #5]
Elevation (feet) NAVD 1988
110
105
100
95
90
85
80
500
550
600
650
700
750
800
850
900
950
1000
Distance (feet)
1977
1984
1986
2001
2007
2009

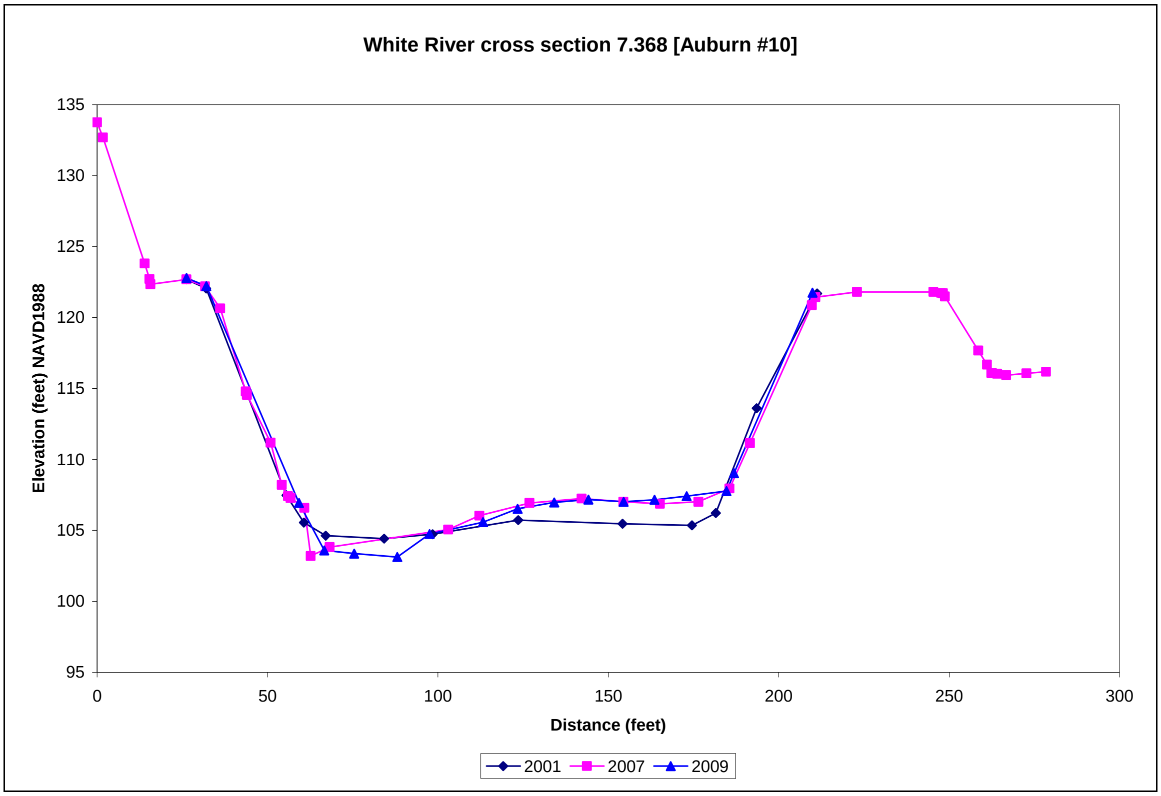

White River cross section 6.891 [Auburn #6]
Elevation (feet) NAVD 1988
115
110
105
100
95
90
85
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
Distance (feet)
2001
2007
2009

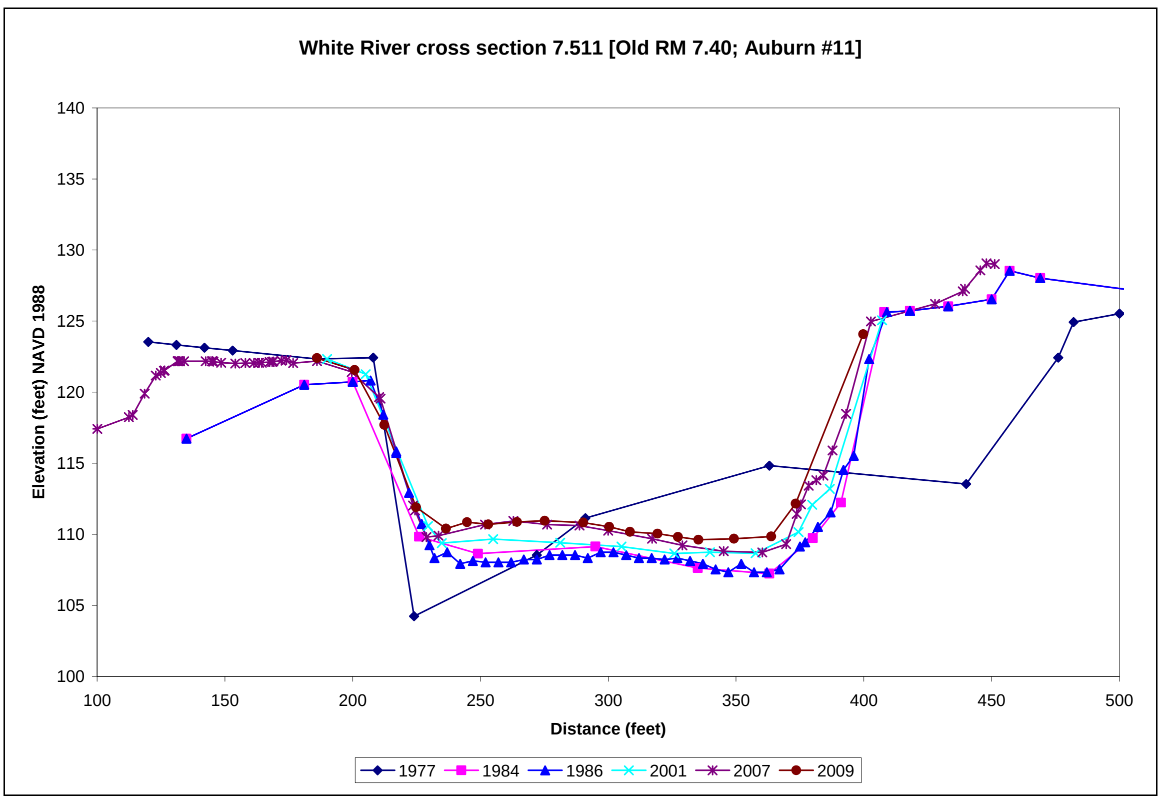

White River cross section 7.001 [Auburn #7]
Elevation (feet) NAVD 1988
120
115
110
105
100
95
90
85
80
350
400
450
500
550
600
650
700
750
800
850
Distance (feet)
2001
2007
2009

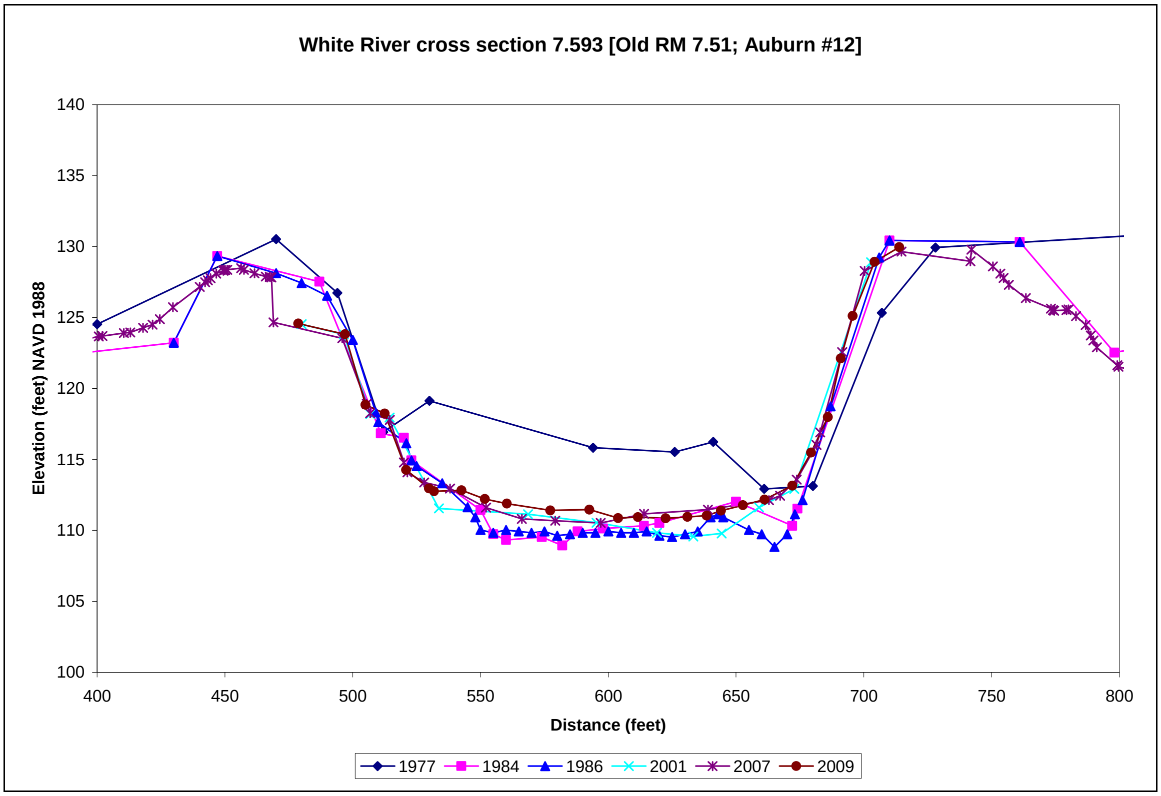

White River cross section 7.087 [Auburn #8]
Elevation (feet) NAVD 1988
120
115
110
105
100
95
90
85
80
200
250
300
350
400
450
500
550
600
Distance (feet)
2001
2007
2009

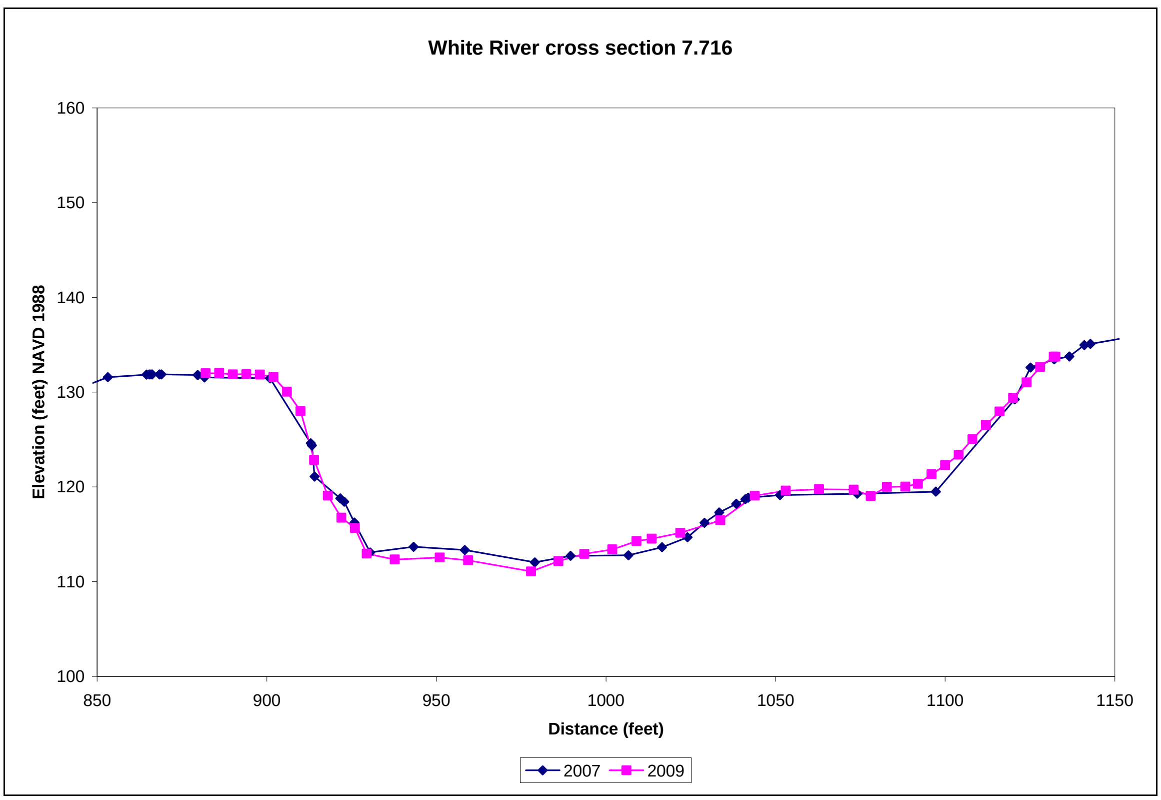

White River cross section 7.170 [Old RM 7.09; Auburn #13]
Elevation (feet) NAVD88
125
120
115
110
105
100
95
90
85
0
50
100
150
200
250
300
350
400
Distance (feet)
1977
1984
1986
2001
2007
2009

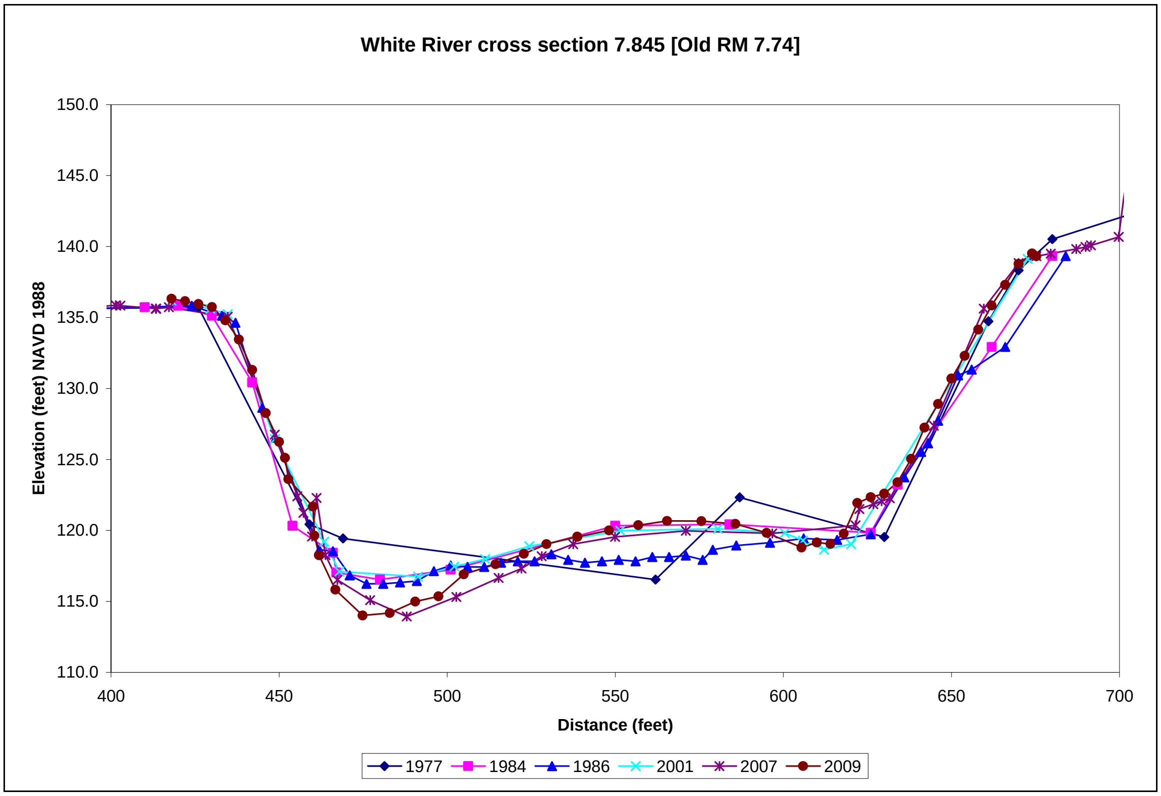

White River cross section 7.252 [Auburn #9]
Elevation (feet) NAVD 1988
125
120
115
110
105
100
95
0
50
100
150
200
250
300
350
Distance (feet)
2001
2007
2009

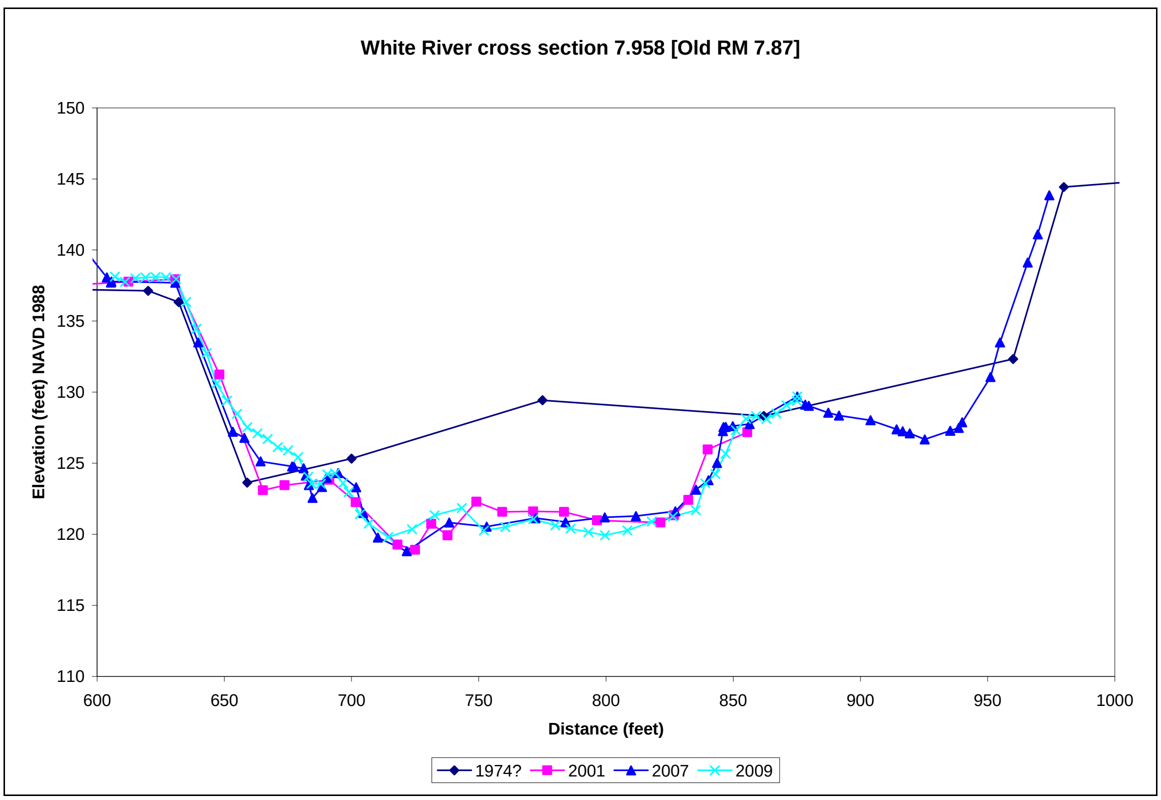

White River cross section 7.368 [Auburn #10]
Elevation (feet) NAVD1988
135
130
125
120
115
110
105
100
95
0
50
100
150
200
250
300
Distance (feet)
2001
2007
2009

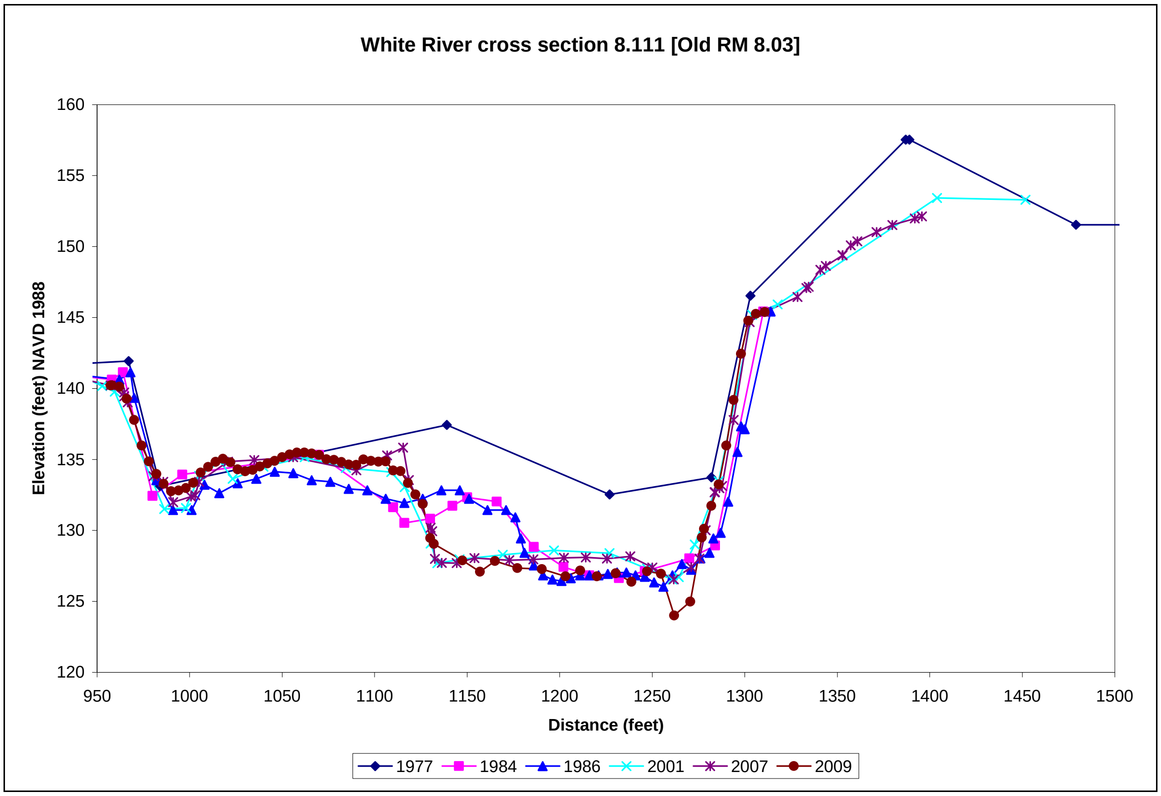

White River cross section 7.511 [Old RM 7.40; Auburn #11]
Elevation (feet) NAVD 1988
140
135
130
125
120
115
110
105
100
100
150
200
250
300
350
400
450
500
Distance (feet)
1977
1984
1986
2001
2007
2009

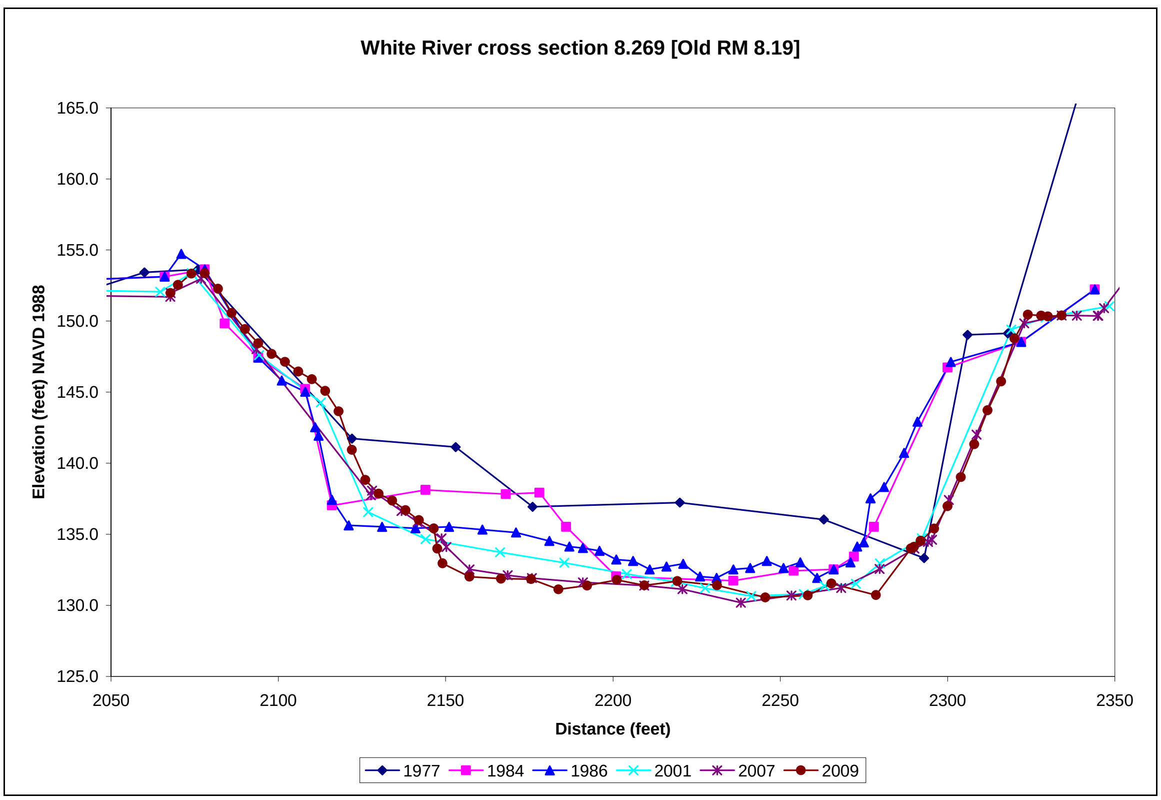

White River cross section 7.593 [Old RM 7.51; Auburn #12]
Elevation (feet) NAVD 1988
140
135
130
125
120
115
110
105
100
400
450
500
550
600
650
700
750
800
Distance (feet)
1977
1984
1986
2001
2007
2009

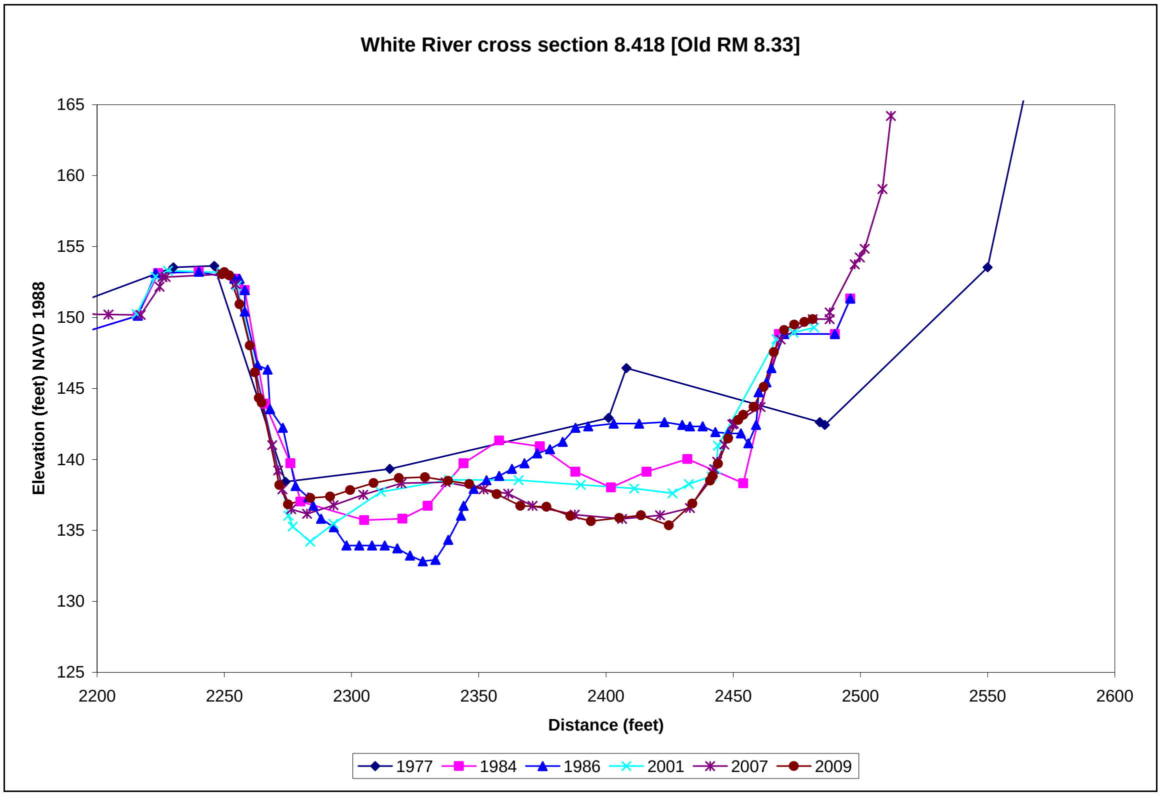

White River cross section 7.716
Elevation (feet) NAVD 1988
160
150
140
130
120
110
100
850
900
950
1000
1050
1100
1150
Distance (feet)
2007
2009

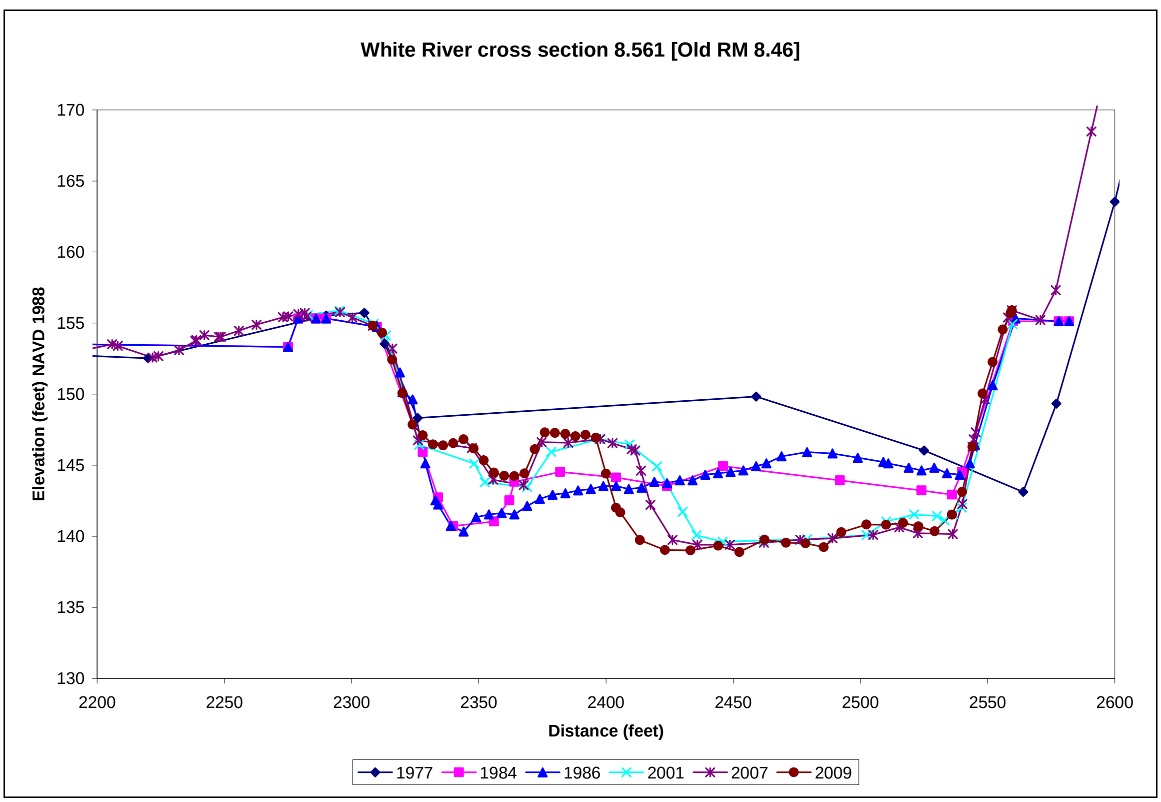

White River cross section 7.845 [Old RM 7.74]
Elevation (feet) NAVD 1988
150.0
145.0
140.0
135.0
130.0
125.0
120.0
115.0
110.0
400
450
500
550
600
650
700
Distance (feet)
1977
1984
1986
2001
2007
2009

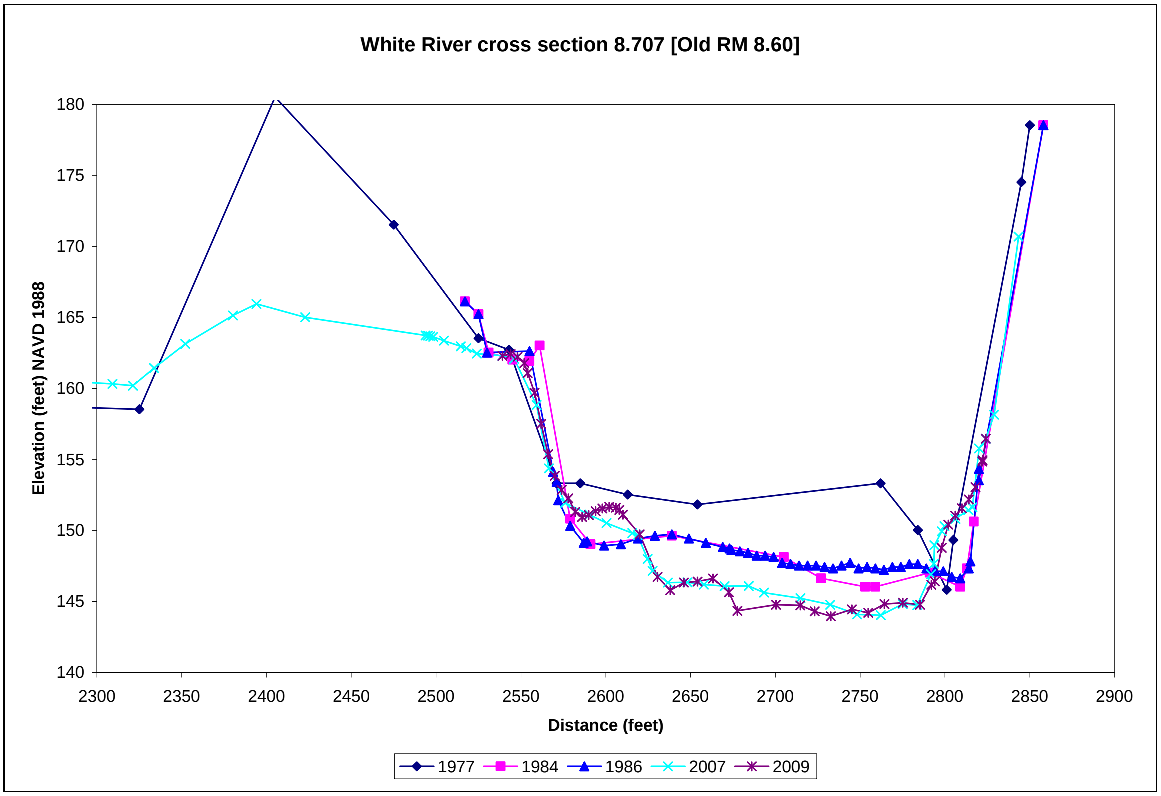

White River cross section 7.958 [Old RM 7.87]
Elevation (feet) NAVD 1988
150
145
140
135
130
125
120
115
110
600
650
700
750
800
850
900
950
1000
Distance (feet)
1974?
2001
2007
2009

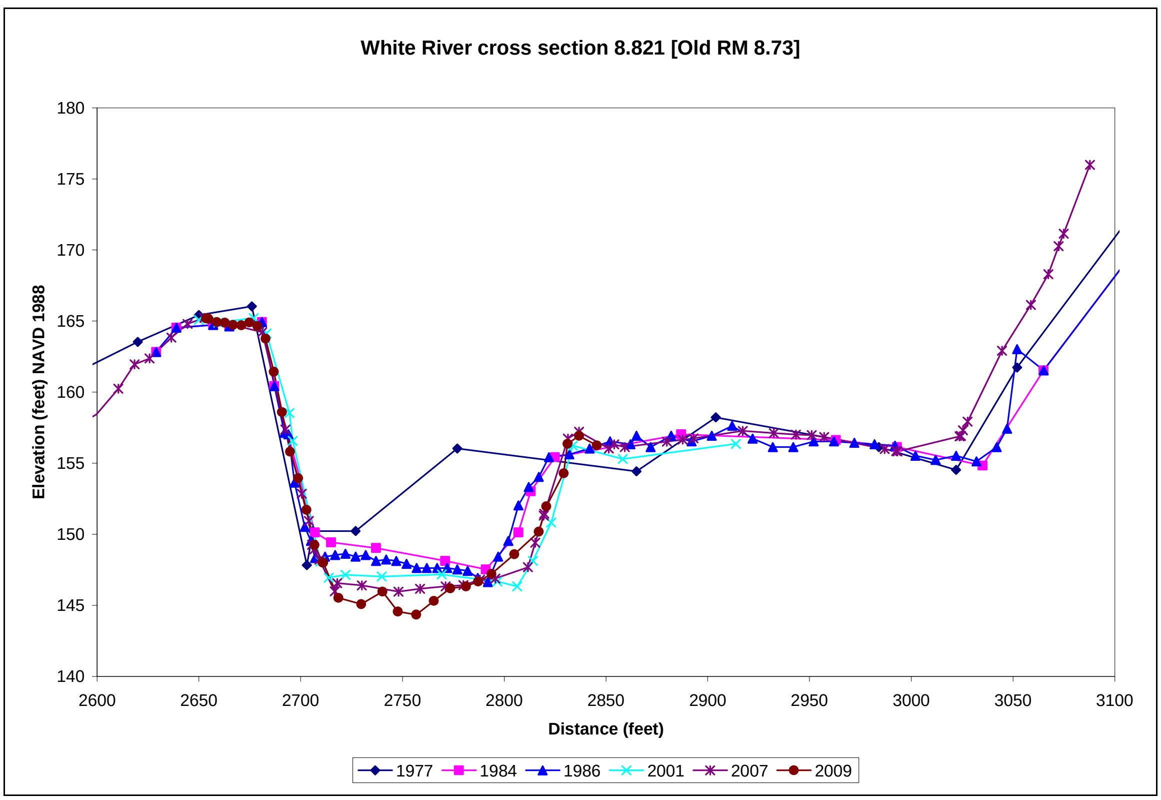

White River cross section 8.111 [Old RM 8.03]
Elevation (feet) NAVD 1988
160
155
150
145
140
135
130
125
120
950
1000
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
Distance (feet)
1977
1984
1986
2001
2007
2009

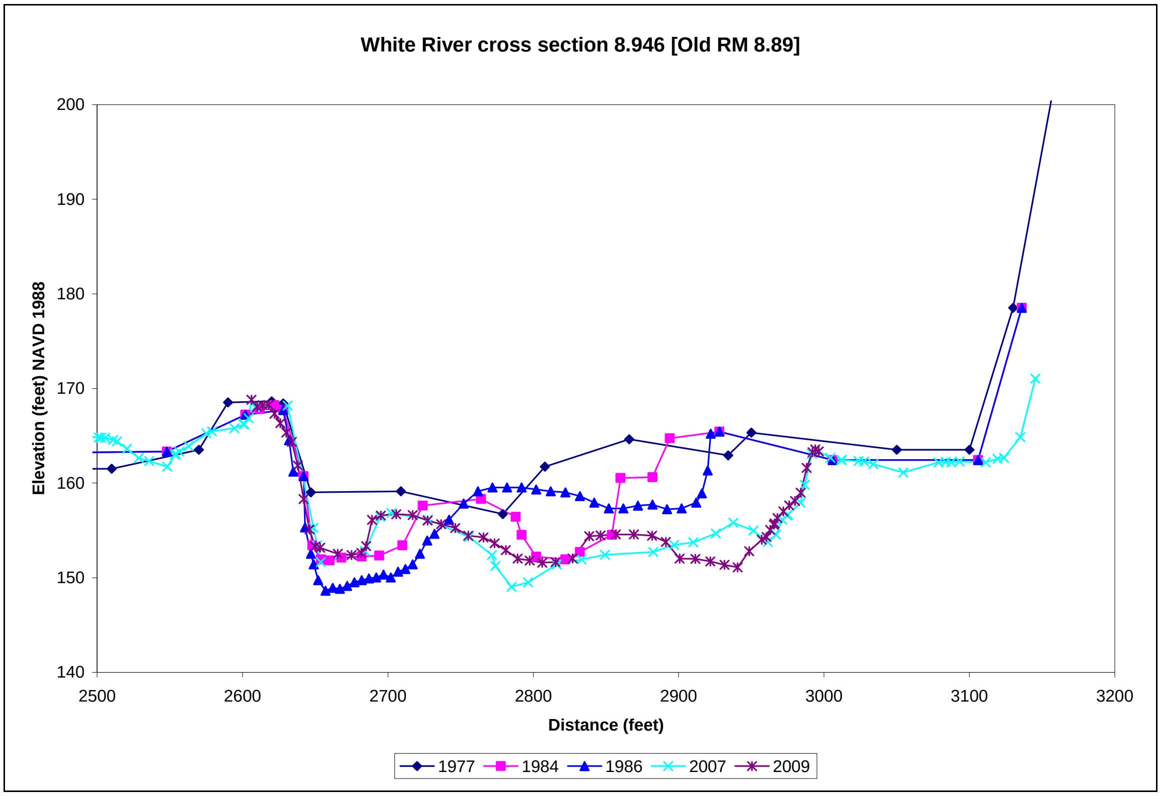

White River cross section 8.269 [Old RM 8.19]
Elevation (feet) NAVD 1988
165.0
160.0
155.0
150.0
145.0
140.0
135.0
130.0
125.0
2050
2100
2150
2200
2250
2300
2350
Distance (feet)
1977
1984
1986
2001
2007
2009

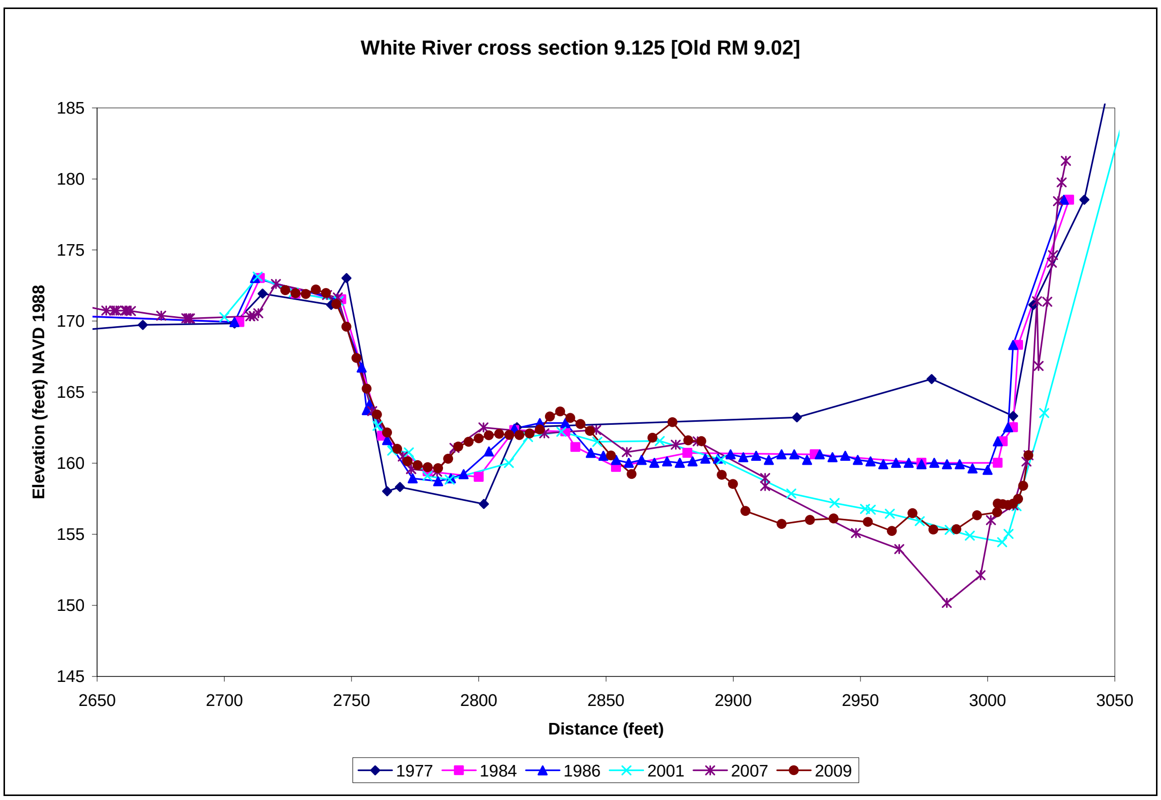

White River cross section 8.418 [Old RM 8.33]
Elevation (feet) NAVD 1988
165
160
155
150
145
140
135
130
125
2200
2250
2300
2350
2400
2450
2500
2550
2600
Distance (feet)
1977
1984
1986
2001
2007
2009

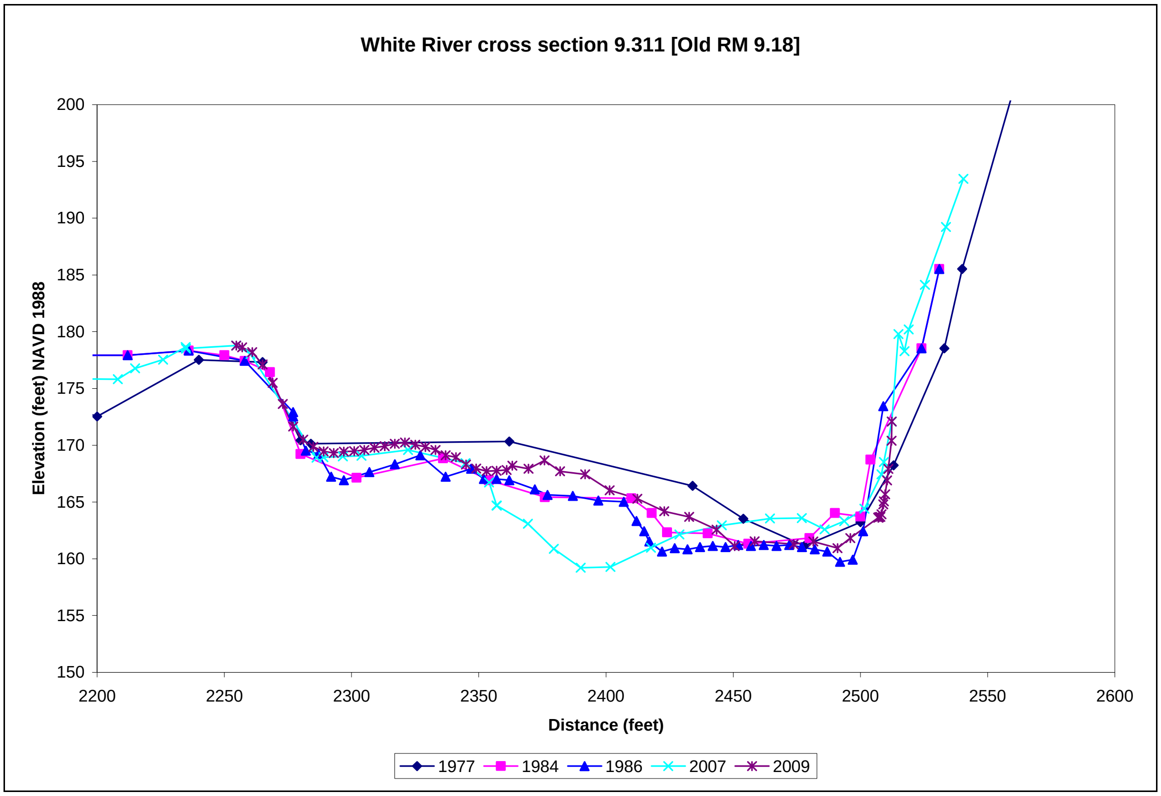

White River cross section 8.561 [Old RM 8.46]
Elevation (feet) NAVD 1988
170
165
160
155
150
145
140
135
130
2200
2250
2300
2350
2400
2450
2500
2550
2600
Distance (feet)
1977
1984
1986
2001
2007
2009

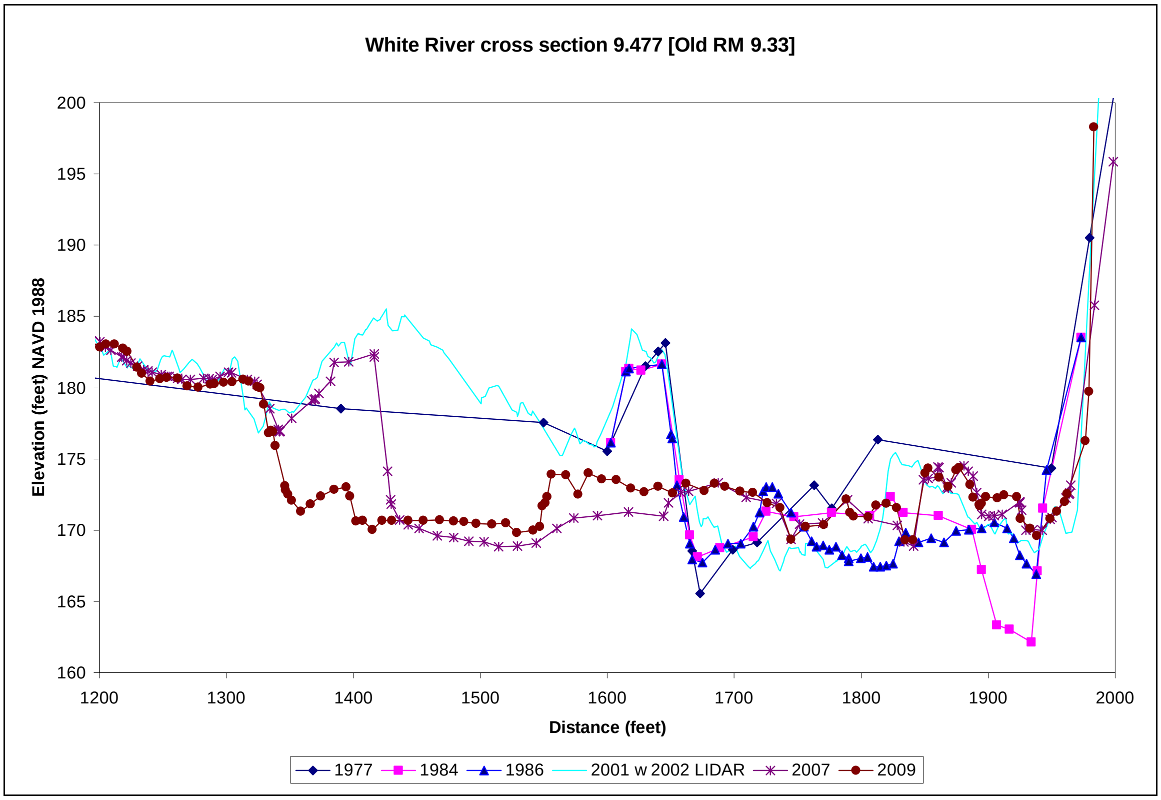

White River cross section 8.707 [Old RM 8.60]
Elevation (feet) NAVD 1988
Distance (feet)
1977
1984
1986
2007
2009

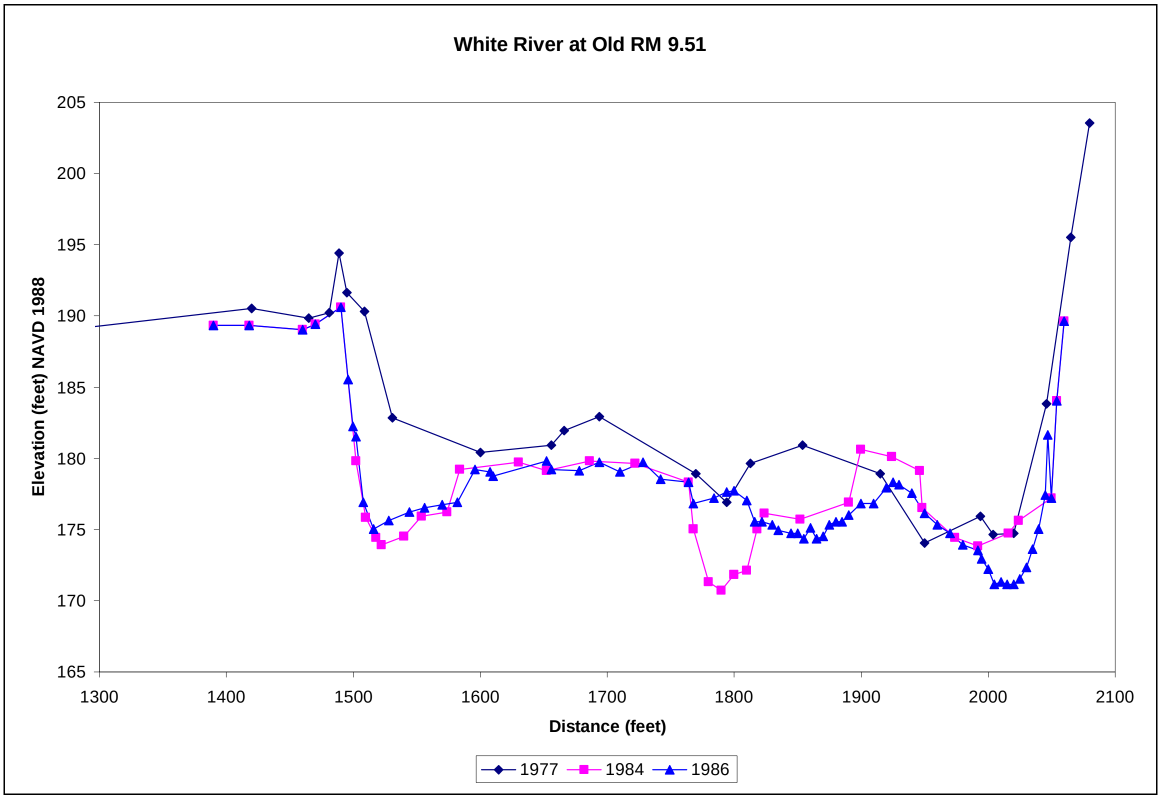

White River cross section 8.821 [Old RM 8.73]
Elevation (feet) NAVD 1988
Distance (feet)
1977
1984
1986
2001
2007
2009

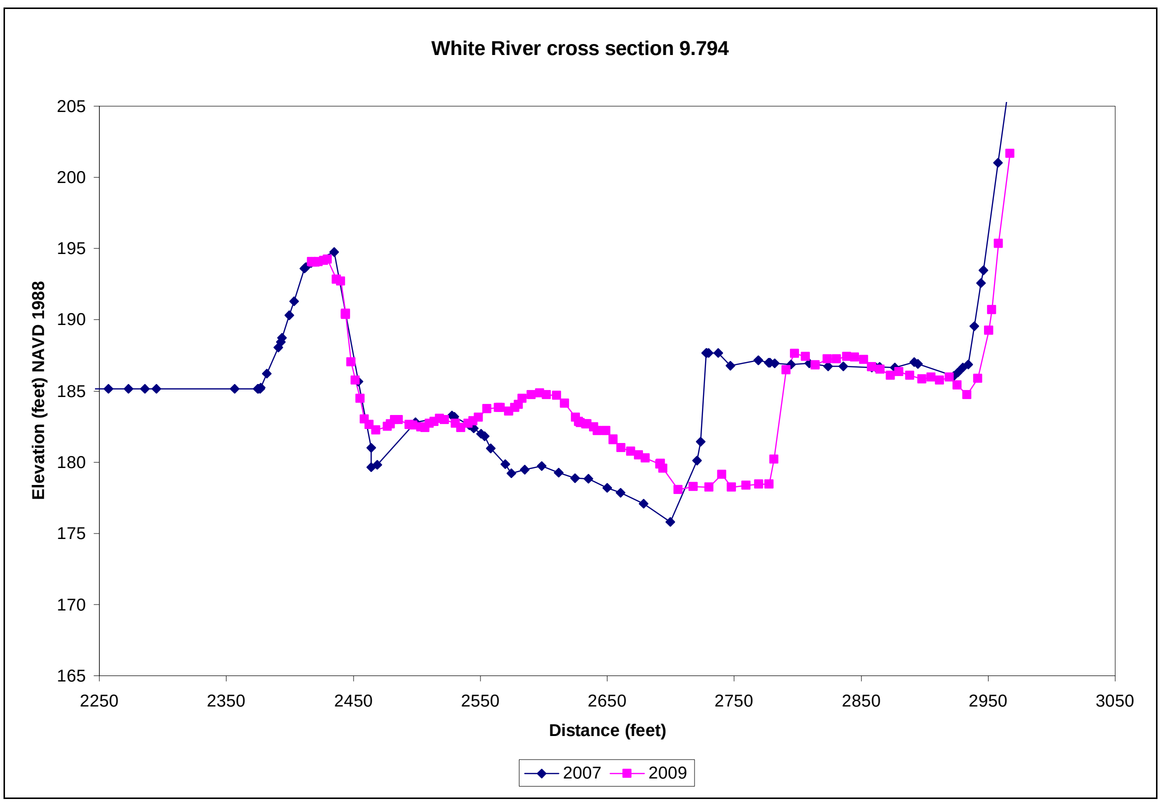

White River cross section 8.946 [Old RM 8.89]
Elevation (feet) NAVD 1988
200
190
180
170
160
150
140
2500
2600
2700
2800
2900
3000
3100
3200
Distance (feet)
1977
1984
1986
2007
2009

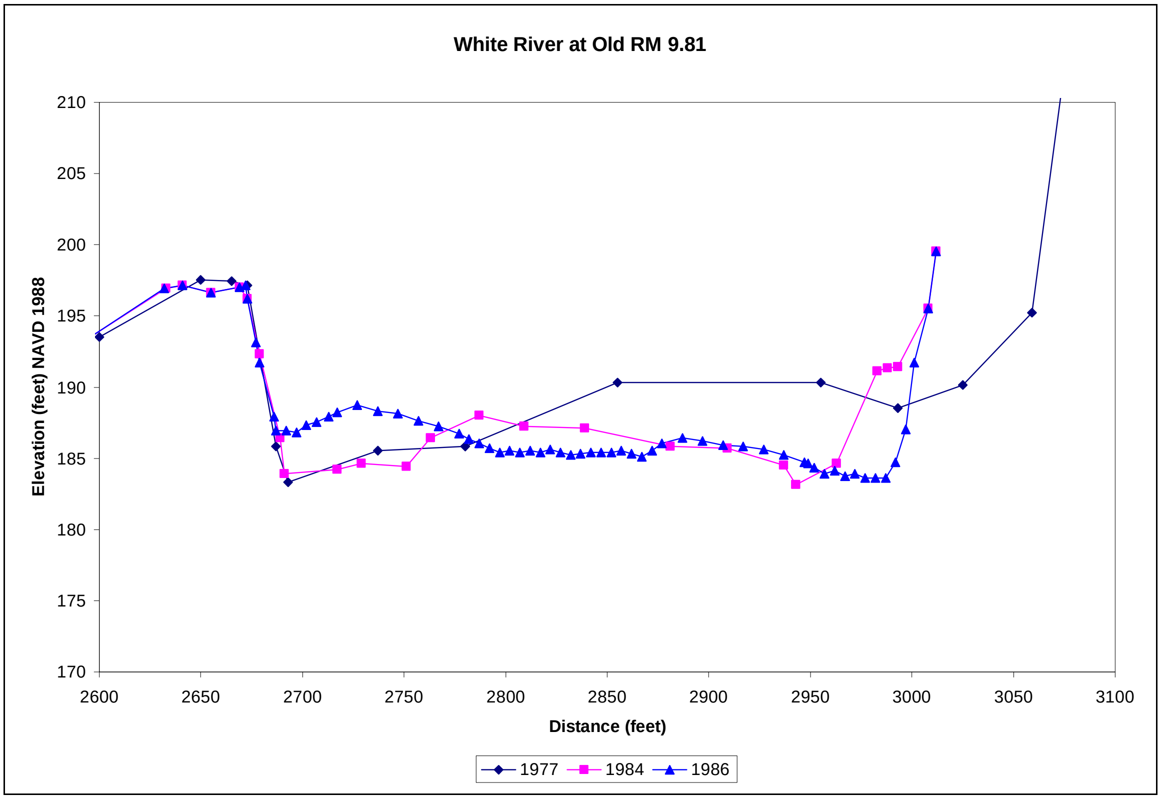

White River cross section 9.125 [Old RM 9.02]
Elevation (feet) NAVD 1988
185
180
175
170
165
160
155
150
145
2650
2700
2750
2800
2850
2900
2950
3000
3050
Distance (feet)
1977
1984
1986
2001
2007
2009

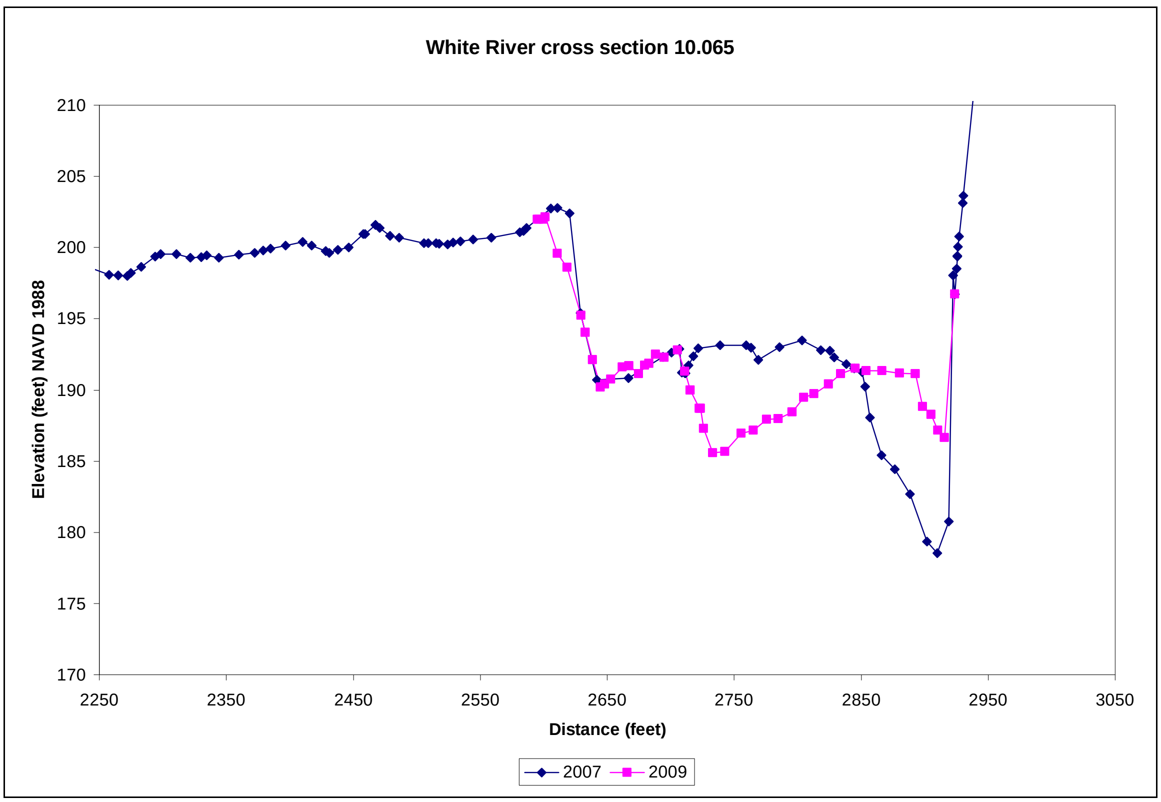

White River cross section 9.311 [Old RM 9.18]
Elevation (feet) NAVD 1988
200
195
190
185
180
175
170
165
160
155
150
2200
2250
2300
2350
2400
2450
2500
2550
2600
Distance (feet)
1977
1984
1986
2007
2009

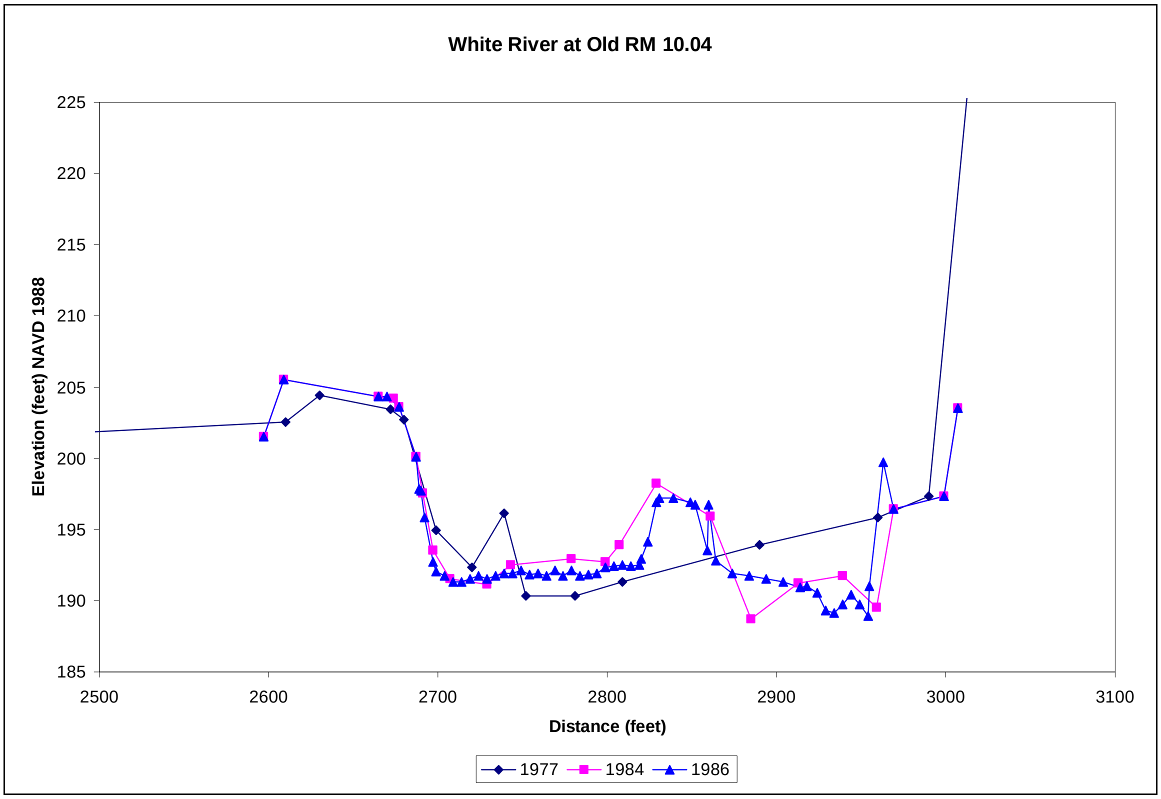

White River cross section 9.477 [Old RM 9.33]
Elevation (feet) NAVD 1988
200
195
190
185
180
175
170
165
160
1200
1300
1400
1500
1600
1700
1800
1900
2000
Distance (feet)
1977
1984
1986
2001 w 2002 LIDAR
2007
2009

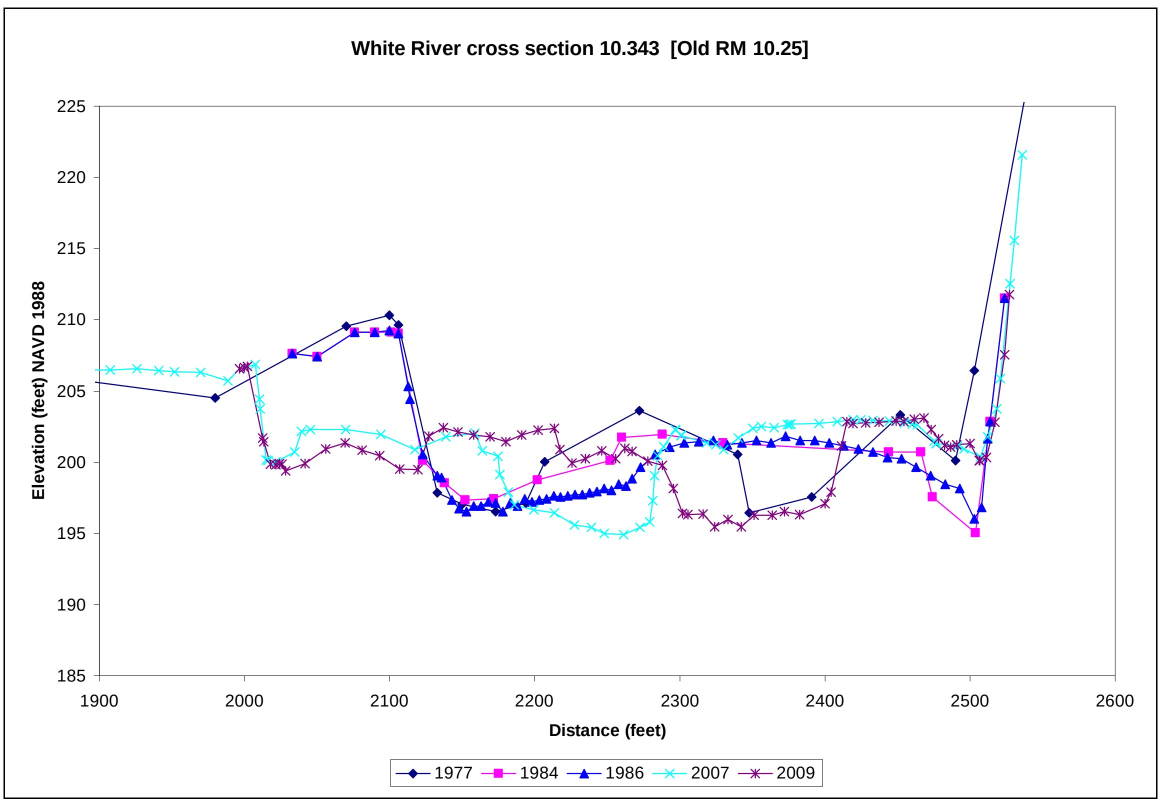

White River at Old RM 9.51
205
200
195
190
185
180
175
170
165
Elevation (feet) NAVD 1988
1300
1400
1500
1600
1700
1800
1900
2000
2100
Distance (feet)
1977
1984
1986

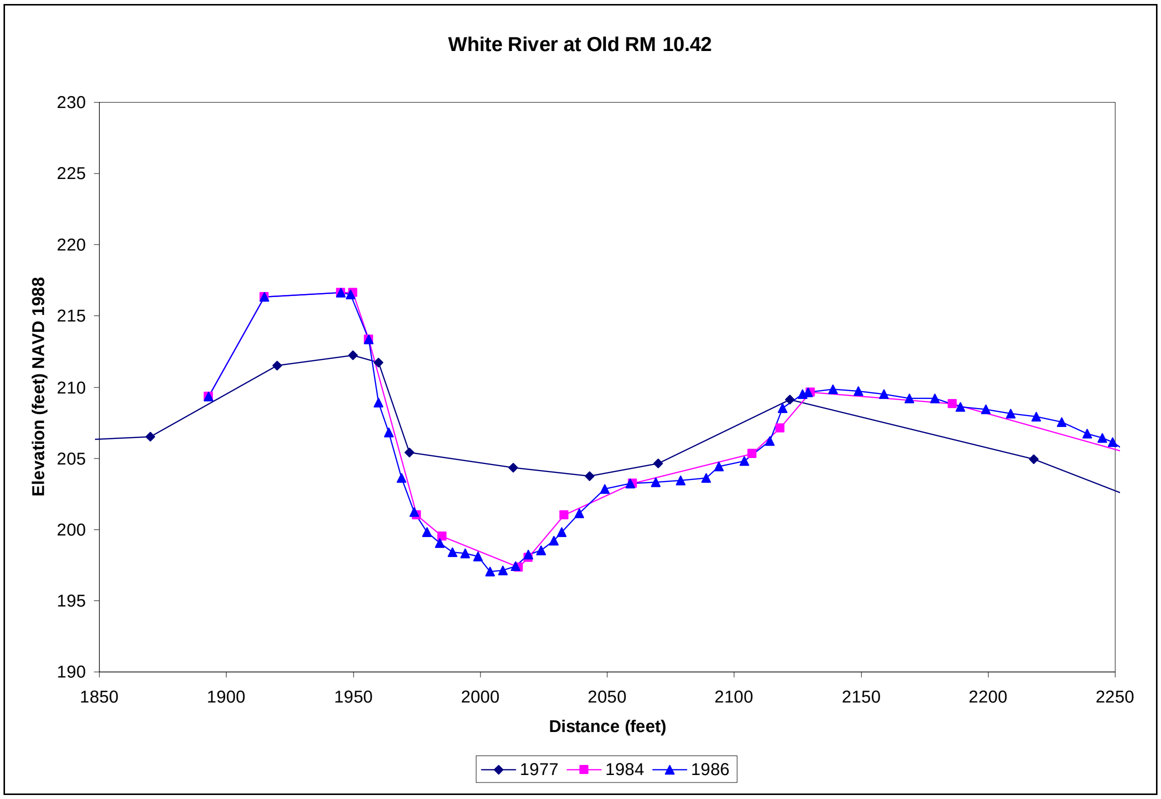

White River cross section 9.794
205
200
195
190
185
180
175
170
165
Elevation (feet) NAVD 1988
2250
2350
2450
2550
2650
2750
2850
2950
3050
Distance (feet)
2007
2009

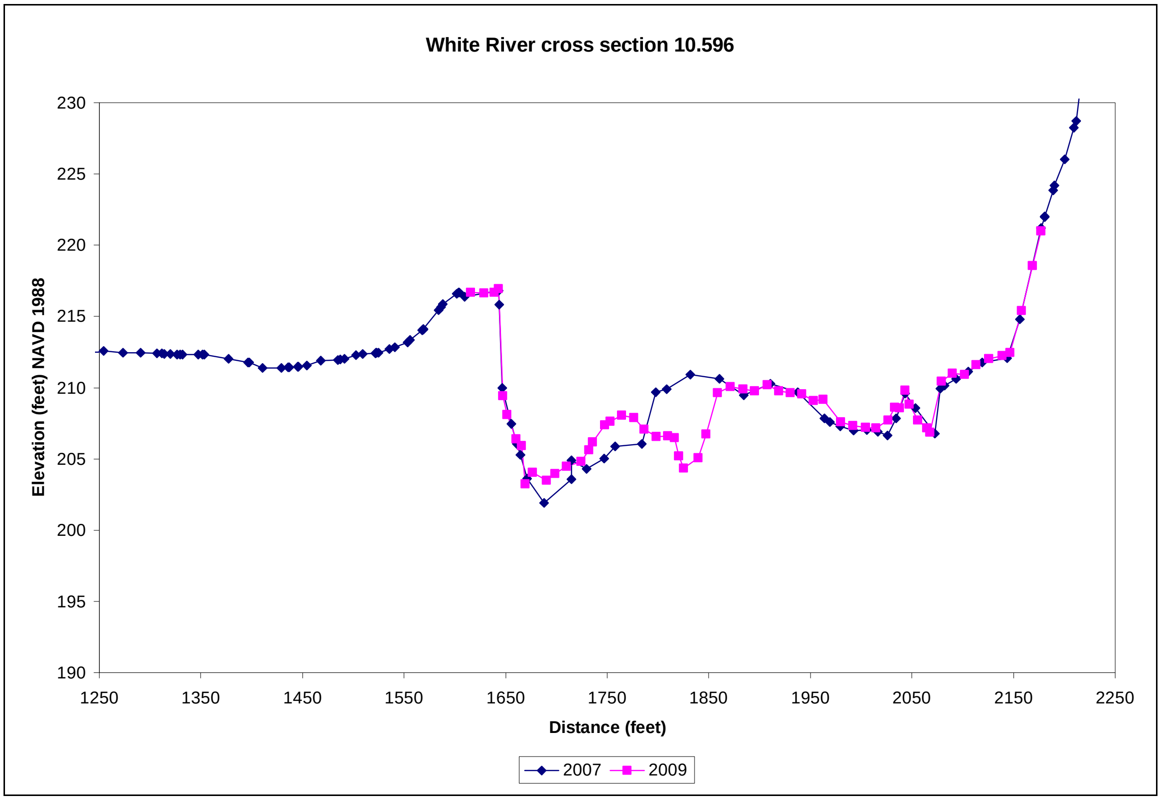

White River at Old RM 9.81
Elevation (feet) NAVD 1988
Distance (feet)
210
205
200
195
190
185
180
175
170
2600
2650
2700
2750
2800
2850
2900
2950
3000
3050
3100
1977
1984
1986

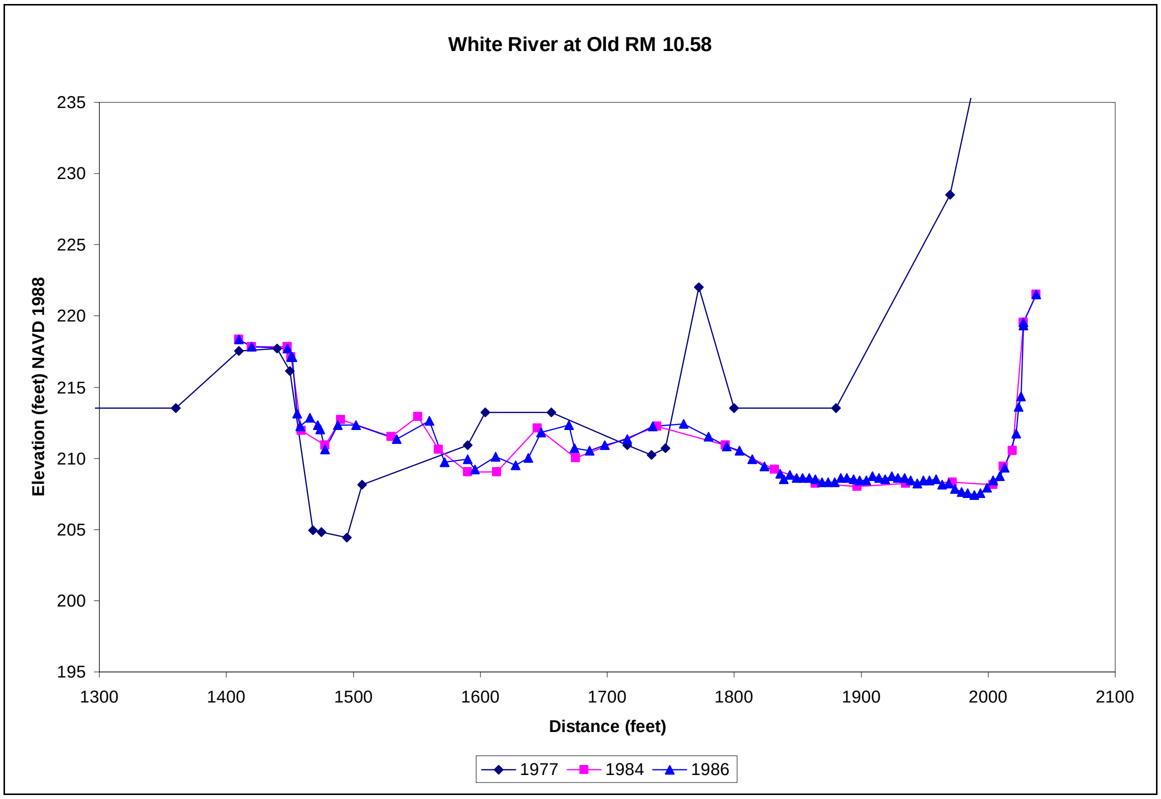

White River cross section 10.065
Elevation (feet) NAVD 1988
Distance (feet)
210
205
200
195
190
185
180
175
170
2250
2350
2450
2550
2650
2750
2850
2950
3050
2007
2009


White River at Old RM 10.04
Elevation (feet) NAVD 1988
225
220
215
210
205
200
195
190
185
2500
2600
2700
2800
2900
3000
3100
Distance (feet)
1977
1984
1986


White River cross section 10.343 [Old RM 10.25]
Elevation (feet) NAVD 1988
225
220
215
210
205
200
195
190
185
1900
2000
2100
2200
2300
2400
2500
2600
Distance (feet)
1977
1984
1986
2007
2009


White River at Old RM 10.42
Elevation (feet) NAVD 1988
230
225
220
215
210
205
200
195
190
1850
1900
1950
2000
2050
2100
2150
2200
2250
Distance (feet)
1977
1984
1986


White River cross section 10.596
Elevation (feet) NAVD 1988
230
225
220
215
210
205
200
195
190
1250
1350
1450
1550
1650
1750
1850
1950
2050
2150
2250
Distance (feet)
2007
2009


White River at Old RM 10.58
Elevation (feet) NAVD 1988
235
230
225
220
215
210
205
200
195
1300
1400
1500
1600
1700
1800
1900
2000
2100
Distance (feet)
1977
1984
1986

APPENDIX C

White River Cross-section Data Tables
(Cross-section 4.44 to Cross-section 10.596)

Table C-1. Lower White River visual aggradation analysis by cross-section.

2009 River Mile	1974	1977	1984	1986	1994	2001	2007	2009	Net Aggradation
4.440	Baseline	Aggradation		Degradation		No Change		Aggradation	Aggradation
4.560	Baseline	Aggradation				Aggradation			Aggradation
4.700									
4.978				Baseline		Aggradation	No Change	Aggradation	Aggradation
	8th St. Bridge								
4.998							Baseline	Degradation	Degradation
5.041							Baseline	Aggradation	Aggradation
5.123	Baseline				Aggradation	Degradation	Aggradation	Aggradation	Aggradation
5.197							Baseline	Aggradation	Aggradation
5.292	Baseline	No Change				Aggradation	Aggradation	Aggradation	Aggradation
5.374							Baseline	Aggradation	Aggradation
5.460	Baseline	Aggradation				Aggradation	Aggradation	Aggradation	Aggradation
5.517							Baseline	Aggradation	Aggradation
5.589							Baseline	Aggradation	Aggradation
5.621	Baseline	Degradation	Degradation	Aggradation		Aggradation	Aggradation	Aggradation	Aggradation
5.712							Baseline	Aggradation	Aggradation
5.822	Baseline					No Change	No Change	Aggradation	Aggradation
5.920							Baseline	Aggradation	Aggradation
6.013							Baseline	Aggradation	Aggradation
6.077	Baseline			Degradation		Aggradation	Aggradation	Aggradation	Aggradation
6.145							Baseline	Aggradation	Aggradation
6.233							Baseline	Aggradation	Aggradation
6.313						Baseline	No Change	Aggradation	Aggradation
6.326	Baseline					No Change	Degradation	Aggradation	No Change
	A Street Bridge								
6.390						Baseline	Degradation	No Change	Aggradation
6.482				Basline			No Change	Aggradation	Aggradation
6.569						Baseline	No Change	Aggradation	Aggradation
6.647						Baseline	Aggradation	Aggradation	Aggradation
6.761				Baseline			Aggradation	Aggradation	Aggradation
6.891						Baseline	Aggradation	Aggradation	Aggradation
7.001						Baseline	Aggradation	No Change	Aggradation
7.087						Baseline	Aggradation	Aggradation	Aggradation
7.170				Baseline			Aggradation	Aggradation	Aggradation
7.252						Baseline	Aggradation	Aggradation	Aggradation
7.368						Baseline	Aggradation	Aggradation	Aggradation
7.511				Basline			Aggradation	Aggradation	Aggradation
7.593						Baseline	Aggradation	No Change	Aggradation
7.608		Baseline		Degradation		Aggradation	No Change		Aggradation
	R Street Bridge								
7.716							Baseline	No Change	No Change
7.845	Baseline			Aggradation		No Change	Degradation	Degradation	No Change
7.958	Baseline					Degradation	No Change	Degradation	Degradation
8.111						Baseline	Degradation	Degradation	Degradation
8.269						Baseline	Degradation	Degradation	Degradation
8.418						Baseline	Degradation	Degradation	Degradation
8.561						Baseline	Degradation	Degradation	Degradation
8.821						Baseline	Degradation	Degradation	Degradation
9.125						Baseline	Aggradation	No Change	Aggradation
9.311									
9.477						Baseline	Aggradation	No Change	Aggradation
9.794							Baseline	No Change	No Change
10.065							Baseline	No Change	No Change
10.343							Baseline	No Change	No Change
10.596							Baseline	Degradation	Degradation

Table C-2. Lower White River thalweg profile data by cross-section (Elevation NAVD 88).

HECRAS River Station	1974/77	HECRAS River Station	1984	HECRAS River Station	2001	HECRAS River Station	2007	HECRAS River Station	2009
5.621	65.6	4.978	53.93	5.123	56.8	4.978	55.95	4.440	53.75
5.822	69.2	5.292	61.63	5.292	57.3	4.998	58.2	4.978	59.520
6.077	74.5	5.621	62.83	5.460	63.0	5.041	57.75	4.998	58.530
6.326	78.5	6.077	69.43	5.621	65.0	5.123	57.58	5.041	60.430
6.390	78.5	6.482	79.13	5.822	69.7	5.197	61.55	5.123	57.640
6.482	80.0	6.891	87.43	6.077	73.1	5.292	60.58	5.197	63.380
6.569	79.8	7.170	97.93	6.313	80.4	5.374	64.07	5.292	62.230
6.891	89.1	7.511	107.23	6.326	80.2	5.460	59.9	5.374	65.570
7.001	95.7	7.593	108.93	6.390	81.4	5.517	67.08	5.460	65.720
7.170	100.2	7.845	116.53	6.482	83.6	5.589	67.09	5.517	64.830
7.368	106.3	8.111	126.63	6.569	86.7	5.621	67.75	5.589	69.520
7.550	113.5	8.269	131.73	6.647	87.7	5.712	67.99	5.621	69.570
7.608	111.6	8.418	135.73	6.761	87.8	5.822	69.7	5.712	71.380
7.621	117.3	8.561	140.73	6.891	93.2	5.920	73.05	5.822	72.350
7.845	121.4	8.821	147.53	7.001	94.1	6.013	70.77	5.920	73.920
8.111	130.2	9.125	159.03	7.087	95.6	6.077	76.02	6.013	72.520
8.269	136.1	9.477	162.13	7.170	94.9	6.145	77.55	6.077	77.020
8.418	138.43	9.510	170.73	7.252	100.4	6.223	77.37	6.145	78.470
8.561	143.13	9.810	183.13	7.368	104.4	6.313	76.71	6.233	76.920
8.707	145.83	10.065	188.73	7.511	108.7	6.326	74.99	6.313	79.030
8.821	147.83	10.343	195.03	7.608	109.6	6.341	74.99	6.326	78.420
8.946	156.73	10.420	197.33	7.845	116.8	6.343	74.99	6.390	80.510
9.125	157.13	10.580	208.03	7.958	118.9	6.363	74.99	6.482	79.510
9.311	161.13			8.111	126.5	6.390	80.02	6.569	86.040
9.477	165.53			8.269	130.7	6.482	79.66	6.647	87.350
9.51	174.03			8.418	134.2	6.569	84.45	6.761	89.230
9.81	183.33			8.561	139.6	6.647	86.7	6.891	94.210
10.065	190.33			8.821	146.3	6.761	87.56	7.001	92.290
10.343	196.43			9.126	154.4	6.891	93.96	7.087	100.530
10.42	201.63			9.477	166.5	7.001	92.04	7.170	100.820
10.58	204.43					7.087	98.92	7.252	102.230
						7.170	96.73	7.368	103.120
						7.252	101.59	7.511	109.620
						7.368	103.19	7.593	110.850
						7.511	108.72	7.716	111.080
						7.593	110.53	7.845	114.010
						7.608	110.53	7.958	119.930
						7.628	110.53	8.111	124.000
						7.716	112.03	8.269	130.730
						7.845	113.94	8.418	135.360
						7.958	118.8	8.561	139.030
						8.111	126.55	8.821	144.340
						8.269	130.18	9.125	155.230
						8.418	135.81	9.311	160.930
						8.561	139.4	9.477	169.310
						8.707	144.04	9.794	178.080
						8.821	145.96	10.065	185.590
						8.946	149.03	10.343	195.480
						9.126	150.17	10.596	203.600
						9.311	159.21		
						9.477	168.83		
						9.794	175.81		
						10.065	178.53		
						10.343	194.91		
						10.596	201.89		

Table C-3. Changes in Lower White River sediment volumes, 2007 to 2009.

Previous River Miles or X Section Label	HECRAS River Station	HECRAS Distance between cross sections (feet)	Change in area at each RS xsection. Channel, Bars ONLY (sq ft)	AVERAGE change in area at adjacent xsections. Channel, Bars ONLY (sq ft)	Change in volume betw adjacent xsections. Channel, Bars ONLY (cu yd)	AVERAGE ANNUAL Change in volume Channel, Bars ONLY (cu yd/year)	Channel Width using TOB to TOB or Ch Stas as approp (ft)	Vertical Change at each xsection 2007 to 2009 (ft)
4.92	4.978	0	298				182	1.6
8th St Br	4.988							
	4.998	104	-142	78	299	150	227	-0.6
	5.041	227	248	53	444	222	354	0.7
5.04	5.123	434	353	301	4,831	2416	451	0.8
	5.197	390	424	388	5,612	2806	498	0.9
5.2	5.292	504	229	327	6,096	3048	325	0.7
	5.374	431	229	229	3,661	1831	272	0.8
5.36	5.460	453	434	332	5,562	2781	225	1.9
	5.517	303	132	283	3,176	1588	219	0.6
	5.589	380	207	170	2,388	1194	223	0.9
5.52	5.621	167	439	323	1,996	998	241	1.8
	5.712	483	355	397	7,096	3548	253	1.4
5.7	5.822	582	175	265	5,711	2855	249	0.7
	5.920	516	196	185	3,545	1772	274	0.7
	6.013	488	211	203	3,676	1838	228	0.9
5.97	6.077	342	118	164	2,082	1041	247	0.5
	6.145	356	176	147	1,936	968	253	0.7
	6.223	413	239	207	3,173	1587	246	1.0
USGS	6.313	477	133	186	3,283	1642	204	0.7
d/s A Str	6.326	65	250	191	460	230	171	1.5
A Str Br								
Aub 1	6.390	**338**	172	211	2,638	1319	260	0.7
Aub 2	6.482	485	158	165	2,958	1479	342	0.5
Aub 3	6.569	462	498	328	5,613	2806	458	1.1
Aub 4	6.647	409	172	335	5,076	2538	350	0.5
Aub 5	6.761	605	163	167	3,752	1876	368	0.4
Aub 6	6.891	687	277	220	5,598	2799	344	0.8
Aub 7	7.001	580	113	195	4,194	2097	307	0.4
Aub 8	7.087	456	282	198	3,342	1671	258	1.1
Aub 13	7.170	435	178	230	3,712	1856	221	0.8
Aub 9	7.252	436	34	106	1,718	859	189	0.2
Aub 10	7.368	610	-27	4	85	42	166	-0.2
Aub 11	7.511	757	79	26	728	364	177	0.4
Aub 12	7.593	434	28	53	855	428	196	0.1
R Str Br								
	7.716	**649**	-26	1	24	12	183	-0.1
7.74	7.845	683	56	15	380	190	196	0.3
7.87	7.958	597	20	38	835	417	189	0.1
8.03	8.111	808	-110	-45	-1,358	-679	298	-0.4
8.19	8.269	837	-13	-62	-1,910	-955	181	-0.1
8.33	8.418	785	26	7	191	95	195	0.1
8.46	8.561	756	-85	-29	-822	-411	177	-0.5
	8.707	766	-40	-62	-1,765	-882	240	-0.2
8.73	8.821	603	-35	-38	-839	-420	139	-0.3
	8.946	662	95	30	736	368	353	0.3
9.02	9.125	945	91	93	3,257	1629	261	0.3
	9.311	983	285	188	6,834	3417	255	1.1
9.33	9.477*	872	782	533	17,227	8614	500	1.6
	9.794	1677	140	461	28,634	14317	504	0.3
	10.065	1430	-148	-4	-224	-112	294	-0.5
	10.343	1469	-262	-205	-11,166	-5583	511	-0.5
	10.596	1331	-88	-175	-8,632	-4316	450	-0.2

2007 - 2009 Totals by Study Reach

Reach Number	Length River Miles	Reach	07 to 09 VOLUME (cu yd)	Annual RATE (cu yd/yr)	Rate per Distance (cy/yr/RM)	Ave Elev (ft)
1	1.272	X-S 4.988 to X-S 6.326	65,028	32,514	25,561	0.87
2	1.203	X-S 6.390 to X-S 7.593	40,269	20,135	16,737	0.52
3	0.553	X-S 7.716 to X-S 8.269	-2,029	-1,014	-1,834	-0.11
4	1.042	X-S 8.269 to X-S 9.311	7,591	3,796	3,643	0.58
5	1.285	X-S 9.311 to X-S 10.596*	25,839	12,920	10,054	0.13

*Significant bank failure between 2001 and 2007, and 2007 and 2009 at cross-section 9.477 required a modified calculation of changes in aggradation volume and depth in reach 5. In-channel aggradation and overbank erosion are differentiated here. Reach 5, X-S 9.311 to Williams Pipeline, totals include in-channel aggradation only.

Table C-4. Changes in Lower White River sediment volumes, 2001 to 2007

Previous River Miles or X Section Label	HECRAS River Station	Distance between cross sections (feet)	Change in area at each cross section (sq ft)	AVERAGE change in area at adjacent cross sections (sq ft)	Change in volume betw adjacent cross sections (cu yd)	AVERAGE ANNUAL Change in volume (cu yd/year)	Channel Width using edges of change in xs area (ft)	Elevation Change at each xsection 2001 to 2007 (ft)
4.92	4.978	**100**	42	42	157	26	167	0.3
d/s 8th Br	4.988							
8th St Br								
5.04	5.123	766	1100	571	16,201	2,700	429	2.6
5.2	5.292	892	494	797	26,340	4,390	262	1.9
5.36	5.460	887	225	359	11,800	1,967	203	1.1
5.52	5.621	850	423	324	10,200	1,700	217	1.9
5.7	5.822	1061	450	436	17,157	2,859	231	1.9
5.97	6.077	1346	316	383	19,100	3,183	218	1.4
USGS	6.313	1246	82	199	9,202	1,534	157	0.5
d/s A Str	6.326	69	-31	26	65	11	161	-0.2
A Str Br	**6.353**							
Aub 1	6.390	338	-132	-82	-1,023	-170	210	-0.6
Aub 2	6.482	485	140	4	67	11	321	0.4
Aub 3	6.569	462	40	90	1,541	257	425	0.1
Aub 4	6.647	409	188	114	1,731	289	327	0.6
Aub 5	6.761	605	272	230	5,157	860	353	0.8
Aub 6	6.891	687	298	285	7,251	1,208	336	0.9
Aub 7	7.001	580	183	240	5,164	861	269	0.7
Aub 8	7.087	456	303	243	4,103	684	234	1.3
Aub 13	7.170	435	264	284	4,571	762	207	1.3
Aub 9	7.252	436	144	204	3,297	549	182	0.8
Aub 10	7.368	610	93	118	2,676	446	131	0.7
Aub 11	7.511	757	108	100	2,810	468	160	0.7
Aub 12	7.593	434	96	102	1,633	272	146	0.7
R Str Br	**7.618**							
7.74	7.845	1331	-117	-11	-526	-88	160	-0.7
7.87	7.958	597	-1	-59	-1,307	-218	199	0.0
8.03	8.111	808	28	14	406	68	314	0.1
8.19	8.269	834	-83	-27	-842	-140	162	-0.5
8.33	8.418	787	-108	-95	-2,781	-464	170	-0.6
8.46	8.561	755	-61	-84	-2,355	-393	214	-0.3
8.73	8.821	1373	-45	-53	-2,676	-446	109	-0.4
9.02	9.125	1605	-85	-65	-3,846	-641	257	-0.3
9.33	9.477*	1859	716	316	21,749	3,625	286	2.5033

2001 - 2007 Totals by Study Reach

Reach Number	Length River Miles	Reach	01 to 07 VOLUME (cu yd)	Annual RATE (cu yd/yr)	Rate per Distance (cy/yr/RM)	Ave Elev (ft)
1	1.272	X-S 4.988 to X-S 6.326	110,066	18,344	14,422	1.4
2	1.203	X-S 6.390 to X-S 7.593	38,979	6,496	5,400	0.6
3	0.553	X-S 7.716 to X-S 8.269	-2,269	-378	-684	-0.3
4	1.042	X-S 8.269 to X-S 9.311	-11,658	-1,943	-1,865	-0.4
5	1.285	X-S 9.311 to X-S 10.596*	21,749	3,625	2,821	2.5

*Significant bank failure between 2001 and 2007, and 2007 and 2009 at cross-section 9.477 required a modified calculation of changes in aggradation volume and depth in reach 5. In-channel aggradation and overbank erosion are differentiated here. Reach 5, X-S 9.311 to Williams Pipeline, totals include in-channel aggradation only.

Table C-5. Changes in Lower White River sediment volumes, 1984 to 2001.

Previous River Miles or X Section Label	HECRAS River Station	Distance between cross sections (ft)	Change in area at each cross section (sq ft)	AVERAGE change in area at adjacent cross sections (sq ft)	Change in volume betw adjacent cross sections (cu yd)	AVERAGE ANNUAL Change in volume (cu yd/year)	Channel Width using edges of change in xs area (ft)	Elevation Change at each xsection 1984 to 2001 (ft)
	4.978							
d/s face 8th Br	4.988	100	470	470	1,740	249	151	3.1
8th St Br	**4.998**							
5.2	5.292	1605	450	460	27,337	1,608	261	1.7
5.52	5.621	1737	429	440	28,279	1,663	211	2.0
5.97	6.077	2408	602	516	45,974	2,704	190	3.2
A Str Br	**6.353**							
Aub 2	6.482	2138	1648	1125	89,108	5,242	317	5.2
Aub 5	6.761	1473	555	1102	60,108	3,536	343	1.6
Aub 13	7.170	2160	169	362	28,947	1,703	211	0.8
Aub 11	7.511	1800	139	154	10,271	604	157	0.9
Aub 12	7.593	434	32	86	1,381	81	149	0.2
R Str Br	**7.618**							
7.74	7.845	1331	-16	8	414	24	168	-0.1
8.03	8.111	1404	-107	-61	-3,192	-188	293	-0.4
8.19	8.269	834	-340	-224	-6,911	-407	160	-2.1
8.33	8.418	787	-101	-221	-6,427	-378	192	-0.5
8.46	8.561	755	-211	-156	-4,367	-257	217	-1.0
8.73	8.821	1373	-245	-228	-11,608	-683	127	-1.9
9.02	9.125	1605	-386	-315	-18,752	-1,103	256	-1.5
9.33	9.477	1859	-220	-303	-20,856	-1,227	275	-0.8

1984 - 2001 Totals by Study Reach

Reach Number	Length River Miles	Reach	84 to 01 VOLUME (cu yd)	Annual RATE (cu yd/yr)	Rate per Distance (cy/yr/RM)	Ave Elev (ft)
1	1.272	X-S 4.988 to X-S 6.326	101,590	5,976	4,698	2.3
2	1.203	X-S 6.390 to X-S 7.593	189,814	11,166	9,281	1.7
3	0.553	X-S 7.716 to X-S 8.269	-9,688	-570	-1,031	-0.9
4	1.042	X-S 8.269 to X-S 9.311	-41,155	-2,421	-2,323	-1.2
5	1.285	X-S 9.311 to X-S 10.596	-20,856	-1,227	-955	-0.8

Table C-6. Changes in Lower White River sediment volumes, 1974/77 to 1984.

Previous River Miles or X Section Label	HECRAS River Station	Distance between cross sections (feet)	Change in area at each cross section (sq ft)	AVERAGE change in area at adjacent cross sections (sq ft)	Change in volume betw adjacent cross sections (cu yd)	AVERAGE ANNUAL Change in volume (cu yd/year)	Channel Width using edges of change in xs area (ft)	Elevation Change at each xsection 1974/79 to 1984 (ft)
4.92	4.978							
d/s face 8th Br	4.988		-421				157	-2.7
8th St Br	**4.998**							
5.2	5.292	1605	-333	-377	-22,412	-2,241	262	-1.3
5.52	5.621	1737	-347	-340	-21,873	-2,187	203	-1.7
5.97	6.077	2408	-569	-458	-40,816	-4,082	190	-3.0
A Str Br	**6.353**							
Aub 2	6.482	2138	-1422	-995	-78,835	-11,262	301	-4.7
Aub 5	6.761	1473	-1693	-1557	-84,972	-12,139	358	-4.7
Aub 13	7.170	2160	-1131	-1412	-112,929	-16,133	220	-5.1
Aub 11	7.511	1800	-316	-724	-48,259	-6,894	160	-2.0
Aub 12	7.593	434	-816	-566	-9,105	-1,301	167	-4.9
R Str Br	**7.618**							
7.74	7.845	1331	5	-405	-19,982	-2,855	170	0.0
8.03	8.111	1404	-1072	-533	-27,737	-3,962	314	-3.4
8.19	8.269	837	-418	-745	-23,100	-3,300	202	-2.1
8.33	8.418	785	-587	-503	-14,616	-2,088	187	-3.1
8.46	8.561	756	-1016	-801	-22,435	-3,205	228	-4.5
8.73	8.821	1373	-366	-691	-35,124	-5,018	237	-1.5
9.02	9.125	1605	-558	-462	-27,455	-3,922	261	-2.1
9.33	9.477	1859	-1089	-823	-56,675	-8,096	297	-3.7
9.51		950	-1360	-1225	-43,105	-6,158	560	-2.4
9.81		1584	-696	-1028	-60,317	-8,617	292	-2.4
10.04		1214	-91	-394	-17,713	-2,530	272	-0.3
10.25	10.343	1109	-58	-75	-3,072	-439	391	-0.1
10.42		898	-185	-122	-4,041	-577	312	-0.6
10.58	10.729	845	256	35	1,110	159	334	0.8

1974/77 to 1984 Totals by Study Reach

Reach Number	Length River Miles	Reach	74/77 to 84 VOLUME (cu yd)	Annual RATE (cu yd/yr)	Rate per Distance (cy/yr/RM)	Ave Elev (ft)
1	1.272	X-S 4.988 to X-S 6.326	-85,101	-12,157	-9,558	-2.0
2	1.203	X-S 6.390 to X-S 7.593	-334,100	-47,729	-39,675	-4.3
3	0.553	X-S 7.716 to X-S 8.269	-70,819	-10,117	-18,295	-1.8
4	1.042	X-S 8.269 to X-S 9.311	-99,630	-14,233	-13,659	-2.8
5	1.285	X-S 9.311 to X-S 10.596	-183,814	-26,259	-20,435	-1.3

Table C-7. Lower White River Change in sediment volumes, 1969 to 1974/77.

Previous River Miles or X Section Label	HECRAS River Station	Volume Change[1] 1969 to 1974 (cu yd)	Reach Volume Change[2] 1970 to 1975 (cu yd)	Channel Length between X sections (feet)	Channel Width Source[2]	Channel Width *average* (feet)	Plan view area (sq ft)	Reach Plan view area (sq ft)	Vertical Change for plan view area (feet)	Vertical Change at each X section[3] 1969-1974 (feet)	Ave Annual Vertical change at each X section[3] (feet/year)	Vertical Change at each Reach[4] 1969-1974 (feet)	Ave Annual Vertical change at each Reach[4] (feet/year)
8th Str Br	**4.988**								0				
5.04	5.123				B	**451**				0.28	0.06		
		7227		892		*388*	346202		0.56				
5.2	5.292				B	**325**				0.39	0.08		
		2033		887		*275*	243989		0.22				
5.36	5.46				B	**225**				-0.01	0.00		
		-1814		850		*233*	198315		-0.25				
5.52	5.621				B	**241**				0.19	0.04		
		6199		1061		*255*	270228		0.62				
5.7	5.822					**268**				0.73	0.15		
		10518		1346		*252*	338768		0.84				
5.97	6.077					**235**				0.95	0.19		
		14237		1457		*248*	361012		1.06				
A Str Br	**6.353**		**38400**					**1758515**				**0.59**	**0.12**
6.33	6.39				B	**260**				1.08	0.22		
	6.482	13727		945		*359*	339435		1.09				
6.52	6.569				B	**458**				0.72	0.14		
	6.647	8892		1700		*401*	681815		0.35				
	6.761												
6.73	6.891				B	**344**				0.55	0.11		
		5240		581		*326*	189056		0.75				
6.96	7.001				B	**307**				0.66	0.13		
	7.087	4941		892		*264*	235577		0.57				
7.09	7.17				B	**221**				0.46	0.09		
	7.252	2712		1045		*193*	202183		0.36				
7.4	7.368				B	**166**							
R Str Br	**7.618**		**35512**					**1648066**				**0.58**	**0.12**
7.74	7.845				B	**196**				-0.32	-0.06		
		-2722		597		*193*	114943		-0.64				
7.87	7.958				B	**189**				-0.45	-0.09		
		-1842		808		*244*	196794		-0.25				
8.03	8.111				B	**298**				0.16	0.03		
		4219		834		*239*	199663		0.57				
8.19	8.269				B	**181**				0.26	0.05		
		-308		787		*188*	147872		-0.06				
8.33	8.418		**-653**		B	**195**		**659271**		0.04	0.01	**-0.03**	**-0.01**
		761		755		*196*	147977		0.14				
8.46	8.561				B	**197**				1.08	0.22		
		10921		739		*198*	146362		2.01				
8.6					B	**199**				1.89	0.38		
		7559		686		*169*	116050		1.76				
8.73	8.821				B	**139**				1.15	0.23		
		4123		845		*246*	207715		0.54				
8.89	8.946					**353**				0.27	0.05		
		-29		686		*307*	210797		0.00				
9.02	9.125				B	**261**				-0.42	-0.08		
		-6,761		845		*258*	218106		-0.84				
9.18	9.311		**16574**		B	**255**		**1047006**		-0.74	-0.15	**0.43**	**0.09**
		-5,055		792		*271*	214236		-0.64				
9.33	9.477					**286**				-0.88	-0.18		
		-16,596		950		*423*	402019		-1.11				
9.51					**C**	**560**				-1.33	-0.27		
	9.794	-38,418		1584		*426*	674784		-1.54				
9.81					**C**	**292**				-1.19	-0.24		
	10.065	-10,742		1214		*282*	342461		-0.85				
10.04					**C**	**272**				-0.64	-0.13		
		-5,911		1109		*332*	367567		-0.43				
10.25	10.343				**C**	**391**				-0.45	-0.09		
		-5,517		898		*352*	315506		-0.47				
10.42					**C**	**312**							
	10.596		**-82239**					**2316574**				**-0.96**	**-0.19**

1969 - 1974 Totals by Study Reach

Reach Number	Length River Miles	Reach	69 to 74 VOLUME (cu yd)	Annual RATE (cu yd/yr)	Rate per Distance (cy/yr/RM)	Ave Elev (ft)[4]
1	1.272	X-S 4.988 to X-S 6.326	38,400	7,680	6,038	0.6
2	1.203	X-S 6.390 to X-S 7.593	35,512	7,102	5,904	0.6
3	0.553	X-S 7.716 to X-S 8.269	-653	-131	-236	0.0
4	1.042	X-S 8.269 to X-S 9.311	16,574	3,315	3,181	0.4
5	1.285	X-S 9.311 to X-S 10.596	-82,239	-16,448	-12,800	-1.0

1 The net changes in sediment volume from 1969 to 1974 (cy) come from Jordan/Avent (1975) Table J-1.
2 Jordan Avent (1975) does not include actual cross section data so channel widths have been inferred from other sources.
Channel widths labeled "B" were taken from the 2007 HECRAS model, from channel station to channel station,
and those channel widths labeled "C" were taken from the 1974/77 to 1984 timeframe. Unlabeled cross sections have customized widths.
3 Some uncertainty was introduced in the calculation of average elevation change at each cross-section due to the sourcing of channel widths from different time periods (as explained in footnote 2), and interpolating channel width between them.
4 Because of the added error involved in averaging average verical elevation change data by cross-section into reach averages, reach level averages have been calculated from reach total volumes and areas.

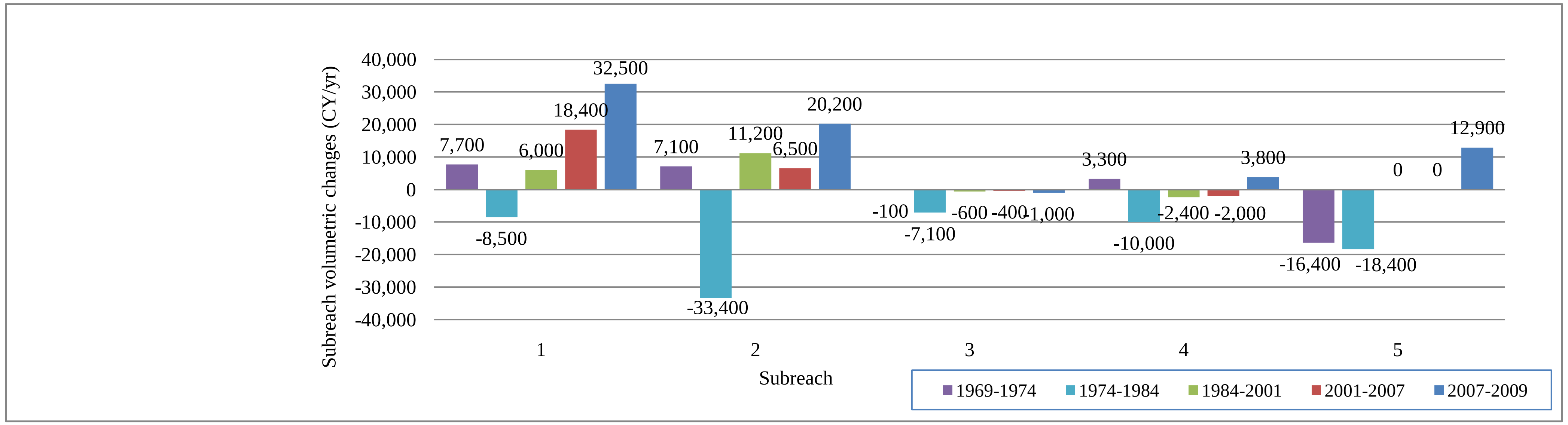


Figure C-1. Changes in Lower White River sediment volume per year by subreach.

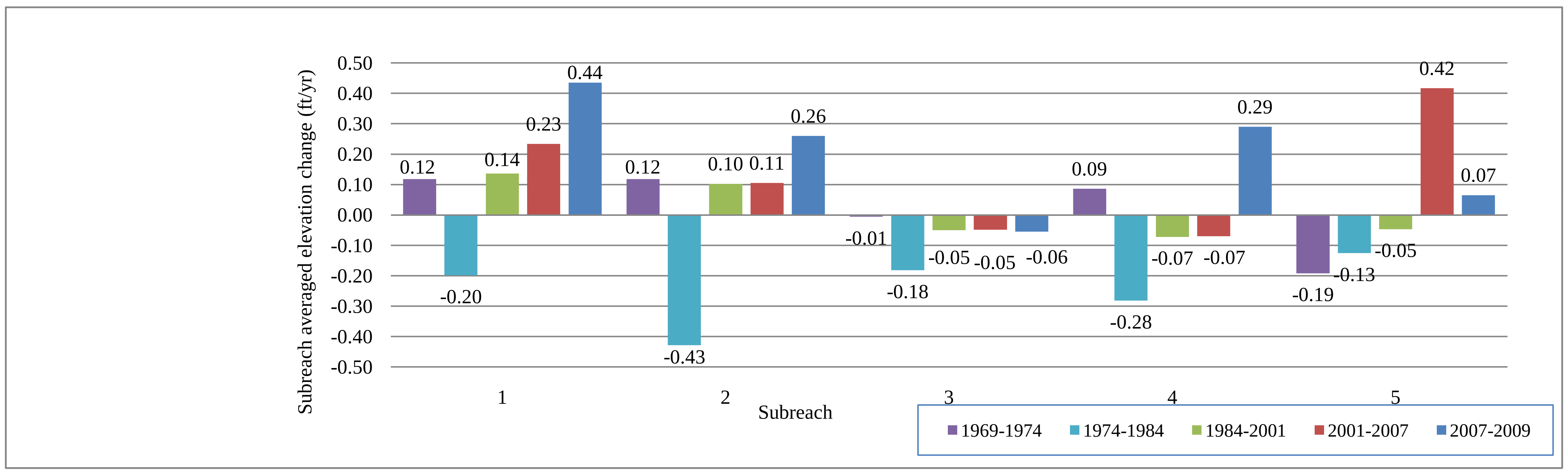


Figure C-2. Changes in Lower White River channel elevation per year by subreach.

APPENDIX D

Analysis of City of Auburn Cross-sections on the White River, 1996 to 2009 (King County 2009c)

DT: **November 24, 2009**
TO: **Jeanne Stypula, Supervising Engineer**
FR: **Terry Butler, Geologist**
RE: **Analysis of City of Auburn cross sections on the White River, 1996-2009**

Introduction and Purpose

There are 13 surveyed cross sections that cross the White River in the 1.2 river miles between the A Street and R Street Bridges along Auburn, WA. The City of Auburn established these cross sections in 1996 and the cross sections have been resurveyed almost every year from 1996 through 2009 to monitor the river channel. The purpose of this memo is to assemble and analyze all cross section survey data collected between 1996 and 2009 at the 13 Lower White River cross sections between the A Street and R Street Bridges, and to characterize changes with regard to sediment accumulation in this river segment during this period.

The King County River and Floodplain Management Section (KC RFMS) monitors sediment accumulation and its potential effect on flood hazards in certain river channels of King County, consistent with the 2006 King County Flood Hazard Management Plan. The Lower White River, including the river segment between A Street and R Street Bridges, is one such channel. Therefore, this memo is a collaborative effort in that the City of Auburn has collected most of the survey data and KC RFMS is organizing and analyzing the data. While this memo can stand on its own, the findings of this analysis of the 13 Auburn cross sections from 1996 through 2009 will be included in a study of sediment trends on the Lower White River, now in preparation. That study has a scope that includes approximate River Mile (RM) 4.4 to 10.6 and consideration of cross section data before 1996 and larger scale factors such as basin sediment yield so as to characterize sediment trends in that six mile study reach. Both this more focused memo and the larger sediment trends study are intended to document past and present channel conditions in order to inform river and floodplain management actions for the affected areas.

Background

The White River is a sediment rich river, draining the glaciers of Mt. Rainier and flowing through the eroding, geologically-young White River Canyon from Buckley to Auburn. The river emerges from its canyon near RM 8 just upstream of the R Street Bridge to flow across the alluvial fan it has constructed downstream towards its confluence with the Puyallup River. The White River alluvial fan is an area of natural deposition where much of the coarse sediment load of the river settles out as the channel gradient decreases. The river segment from A Street to R Street Bridges and the 13 river cross sections evaluated in this memo are located in this depositional area of the White River alluvial fan. Much of the Lower White River was channelized and lined by levees or revetments on both banks in the early part of the last century, including the segment from A Street to R Street. While the extensive river engineering of last century is not described in this

memo, it should be recognized as a factor that can affect river hydraulics and sediment transport and deposition.

The City of Auburn established 13 river cross sections at a spacing of approximately every 400 to 600 feet in the mid-1990s to monitor sediment levels in the White River channel between the A Street and R Street Bridges (as shown in **Figure 1**). The cross sections have been surveyed annually in most years since 1996, usually by the City of Auburn, where the sections were labeled sequentially in the upstream direction (with section 13 added after the others). In 2007, the same 13 cross sections and others throughout the Lower White River were surveyed for the Floodplain Mapping Study for the White River (Northwest Hydraulic Consultants [NHC] 2009a), during which effort the cross sections were labeled by River Mile. The 13 Auburn cross sections are referred to by River Mile in this memo. Equivalencies between cross section labels are summarized in **Table 1.**

Table 1: Equivalencies of cross section labels, from downstream to upstream

River Mile (RM)	City of Auburn section number	Flood study work map cross section (NHC 2009a)
6.390	1	Q
6.482	2	R
6.569	3	S
6.647	4	T
6.761	5	U
6.891	6	V
7.001	7	W
7.987	8	X
7.170	13	Y
7.252	9	Z
7.368	10	AA
7.511	11	AB
7.593	12	AC

Methods

Prior to 2004, diversion of White River flows into Lake Tapps resulted in summer low flows through this study reach such that the cross sections data could be collected by wading the river. Horizontal and vertical control were established by the City of Auburn and survey data points were collected across the full cross using traditional land-based survey methods (e.g., Total Station) from 1996 through 2003. Dates and sources of survey data through the full study period are summarized in **Table 2**.

Since the reduction of diversion of White River flows into Lake Tapps in 2004, all in-water survey points have been collected by boat, using either traditional survey methods

or a combination of Real Time Kinetic-Global Positioning System and survey grade echosounding equipment. The land portion of the cross sections is still surveyed using traditional survey methods. LiDAR (Light Distance and Ranging) imagery collected in February 2009 was consulted in preparation of the 2009 cross sections. Data from different sources within the same year was combined by King County using standard AutoCAD and spreadsheet methods

Table 2: Cross section data sources

Year	Full Cross Section	In Water Only	On Land Only
1996	City of Auburn		
1997	City of Auburn		
1998	City of Auburn		
1999	City of Auburn		
2000	City of Auburn		
2001	City of Auburn		
2002	City of Auburn		
2003	City of Auburn		
2004			City of Auburn
2005	No survey in 2005		
2006		DEA	
2007	MGS for flood study		
2008		DEA	City of Auburn
2009		NW Hydro	City of Auburn; LiDAR consulted
Abbreviations			
DEA	David Evans and Associates, Inc.		
MGS	Minister-Glaeser Surveyors, Inc.		
NW Hydro	Northwest Hydro, Inc.		

Because the 2004 survey collected data points only on land surfaces and did not collect data at every one of the 13 Auburn cross sections, the 2004 data are not included in this analysis. Although the 2006 survey by DEA focused on the in-water part of the cross section, data points were collected across sufficient portions of every cross section so that the data appear to adequately represent every cross section and the 2006 data are included in this analysis.

Survey data collected in all years except 2007 were referenced to the NAD 1927 horizontal datum and NGVD 1929 vertical datum in the State Planes Coordinate System South, using horizontal and vertical control established by the City of Auburn. Survey data collected in 2007 were referenced to the NAD 1983 horizontal datum and the NAVD 1988 vertical datum. All data and analyses in this memo reference the NAD 1983 horizontal datum and the NAVD 1988 vertical datum in the State Planes Coordinate System North. Horizontal coordinates were converted using the established relation

between the State Planes North and South Systems. Elevations were converted by the equation NAVD88 = NGVD 1929 plus 3.53 feet.

The horizontal and vertical coordinates of each survey data point were converted to two dimensions in Station-Elevation format for plotting purposes. All cross sections are plotted looking downstream. The change in cross sectional area at each cross section through each time interval was calculated using a proprietary analytical tool (NHC 2009b) that functions as an adjunct to the HEC-RAS hydraulic model (US Army Corps of Engineers 2009). Change in sediment volume during a given time interval was calculated as the average of the change in cross sectional area at two consecutive cross sections times the distance between the cross sections. The reach-scale change in sediment volume in that interval was the summation of volumes between all cross sections.

Findings

<u>Cross section plots, general observations:</u>

All survey data are displayed in plan view illustrating where they were collected in **Figure 2** and in cross section view at each cross section location in **Figure 3** through **Figure 15**. As is evident in **Figure 2**, there is some variability in the location of the data collected relative to the cross section alignment, with the variability generally increasing toward the right bank. This variability in plan view of the data point locations may account for some of the variability evident in cross section view of some of the cross sections, e.g., the differences in surveyed cross section width evident at cross section 6.390 (**Figure 3**).

The results at cross sections 7.511 and 7.593 are anomalous for the years 1996 through 1999 as compared to the other cross section locations. For the purposes of these analyses, the station and elevation of the cross section data from these four years were revised by eye so as to best fit at both left bank and right bank toes of slope (**Figures 16** and **17)**. Revising data by eye is not a preferred approach, but the need for continuous data for comparison purposes, the relatively limited extent of the revised data and the likelihood that the revisions are representative in this area justify the approach in this case. Also, the plot at cross section 6.647 (**Figure 6**) from 1998 is unusually high relative to other years, is suspect, and therefore was not included in these analyses.

Some initial observations can be made by visual inspection of the cross section plots. There appear to be more channel changes, typically as sediment deposition, in the downstream part of this study reach, from cross sections 6.390 through 7.170, and less channel changes in the upstream part of this study reach, from cross sections 7.252 to 7.593. Also, there appears to have been markedly greater deposition throughout the full study reach in 2007, 2008, and 2009. Fewer changes and lesser increases in bed elevations, indicating less deposition, are evident for the period from 1996 to 2006 throughout the study reach

Thalweg elevations:

A longitudinal profile of the channel bed is created by plotting the thalweg elevation, or lowest point in the channel, from each cross section, relative to river mile. Comparison of this profile through time can indicate deposition or erosion, locally or on the reach scale. Thalweg elevations and changes in elevations are plotted in **Figure 18** and **Figure 19** and summarized in **Table 3** and **Table 4**. From this information, it is apparent that the 2007, 2008 and 2009 thalweg elevations are locally higher at cross section 7.087 and at cross section 7.170 in 2009 (**Figure 18**). Generally, the magnitude of change in thalweg elevation, either positive or negative, appears to be less at cross sections 7.252 upstream than downstream of cross section 7.170 (**Figure 19**). No other spatial trend is readily apparent throughout the reach. No temporal trend seems obvious from these data (**Figures 18 and 19**); there are large and small changes in thalweg elevations in all intervals.

The general consistency within shorter parts of this 1.2 mile study reach, as evidenced in cross section plots and in thalweg elevation changes, suggest that shorter parts of this study reach, or sub-reaches, could be identified and used in subsequent figures and tables. Specifically, two sub-reaches are identified: from cross sections 6.390 to 7.170 and from cross sections 7.170 to 7.593.

Sediment volumes:

Changes in sediment volume for the entire study reach and for the two sub-reaches are shown in **Table 5** and **Figure 20**. Changes in cross sectional area at each of the 13 cross sections through 11 time intervals (approx 140 comparisons) were recorded separately but are not included with this memo, for brevity purposes. Full documentation of all data can be made available upon request.

Note that a positive number for change in sediment volume indicates the volume of sediment deposited and a negative number indicates the volume eroded. Because there was no gravel extraction during any of the intervals from 1996 through 2009 the calculated change in sediment volume equals the amount of deposition (or erosion) for each time interval. Also, because most time intervals between surveys are one year, the change in volume is identical to an average annual rate of deposition (or erosion). For the 2003-2006 interval, an annual rate can be estimated by dividing by three (although it must be noted that actual sediment deposition is highly episodic and most likely did not proceed at the even pace suggested by simply dividing this interval by its number of years).

There was a wide range of changes in sediment volume through the full study reach, from a minimum of -17,900 cubic yards from 2001 to 2002 to a maximum of 47,400 cubic yards from 2006 to 2007 (**Table 5**). For the full study reach from A Street to R Street Bridges, the estimated total volume of sediment deposited during the 13-year period from 1996 through 2009 is about 104,000 cubic yards. Simple division yields an average annual deposition rate of about 8,000 cu yd/yr (with the same caveat that actual sediment

deposition is highly episodic) and an average rate per distance of 6700 cu yd/yr/RM. This is a large total volume of deposition but there is much variability from year to year and almost half of the net total was deposited in one year (2006-2007). All of the same calculations in the right hand boxes of **Table 5** provide volumes and rates of deposition in the two sub-reaches described previously, and illustrate their differences.

An informative metric is the average change in bed elevation, calculated on the reach-scale and sub-reach-scale by dividing the deposition (or erosion) volume by the plan view area of the river bed. This is another simplifying calculation that suggests that sediment has deposited (or eroded) *uniformly* throughout the study reach, which does not actually occur. But it provides a standard means of comparison and is a widely used metric. The changes in bed elevation for the full reach and sub-reaches correspond directly to the changes in sediment volume, since they result from the sediment volume divided by a constant (the plan view area). These numbers are reported in the right side columns of each box in **Table 5**. The change in bed elevation for the full reach for the 13-year period is about 1.5 feet of deposition. An average annual rate, assuming constant and uniform deposition, would be about a tenth of a foot per year. The corresponding numbers are a bit higher for the downstream sub-reach (cross sections 6.390 to 7.170) and a bit lower for the upstream sub-reach (cross sections 7.170 to 7.593). These same numbers are shown graphically in **Figure 21**.

These reach-scale volumes and rates of sediment deposition and the rates of change in bed elevations are relatively large when averaged over the full period of study, as compared to other King County rivers. For example, these White River results are equal to or higher than the same calculations on the lower Tolt River and the lower Raging River, both of which are leveed rivers emerging from steeper canyons or valleys and flowing across an alluvial fan at the downstream end of a sediment-rich basin.

A change in bed elevation also was calculated at each cross section by dividing the change in cross sectional area by the channel width. (The specific channel width used is the width through which the change in cross sectional area occurred, which typically is from left bank toe of slope to right bank toe of slope.) The change in bed elevation at each cross section for each time interval is listed in **Table 6** and shown in **Figure 22**. The increases in sediment levels from 2006-2007 are evident, with the plot for that interval consistently higher in elevation than other plots. The 2008-2009 plot also is relatively high. The plots for the 1998-1999, 2001-2002, and 2003-2006 intervals show relatively low elevations at most cross sections, signifying erosion at many places in this study reach in those time intervals. The positions of all plots in **Figure 22** are consistent with the numerical values in **Table 5**.

<u>Hydrology:</u>

A major determinant on the movement and deposition of sediment is the discharge of the river, both in terms of magnitude and duration. The peak annual flows from Water Year 1988 through 2009 at USGS gage 12100496, White River at Auburn (at the downstream side of the BNRR Bridge at approx RM 6.3) are shown in **Figure 23**. Comparison of

changes in sediment volume to the peak flows during the same time intervals reveals no obvious correlation (**Figure 24**). The largest volume of deposition (47,000 cu yd) did occur in the same period as the largest magnitude flow (14,500 cfs), 2006-2007. But there also is a wide fluctuation in changes in sediment volumes, such as large net erosion (-17,900 cu yds in 2001-2002), moderate deposition (9700 cu yds in 1999-2000) and large deposition (25,100 cu yds in 2007-2008), that occurred during intervals with seemingly similar moderate peak magnitude flows. The duration of high flows during these peak annual floods, as well as any other substantial flows less than the annual peak that occurred in the same time interval, are not considered in the simple comparison in **Figure 24** and may have affected the net erosion or deposition within the given time interval. Further analysis would be needed to establish a quantitative relationship between flow and sediment movement and deposition in this reach.

Summary:

Channel monitoring by nearly annually repeated survey of 13 White River cross sections has produced a comprehensive documentation of channel changes between 1996 and 2009. The net total deposition for the full study reach from A Street to R Street Bridges over this 13-year period was approximately 104,000 cubic yards. The corresponding change in bed elevation for the same period was 1.5 feet, if averaged evenly over the plan view area of the full study reach. This reach-averaged depth of deposition translates to an average annual rate of deposition of about one tenth of a foot per year. It is important to remember that sediment movement and deposition actually is highly episodic and that these calculated averages are best used for comparison purposes only.

Beyond the averaged values for the full period, there was much variability in the reach-scale changes in sediment volume from year to year, ranging from almost 18,000 cubic yards of erosion in one year to over 47,000 cubic yards of deposition in another year. While the latter maximum deposition did occur in the same year as the largest magnitude of peak flow in this study period, the variability of changes in sediment volume in other years did not seem to be fully explained by variation in the magnitude of the peak annual flow. Regardless, these are large quantities of sediment deposition, both in an absolute sense on the White River and relative to other similar rivers in the region.

Broader context for the relatively focused findings of this analysis of these 13 Auburn cross sections may be provided by the Lower White River sediment trends study now in progress, which covers six river miles and includes some historical perspective. Ongoing monitoring of these 13 Auburn cross sections also will provide increased temporal context for the findings herein, and will continue to inform river and floodplain management in this area.

References:

Northwest Hydraulic Consultants. 2009a. Floodplain mapping study for the White River, King County WA. *Zone 2 (RM 5.6 to RM 10.6).* Prepared for King County River and Floodplain Management Unit, Water and Land Resources Division, Dept of Natural Resources, Seattle WA. Prepared by Northwest Hydraulic Consultants, Inc., Seattle WA. July 2009.

Northwest Hydraulic Consultants. 2009b. RASMOD analytical tool used in calculating changes in cross sectional area. Prepared for sole use by King County River and Floodplain Management Unit. Prepared by Northwest Hydraulic Consultants, Inc., Seattle WA. April 2009.

US Army Corps of Engineers. 2009. Hydrologic Engineering Center-River Analysis System (HEC-RAS) hydraulic model. Hydrologic Engineering Center. Davis, CA.

Table 3: THALWEG ELEVATIONS at 13 AUBURN CROSS SECTIONS, 1996 through 2003 and 2006 through 2009
- All elevations are in feet and referenced to vertical datum NAVD 1988

Cross Section	Auburn Section Number	Thalweg Elevation (in feet) 1996	1997	1998	1999	2000	2001	2002	2003	2006	2007	2008	2009
6.390	1	79.8	79.0	82.0	79.3	80.8	81.4	80.2	79.1	79.1	80.0	82.3	80.5
6.482	2	78.6	80.5	80.1	80.9	81.5	83.7	82.6	82.1	77.6	79.7	78.9	79.3
6.569	3	84.7	86.1	85.7	86.2	86.4	86.8	86.8	87.0	85.5	84.5	85.7	86.0
6.647	4	85.9	86.6	**89.2**	86.1	86.0	87.8	86.3	86.3	85.2	86.7	86.9	87.4
6.761	5	88.5	89.8	89.9	85.9	87.0	87.8	87.6	87.5	87.0	87.6	88.7	89.2
6.891	6	93.9	93.5	93.7	92.8	93.1	93.2	93.6	93.2	92.5	94.0	94.2	94.2
7.001	7	93.0	92.7	93.3	91.8	92.7	94.1	93.4	93.0	92.7	92.0	94.7	92.9
7.087	8	97.0	97.9	97.9	95.3	94.9	95.6	94.5	94.8	96.2	98.9	97.9	100.5
7.170	13	98.9	N/A	97.9	97.2	96.9	94.9	94.4	94.7	97.3	96.7	98.5	100.8
7.252	9	101.4	100.6	101.2	100.3	99.1	100.5	100.5	100.3	100.2	101.6	102.4	102.2
7.368	10	103.4	103.1	103.3	102.7	103.3	104.5	103.0	103.3	103.5	103.2	102.8	103.1
7.511	11	109.0	108.5	108.4	108.1	108.4	108.7	108.3	108.7	109.0	108.7	109.7	109.6
7.593	12	109.6	109.3	108.9	109.1	109.6	109.6	109.6	109.8	110.2	110.5	110.6	110.9

Notes

N/A   Data not available.

Bold: The 1998 data at cross section 6.647 are suspect.

Table 4: CHANGE IN THALWEG ELEVATION at 13 AUBURN CROSS SECTIONS, 1996 through 2003 and 2006 through 2009
- Elevation change, in feet, was calculated as the elevation of the later year minus the elevation of the earlier year

Cross Section	Auburn Section Number	Change in thalweg elevation (in feet) 1996 to 1997	1997 to 1998	1998 to 1999	1999 to 2000	2000 to 2001	2001 to 2002	2002 to 2003	2003 to 2006	2006 to 2007	2007 to 2008	2008 to 2009
6.390	1	-0.8	3.1	-2.8	1.5	0.6	-1.2	-1.2	0.0	0.9	2.3	-1.8
6.482	2	1.9	-0.4	0.8	0.7	2.1	-1.1	-0.5	-4.4	2.0	-0.8	0.5
6.569	3	1.4	-0.4	0.5	0.2	0.4	0.0	0.2	-1.4	-1.1	1.2	0.4
6.647	4	0.7	**2.6**	**-3.0**	-0.1	1.7	-1.4	-0.1	-1.1	1.5	0.2	0.5
6.761	5	1.3	0.2	-4.0	1.1	0.9	-0.2	-0.1	-0.6	0.6	1.1	0.5
6.891	6	-0.4	0.2	-0.8	0.3	0.1	0.3	-0.4	-0.6	1.4	0.2	0.0
7.001	7	-0.3	0.6	-1.5	0.9	1.4	-0.7	-0.3	-0.3	-0.7	2.7	-1.8
7.087	8	0.9	0.0	-2.5	-0.4	0.7	-1.1	0.3	1.3	2.8	-1.0	2.5
7.170	13	N/A	N/A	-0.7	-0.3	-2.0	-0.5	0.3	2.7	-0.6	1.8	2.3
7.252	9	-0.8	0.6	-0.9	-1.2	1.4	0.0	-0.2	-0.2	1.4	0.8	-0.2
7.368	10	-0.3	0.2	-0.5	0.6	1.2	-1.5	0.3	0.2	-0.3	-0.3	0.3
7.511	11	-0.5	-0.1	-0.3	0.4	0.3	-0.4	0.4	0.3	-0.3	0.9	0.0
7.593	12	-0.3	-0.4	0.2	0.5	0.0	0.0	0.1	0.4	0.3	0.1	0.3

Notes

N/A Data not available.

Bold: The 1998 data at RM 6.647 are suspect.

Table 5: **Summary of changes in sediment volumes on the White River from Cross Sections 6.390 to RM 7.593, from 1996 to 2009**

	Full study Reach RM 6.390 to 7.593		Sub Reach RM 6.390 to 7.170		Sub Reach RM 7.170 to 7.593	
Time Interval (A)	Change in Sediment Volume (cu yd)	Reach Averaged Change in Bed Elev (ft)	Change in Sediment Volume (cu yd)	SubReach Averaged Change in Bed Elev (ft)	Change in Sediment Volume (cu yd)	SubReach Averaged Change in Bed Elev (ft)
1996 to 1997	6,800	0.10	7,500	0.14	-700	-0.05
1997 to 1998 (B)	8,500	0.12	8,700	0.16	-200	-0.01
1998 to 1999 (B)	-2,900	-0.04	100	0.00	-3,000	-0.20
1999 to 2000	9,700	0.14	5,700	0.11	4,000	0.26
2000 to 2001	13,800	0.20	9,700	0.18	4,100	0.27
2001 to 2002	-17,900	-0.26	-10,900	-0.20	-6,900	-0.45
2002 to 2003	9,900	0.14	6,700	0.12	3,100	0.20
2003 to 2006 (A)	-8,800	-0.13	-10,200	-0.19	1,500	0.10
2006 to 2007	47,400	0.69	39,000	0.73	8,400	0.55
2007 to 2008	25,100	0.36	22,900	0.43	2,300	0.15
2008 to 2009	12,200	0.18	12,200	0.23	0	0.00
Total Deposition 1996-2009 (cu yd):	104,000	(C)	91,400	(C)	12,600	(C)
Plan View Area (sq ft)		1,860,000		1,450,000		410,000
Length (River Miles (RM))		1.20		0.78		0.42
Ave. annual deposition (cy/yr)		8000		7000		1000
Rate per distance (cuyd/yr/RM)		6700		9000		2400
Reach averaged change in bed elevation, 1996-2009 (ft)		1.5		1.7		0.8
Average annual change in bed elevation (ft/yr)		0.12		0.13		0.06

Notes:

A: Change in Sediment Volume values equal an average annual deposition volume for all listed intervals except for 2003-2006, whose average annual deposition would be approx -2900 cu yd/yr (where -8,800 cu yd / 3yrs = approx -2900 cu yd/yr).

B: Calculations involving 1998 do include data at RM 6.647, which is suspect.

C: Numbers may not add up exactly due to rounding.

Table 6: Change in channnel-averaged bed elevations at each cross section, for each time interval

Cross Section	Auburn Cross Section Number	1996 to 1997 Change (feet)	1997 to 1998 Change (feet)	1998 to 1999 Change (feet)	1999 to 2000 Change (feet)	2000 to 2001 Change (feet)	2001 to 2002 Change (feet)	2002 to 2003 Change (feet)	2003 to 2006 Change (feet)	2006 to 2007 Change (feet)	2008 to 2008 Change (feet)	2008 to 2009 Change (feet)
6.390	1	0.1	2.3	-0.9	0.8	-0.1	-1.5	-0.1	B	B	0.9	-0.3
6.482	2	0.0	0.3	0.3	-0.2	0.9	-0.6	0.1	-0.3	1.3	0.7	-0.3
6.569	3	0.6	0.0	0.9	0.1	0.1	-0.1	0.1	-1.3	1.0	0.9	0.2
6.647	4	0.3	A	A	0.2	0.2	-0.3	0.2	-0.7	0.6	0.8	0.1
6.761	5	0.0	0.0	0.1	0.6	-0.2	-0.2	0.2	-0.5	1.0	0.7	-0.2
6.891	6	0.1	0.1	0.0	-0.1	0.3	0.0	0.1	-0.4	1.1	0.2	0.7
7.001	7	0.3	0.9	-1.2	0.2	0.2	0.0	-0.1	-0.1	1.0	-0.1	0.4
7.087	8	0.0	0.4	-0.4	-0.3	0.4	-0.5	0.5	0.4	0.9	0.4	0.8
7.170	13	B	B	-0.5	0.4	0.1	-0.6	0.4	0.4	1.1	0.0	0.8
7.252	9	0.1	0.1	-0.3	-0.2	0.4	-0.6	0.3	-0.2	1.4	0.2	0.2
7.368	10	0.0	0.0	-0.4	0.3	0.5	-0.7	0.4	0.2	0.9	-0.2	0.0
7.511	11	-0.6	-0.1	-0.3	0.8	0.4	-0.7	0.3	0.3	0.4	0.5	0.0
7.593	12	0.5	-0.3	0.3	0.2	0.1	-0.1	0.2	0.3	0.2	0.6	-0.4

Notes:
A: Data deleted as suspect
B: Missing data

Analysis of City of Auburn cross sections on the White River, 1996-2009

Figures

Figure 1: White River study reach and cross section locations

Figure 2: Plan view of 1996 though 2009 data points surveyed at 13 Auburn cross sections

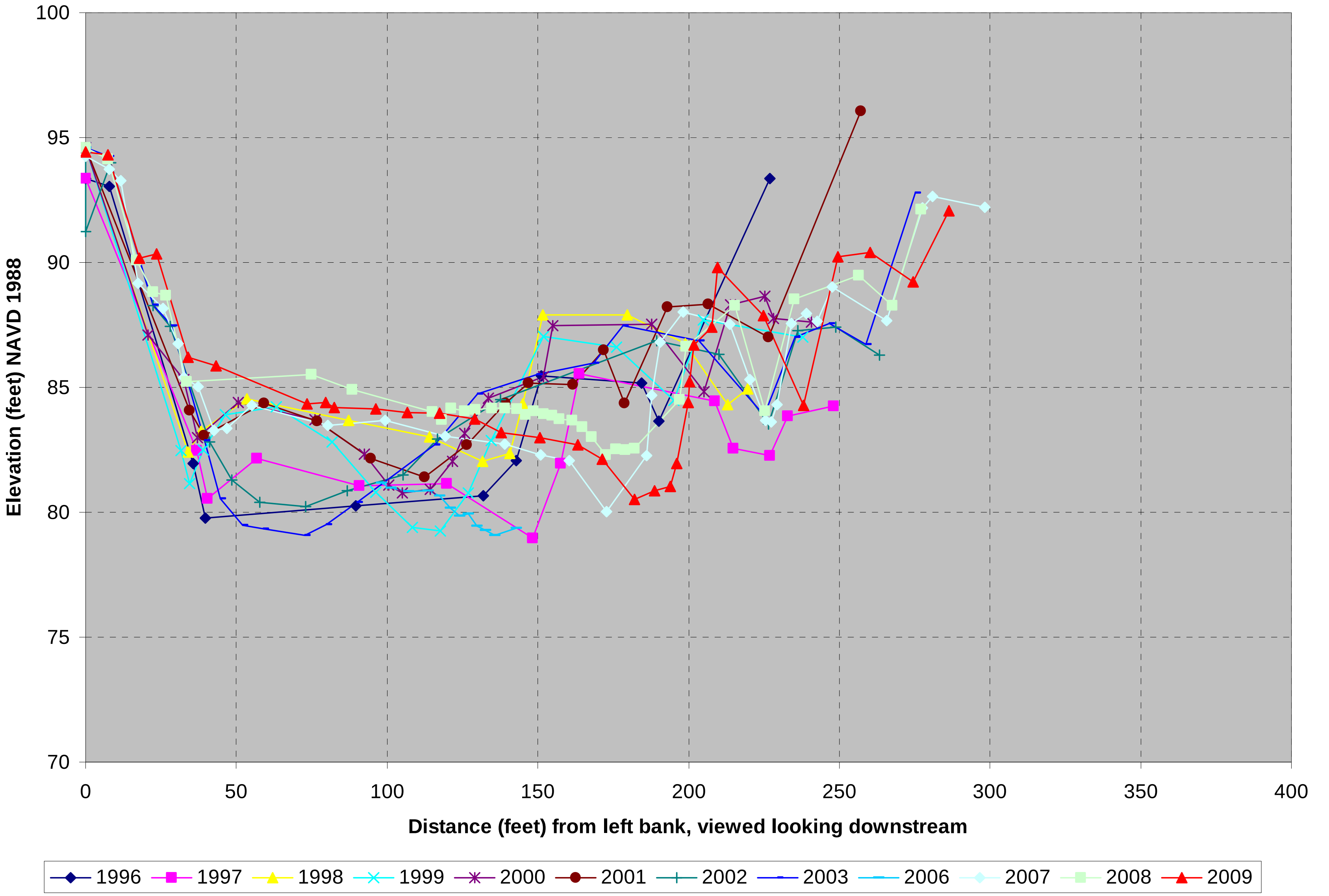


Figure 3: White River cross section 6.390 (Auburn #1), with data from 1996 through 2009

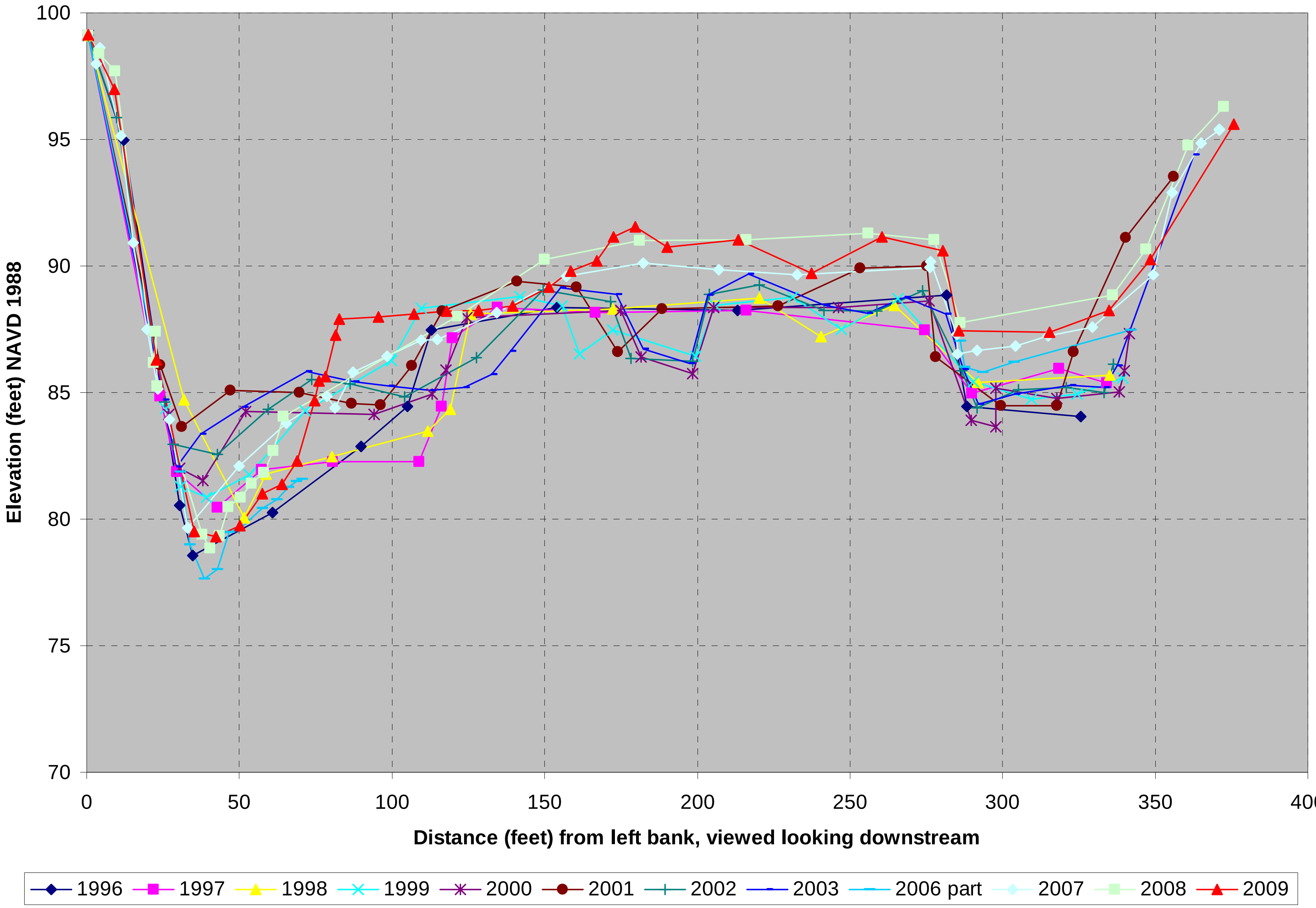


Figure 4: White River cross section 6.482 (Auburn #2), with data from 1996 through 2009

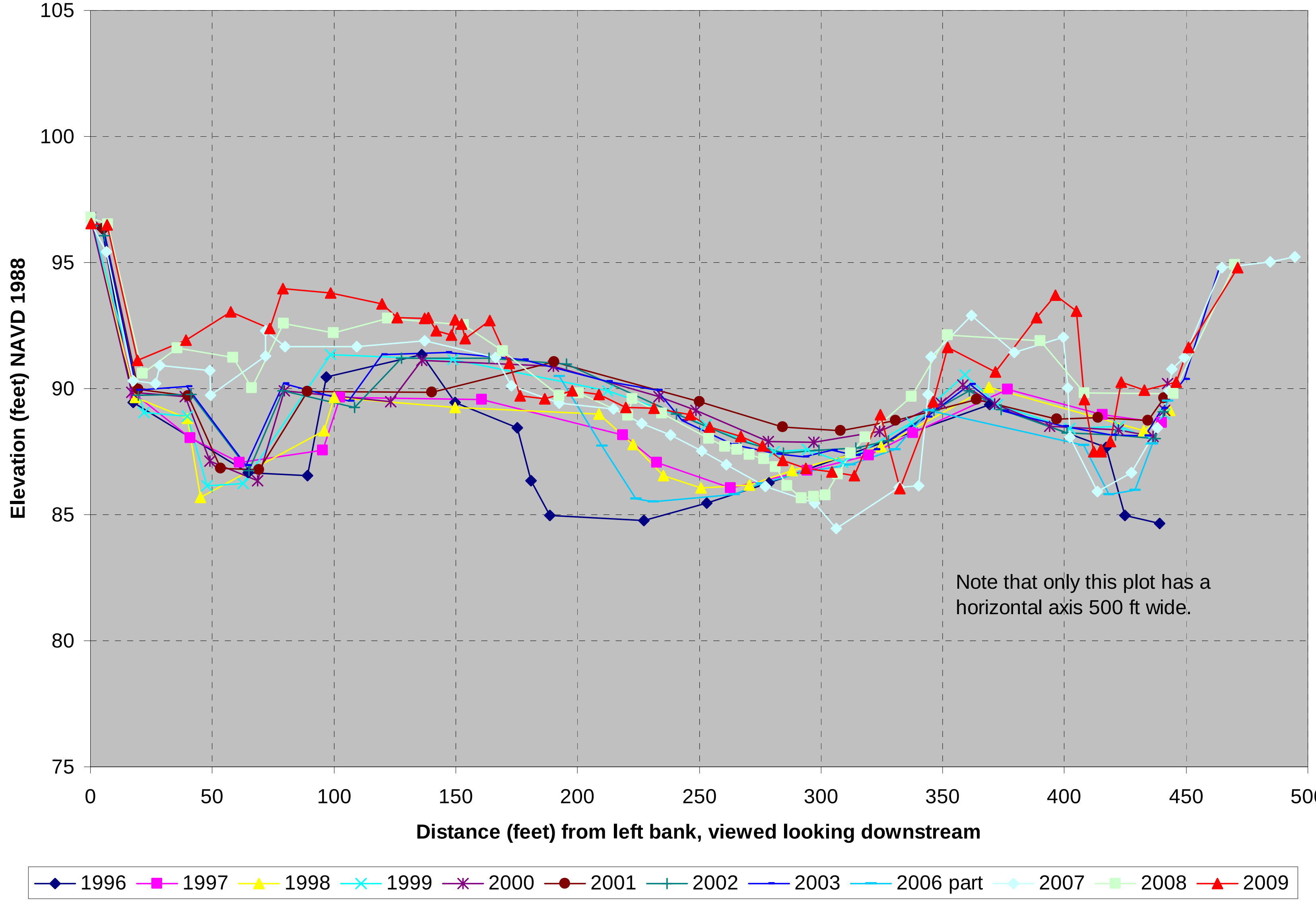


Figure 5: White River cross section 6.569 (Auburn #3), with data from 1996 through 2009

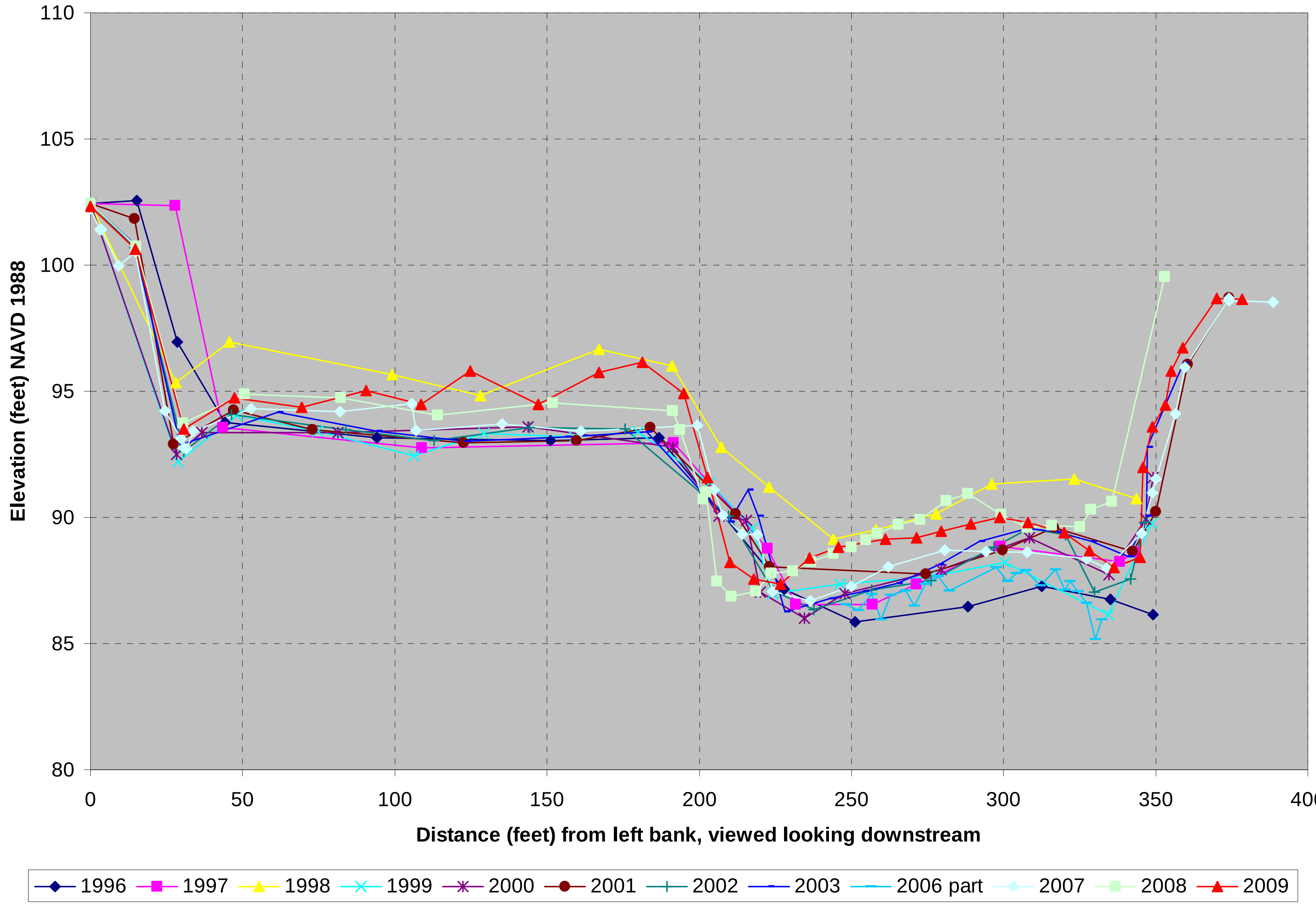


Figure 6: White River cross section 6.647 (Auburn #4), with data from 1996 through 2009

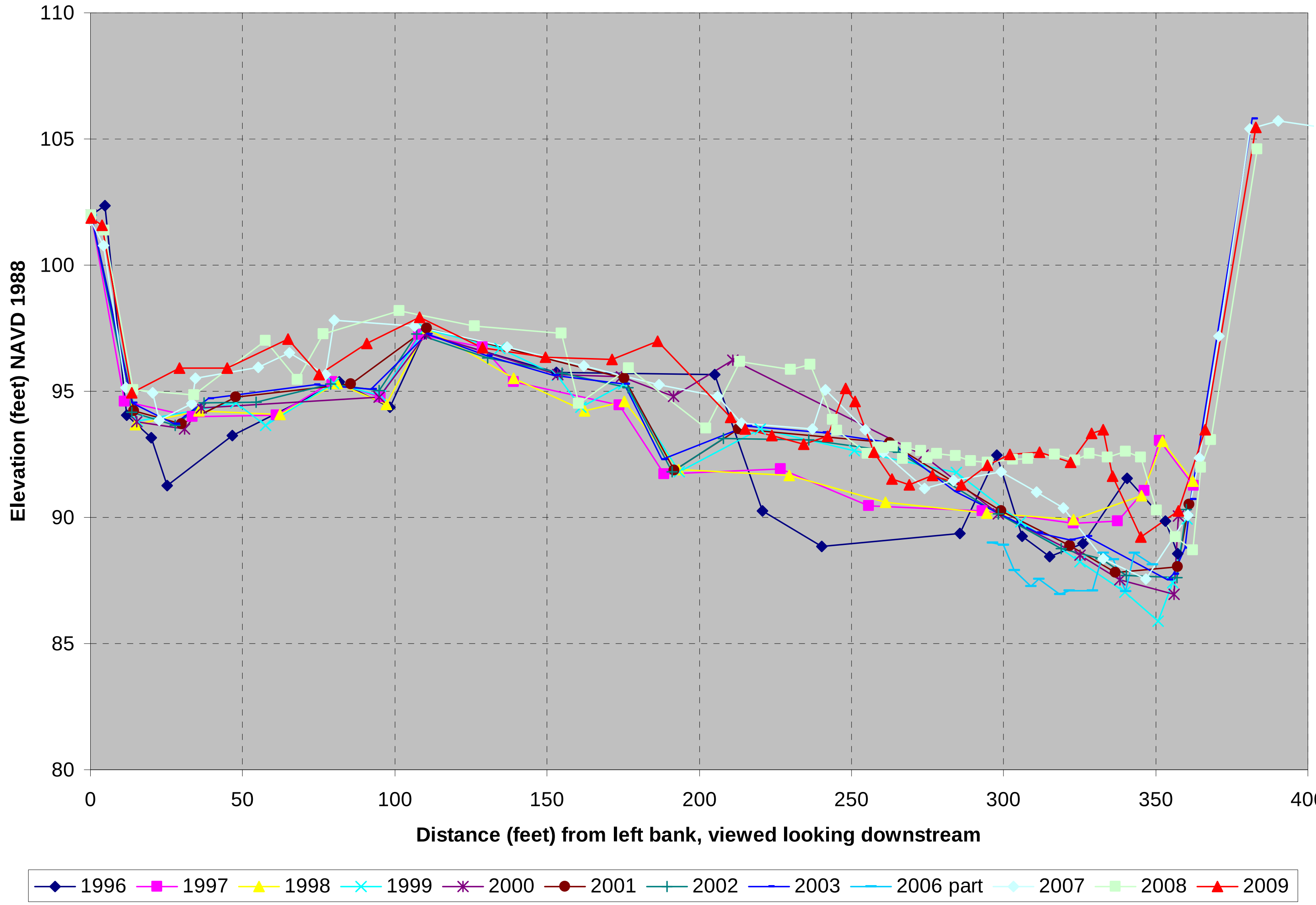


Figure 7: White River cross section 6.761 (Auburn #5), with data from 1996 through 2009

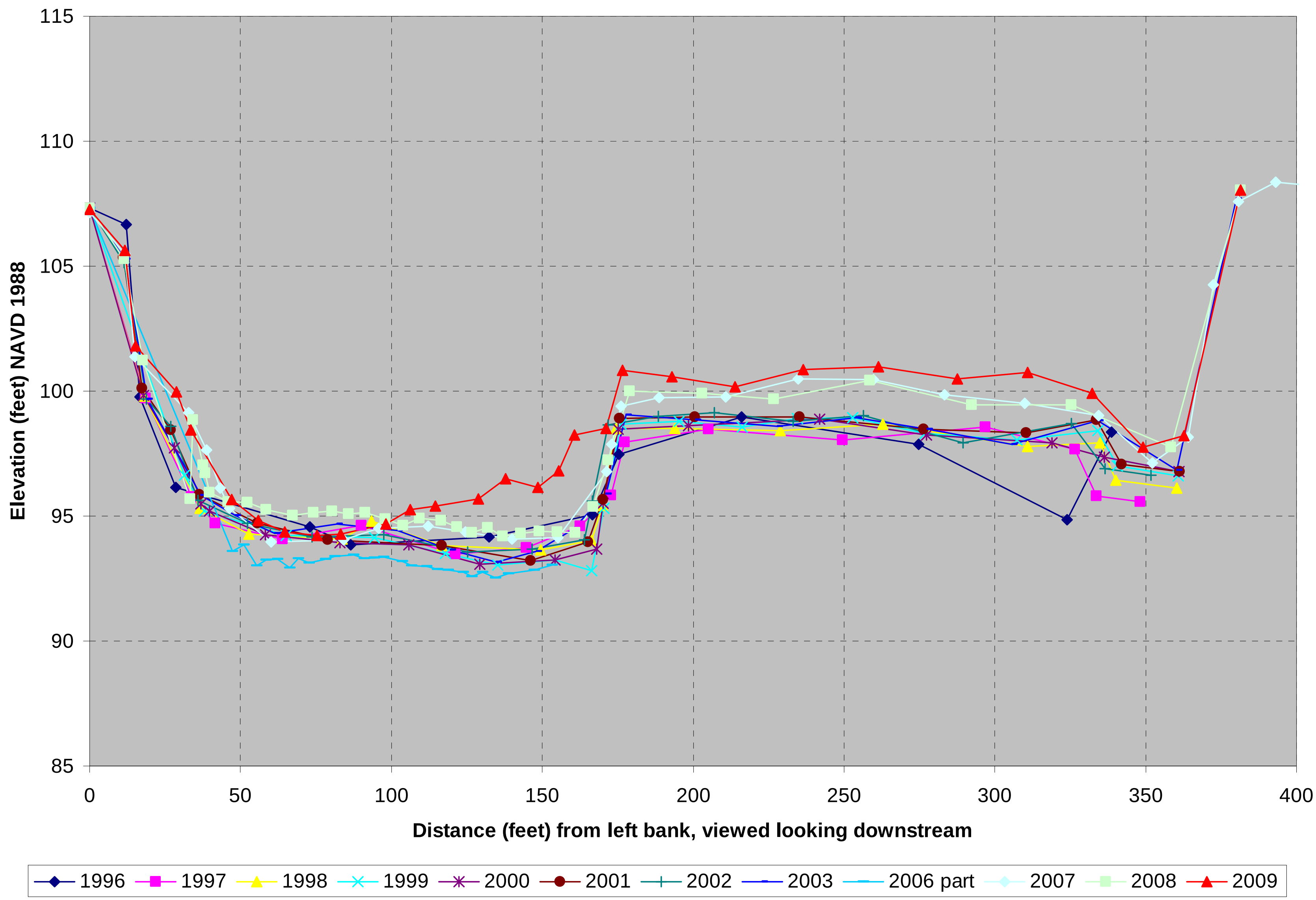


Figure 8: White River cross section 6.891 (Auburn #6), with data from 1996 through 2009

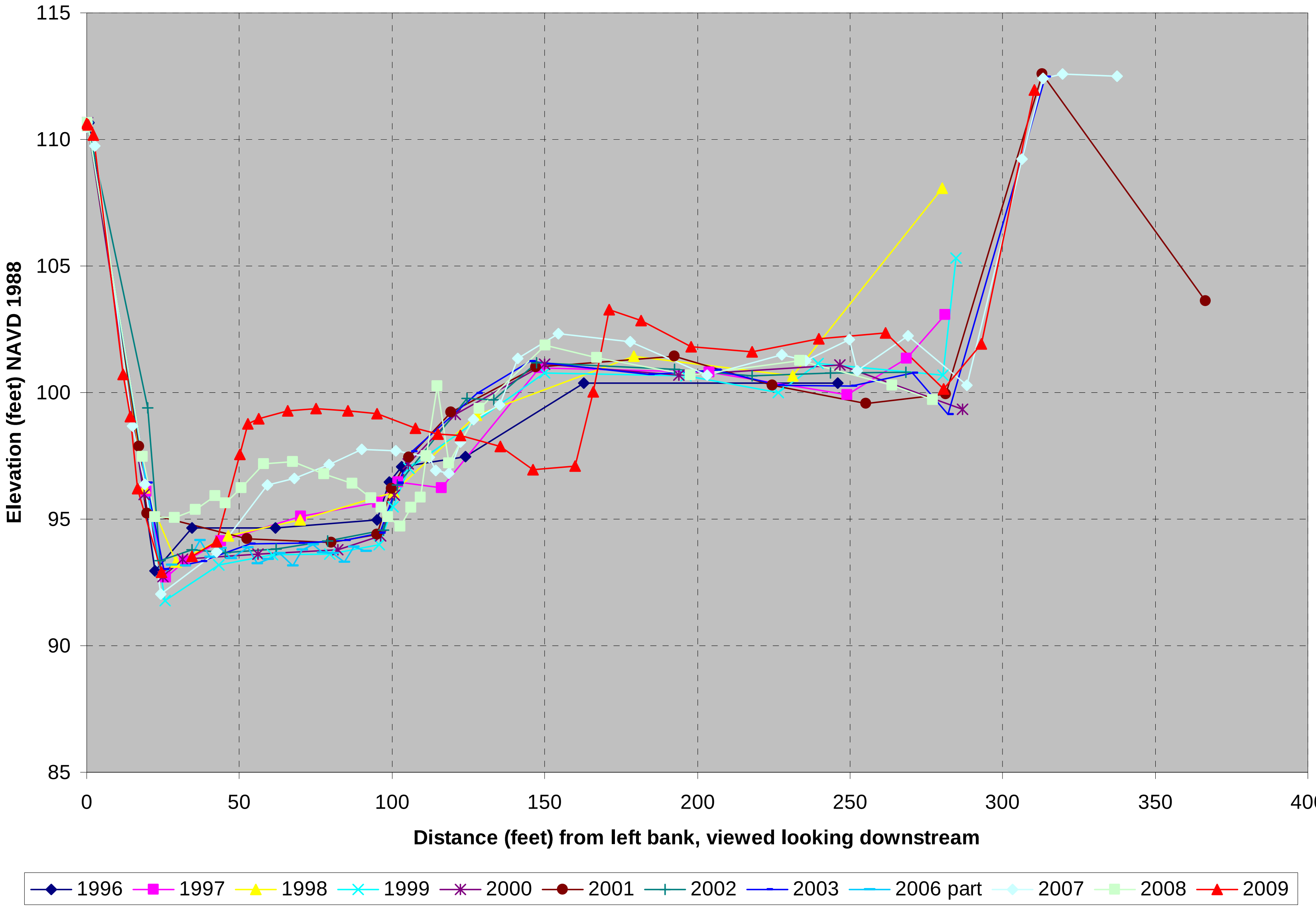


Figure 9: White River cross section 7.001 (Auburn #7), with data from 1996 through 2009

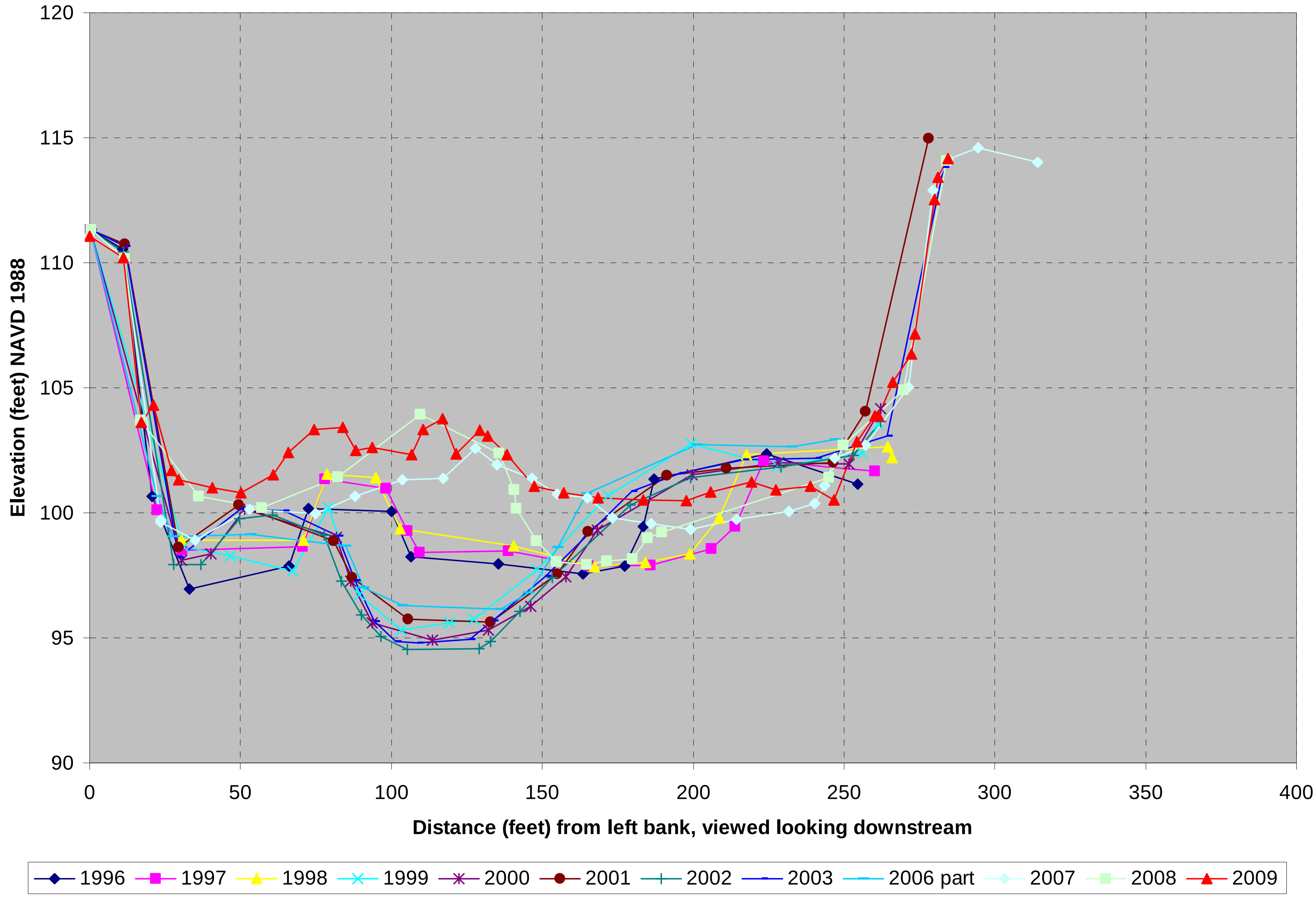


Figure 10: White River cross section 7.087 (Auburn #8), with data from 1996 through 2009

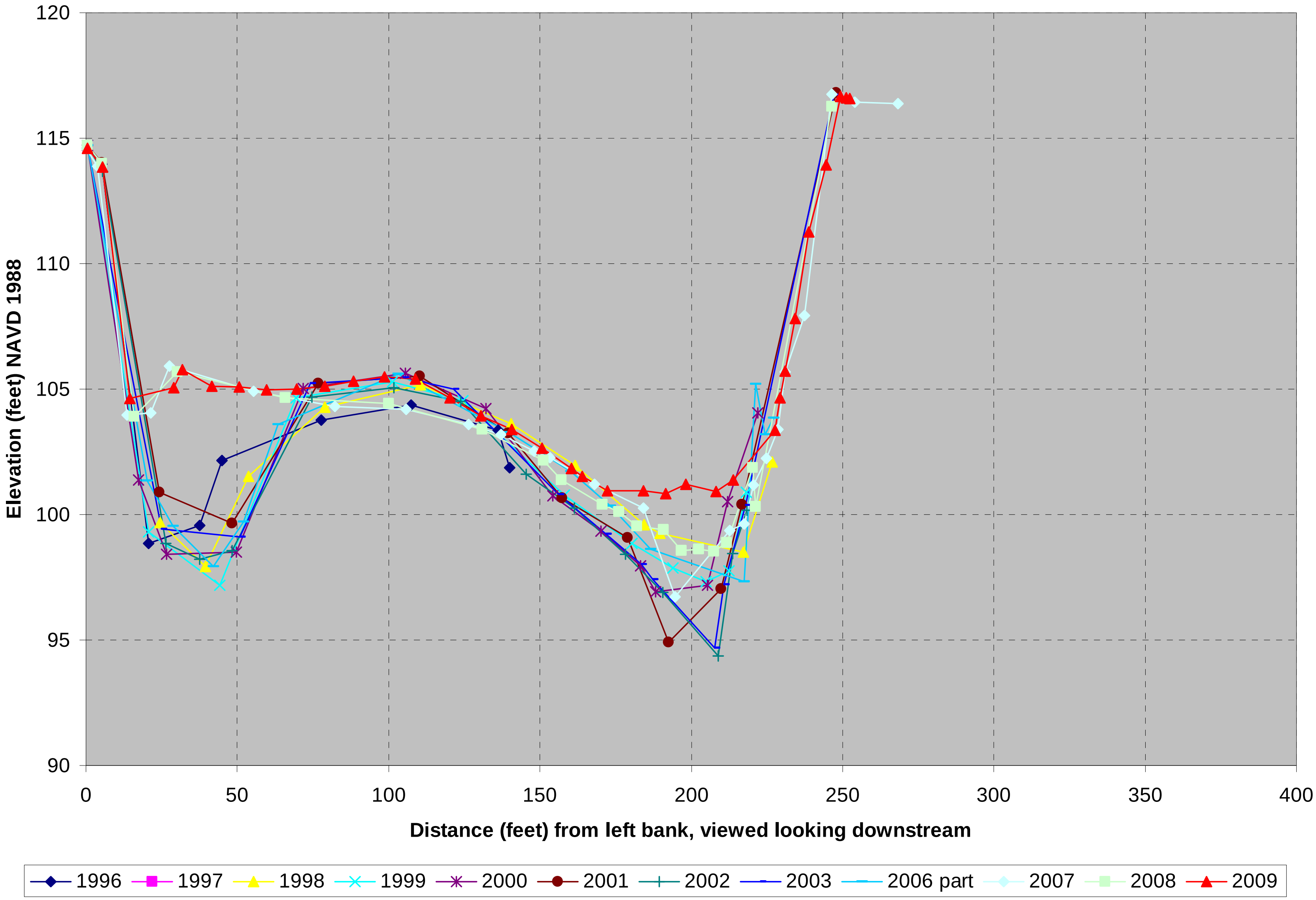


Figure 11: White River cross section 7.170 (Auburn #13), with data from 1996 through 2009

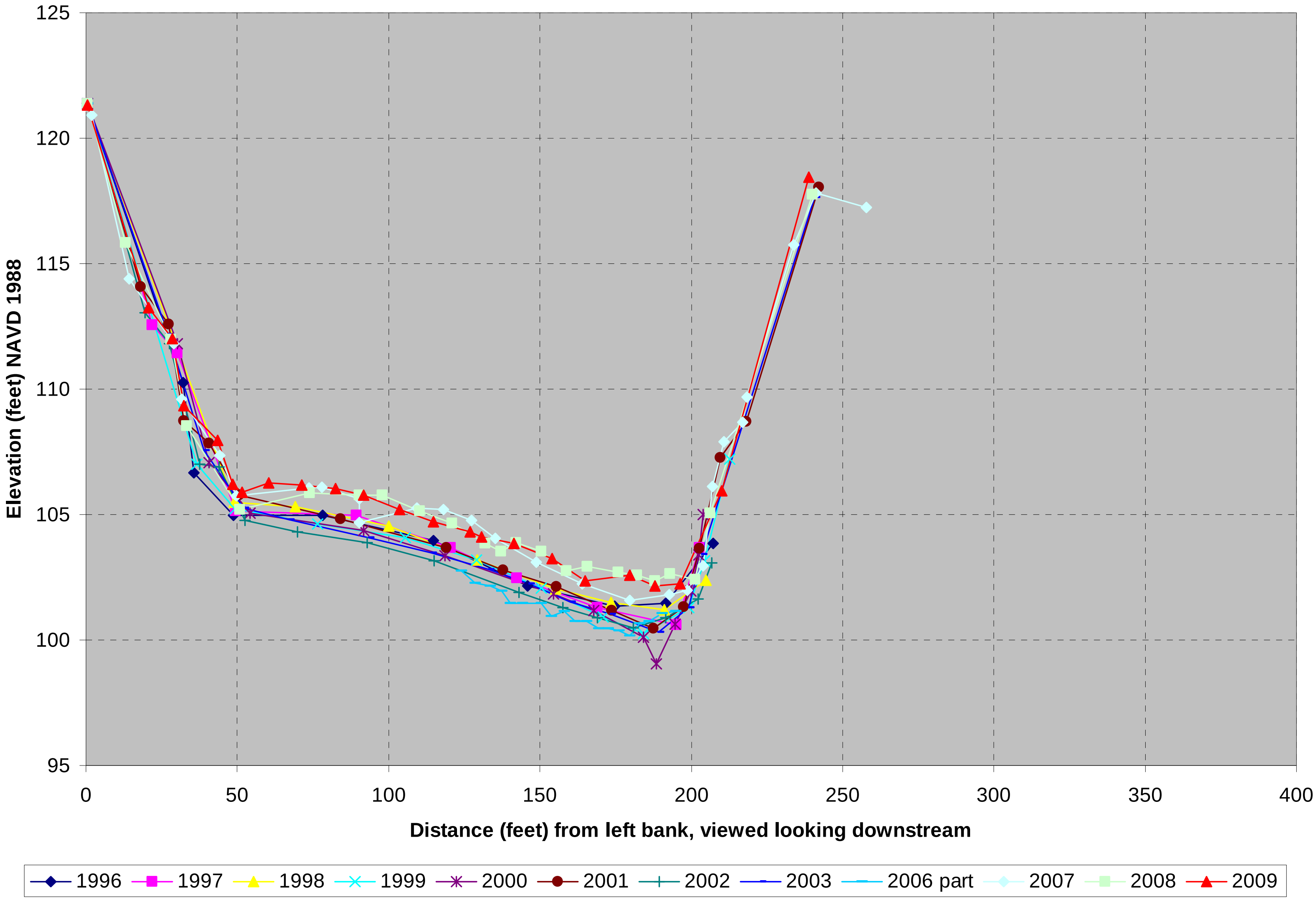


Figure 12: White River cross section 7.252 (Auburn #9), with data from 1996 through 2009

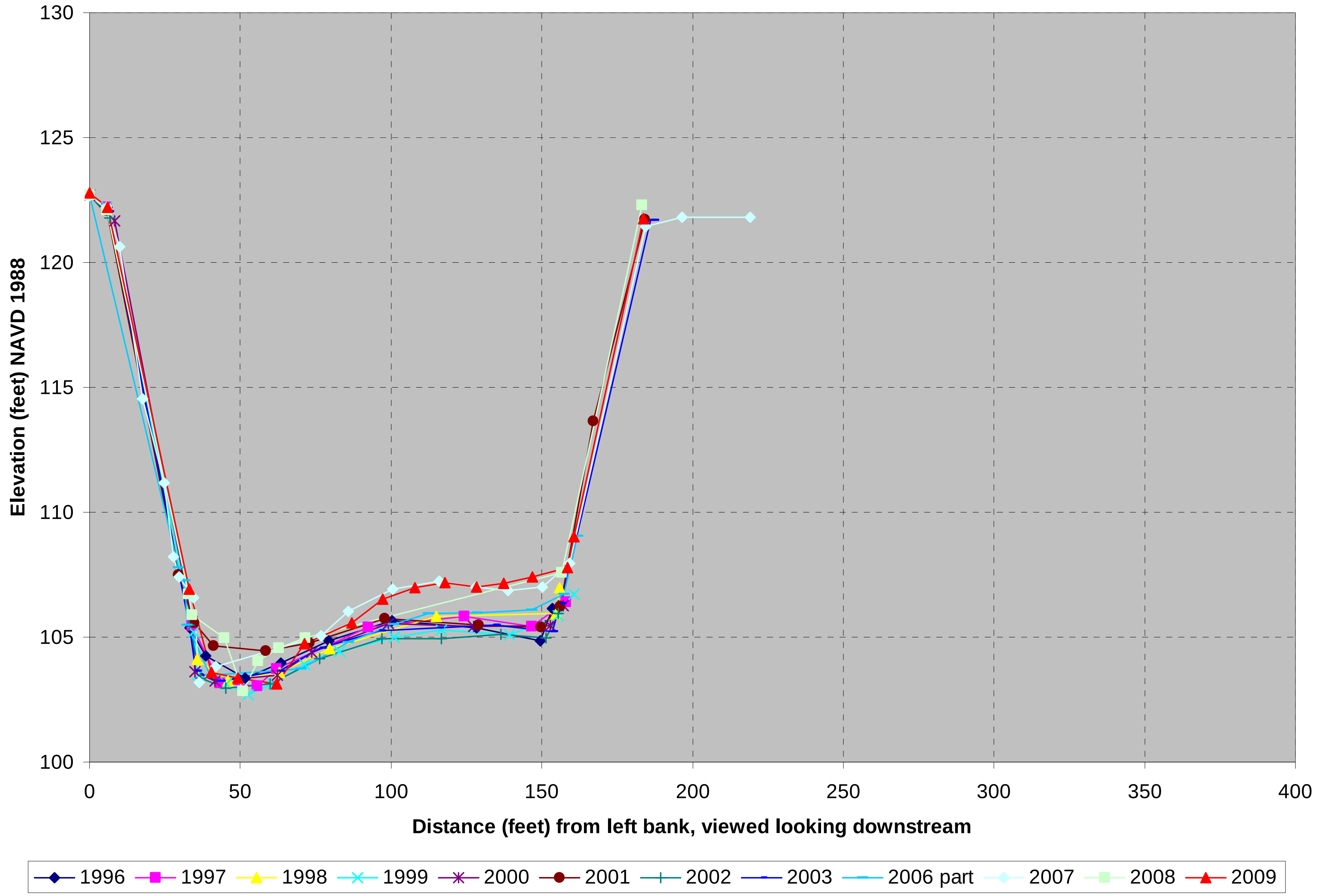


Figure 13: White River cross section 7.368 (Auburn #10), with data from 1996 through 2009

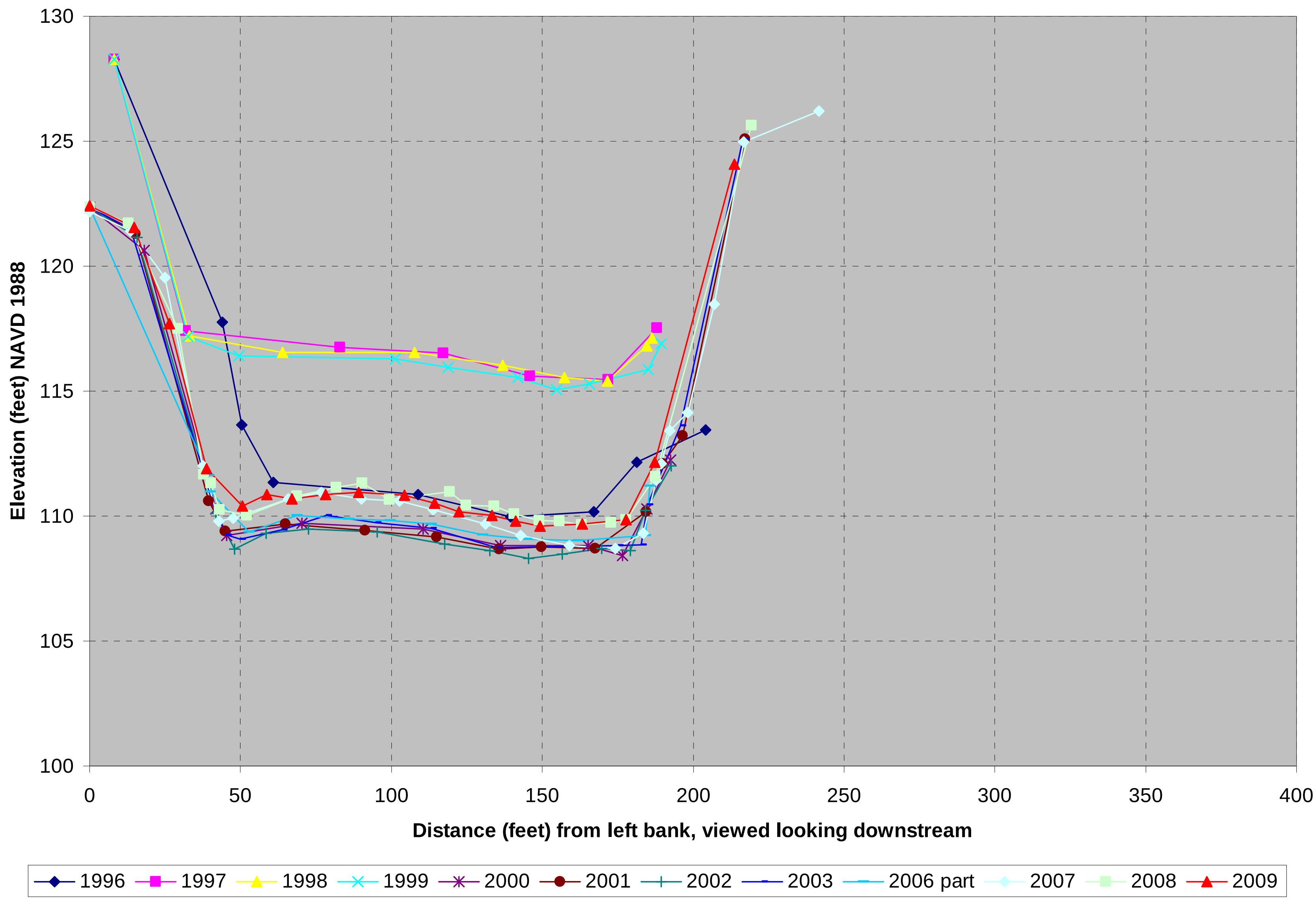


Figure 14: White River cross section 7.511 (Auburn #11), with data from 1996 through 2009

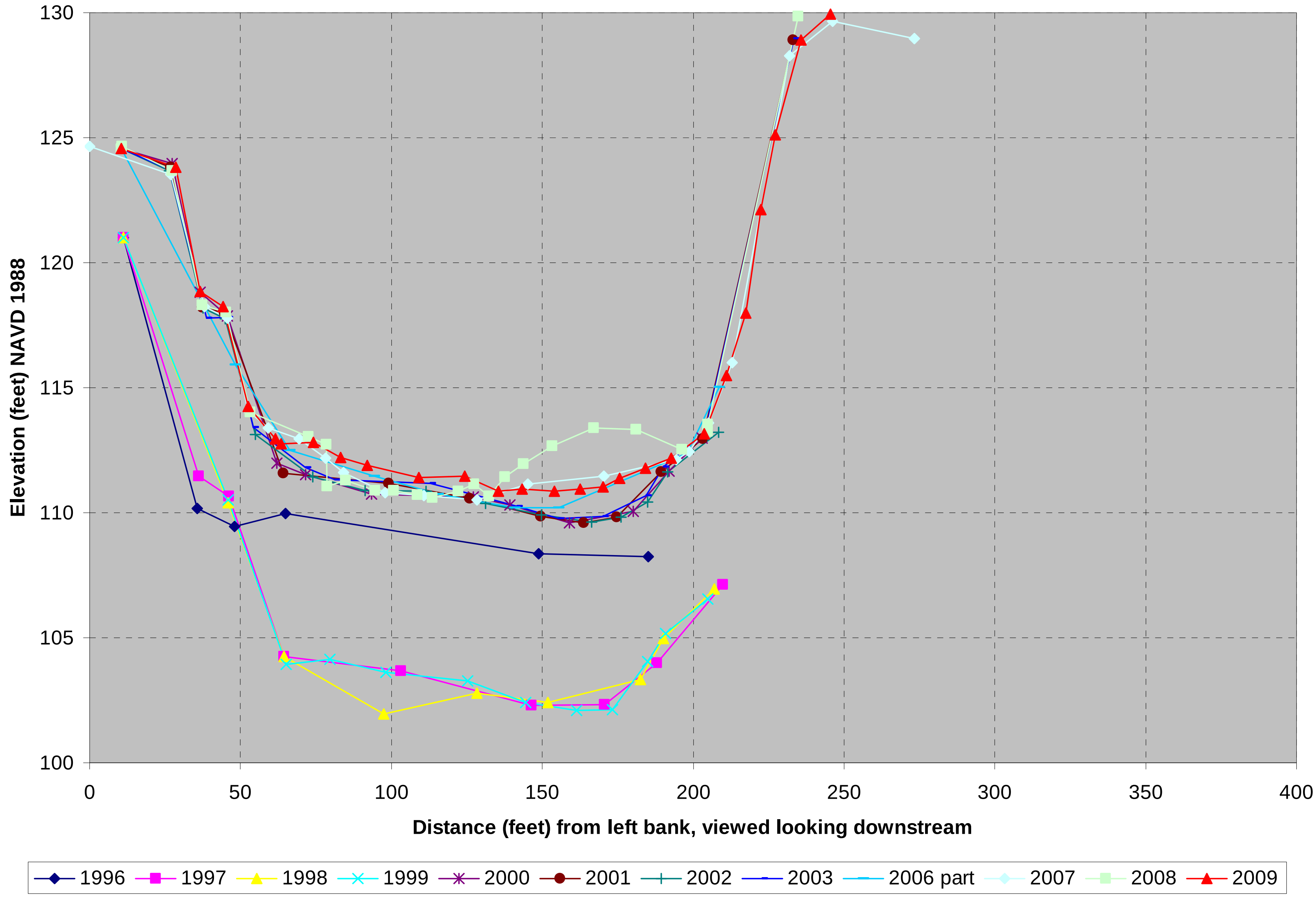


Figure 15: White River cross section 7.593 (Auburn #12), with data from 1996 through 2009

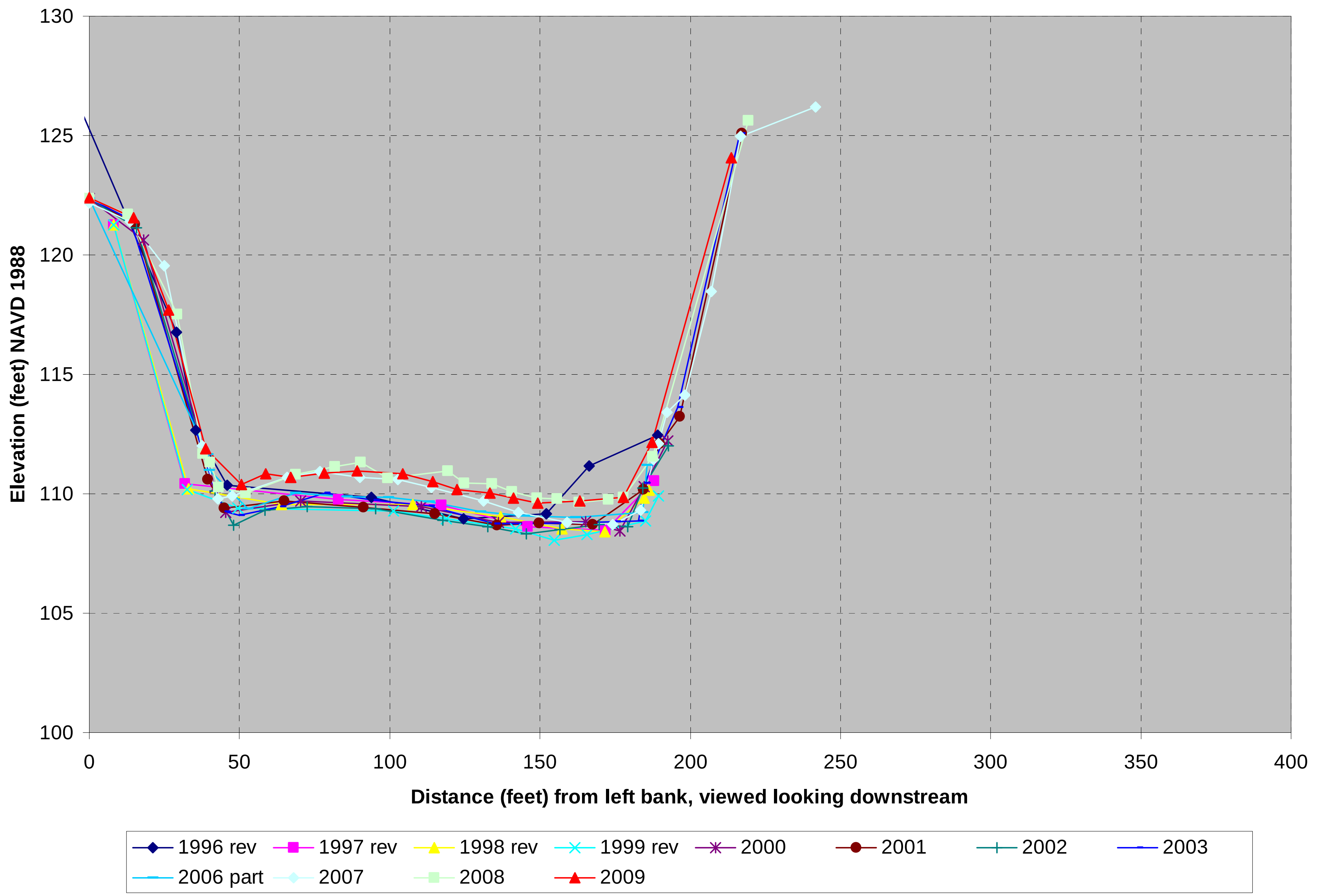


Figure 16: White River cross section 7.511 (Auburn #11), with revisions to 1996 through 1999 data

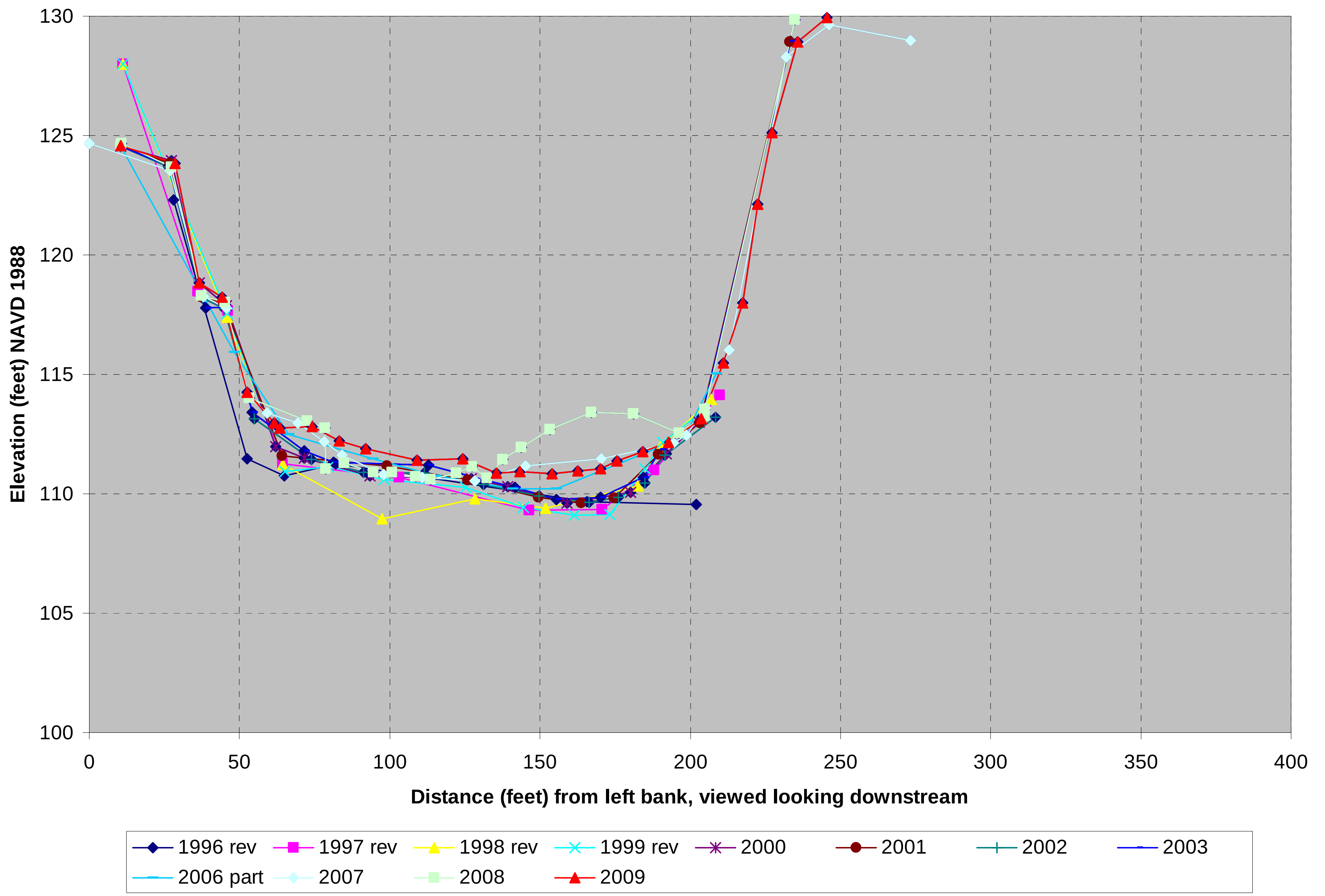


Figure 17: White River cross section 7.593 (Auburn #12), with revisions to 1996 through 1999 data

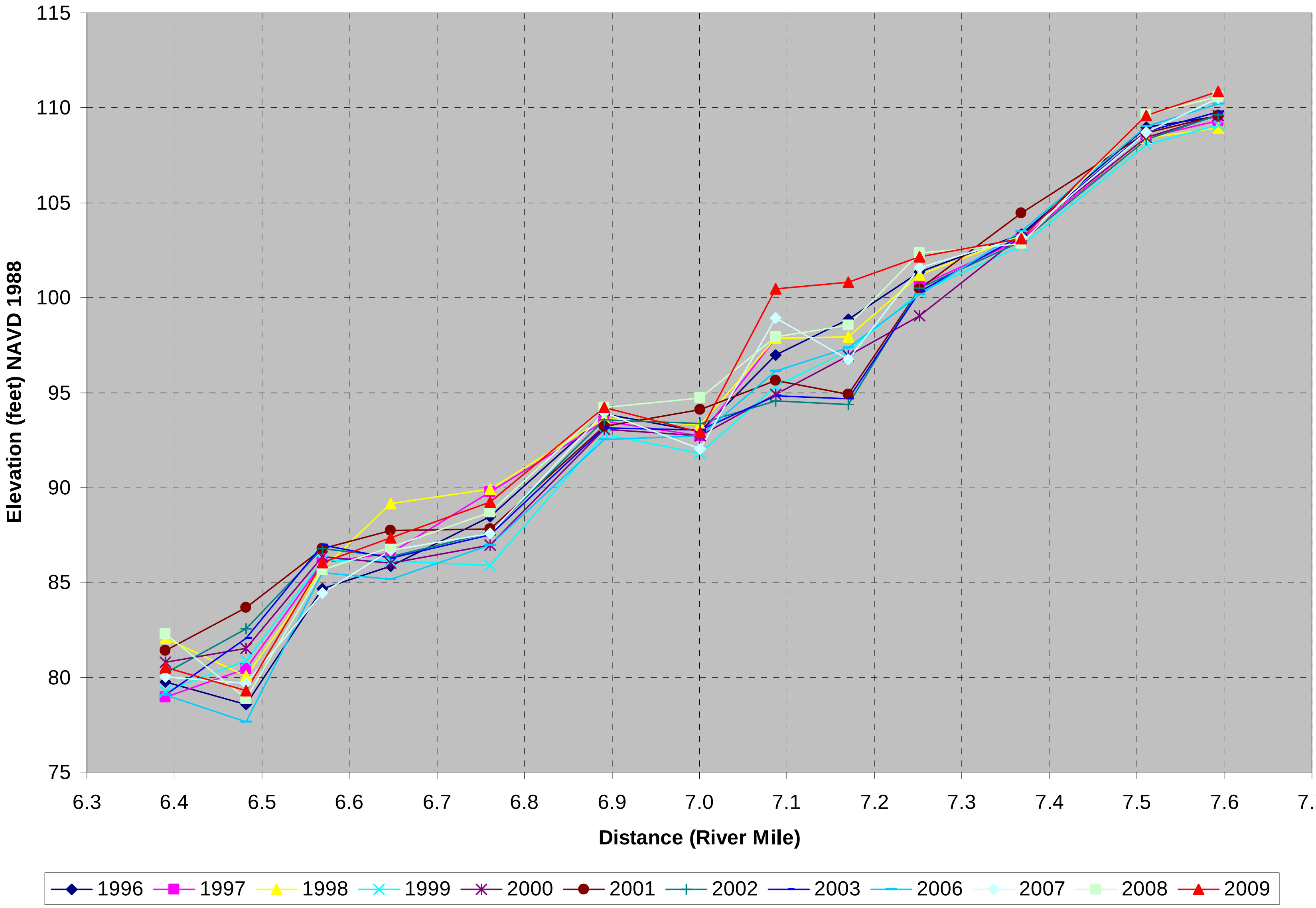


Figure 18: Longitudinal profile view of White River thalweg elevations from cross sections 6.390 to 7.593 in 1996 through 2009

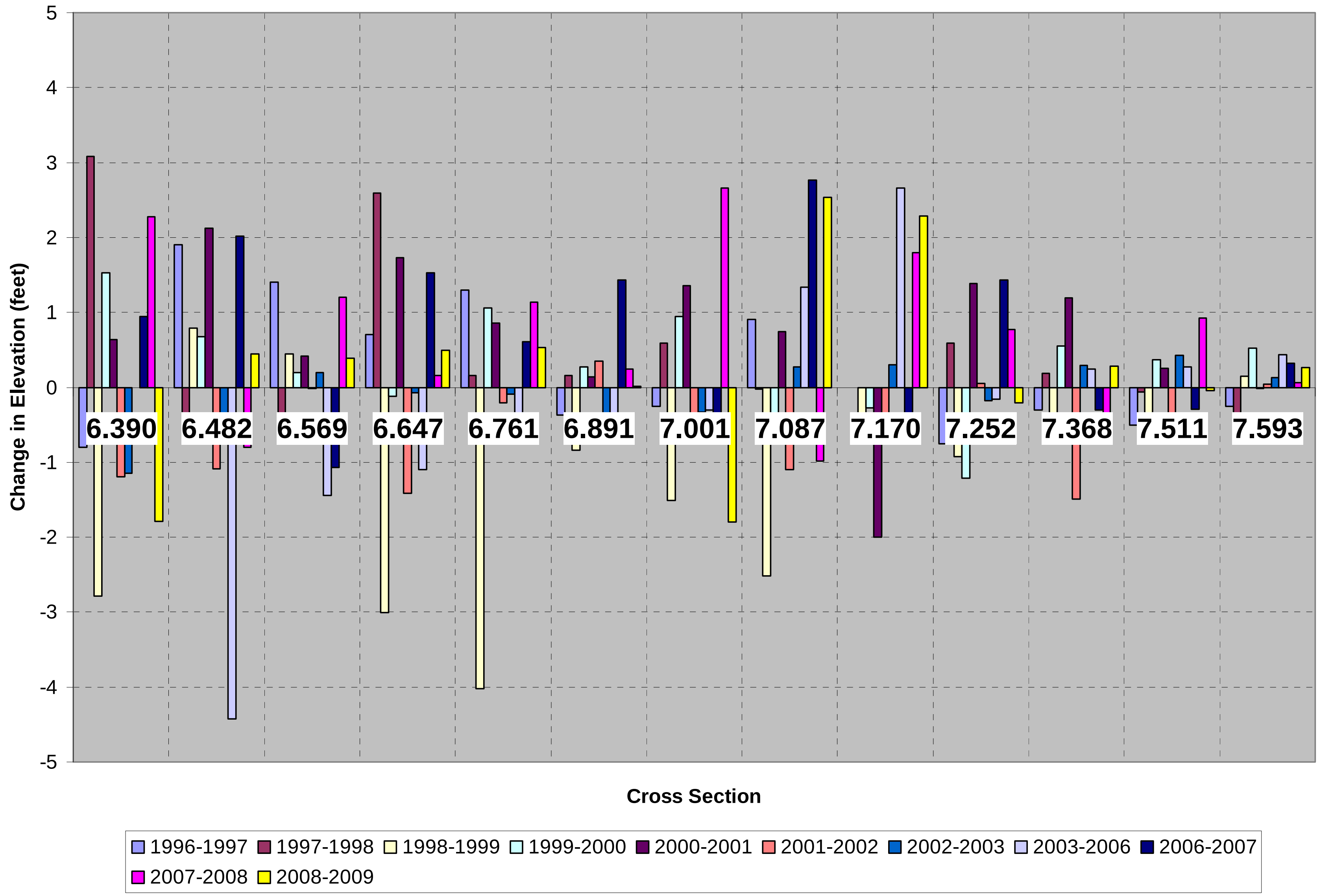


Figure 19: Change in thalweg elevation at White River cross sections 6.390 to 7.593 for 1996 through 2009

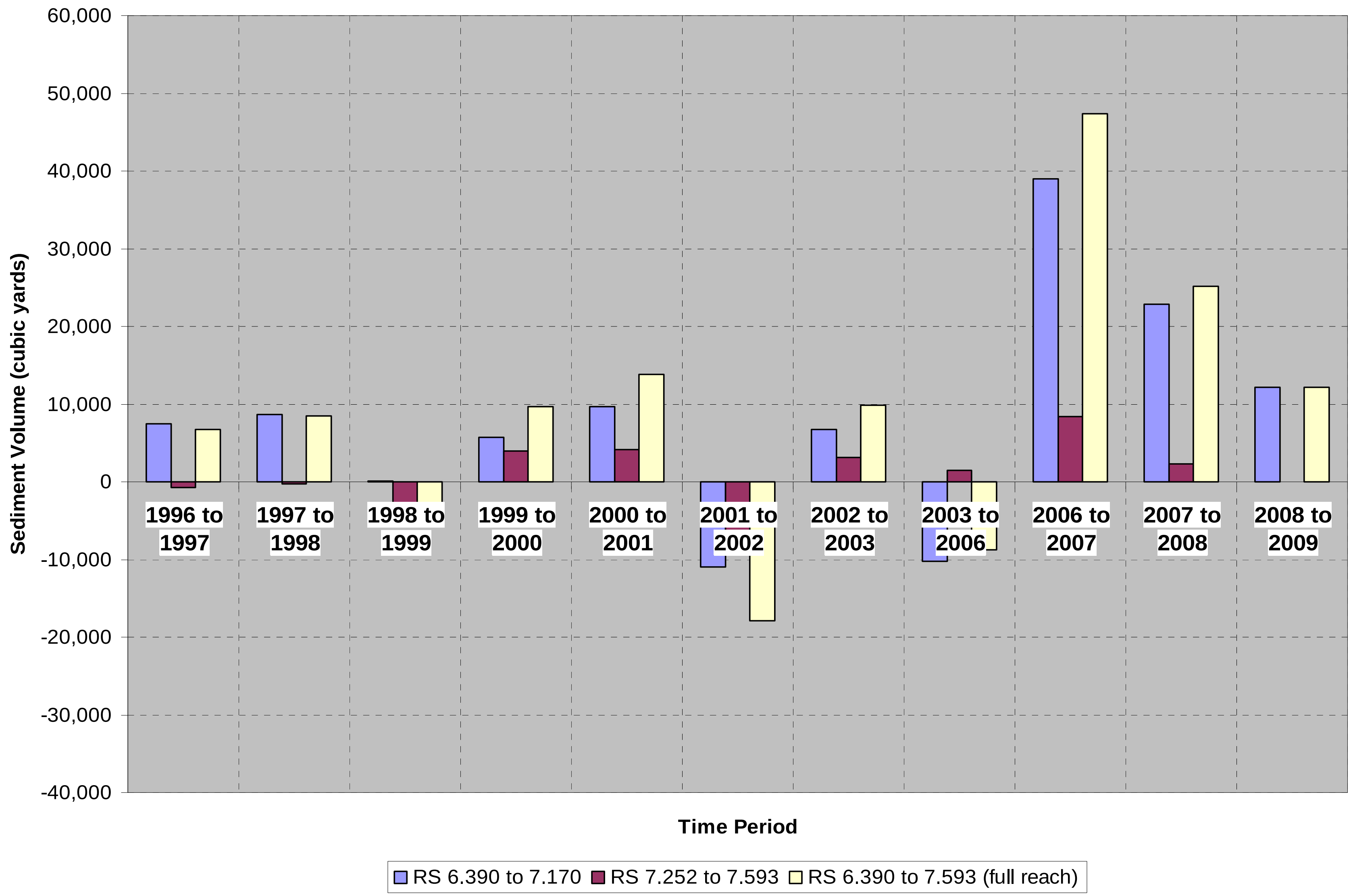


Figure 20: Change in sediment volumes in the White River (cross sections 6.390 to 7.593) in the full study reach and two sub-reaches, for 1996 though 2009

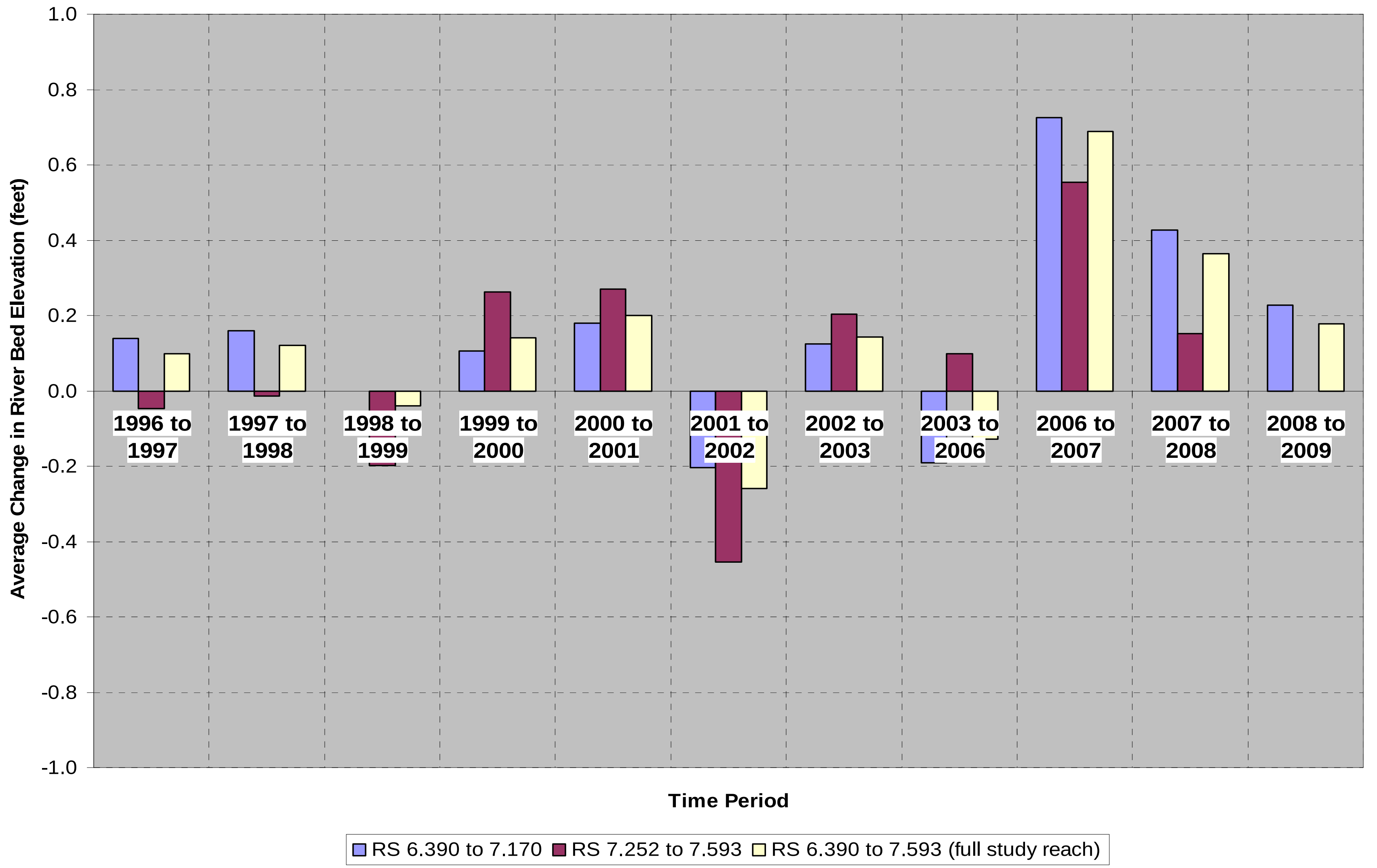


Figure 21: Change in average bed elevation in the White River (cross sections 6.390 to 7.593) in the full study reach and two sub-reaches, for 1996 through 2009

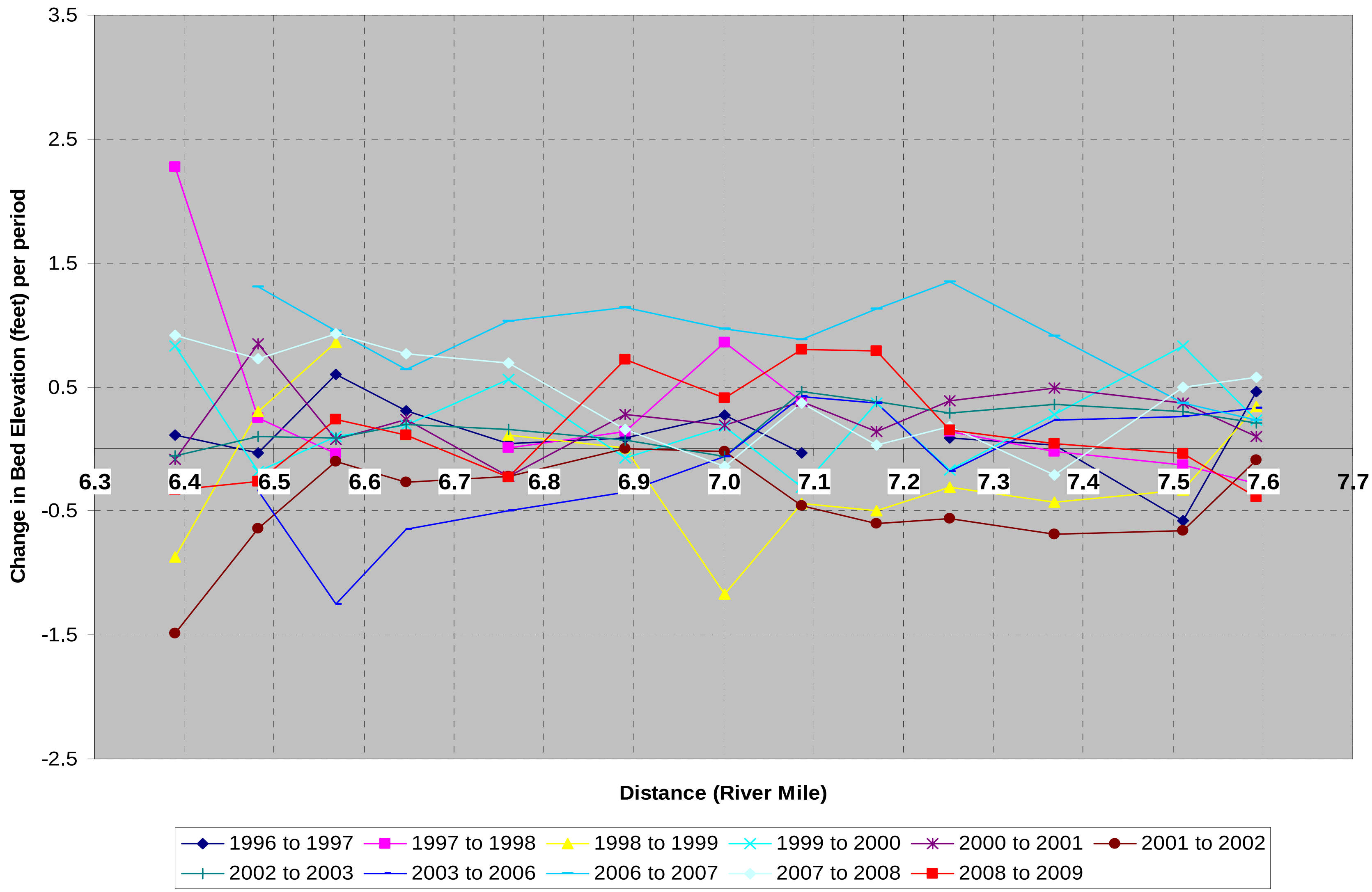


Figure 22: Average change in the White River bed elevation at each cross section from 6.390 to 7.593, for intervals from 1996 through 2009

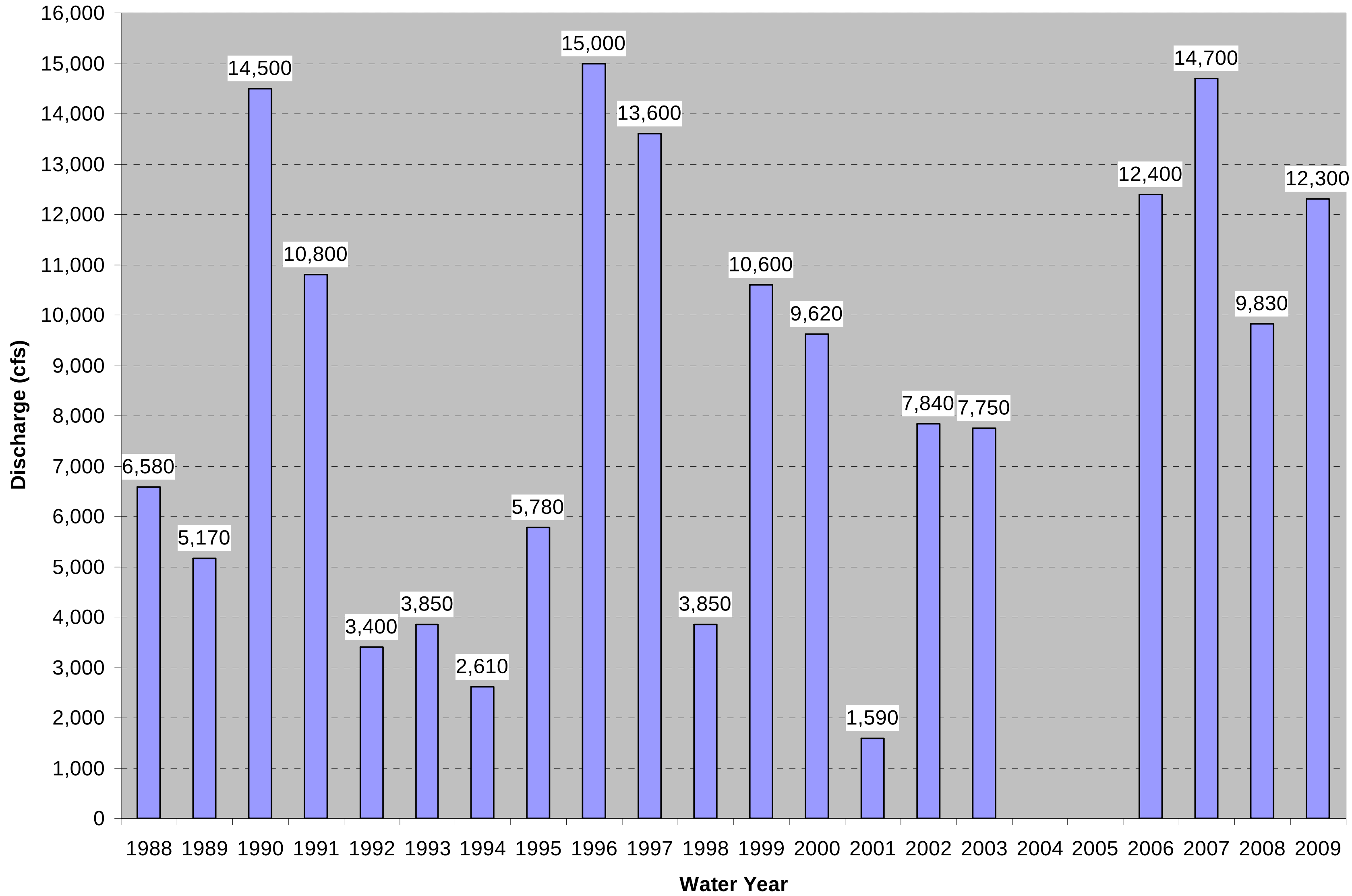


Figure 23: Peak annual flows at USGS gage 12100496, White River at Auburn for 1988 through 2009

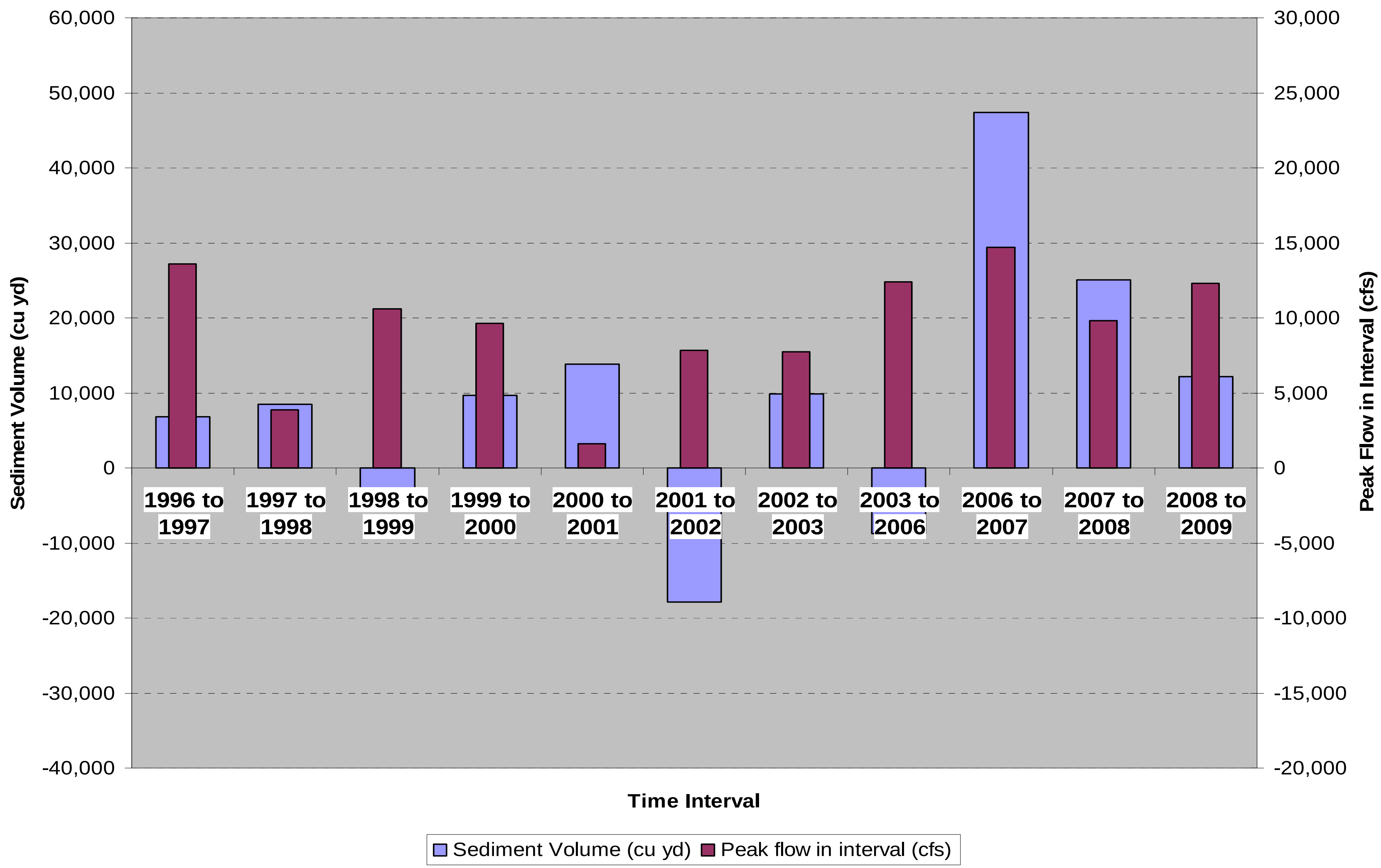


Figure 24: White River peak annual flows and change in sediment volume for the full study reach during each time interval from 1996 through 2009

APPENDIX E

White River Field Data Forms
(Cross-section 4.44 to Cross-section 10.596)

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 8/17/09 **GPS Points:** RM. X-sec 4.99
Surveyor(s): T Goldsmith, C Smith **Weather:** Clear, Sunny
Cross Section Id: X-Sec 4.99 **Photos:** CMR
Form Completed by: T Goldsmith

Bank Descriptions

Left: Bar		Right:	
Height (ft)	4-5'	*Height(ft):*	5 10-12'
Material:	Alluvium	*Material:*	Rip Rap
Erosional/Depositional:	Depositional	*Erosional/Depositional:*	~ Erosional ~ Rip Rap

Channel Description:

Wetted Width (ft): 105'
Bankful Width (ft): 275'-300' (from X-sec)
Substrate Material: Cobble, gravel
Floodplain width (ft): ~ see LiDAR
Thalweg: RB at Rip Rap

Pebble Counts:

Surface Collected? yes — u/s end of bar
Subsurface Collected? yes — u/s end of bar

Bank Vegetation

	Left Bank: Bar	Right Bank: (Rip Rap)
Type:	willow	Deciduous
Age:	young	——

Riparian Vegetation

	Left Bank:	Right Bank:
Type:	Deciduous	Deciduous
Age:	mature	mature

Notes: Sporadic willow grow on bar — Sparse — Sparse

Flood Inundation Levels:

LB Bar inundation - sand deposits on d/s end inside arc of the bar

Artificial Channel Constraints

Description/Location: RR ~ levee

Side Channels:

Description/Location: None - active

General Notes/Comments:

- LB Bar
- Site of historical gravel bar (LB) scalping
- Plane bed, with riffle at RR
- Access at Parsons Construction
- Concrete slab at RR
- No functional LWD
- flotsam on bar

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 8/17/09 **GPS Points:** old Gauge
Surveyor(s): J. Goldsmith C. Booth **Weather:** clear, sunny
Cross Section Id: 4.978 X-Sec **Photos:** CMB
Form Completed by: J. Goldsmith

Bank Descriptions

Left:		Right:	
Height (ft)	8'	*Height(ft):*	8'
Material:	Rip Rap	*Material:*	Rip Rap
Erosional/Depositional:	—	*Erosional/Depositional:*	Ø

Channel Description:

Wetted Width (ft): 170'
Bankful Width (ft): 180'
Substrate Material: Cobble Gravel
Floodplain width (ft): 180'
Thalweg: Channel Center

Pebble Counts:

Surface Collected? Ø
Subsurface Collected? Ø

Bank Vegetation

	Left Bank:	Right Bank: Brush
Type:	Brush	Deciduous
Age:	young	young
Notes:		

Riparian Vegetation

	Left Bank:	Right Bank: Cottonwood
Type:	Deciduous	Deciduous
Age:	mature	mature
	Sparse	Sparse

Flood Inundation Levels:

Levee to Levee

Artificial Channel Constraints

Description/Location: RB/LB Levee

Side Channels:

Description/Location: NA

General Notes/Comments:

- old gauge site USGS
- [illegible] d/s 8th st Br
- Bridge & supports in River
- Bar deposits d/s of the bridge
- Site accessed from lumber yard

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: July 30, 2009 **GPS Points:** X Sec 5.123
Surveyor(s): Goldsmith, Barton, Butler **Weather:** Sun, clear
Cross Section Id: X sec 5.123 **Photos:** T. Butler
Form Completed by: J. Goldsmith King County

Bank Descriptions

Left: (Levee) River side
Height (ft) 6–8
Material: Rip Rap
Erosional/Depositional: Stable (rip rap)

Right: Bar
Height(ft): 3–4'
Material: Alluvium
Erosional/Depositional: Deposition at Bar

Channel Description:

Wetted Width (ft): ~ 100'
Bankful Width (ft): ~ check X-section 410'
Substrate Material: ~ Cobble, gravel, sand
Floodplain width (ft): ~ 400'
Thalweg: LB

Pebble Counts:

Surface Collected? NA
Subsurface Collected? NA

Bank Vegetation

Left Bank: willow shrubs
Type: Deciduous
Age: young

Right Bank: (Bar)
Type: Deciduous
Age: young

Riparian Vegetation

Left Bank: Very little
Type:
Age:

Right Bank: a few Big Cottonwood
Type: Deciduous
Age: mature

Notes: A few Trees Sparse

Flood Inundation Levels:

Flood on bars and side channels,

Artificial Channel Constraints

Description/Location: LB ~ Levee
RB ~ At edge of floodplain ~ high area

Side Channels:

Description/Location: RB Side Channels created by u/s natural wood

General Notes/Comments:

— RB Bar ~ Functional wood trapping sediment
— Natural log jam upstream
— Bar covered with young alder
— RB Revetment at floodplain edge

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: July 30, 2009 **GPS Points:** x.sec 5.197
Surveyor(s): Goldsmith, Barton, Butler **Weather:** clear, sun
Cross Section Id: 5.197 **Photos:** T. Butler
Form Completed by: J. Goldsmith

Bank Descriptions

Left:
Height (ft) LB lower
Material: Rip Rap
Erosional/Depositional: Dep

Right:
Height(ft): 2 - 3'
Material: Alluvium
Erosional/Depositional: Deposition u/s of log jam

Channel Description:

Wetted Width (ft): 170'
Bankful Width (ft): 500' (from x-section)
Substrate Material: cobble, gravel, sand
Floodplain width (ft): See x-section
Thalweg: RB at Natural log Jam

Pebble Counts:

Surface Collected? NA
Subsurface Collected? NA

Bank Vegetation

Left Bank:
Type: Deciduous
Age: young

Right Bank:
Type: Deciduous
Age: young

Notes: (growing on bar)

Riparian Vegetation

Left Bank:
Type: Deciduous
Age: mature

Right Bank:
Type: Deciduous
Age: mature

Notes: <Sparse to dense>

Flood Inundation Levels:

overbank flooding on RB Bar and forested

Artificial Channel Constraints

Description/Location: Right Bank numerous side channels through the floodplain forest

Side Channels:

Description/Location: RB

General Notes/Comments:

- Section notes taken u/s of natural log jam on RB.
- Large LB Bar ~ cobble ~
- Log jam engaged with active river flow
- young willows on log jam

King County: White River Sediment Trends
Herrera Environmental Consultants Project No. 08-04059-013

Date: July 30th 2009 **GPS Points:** 5292
Surveyor(s): Goldsmith Barton Butler **Weather:** Clear, sun
Cross Section Id: X-Sec 5292 **Photos:** CMB
Form Completed by: J Goldsmith

Bank Descriptions

	Left: (Levee)		Right: (No levee)
Height (ft)	8'	*Height(ft):*	4'
Material:	rip rap	*Material:*	Rip Rap (sporadic)
Erosional/Depositional:	Side channel at LB levee base.	*Erosional/Depositional:*	Thalweg at RB

Channel Description:
Wetted Width (ft): 55'
Bankful Width (ft):
Substrate Material: Cobble
Floodplain width (ft): levee to levee
Thalweg: RB

Pebble Counts:
Surface Collected? Yes
Subsurface Collected? Yes

Bank Vegetation

	Left Bank: (levee)	Right Bank: (No levee)
Type:	deciduous/shrub	Deciduous, Shrub
Age:	young	young
Notes:	sparse	

Riparian Vegetation

	Left Bank:	Right Bank:
Type:	Deciduous	Deciduous
Age:	young	mature
Notes:	sparse	sparse

Flood Inundation Levels:

Artificial Channel Constraints
Description/Location: LB levee
RB rip rap

Side Channels:
Description/Location: At LB flowing

General Notes/Comments:
- Side channel at LB flowing H_2O
- RB wetland Restoration area

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: July 30, 2009 **GPS Points:** X-Sec 5374
Surveyor(s): Goldsmith, Barton, Butler **Weather:** Clear, hot!
Cross Section Id: 5374 **Photos:** CMB
Form Completed by: J. Goldsmith

Bank Descriptions

Left:
Height (ft) 6'-7' (River side)
Material: Riprap
Erosional/Depositional: Side channel at LB

Right:
Height(ft):
Material:
Erosional/Depositional:

Channel Description:

Wetted Width (ft):
Bankful Width (ft):
Substrate Material:
Floodplain width (ft):
Thalweg:

Pebble Counts:

Surface Collected? NA
Subsurface Collected? NA

Bank Vegetation

Left Bank: *Type:* *Age:*
Right Bank: *Type:* *Age:*

Riparian Vegetation

Left Bank: *Type:* *Age:*
Right Bank: *Type:* *Age:*

Notes:

Flood Inundation Levels:
Evidence bar is overtopped

Artificial Channel Constraints
Description/Location: LB - Levee - yes
RB - Levee - ??

Side Channels:
Description/Location: at LB, flowing H2O ≈ 30-40 cfs

General Notes/Comments:
~ Flowing side channel at LB
~ Side channel at LB not able to cross
~ Form not completed

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: July 30, 2009 **GPS Points:**
Surveyor(s): Goldsmith, Barton, Butl **Weather:** Clear, sun
Cross Section Id: XSec 5.460 **Photos:** CMR
Form Completed by: J. Goldsmith

Bank Descriptions

Left:
Height (ft) Levee
Material:
Erosional/Depositional:

Right:
Height(ft): Berm ~5'
Material: Rip Rap
Erosional/Depositional:

Channel Description:
Wetted Width (ft):
Bankful Width (ft): Levee to RB Berm
Substrate Material:
Floodplain width (ft): Levee to RB berm
Thalweg: LB

Pebble Counts:
Surface Collected? NA
Subsurface Collected? NA

Bank Vegetation
Left Bank:
Type:
Age:
Right Bank: deciduous
Type: Blackberry
Age: young

Riparian Vegetation
Left Bank:
Type: Decid
Age:
Right Bank:
Type: Deciduous
Age: young to mature

Notes:

Flood Inundation Levels:
overbar deposits

Artificial Channel Constraints
Description/Location: LB ~ Levee
RB ~ Temp Berm

Side Channels:
~25' wetted width
Description/Location: RB Side Channel ~ Flowing H_2O

General Notes/Comments:
~ cannot access the bar, side channel limits access

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: July 30, 2009 **GPS Points:** 5.261 ~~5.621~~
Surveyor(s): Goldsmith, Barton, Butler **Weather:** Sun Clear
Cross Section Id: XSEC 5.621 **Photos:** CMB
Form Completed by: J. Goldsmith

Bank Descriptions

Left:		Right:	
Height (ft)	6' (Riverside)	*Height(ft):*	6-7'
Material:	Rip Rap	*Material:*	Rip Rap
Erosional/Depositional:	Deposition (bar)	*Erosional/Depositional:*	Thalweg at RB

Channel Description:

Wetted Width (ft): 105'
Bankful Width (ft): Levee to levee ~240'
Substrate Material: Cobble, gravel, sand
Floodplain width (ft): levee to levee ~240'
Thalweg: RB

Pebble Counts:

Surface Collected? NA
Subsurface Collected? NA

Bank Vegetation (levees)

Left Bank:
Type: Shrub/Deciduous Trees
Age: young

Right Bank:
Type: Shrub
Age: young

Notes:

Riparian Vegetation

Left Bank:
Type: Deciduous
Age: young to mature ~ sparse to Dense

Right Bank:
Type: Deciduous
Age: young to mature Sparse

Flood Inundation Levels:

on bar ~ levee to levee

Artificial Channel Constraints

Description/Location: RB Levee
LB Levee

Side Channels:

Description/Location: NA

General Notes/Comments:

Functioning Pieces: [72' Conifer – 20" DBH / 60' Conifer –]

- LWD Accumulation at section with scour
- Hornet nest
- LB Bar ~ Sand, gravel, cobble
- Plane bed channel
- GPS pt labeled incorrectly.

King County: White River Sediment Trends
Herrera Environmental Consultants Project No. 08-04059-013

Date:	July 30, 2009	**GPS Points:**	XSec5712
Surveyor(s):	Goldsmith, Barton, Ruttle	**Weather:**	Clear/Sun
Cross Section Id:	5712	**Photos:**	CMB
Form Completed by:	J. Goldsmith		

Bank Descriptions

Left:		Right:	
Height (ft)	levee	*Height(ft):*	levee / ~6'
Material:	rip rap	*Material:*	~Rip Rap
Erosional/Depositional:	bar deposition	*Erosional/Depositional:*	Thalweg at RB

Channel Description: unvegetated channel

Wetted Width (ft):	mainchannel ~ 560'
Bankful Width (ft):	Levee to Levee 240'
Substrate Material:	Cobble, gravel
Floodplain width (ft):	Levee to Levee 240'
Thalweg:	Right Bank at Levee

Pebble Counts:

Surface Collected? NA
Subsurface Collected? NA

Bank Vegetation

Left Bank:	Right Bank:
Type: Shrub / blackberry	*Type:* Shrub
Age: young	*Age:* young

Notes:

Riparian Vegetation

Left Bank:	Right Bank:
Type: Deciduous	*Type:* Deciduous
Age: young to mature	*Age:* mature
Dense	Dense

Flood Inundation Levels:

Artificial Channel Constraints
Description/Location: LB Levee
RB Levee

Side Channels:
Description/Location: Flow at near LB levee

General Notes/Comments:
- d/s end LB Bar
- Cobble, gravel, sand
- Recent RB Levee Repair ('06 per TB)

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: July 30, 2009 **GPS Points:**

Surveyor(s): Goldsmith, Barton, Butler **Weather:** Sun, clear

Cross Section Id: ≈ 5.920 **Photos:** T. Butler

Form Completed by: J. Goldsmith

Bank Descriptions

Left:
Height (ft) Levee
Material: Rip Rap
Erosional/Depositional: LB, Thalweg

Right:
Height(ft): Temp Berm
Material:
Erosional/Depositional: Depositional / bar w/ wood

Channel Description:

Wetted Width (ft): ≈ 110'
Bankful Width (ft):
Substrate Material:
Floodplain width (ft): Levee to Temp Berm
Thalweg: LB

Pebble Counts:

Surface Collected? N/A
Subsurface Collected? N/A

Bank Vegetation

Left Bank: Trees
Type: Shrubs, decidious
Age:

Right Bank: Trees
Type: Decidious
Age: mature

Riparian Vegetation

Left Bank:
Type: Decidious
Age: young to mature

Right Bank:
Type: Park Decidious
Age: Park

Notes: young

Flood Inundation Levels: ~ Flood deposits on RB bar.

Artificial Channel Constraints

Description/Location: LB ~ Levee
RB ~ Temp Berm

Side Channels:

Description/Location: Dry side channel along RB

General Notes/Comments:

~ Wood accumulation along RB just upstream 5.920 ~ RM 5.4
~ LWD present < 5 year per T. Butler
~ CMB notes on large wood accumulation
~ Pacific Mayor on-site intends to remove LWD accumulation
~ verify wood d/s extent on 2009 air photos.
~ Young Alder ≈ 5-10 years on bar

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: July 30, 2009 **GPS Points:** 6.013
Surveyor(s): Goldsmith, Barton, Buth **Weather:** clear, sun
Cross Section Id: 6.013 **Photos:** CMB
Form Completed by: J. Goldsmith

Bank Descriptions

Left: Levee
Height (ft) 8'
Material: Rip Rap
Erosional/Depositional: Thalweg at LB

Right:
Height(ft): ~6'
Material: Fill
Erosional/Depositional: Bar at bar

Channel Description:
Wetted Width (ft): ~80'
Bankful Width (ft): Levee to berm (temp)
Substrate Material: Cobble, gravel, sand 300'
Floodplain width (ft): Levee to Temp. berm
Thalweg: L.B. 300'

Pebble Counts:
Surface Collected? yes
Subsurface Collected? yes

Bank Vegetation
Left Bank: *Type:* Deciduous Shrub *Age:* young
Right Bank: *Type:* willow *Age:* young

Riparian Vegetation
Left Bank: *Type:* Deciduous *Age:* mature
Right Bank: *Type:* None *Age:* None } Park

Notes:

Flood Inundation Levels:

Artificial Channel Constraints
Description/Location: RB ~ Berm (Temporary at Bank)
LB ~ Levee

Side Channels:
Description/Location: None

General Notes/Comments:
- RB Access at Pacific Park
- Pebble Count at RB bar
- RB ~ concrete levee exposed just u/s

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: July 30, 2009 **GPS Points:** X Sec 6.145
Surveyor(s): Goldsmith, Rautio, Butler **Weather:** clear, hot
Cross Section Id: X Sec 6.145 **Photos:** CMR
Form Completed by: J. Goldsmith

Bank Descriptions

Left:
Height (ft) 16'
Material: Rip Rap
Erosional/Depositional: Bar at LB

Right:
Height(ft): 8' ~
Material: Concrete levee
Erosional/Depositional: ∅

Channel Description:

Wetted Width (ft): 55' ~120'
Bankful Width (ft): Levee to levee ~290'
Substrate Material: cobble
Floodplain width (ft): levee to Levee
Thalweg:

Pebble Counts:

Surface Collected? NA
Subsurface Collected? NA

Bank Vegetation

Left Bank:
Type: shrub/deciduous
Age: young

Right Bank: NA
Type: Concrete
Age: levee

Riparian Vegetation

Left Bank:
Type: Deciduous
Age: young to mature

Right Bank: Really Non
Type: few
Age: trees (open)

Notes:

Flood Inundation Levels:

overbank sand deposits

Artificial Channel Constraints

Description/Location: RB Levee
LB Levee

Side Channels:

Description/Location: Dry at LB between bar + levee
sand substrate at ELJ

General Notes/Comments:

- Section at d/s end of log jam bar
- Channel feature at RB gone since April 2009 survey (April)
- D/S of depositional influence of 6.233 log jams

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: July 30 2009
GPS Points: X-Sec 6.313
Surveyor(s): Goldsmith, Barton, Butler
Weather: Sunny, clear
Cross Section Id: 6.313
Photos: Cmr 2105-2417
Form Completed by: J. Goldsmith

Bank Descriptions

Left: (or backside)
Height (ft) 16' (at max)
Material: RipRap (4')
Erosional/Depositional: (Depositional circled) Bar at bank

Right: (Trailer Park at RB)
Height(ft): 6'
Material: concrete slab
Erosional/Depositional: Ø

Channel Description:

Wetted Width (ft): 55'
Bankful Width (ft): 190' feet
Substrate Material: cobble bar, w/ sand
Floodplain width (ft): levee to levee
Thalweg: Right Bank

Pebble Counts:

Surface Collected? N/A
Subsurface Collected? N/A

Bank Vegetation

Left Bank: Blackberry
Type: Deciduous
Age: young

Right Bank:
Type: Shrubs
Age: young

Riparian Vegetation

Left Bank:
Type: Deciduous
Age: young

Right Bank: very
Type: sparse
Age: young to mature.

Notes:

Flood Inundation Levels:

levee to levee, levee breach on RB during Jan '09 flood

Artificial Channel Constraints

Description/Location: RB Levee
LB

Side Channels:

Description/Location: None. Channel confined by levee

General Notes/Comments:

- Section immediately d/s of A-street Bridge
- large bar development on left Bank
- Old U.S.G.S. gauge on LB, not engaged
- Near RB Abutment Bridge
- Log jam removed at bridge center abutment.
- Ponded H_2O at LB levee.

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 7.1.2009 **GPS Points:** 6.390
Surveyor(s): J.G. Imsl **Weather:** sun ~ 80°F
Cross Section Id: 6.390 **Photos:** 2005 - 2017
Form Completed by: J. Goldsmith

Bank Descriptions

Left:
Height (ft) Sand 4'
Material: Sand / Rip Rap
Erosional/Depositional: Stable

Right:
Height(ft): Bar ~ 3-4'
Material: gravel / sand
Erosional/Depositional: - Depositional at bar - Erosion at bridge

Channel Description:
Wetted Width (ft): 159'
Bankful Width (ft): 186'
Substrate Material: Cobble, boulder
Floodplain width (ft): 228
Thalweg: uniform flow

Pebble Counts:
Surface Collected? Ø
Subsurface Collected? Ø

Bank Vegetation
Left Bank: (levee)
Type: Deciduous
Age: young to mature
Right Bank:
Type: Deciduous
Age: young

Riparian Vegetation
Left Bank:
Type: blackberry
Age:
Right Bank: (Bar)
Type: Deciduous
Age: young to mature

Notes:

Flood Inundation Levels:
LB ~ overbank flood deposits at levee toe.

Artificial Channel Constraints
Description/Location: LB Levee ~ 10'

Side Channels:
Description/Location: LB - None; RB at d/s mid-channel island bar

General Notes/Comments:
- No Functional LWD.
- RB - Vegetated Bar / Floodplain
- Cross-section immediately u/s of bridge (A street
- Powerlines overhead

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 7-1-09 **GPS Points:** X-sec 6.407

Surveyor(s): MS JG SM **Weather:** Sun ~ 80°F

Cross Section Id: 6.407 **Photos:**

Form Completed by: J. Goldsmith

Bank Descriptions

Left:
Height (ft) Levee ~ 15'
Material: Rip Rap
Erosional/Depositional: eroding ?

Right:
Height(ft): Bar
Material:
Erosional/Depositional: Depositional

Channel Description:

Wetted Width (ft): 66'
Bankful Width (ft): 69'
Substrate Material: cobble/boulder
Floodplain width (ft): 300'
Thalweg: LB

Pebble Counts:

Surface Collected? Ø
Subsurface Collected? Ø

Bank Vegetation

Left Bank: (levee)
Type: mixed
Age: young to mature

Right Bank:
Type: Deciduous
Age: young to mature

Riparian Vegetation

Left Bank: NA
Type: Park
Age:

Right Bank:
Type: Deciduous
Age:

Notes:

Flood Inundation Levels:

Artificial Channel Constraints

Description/Location: LB ~ Levee
RB ~ Levee Trailer Park

Side Channels:

Description/Location: LB ~ None, RB ~ yes, flowing

General Notes/Comments:

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 2/11/09 **GPS Points:** 6.569
Surveyor(s): MS TG SM **Weather:** sunny-clear
Cross Section Id: X-5 6.569 **Photos:** 993-2003
Form Completed by: MS

Bank Descriptions

Left:
Height (ft) 1'
Material: Sand
Erosional/Depositional:

Right:
Height(ft): 2-3'
Material: sand, gravel
Erosional/Depositional:

Channel Description:
Wetted Width (ft): 121'
Bankful Width (ft): 195'
Substrate Material: sand/gravel
Floodplain width (ft): 475'
Thalweg: plane bed / center

Pebble Counts:
Surface Collected? No
Subsurface Collected? No

Bank Vegetation
Left Bank: *Type:* re-sprouted cottonwood *Age:* 1-5
Right Bank: *Type:* — *Age:* —

Riparian Vegetation
Left Bank: *Type:* young deciduous *Age:* 2-5 yrs
Right Bank: *Type:* young deciduous *Age:* 2-5 yrs

Notes:

Flood Inundation Levels:

Artificial Channel Constraints
Description/Location: RB levee 3'
LB levee 5'

Side Channels:
Description/Location: 2 LB side channels, one wet, stagnant water, 1 dry

General Notes/Comments:
functioning wood at head of Bar on RB, side channel flow on RB behind bar

RB bar is vegetated

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 2-1-09
GPS Points: X-sec 6.647
Surveyor(s): MS JG BM
Weather: Sunny - clear
Cross Section Id: 6.647
Photos:
Form Completed by: MS, JG

Bank Descriptions (low levee along RB)

Left:		Right:	
Height (ft)	3'	*Height(ft):*	3'
Material:	Sand	*Material:*	earth, levee rock levee
Erosional/Depositional:	depositional	*Erosional/Depositional:*	– stable

Channel Description:

Wetted Width (ft):	147'
Bankful Width (ft):	165'
Substrate Material:	sand / gravel
Floodplain width (ft):	350'
Thalweg:	plane bed

Pebble Counts:

Surface Collected?	No.
Subsurface Collected?	No

Bank Vegetation

Left Bank:	Right Bank: willow/dogwood
Type: <5' deciduous	*Type:* Deciduous
Age: young	*Age:* young

Riparian Vegetation

Left Bank:	Right Bank:
Type: Deciduous	*Type:* grass
Age: young +/ mature) on bar	*Age:* young

Notes:

Flood Inundation Levels:

LB bar ~ vegetated ~ inundated ~ overbank sands

Artificial Channel Constraints

Description/Location: RB ~ levee at Trailer Park ~8'
LB levee at Park ~5'

Side Channels:

Description/Location: LB ~ Dry side chan

General Notes/Comments:

~ No functional LWD
~ Plane bed channel
~ Vegetated LB Bar ~ Flood Deposits
~ Side channel LB Bar

King County: White River Sediment Trends
Herrera Environmental Consultants Project No. 08-04059-013

Date: 7-1-09 **GPS Points:** 6.761
Surveyor(s): MS JG SM **Weather:** sunny clear
Cross Section Id: 6.761 **Photos:**
Form Completed by: M. Strazer

Bank Descriptions

Left:
Height (ft) 2'
Material: sand/gravel
Erosional/Depositional: depositional

Right:
Height(ft): 2'
Material: levee material
Erosional/Depositional: depositional

Channel Description:
Wetted Width (ft): 156'
Bankful Width (ft): 186'
Substrate Material: gravel/cobble
Floodplain width (ft): see lidar, levee to levee (~400')
Thalweg: RB/center

Pebble Counts:
Surface Collected? No
Subsurface Collected? No

Bank Vegetation
Left Bank: *Type:* NA *Age:* —
Right Bank: *Type:* young deciduous *Age:* < 5yrs

Riparian Vegetation
Left Bank: *Type:* young deciduous *Age:* 5yrs
Right Bank: *Type:* young deciduous *Age:* 5-10 yrs

Notes:

Flood Inundation Levels:
3' above waterlevel (see photo of flood debris)

Artificial Channel Constraints
Description/Location: LB levee - 6-7' (complex channel flow btwn levee & mainstem)
RB levee - 7-8' (flow against levee toe)

Side Channels:
Description/Location: yes, 2-3 sidechannels, complex network of wood, debris, young growth

General Notes/Comments:
large vegetated bar above X-S, braided channel above X-S, which reconnects at X-S
functioning wood → cottonwood creating some deposition, non-embedded, ~16" DBH, ~25'

several large pieces of wood ob here

complex channel on LB.

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 9/1/09
GPS Points: 6.891
Surveyor(s): MS JG SM
Weather: sunny/clear
Cross Section Id: 6.891
Photos: 958-62
Form Completed by: MS

Bank Descriptions

Left:
Height (ft) 2'
Material: sand
Erosional/Depositional: NA

Right:
Height(ft): 2'
Material: sand
Erosional/Depositional: NA

Channel Description:

Wetted Width (ft): 138'
Bankful Width (ft): ~~13~~ 144'
Substrate Material: gravel/sand
Floodplain width (ft): 192'
Thalweg: plane bed

Pebble Counts:

Surface Collected? No
Subsurface Collected? No

Bank Vegetation

Left Bank: *Type:* light brush *Age:* 1-2 yrs
Right Bank: *Type:* light brush *Age:* 1-2 yrs

Riparian Vegetation

Left Bank: *Type:* young willows *Age:* 5-10 yrs
Right Bank: *Type:* young willows *Age:* 5-10 yrs

Notes:

Flood Inundation Levels:

1' – debris

Artificial Channel Constraints

Description/Location: LB levee - 5'
RB levee - 4'

Side Channels:

Description/Location: —

General Notes/Comments:

Just downstream of X-S is a gravel depositional bar

85 81
243

King County: White River Sediment Trends

Herrera Environmental Consultants

Project No. 08-04059-013

Date: 7-1-09
GPS Points: 7.087
Surveyor(s): MS JG SM
Weather: Sun ~ 80°F
Cross Section Id: 7.087
Photos: 934-957
Form Completed by: MS

Bank Descriptions

Left:		Right:	
Height (ft)	1'	*Height(ft):*	1'
Material:	gravel/sand	*Material:*	sand, slumping levee riprap
Erosional/Depositional:	depositional	*Erosional/Depositional:*	erosional

Channel Description:

Wetted Width (ft): See reverse
Bankful Width (ft): 243'
Substrate Material: gravel/cobble
Floodplain width (ft): ~~180~~ 255
Thalweg: center/RB

Pebble Counts:

Surface Collected? No
Subsurface Collected? No

Bank Vegetation

Left Bank:		Right Bank:	
Type:	NA	*Type:*	grass
Age:	–	*Age:*	<1

Riparian Vegetation

Left Bank:		Right Bank:	
Type:	mature cottonwood	*Type:*	young cottonwood on levee
Age:	10 yrs	*Age:*	< 10 yrs

Notes:

Flood Inundation Levels:

Artificial Channel Constraints

Description/Location: RB levee

Side Channels:

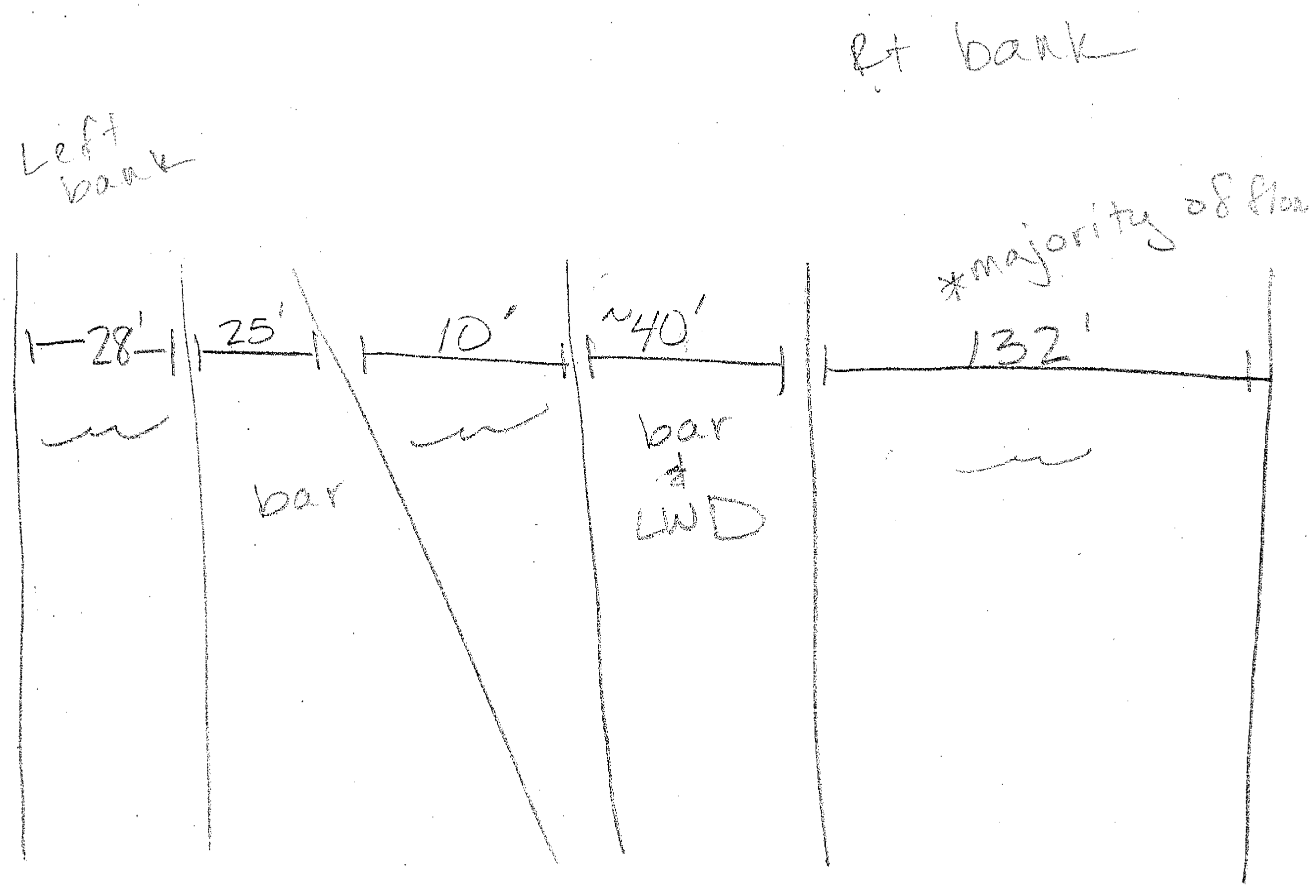
Description/Location: 2 side channels created by wood clusters & sediment accumulation behind them

General Notes/Comments:

→ wood influencing deposition/erosion

1 wood cluster U/S of X-S, creating stable bar/as evidenced by 5-10 yr old cottonwoods growing

1 wood cluster on ~~RB~~ X-S, just D/S of stable bar


Rt bank
Left bank
*majority of flow
28'
25'
10'
~40'
132'
bar
bar
&
LWD

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 7/1/09
GPS Points: ?
Surveyor(s): MS JG Sarah McCarthy
Weather: Sunny/clear
Cross Section Id: 7.170
Photos: 923 - 933
Form Completed by: MS

Bank Descriptions

Left:		Right:	
Height (ft)	3'	*Height(ft):*	3'
Material:	cobble	*Material:*	levee riprap
Erosional/Depositional:	depositional bar	*Erosional/Depositional:*	eroding levee riprap, little veg.

Channel Description:

Wetted Width (ft): 192'; ☆ Effective wetted edge = 90'
Bankful Width (ft): 210'
Substrate Material: cobble/boulder
Floodplain width (ft): 222'
Thalweg: RB

Pebble Counts:

Surface Collected? Yes
Subsurface Collected? Yes

Bank Vegetation

Left Bank:	Right Bank:
Type: medium deciduous	*Type:* medium deciduous trees
Age: 15 yr	*Age:* 15 yr

Riparian Vegetation

Left Bank:	Right Bank:
Type: mature mix	*Type:* mature mix
Age: 25 yr	*Age:* 25 yr

Notes:

Flood Inundation Levels:

Artificial Channel Constraints

Description/Location: RB levee → toe eroding & large pieces exposed, upper levee is earthen & vegetated

Side Channels:

Description/Location: Yes, minor flow around bar on LB

General Notes/Comments:

large LB gravel bar ≥ 42' wide

King County: White River Sediment Trends
Herrera Environmental Consultants Project No. 08-04059-013

Date:	7/2/09	**GPS Points:**	Ø
Surveyor(s):	MS JG Sarah McCarthy	**Weather:**	sunny/clear
Cross Section Id:	~~7.368~~ ~~7.252~~	**Photos:**	918-21, 927
Form Completed by:	7.368	J. Goldsmith, M. Strez	

Bank Descriptions

Left: (levee)		Right:	
Height (ft)	15'	*Height(ft):*	20'
Material:	Rip Rap	*Material:*	Rip Rap
Erosional/Depositional:	Stable	*Erosional/Depositional:*	Stable

Channel Description:

Wetted Width (ft): 132'
Bankful Width (ft): 138'
Substrate Material: Cobble
Floodplain width (ft): 150''
Thalweg: Near LB

Pebble Counts:

Surface Collected? Ø
Subsurface Collected? Ø

Bank Vegetation / **Riparian Vegetation**

Bank Vegetation Left Bank: (levee)	Right Bank: Sparse	Riparian Vegetation Left Bank: (levee)	Right Bank: (levee
Type: mixed	*Type:* Deciduous	*Type:*	*Type:*
Age: mature	*Age:* mature	*Age:*	*Age:*

Notes:

Flood Inundation Levels:

Artificial Channel Constraints

Description/Location: LB Levee
RB Levee

Side Channels:

Description/Location: LB - None

General Notes/Comments:

- No functional LWD
- Riffle

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 7-1-09 **GPS Points:**
Surveyor(s): MS JG Sarah (KC) **Weather:** sunny/clear
Cross Section Id: 7.5 L **Photos:** 912-17
Form Completed by: MS

Bank Descriptions

Left:		Right:	
Height (ft)	2'	*Height(ft):*	3'
Material:	levee riprap	*Material:*	levee riprap/trees
Erosional/Depositional:	N/A	*Erosional/Depositional:*	N/A

Channel Description:

Wetted Width (ft): 147'
Bankful Width (ft): 153'
Substrate Material: Cobble
Floodplain width (ft): ~~153~~ 192'
Thalweg: plane bed

Pebble Counts:

Surface Collected? No
Subsurface Collected? No

Bank Vegetation

Left Bank:	Right Bank:
Type: willows/cottonwood	*Type:* willows
Age: 5 yrs	*Age:* 2-5 yrs

Riparian Vegetation (levee)

Left Bank: mixed	Right Bank:
Type: cottonwoods	*Type:* cottonwoods
Age: 10 yrs	*Age:* 10 yrs

Notes:

Flood Inundation Levels:
4' (see photo 917) & debris in trees
LB overbank fl

Artificial Channel Constraints
Description/Location: LB levee - 8'
— RB levee - 12'

Side Channels:
Description/Location: No

General Notes/Comments:
very little bank width on either LB or RB
→ all levee

No sed. accumulation/deposition

- No functional LWD

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 9-1-09 **GPS Points:**

Surveyor(s): MS JG Sarah (KC) **Weather:** sunny/clear

Cross Section Id: 7.593 **Photos:** 905-71

Form Completed by:

Bank Descriptions

Left:		Right:	
Height (ft)	4' (bankful lip)	*Height(ft):*	6-7'
Material:	cobble/sand	*Material:*	sand / levee riprap
Erosional/Depositional:	NA - levee	*Erosional/Depositional:*	NA - levee

Channel Description:

Wetted Width (ft): 150'

Bankful Width (ft): ~~20ft~~ 162'

Substrate Material: Cobble

Floodplain width (ft): 204'

Thalweg: plane bed

Pebble Counts:

Surface Collected? No

Subsurface Collected? No

Bank Vegetation

Left Bank:	Right Bank:
Type: grass/willows	*Type:* Cottonwoods
Age: 1 yr	*Age:* 10-15 yr

Riparian Vegetation

Left Bank:	Right Bank:
Type: NA	*Type:* Cottonwoods
Age:	*Age:* 10-15

Notes: 1yr

Flood Inundation Levels: 5'

Artificial Channel Constraints

Description/Location: LB & RB levees ~12' ~20' height

Side Channels:

Description/Location: NA

General Notes/Comments:

LB levee = trail

X-S downstream of R St. Bridge

No functional LWD

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 6/30/09 **GPS Points:** Ø
Surveyor(s): MS JG TB **Weather:** Sunny/clear 75°F
Cross Section Id: 7.716 **Photos:**
Form Completed by: MS

Bank Descriptions

Left:		Right:	
Height (ft)	25' - levee	*Height(ft):*	10' levee
Material:	mixed	*Material:*	cobble veg bar / sand / gravel
Erosional/Depositional:	erosional - no active erosion visible ~ King County Repair d/s	*Erosional/Depositional:*	depositional, veg bar

Channel Description:

Wetted Width (ft): 110'
Bankful Width (ft): ≈160'
Substrate Material: cobble / boulder
Floodplain width (ft): levee to levee 400'
Thalweg: plane bed

Pebble Counts:

Surface Collected? No
Subsurface Collected? No

Bank Vegetation

Left Bank: (levee)	Right Bank: (levee)
Type: Deciduous/sparse	*Type:* mixed sparse
Age: young to mature	*Age:*

Riparian Vegetation

Left Bank: Park Trail	Right Bank: Homes
Type:	*Type:*
Age:	*Age:*

Notes:

Flood Inundation Levels:
LB ~ Flotsam 2' above WSEL

Artificial Channel Constraints
Description/Location: LB - Levee
RB Levee

Side Channels:
Description/Location: LB ~ None RB ~ potentially at base of levee

General Notes/Comments:
- LB King County Flood Project u/s of R Street Bridge
- Some LWD on RB bar ~ not functional
- X-Section u/s of R street bridge

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 6/30/09 **GPS Points:**

Surveyor(s): MS JG TB **Weather:** Sunny

Cross Section Id: 7.845 **Photos:** 880-85

Form Completed by: MS

Bank Descriptions

Left:
Height (ft) 30' - levee
Material: levee boulders
Erosional/Depositional: erosional

Right:
Height(ft): 4'
Material: cobble
Erosional/Depositional: depositional

Channel Description:

Wetted Width (ft): 165'
Bankful Width (ft): 185'
Substrate Material: Cobble / Boulder
Floodplain width (ft): 185'
Thalweg: left bank

Pebble Counts:

Surface Collected? No
Subsurface Collected? No

Bank Vegetation

Left Bank: *Type:* 5yr willows / grass *Age:* 5 yr
Right Bank: *Type:* 5yr willows / 10 [illegible] *Age:* 5 yr

Riparian Vegetation

Left Bank: *Type:* NA levee *Age:*
Right Bank: *Type:* 10 yr alders *Age:* 10'

Notes: willows on LB are on levee, & leaning over thalweg of river

Flood Inundation Levels:

probably not higher than grass veg on levee (some flotsam visible here too)

Artificial Channel Constraints

Description/Location: LB levee fortified w/ rip rap

Side Channels:

Description/Location: RB

General Notes/Comments:

large gravel/cobble bar midchannel, bar is vegetated on d/s end, minor amts of wood on bar racked there

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date:	6/30/09	**GPS Points:**	—
Surveyor(s):	MS JG TB	**Weather:**	Sunny/clear
Cross Section Id:	9.958	**Photos:**	
Form Completed by:	MS		

Bank Descriptions

Left:		Right:	
Height (ft)	6'	*Height(ft):*	7'
Material:	Cobble	*Material:*	cobble
Erosional/Depositional:	Depositional	*Erosional/Depositional:*	NA - no active erosion visible

Channel Description:

Wetted Width (ft):	150'		
Bankful Width (ft):	320'	Surface	
Substrate Material:	Boulders	Collected?	U/S
Floodplain width (ft):		Subsurface	
Thalweg:	plane bed/uniform	Collected?	U/S

Pebble Counts:

Bank Vegetation

Left Bank:	Right Bank:
Type: light decid	*Type:* light shrub, decid
Age: 5 yrs	*Age:* 5 yrs

Riparian Vegetation

Left Bank:	Right Bank:
Type:	*Type:*
Age:	*Age:*

Notes:

Flood Inundation Levels:

Artificial Channel Constraints

Description/Location:

Side Channels:

Description/Location:

General Notes/Comments:

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 6/30/09 **GPS Points:** N/A
Surveyor(s): MS JG TB **Weather:** sunny/clear
Cross Section Id: 8.111 **Photos:** 848-58
Form Completed by: J. Goldsmith

Bank Descriptions

Left: Levee
Height (ft) 6
Material: Rip Rap
Erosional/Depositional: Bar along Left bank

Right: Levee
Height(ft):
Material: rip rap(?)
Erosional/Depositional: —

Channel Description:

Wetted Width (ft): 150'
Bankful Width (ft): 180'
Substrate Material: Cobble
Floodplain width (ft): levee to levee (see Lidar)
Thalweg: uniform flow ~ plane bed

Pebble Counts:

Surface Collected? Ø
Subsurface Collected? Ø

Bank Vegetation

Left Bank: mostly
Type: deciduous
Age: young

Right Bank:
Type: deciduous
Age: young

Notes:

Riparian Vegetation

Left Bank:
Type: Deciduous
Age: young to mature

Right Bank: mostly
Type: deciduous
Age: young to mature

Flood Inundation Levels:

Artificial Channel Constraints

Description/Location: LB Levee (at Park)
RB levee

Side Channels:

Description/Location: LB

General Notes/Comments:

- LB levee offset from bankfull width
floodplain secondary channel along LB bar
- No functional LWD
- ≈ 200' LB Bar, partially vegetated

King County: White River Sediment Trends
Herrera Environmental Consultants Project No. 08-04059-013

Date: 6/30/09 **GPS Points:**
Surveyor(s): MS JG T **Weather:** Sunny
Cross Section Id: 8.269 **Photos:** 838 - 845
Form Completed by: J. Goldsmith

Bank Descriptions

Left:
Height (ft) levee
Material: Rip Rap
Erosional/Depositional: —

Right:
Height(ft): levee
Material: Riprap
Erosional/Depositional: stable —

Channel Description:
Wetted Width (ft): 140'
Bankful Width (ft): 180'
Substrate Material: Cobble ~ boulder
Floodplain width (ft): 200'
Thalweg: ~ uniform plane bed

Pebble Counts:
Surface Collected? Ø
Subsurface Collected? Ø

Bank Vegetation
Left Bank: (levee)
Type: mixed
Age: young to mature
Right Bank: (levee)
Type: Deciduous
Age: young to mature
Notes:

Riparian Vegetation
Left Bank:
Type:
Age:
Right Bank:
Type:
Age:

Flood Inundation Levels:
LB ~ some overbank

Artificial Channel Constraints
Description/Location: RB Levee
LB Levee

Side Channels:
Description/Location: None

General Notes/Comments:
- Plane bed channel
- No functional LWD

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 6/30/09 **GPS Points:** 8.418
Surveyor(s): MS JCo TB **Weather:** sunny/clear
Cross Section Id: 8.418 **Photos:** #829 - 837
Form Completed by: MS

Bank Descriptions

Left:		Right: <Steep Bluff>	
Height (ft)	(levee) 18'	*Height(ft):*	6' (levee)
Material:	cobble/boulder	*Material:*	sand/ines
Erosional/Depositional:	small amt of deposition on mid-channel bar toward LB	*Erosional/Depositional:*	NA / Stable

Channel Description: **Pebble Counts:**

Wetted Width (ft):	175'		
Bankful Width (ft):	200'	Surface Collected?	No
Substrate Material:	Cobble / Boulder		
Floodplain width (ft):	200'	Subsurface Collected?	No
Thalweg:	Right of Center		

Bank Vegetation **Riparian Vegetation**

Left Bank: (levee) mixed ~4"-6"	Right Bank: Deciduous Alder	Left Bank: Levee	Right Bank:
Type: Light shrubs	*Type:* small trees	*Type:* NA	*Type:* mixed
Age: 2-3 yrs	*Age:* ~10yrs	*Age:* at peak	*Age:* young to mature

Notes:

Flood Inundation Levels:
Limited by LB levee.

Artificial Channel Constraints
Description/Location: RB levee
LB levee

Side Channels:
Description/Location: N/A

General Notes/Comments:
- Access from game farm park levee trail
- No functional LWD
- 1 mid-channel bar near left bank
- Plane-bed channel

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: August 17, 2009 **GPS Points:** X-Sec 8.561
Surveyor(s): JT Goldsmith, C **Weather:** clear sunny
Cross Section Id: 8.561 **Photos:** CMR
Form Completed by: JT Goldsmith

Bank Descriptions

Left: Revetment		Right: Revetment	
Height (ft)	6'	*Height(ft):*	Bar
Material:	Alluvium	*Material:*	Alluvium
Erosional/Depositional:	Erosion	*Erosional/Depositional:*	Depositional

Channel Description:

Wetted Width (ft): 120'
Bankful Width (ft): Revetment to Revetment
Substrate Material: cobble, boulder
Floodplain width (ft): Revetment to Revetment
Thalweg: plane-bed ~ wetted width

Pebble Counts:

Surface Collected? Ø
Subsurface Collected? Ø

Bank Vegetation

Left Bank:	Right Bank:
Type: young alder	*Type:* Alder
Age: 2-3 yr	*Age:*

Riparian Vegetation

Left Bank: Alder	Right Bank:
Type: Deciduous	*Type:* Deciduous
Age: young - 15 yr	*Age:* mature

Notes: Dense

Flood Inundation Levels:

LB inundation at base of levee.

Artificial Channel Constraints

Description/Location: LB Levee
RB Steep Bluff

Side Channels:

Description/Location: LB ~ overbank flow at LB levee

General Notes/Comments:

- General channel incision ~ LB
- Alluvium cut bank (Left)

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 6/30/09
GPS Points:
Surveyor(s): MS JG TB
Weather: Sunny/clear
Cross Section Id: 8.707
Photos: 807-813, 814-20
Form Completed by: MS

Bank Descriptions

Left:		Right:	
Height (ft)	4-5	*Height(ft):*	60' - steep bluff
Material:	cobble/boulder	*Material:*	sand, mud flow
Erosional/Depositional:	depositional	*Erosional/Depositional:*	Erosional

Channel Description:

Wetted Width (ft): 150'
Bankful Width (ft): 180'
Substrate Material: boulder
Floodplain width (ft): 225'
Thalweg: center/Right

Pebble Counts:

Surface Collected? No
Subsurface Collected? No

Bank Vegetation

Left Bank:	Right Bank:
Type: NA	*Type:* light grass
Age: NA	*Age:* < 1 yr

Riparian Vegetation

Left Bank:	Right Bank:
Type: Cottonwood/Alder	*Type:* NA
Age: < 5 yr	*Age:* —

Notes:

Flood Inundation Levels:

Bankful

Artificial Channel Constraints

Description/Location: LB levee

Side Channels:

Description/Location: NA

General Notes/Comments:

LB inside slight bend in river, RB undercutting of bluff, D/S of X-S is a 24" DBH piece wood w/ rw

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 6/30/09 **GPS Points:** X-Sec 8.821

Surveyor(s): MS, JG, TB **Weather:** Sunny/clear

Cross Section Id: 8.821 **Photos:** 800-806

Form Completed by: T. Goldsmith

Bank Descriptions

Left:
Height (ft) 12'
Material: cobble/boulder
Erosional/Depositional: Levee

Right: (Bar)
Height(ft): 3'
Material: gravel, cobble, boul
Erosional/Depositional: Depositional

Channel Description:

Wetted Width (ft): 100'
Bankful Width (ft): 1620'
Substrate Material: cobble
Floodplain width (ft): 120'
Thalweg: mid-channel

Pebble Counts:

Surface Collected? Ø
Subsurface Collected? Ø

Bank Vegetation

Left Bank: (levee)
Type: mixed
Age: young to mat

Right Bank: (Bar)
Type: Deciduous (few trees)
Age: young

Riparian Vegetation

Left Bank: (levee)
Type:
Age:

Right Bank:
Type: Alder
Age: young

Notes: Evidence of RB slide

Flood Inundation Levels:

Artificial Channel Constraints

Description/Location: LB Levee

Side Channels:

Description/Location: LB - None

General Notes/Comments:

- LB Levee
- Old Auburn Gauge Site

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 6/30/09 **GPS Points:** XSC 8.996
Surveyor(s): MS, TG, Terry Butler **Weather:** Sunny/Clear
Cross Section Id: 8.946 **Photos:** 785-99
Form Completed by: J. Goldsmith

Bank Descriptions

Left: (At levee) Right: (vegetated)

	Left	Right
Height (ft)	12'	
Material	Rip Rap	Alluvium
Erosional/Depositional	somewhat erosional	erosional

Channel Description:

Wetted Width (ft): 345'
Bankful Width (ft): 345'
Substrate Material: gravel/cobble
Floodplain width (ft): ~400' (DAC)
Thalweg: Right Bank

Pebble Counts:

Surface Collected? Ø
Subsurface Collected? Ø

Bank Vegetation

Left Bank: (levee) Type: Alder / some conifer Age: young
Right Bank: Type: deciduous Age: young to mature

Notes: Alder growing out of the levee

Riparian Vegetation

Left Bank: (levee) Type: Deciduous/conifer Age: young
Right Bank: Type: Deciduous, some conifer Age: young to mature

Flood Inundation Levels:

Artificial Channel Constraints

Description/Location: Left Bank Levee

Side Channels:

Description/Location: None on LB

General Notes/Comments:

~ At section survey pt ~ located on levee
~ mid channel bar

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 6/30/09
GPS Points: X-Sec 9.125
Surveyor(s): MS, JG, Terry B
Weather: Sunny ~ Clear
Cross Section Id: 9.125
Photos: 773-74 side channel #1, 775-76 side channel #2, 777-84 LB bar & channel
Form Completed by:

Bank Descriptions

Left:		Right:	
Height (ft)		*Height(ft):*	200'
Material:	Cobble	*Material:*	mudflow
Erosional/Depositional:	Deposition	*Erosional/Depositional:*	erosion

Channel Description:

Wetted Width (ft): 100'
Bankful Width (ft): 150'
Substrate Material: Cobble
Floodplain width (ft): 300'
Thalweg: mid-channel

Pebble Counts:

Surface Collected? Ø
Subsurface Collected? Ø

Bank Vegetation

Left Bank:	Right Bank:
Type: young	*Type:* None
Age: Decades	*Age:* NA

Riparian Vegetation

Left Bank:	Right Bank:
Type:	*Type:*
Age:	*Age:*

Notes: Vegetated bar

Flood Inundation Levels:

At LB levee

Artificial Channel Constraints

Description/Location: Left Bank levee
Right Bank Steep Cliff

Side Channels:

Description/Location: Along bar, at levee base ~ No flowing H2O

General Notes/Comments:

~ Cobble/sand bar
— bar 90% vegetated
— No real functional LWD
— survey control/section

King County: White River Sediment Trends Data taken from LB
Herrera Environmental Consultants Project No. 08-04059-013

Date: 6/30/09 **GPS Points:** #9.311
Surveyor(s): Marc Strazer, Jennifer Goldsm **Weather:** Clear / Sunny
Cross Section Id: 9.311 **Photos:** 751 - 56 panorama U/S → D/S
Form Completed by: MS

761 - 768 panorama of bar
769 - 72 side channel

Bank Descriptions

Left:		Right:	
Height (ft)	3'	*Height(ft):*	70'
Material:	cobble / sand	*Material:*	sandy, lightly vegetated
Erosional/Depositional:	50' of deposition since 2007 survey	*Erosional/Depositional:*	Actively eroding

Channel Description:

Wetted Width (ft): 75'
Bankful Width (ft): 150'
Substrate Material: cobble / boulder
Floodplain width (ft): 225'
Thalweg: RB / mid

Pebble Counts:

Surface Collected? Yes
Subsurface Collected? Yes

Bank Vegetation

Left Bank:	Right Bank:
Type: small trees	*Type:* small trees, early succ.
Age: 5-6 yrs	*Age:*

Riparian Vegetation

Left Bank:	Right Bank:
Type:	*Type:*
Age:	*Age:*

Notes:

Flood Inundation Levels:
flood waters go overbank, to inundate base of levee & activate side channels

Artificial Channel Constraints
Description/Location: LB levee (transcanada levee)

Side Channels:
Description/Location: inactive, highflow against levee (overbank flood deposits - sand)

General Notes/Comments:
no LWD on RB bar, broken culvert (cement 18"), levee riprap material in bar

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: June 25, 09 **GPS Points:** Sec 9.477
Surveyor(s): Goldsmith, Barton **Weather:** overcast
Cross Section Id: X-9.477 **Photos:** JG, CMB
Form Completed by: J. Goldsmith

Bank Descriptions

Left:
Height (ft) 7'
Material: Alluvium
Erosional/Depositional: cut bank eroding

Right:
Height(ft): Bar ~0-3'
Material: Sand, gravel, cobble
Erosional/Depositional: Depositional

Channel Description:

Wetted Width (ft): ~150'
Bankful Width (ft): ~350'
Substrate Material: Gravel, cobble
Floodplain width (ft): ~400'
Thalweg: RB at Bar

Pebble Counts:

Surface Collected? Ø
Subsurface Collected? Ø

Bank Vegetation

Left Bank:
Type: None
Age: eroding

Right Bank: small
Type: Bar ~ understory
Age:

Riparian Vegetation

Left Bank:
Type: mixed
Age: young

Right Bank: Deciduous
Type: mixed
Age: young & mature

Notes:

Flood Inundation Levels:

Artificial Channel Constraints

Description/Location: Left Bank ~ no rip rap at section

Side Channels:

Description/Location: Ø

General Notes/Comments:

No left bank levee.

King County: White River Sediment Trends
Herrera Environmental Consultants Project No. 08-04059-013

Date: 6/25/09 **GPS Points:** RM 9.477
Surveyor(s): CMB / JG / TB **Weather:** overcast 65°
Cross Section Id: 9.477 **Photos:**
Form Completed by: CMB

Bank Descriptions

Left:		Right:	
Height (ft)	8'	Height(ft):	low (not very visible)
Material:	Grv / CB / BLD.	Material:	alluvium
Erosional/Depositional:	erosion	Erosional/Depositional:	depositional

Channel Description:

Wetted Width (ft): ~~120~~ 150'
Bankful Width (ft): 400'
Substrate Material: gravel w/ cobble
Floodplain width (ft): 450 - 500'
Thalweg: channel center

Pebble Counts:

Surface Collected? no
Subsurface Collected? no

Bank Vegetation

Left Bank:		Right Bank:	
Type:	none	Type:	Alder
Age:		Age:	5 - 10

Riparian Vegetation

Left Bank: shrub		Right Bank:	
Type:	thick conifers	Type:	Alders
Age:	30 year +	Age:	5 - 10 - 20 progression

Notes:

Flood Inundation Levels:

Artificial Channel Constraints
Description/Location: levee eroded from this section.

Side Channels:
Description/Location: perhaps right bank @ high flow

General Notes/Comments:
- section was downcutting from 1984 - 2007 ~ 10' (confirm)
- aggradation from 2007 - 2009 (~ 4-5')
- erosion of downstream levee segment / channel widening caused decreasing transport capacity and increased deposition
- steep rapid @ 9.35 to grab old profile.

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 6/25/09 **GPS Points:** RM 9.794
Surveyor(s): CB / JG / TR **Weather:** overcast / ptl sun 65°
Cross Section Id: RM 9.794 **Photos:** pan - 2541-2552
Form Completed by: CMB

Bank Descriptions

Left:		Right:	
Height (ft)	none	*Height(ft):*	4-5'
Material:		*Material:*	Alluvium (GV / CB)
Erosional/Depositional:	depositional	*Erosional/Depositional:*	erosional

Channel Description:

Wetted Width (ft): ~ 80-100 ft
Bankful Width (ft): ~ 300 ft.
Substrate Material: COBBLE w/ GV / BOULDER / sand
Floodplain width (ft): ~ 400 ft.
Thalweg: RIGHT SIDE OF CMZ
no distinct deepest section

Pebble Counts:

Surface Collected? YES 2554
Subsurface Collected? YES 2553

Bank Vegetation

Left Bank:		Right Bank:	
Type:	Alder	*Type:*	Alder
Age:	10	*Age:*	20-30 year

Riparian Vegetation

Left Bank:		Right Bank:	
Type:	Alder	*Type:*	Alder
Age:	10	*Age:*	20-30

Notes: some ~10 yr conifers some ~10 yr conifers

Flood Inundation Levels:

Artificial Channel Constraints

Description/Location: levee at left margin

Side Channels:

Description/Location: adjacent to levee at left margin

General Notes/Comments:

- does not feel like a downcutting section
- right bank floodplain accessed at 10+ K1 flows but left bank has no bank and high connectivity w/ 50' wide floodplain front and side channel w/ same elevation as bar feature

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: June 25, 2009
GPS Points: XSEC RM 9.79 C
Surveyor(s): Goldsmith, Barton, Butler
Weather: overcast
Cross Section Id: RM 9.79
Photos: CMB Camera
Form Completed by: J Goldsmith

Bank Descriptions

Left:
Height (ft) levee ~10'
Material: rip rap
Erosional/Depositional: bar at LB wetted edge

Right:
Height(ft): 6'
Material: Alluvium (cobble gravel)
Erosional/Depositional: cut bank, erosion

Channel Description:

Wetted Width (ft): 100'
Bankful Width (ft): 300'
Substrate Material: cobble, boulder, gravel
Floodplain width (ft): ~250'
Thalweg: mid-channel

Pebble Counts:

Surface Collected? yes
Subsurface Collected? yes

Bank Vegetation

Left Bank: *Type:* Small Deciduous Trees *Age:* young
Right Bank: *Type:* understory *Age:* young
Notes:

Riparian Vegetation

Left Bank: *Type:* Deciduous *Age:* young to mature
Right Bank: *Type:* Deciduous *Age:* mature

Flood Inundation Levels:

→ Bar, side channel ~ flotsam in trees ~ understory

Artificial Channel Constraints

Description/Location: Left Bank Levee

Side Channels:

Description/Location: At left bank levee, flowing H_2O ~15' wide sand substrate

General Notes/Comments:

Cross section @ powerlines

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: June 25, 09 **GPS Points:** Rm 10.065
Surveyor(s): Goldsmith / Barton **Weather:** overcast / dry
Cross Section Id: 10,065 X sec **Photos:** CmB - channel
Form Completed by: J. Goldsmith JG - side channel

Bank Descriptions

Left:
Height (ft) levee
Material: rip rap
Erosional/Depositional:
— 5' bank, alluvium at thalweg, vertical bank

Right:
Height(ft): steep bluff ~ > 100'
Material: glacial
Erosional/Depositional: steep bluff, high eroding

Channel Description:
Wetted Width (ft): ~ 100'
Bankful Width (ft): ~ 150
Substrate Material: cobble & boulder
Floodplain width (ft): 250'
Thalweg: left bank

Pebble Counts:
Surface Collected? Ø
Subsurface Collected? Ø

Bank Vegetation
Left Bank: (levee)
Type: mixed
Age: young - mature
Notes: Trees growing out of levee

Right Bank:
Type: None ~
Age: eroding mature

Riparian Vegetation
Left Bank: (side channel)
Type: deciduous
Age: young
4-10" Able in side channel area,

Right Bank:
Type: mixed
Age: young to mature
(Higher up on bluff

Flood Inundation Levels:
Left bank ~ side channel, recently activated,

Artificial Channel Constraints
Description/Location: Left Bank ~ levee
Right Bank ~ steep bluff

Side Channels:
Description/Location: Along left bank levee ≈ 50' width
No flowing H_2O

General Notes/Comments:
— Just up stream, levee eroding ~
— Rip rap in the river along left bank
— Left bank ~ overbank flood deposits — sand / gravel

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date:	6/25/09	**GPS Points:**	~~GPS [illegible]~~ RM 10.065
Surveyor(s):	CB/JG/TR	**Weather:**	clear ~64°F
Cross Section Id:	10.065	**Photos:**	2516 - 2535
Form Completed by:	CMB		side channel 2529-2535

Bank Descriptions

Left:		Right:	
Height (ft)	3-4	*Height(ft):*	60' +
Material:	alluv. (gravel/cobble) w/ boulder	*Material:*	glacial / osceola mudflow?
Erosional/Depositional:	erosional	*Erosional/Depositional:*	erosional

Channel Description:

Wetted Width (ft):	~100'		
Bankful Width (ft):	~200'	Surface	
Substrate Material:	gravel / cobble / boulder [illegible]	Collected?	no
Floodplain width (ft):	~300	Subsurface	
Thalweg:	left edge of main channel	Collected?	no

Pebble Counts:

Bank Vegetation / Riparian Vegetation

Bank Vegetation – Left Bank:		Bank Vegetation – Right Bank:		Riparian Vegetation – Left Bank:		Riparian Vegetation – Right Bank:	
Type:	Alder	*Type:*	Alder	*Type:*	Alder	*Type:*	–
Age:	~10 years	*Age:*	10-20 year	*Age:*	10-20 year	*Age:*	–

Notes: eroded

Flood Inundation Levels:

Artificial Channel Constraints

Description/Location: levee at left margin

Side Channels:

Description/Location: left of left margin of main channel up against levee

General Notes/Comments:

- confinement by levee may be forcing flow to [illegible] RM to right bank outcrop
- 3 accumulations of wood downstream appear stable and influencing channel [illegible]
- does not indicate [illegible] degradation

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 6/25/09 **GPS Points:** GPS #5
Surveyor(s): CB/JG/TD **Weather:**
Cross Section Id: RM 10.345 **Photos:** 2477 - 2481
Form Completed by: CMB

Bank Descriptions

Left:
Height (ft) 10 ft
Material: alluvium / fill
Erosional/Depositional: erosion into old levee alignment

Right:
Height(ft): 5-6'
Material: alluvium
Erosional/Depositional: erosional

Channel Description:

Wetted Width (ft): 50' left side / 100' right
Bankful Width (ft): 400 ft.
Substrate Material: Gravel / Cobble
Floodplain width (ft):
Thalweg: right channel

Pebble Counts:

Surface Collected? yes
Subsurface Collected? yes

Bank Vegetation

Left Bank: *Type:* Alder *Age:* 10 year
Right Bank: *Type:* none *Age:*
Notes: erosion

Riparian Vegetation

Left Bank: *Type:* Doug fir *Age:* 30 year +
Right Bank: *Type:* Alder *Age:* 20 year +

Flood Inundation Levels:

Artificial Channel Constraints

Description/Location: left bank levee is being eroded and not maintained. ~~[illegible]~~ [illegible]

Side Channels:

Description/Location:

General Notes/Comments:

Right bank floodplain is at ~ 5-6' above channel
- likely inundated by 2-5 year + events
- mid-channel bar has ~ 2 year alder (veg extent terminates at downstream end of section)

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: June 25, 2009 **GPS Points:** yes
Surveyor(s): Goldsmith / Barton **Weather:** overcast
Cross Section Id: 10.596 **Photos:** CMB - Camera
Form Completed by: Goldsmith

Bank Descriptions

Left:
Height (ft) 7-8'
Material: Alluvium
Erosional/Depositional: cut bank / levee

Right:
Height(ft): 0-3' / Bar
Material: cobble / Gravel
Erosional/Depositional: Depositional

Channel Description:

Wetted Width (ft): 180'
Bankful Width (ft): 200' - 150'
Substrate Material: cobble / Gravel
Floodplain width (ft): 250'
Thalweg: At levee, left bank

Pebble Counts:

Surface Collected? Ø
Subsurface Collected? Ø

Bank Vegetation

Left Bank: (levee)
Type:
Age: Young

Right Bank:
Type: Alder / Grass
Age: Young

Notes: No veg

Riparian Vegetation

Left Bank:
Type: Alder at levee
Age: Young

Right Bank:
Type:
Age: young

Flood Inundation Levels:

Artificial Channel Constraints

Description/Location: U/S extent at levee

Side Channels:

Description/Location: At levee

General Notes/Comments:

- At U/S of levee (left bank
- levee fill
- LWD on right bank

King County: White River Sediment Trends

Herrera Environmental Consultants Project No. 08-04059-013

Date: 6/25/09 **GPS Points:** GPS #2

Surveyor(s): CMB - JG - TB/ KC) **Weather:** overcast - 60°F

Cross Section Id: RM 10.596 **Photos:** 2456-2465

Form Completed by: CMB

Bank Descriptions

Left:		Right:	
Height (ft)	~ 8-9'	*Height(ft):*	low
Material:	GRAVEL/	*Material:*	alluvium
Erosional/Depositional:	DOWN CUTTING	*Erosional/Depositional:*	deposition

- fill may accentuate effect (levee fill)

Channel Description:

Wetted Width (ft): 150 feet

Bankful Width (ft): 200 - 250 feet.

Substrate Material: gravel/cobble w/ boulder

Floodplain width (ft):

Thalweg: left of center

Pebble Counts:

Surface Collected?

Subsurface Collected?

Bank Vegetation

Left Bank:		Right Bank:	
Type:	? Alders	*Type:*	Grass/Alders
Age:	20-year +	*Age:*	young classes

Notes: along levee abutment.

Riparian Vegetation

Left Bank:		Right Bank:	
Type:		*Type:*	
Age:		*Age:*	

Flood Inundation Levels:

Artificial Channel Constraints

Description/Location: upstream extent of Trans Canada levee

Side Channels:

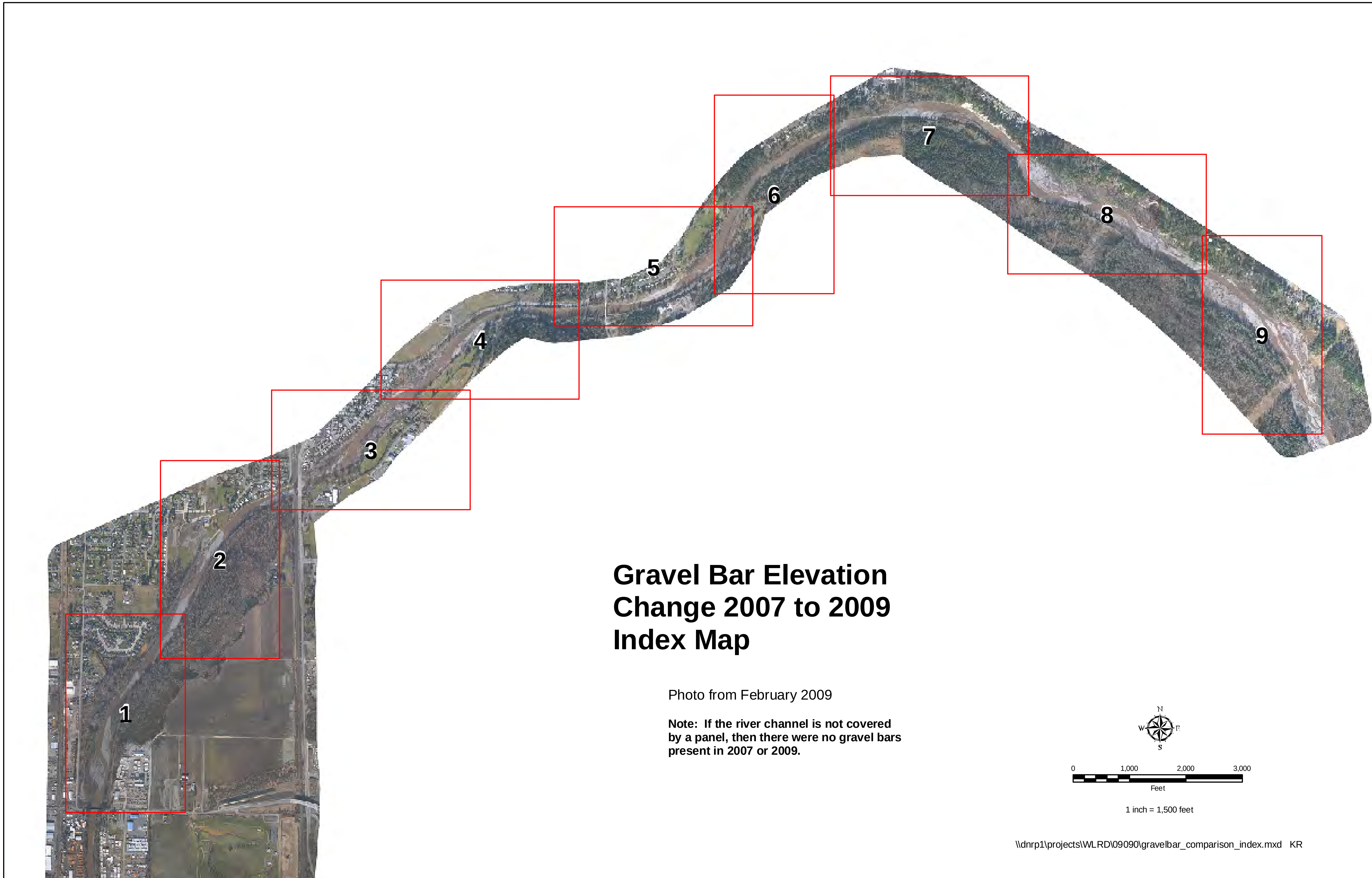
Description/Location:

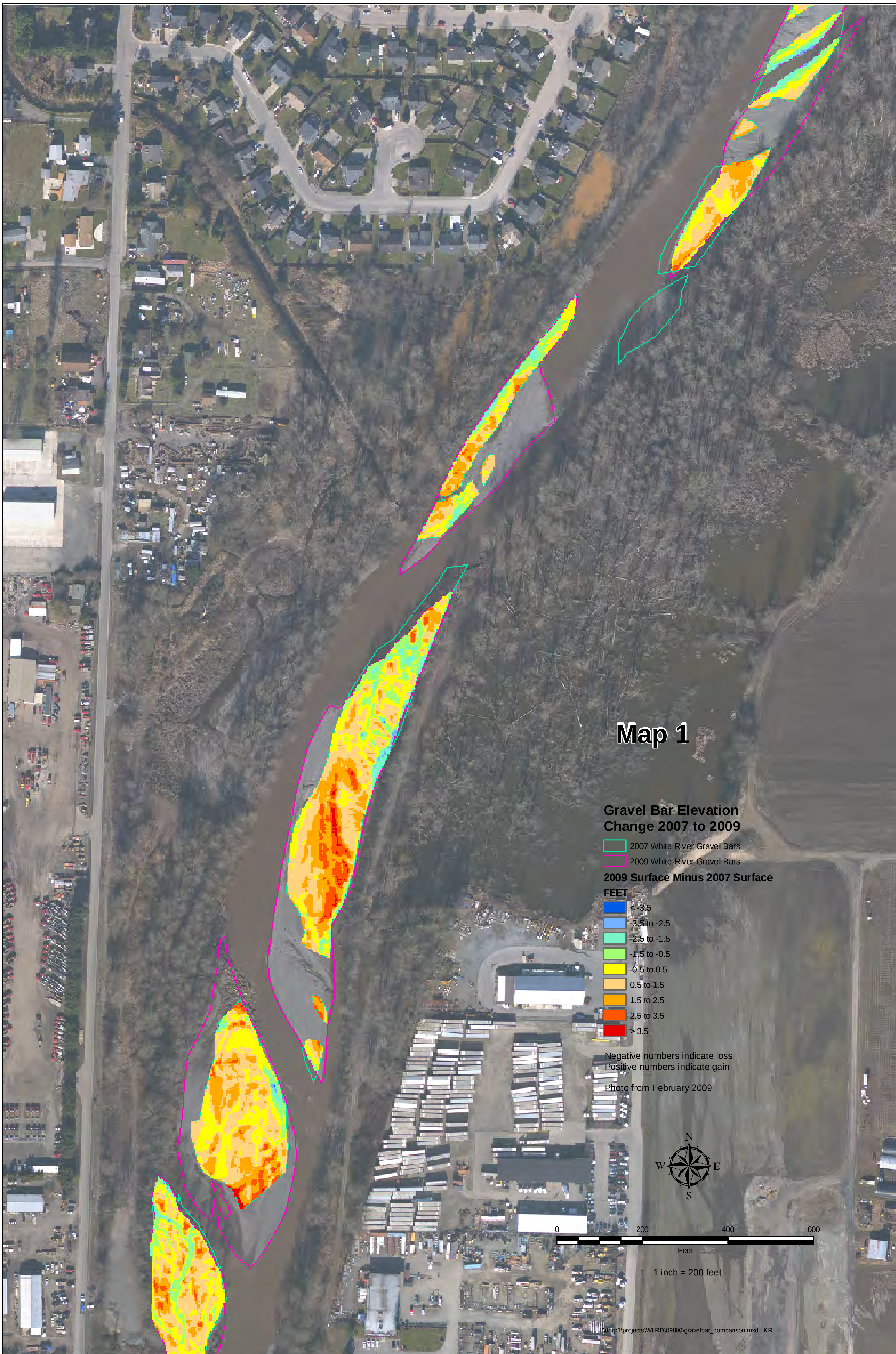
General Notes/Comments:

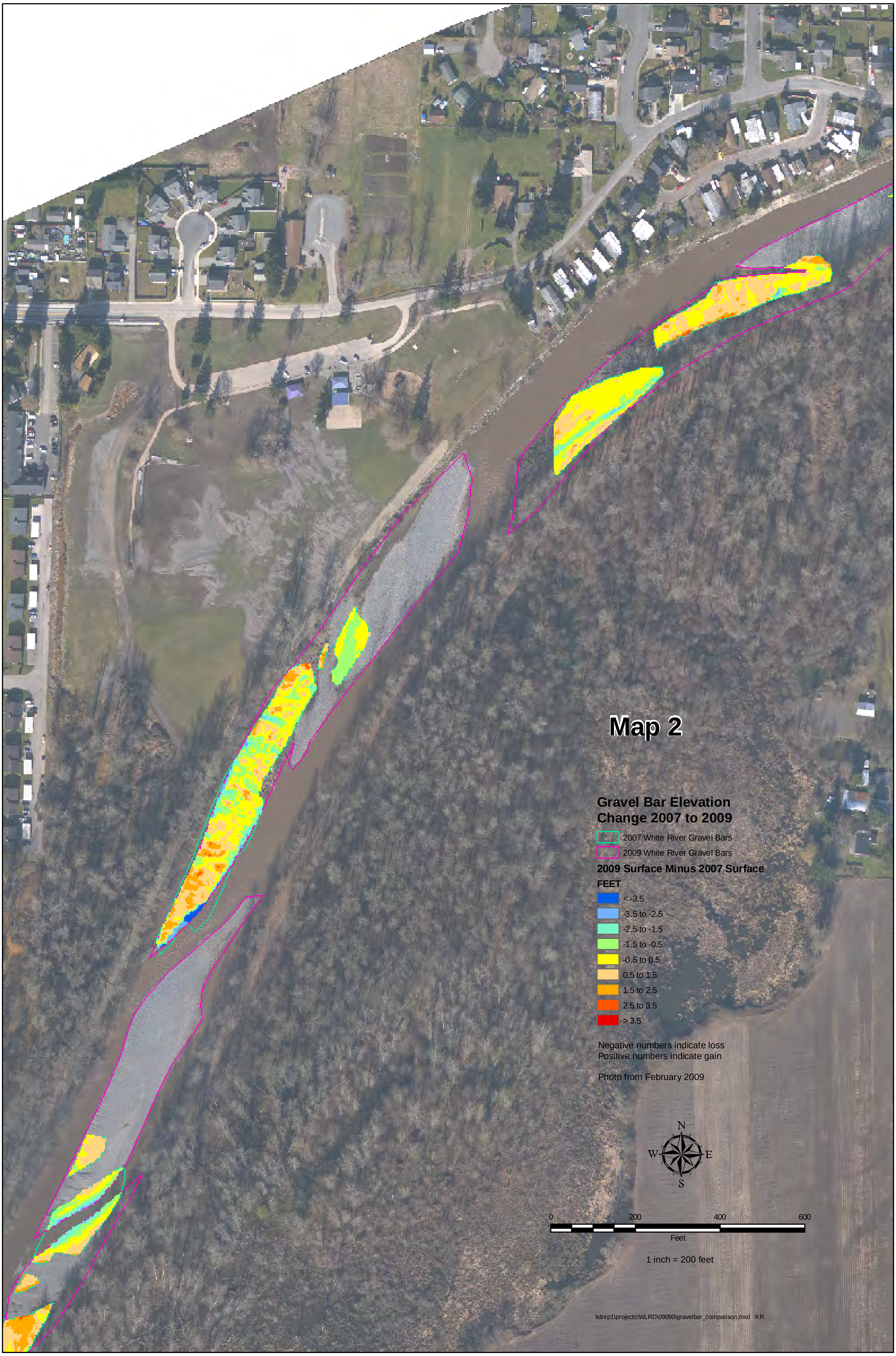
- levee fill in left bank. downcutting is unsure as fill accentuates sense of incision.

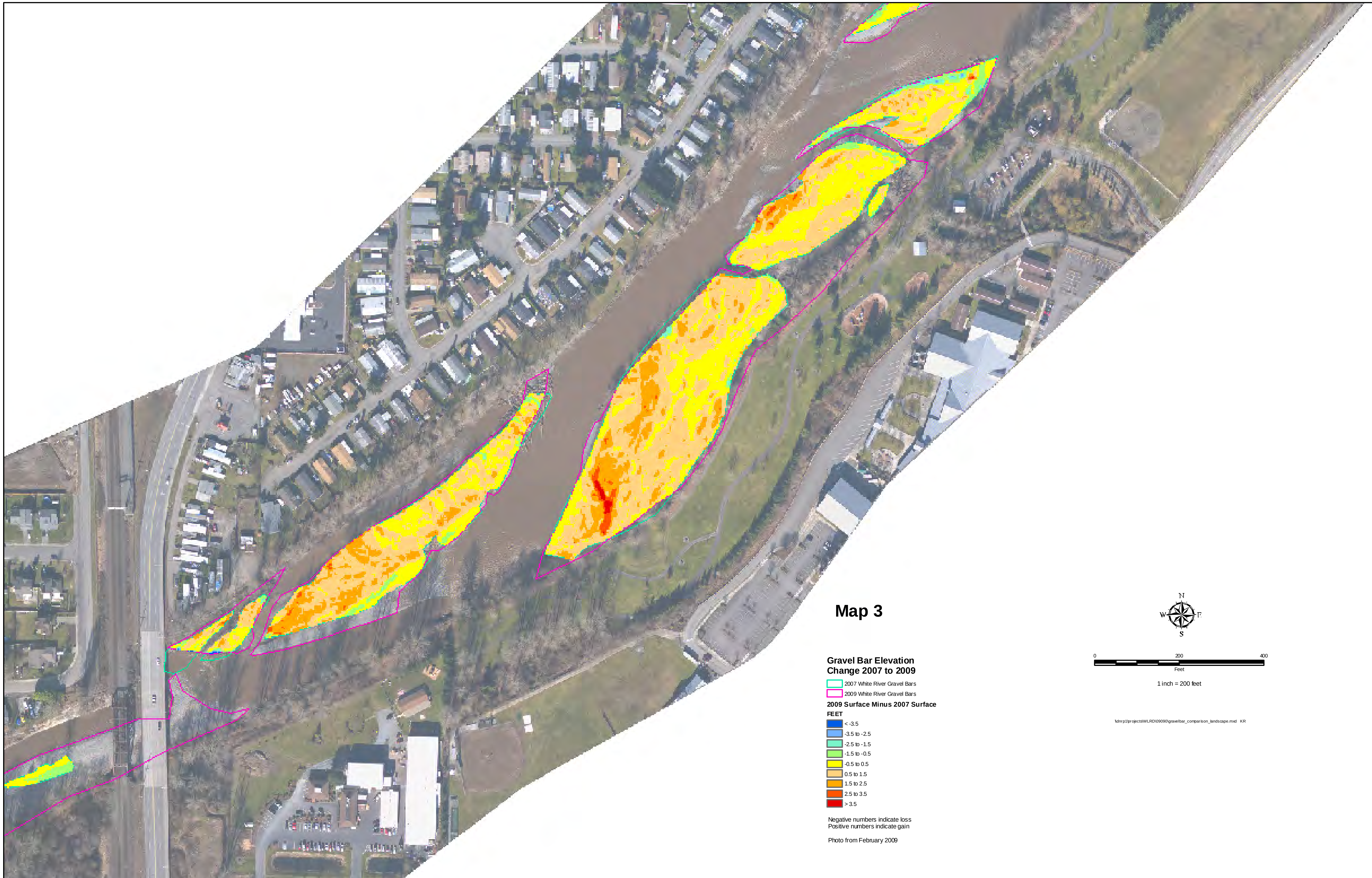
APPENDIX F

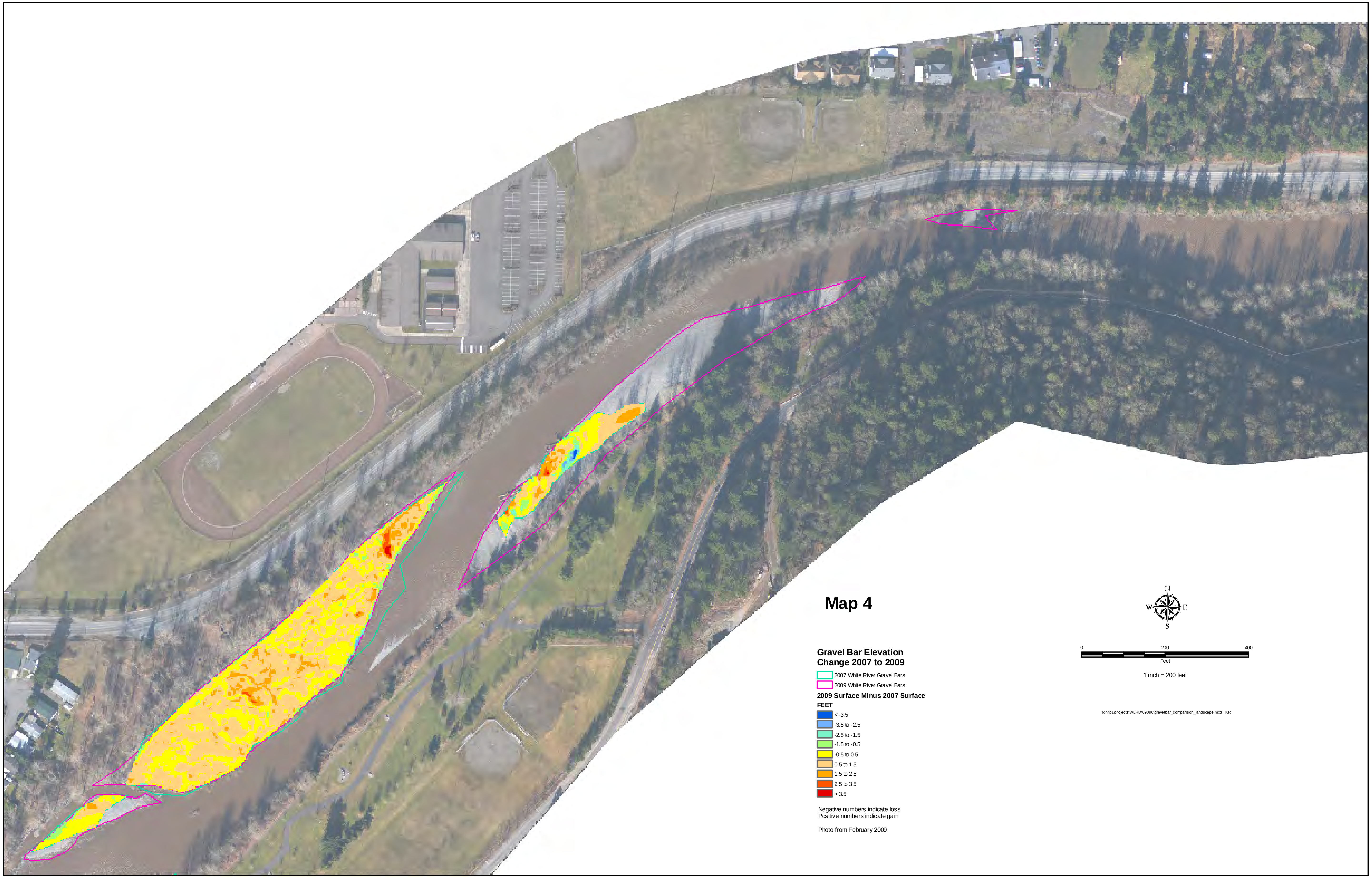
Gravel Bar Elevation Changes, 2007 to 2009

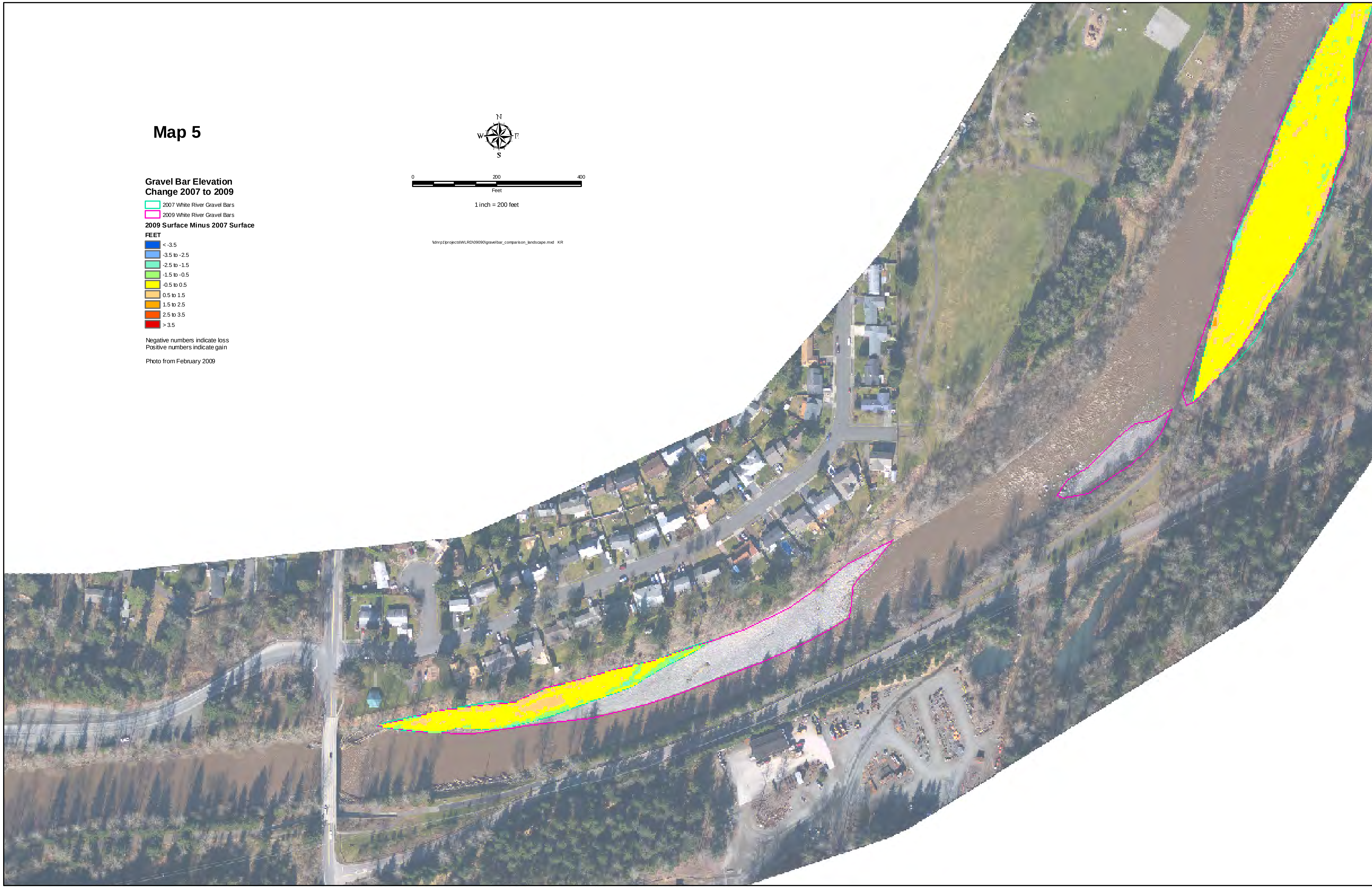

1
2
3
4
5
6
7
8
9
Gravel Bar Elevation Change 2007 to 2009 Index Map
Photo from February 2009
Note: If the river channel is not covered by a panel, then there were no gravel bars present in 2007 or 2009.
N
W
E
S
0
1,000
2,000
3,000
Feet
1 inch = 1,500 feet
\\dnrp1\projects\WLRD\09090\gravelbar_comparison_index.mxd KR

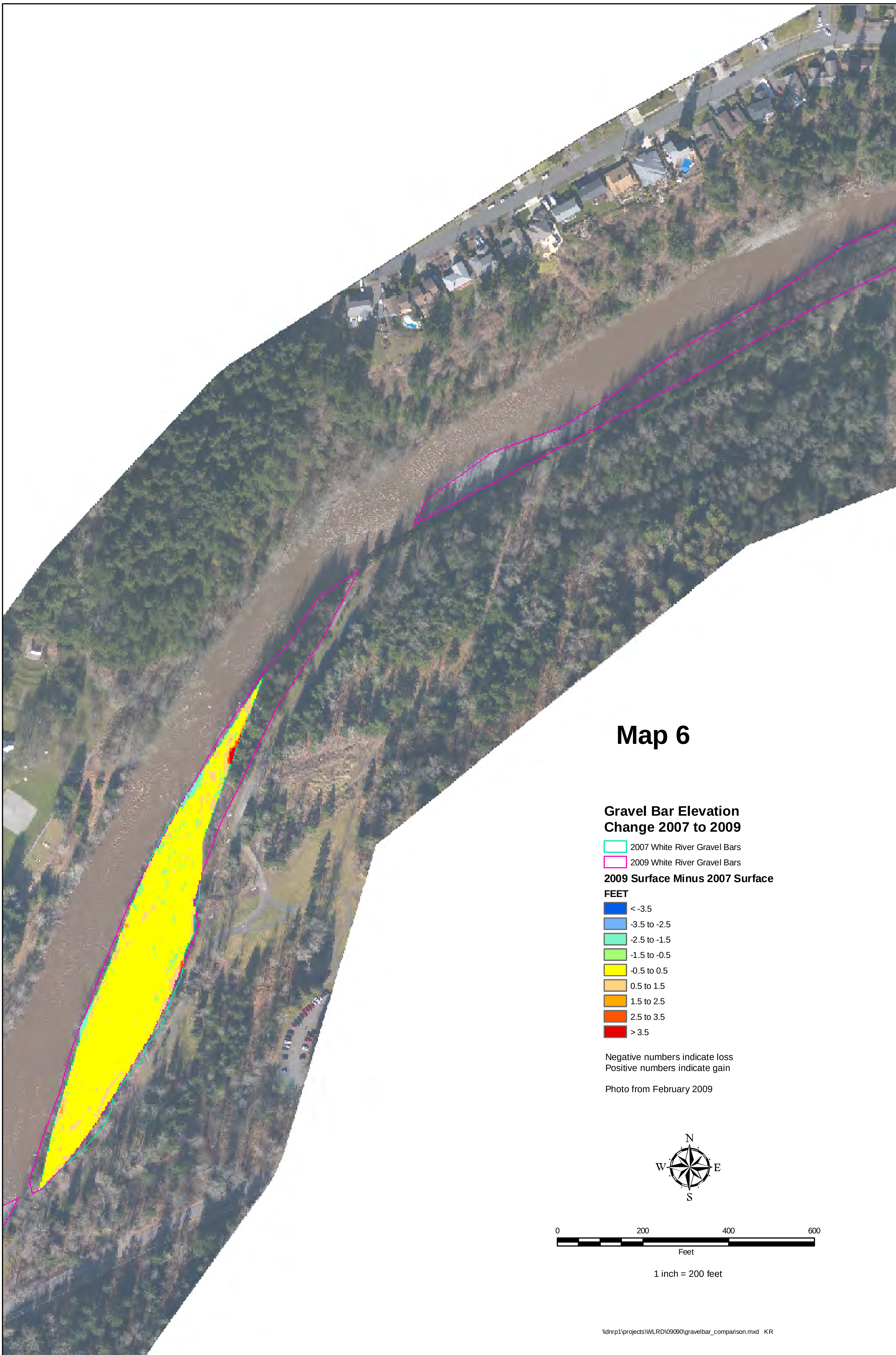

Map 1
Gravel Bar Elevation Change 2007 to 2009
2007 White River Gravel Bars
2009 White River Gravel Bars
2009 Surface Minus 2007 Surface
FEET
< -3.5
-3.5 to -2.5
-2.5 to -1.5
-1.5 to -0.5
-0.5 to 0.5
0.5 to 1.5
1.5 to 2.5
2.5 to 3.5
> 3.5
Negative numbers indicate loss
Positive numbers indicate gain
Photo from February 2009
N
W
E
S
0
200
400
600
Feet
1 inch = 200 feet
\\dnrp1\projects\WLRD\09090\gravelbar_comparison.mxd KR

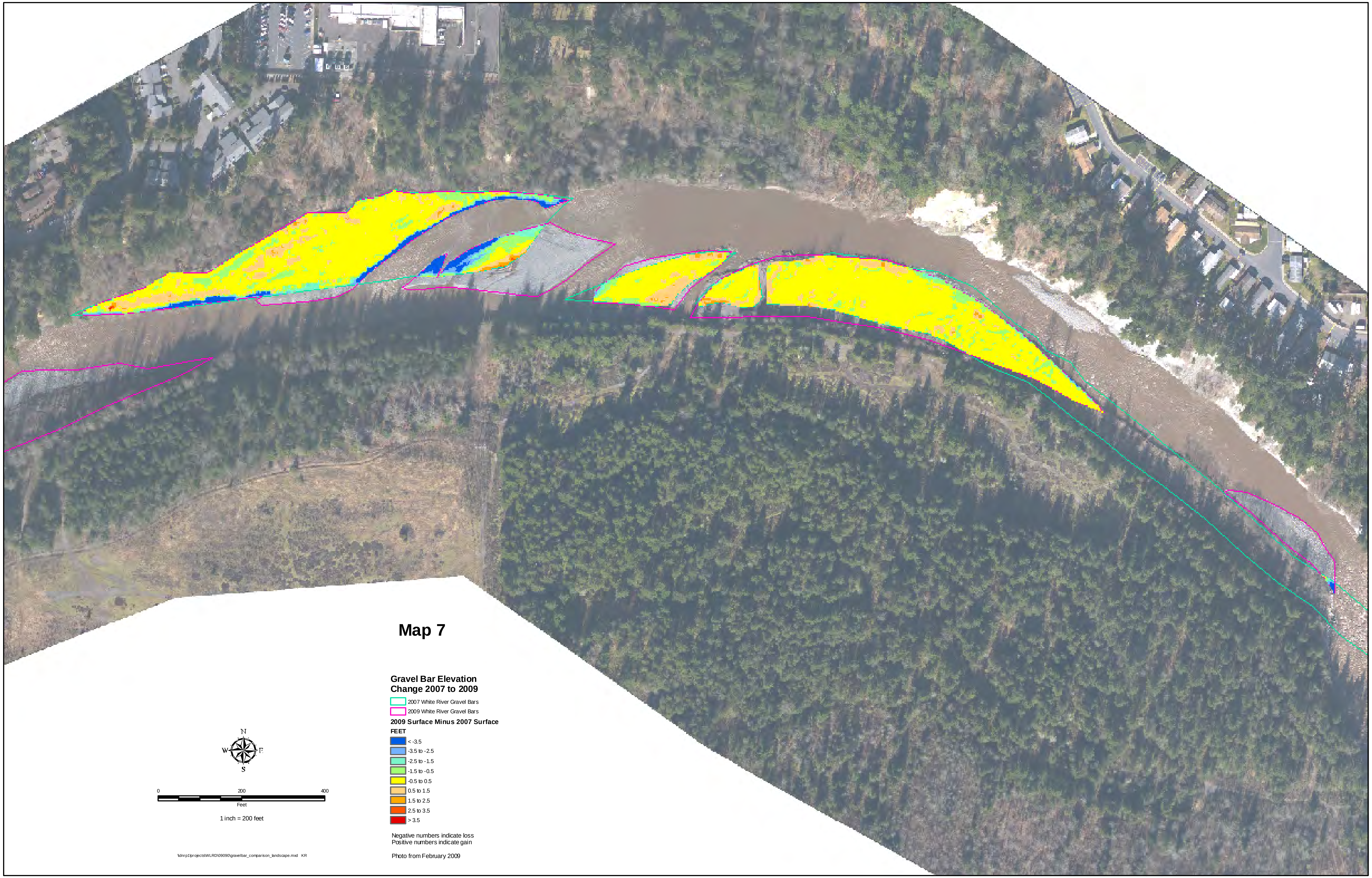

Map 2
Gravel Bar Elevation Change 2007 to 2009
2007 White River Gravel Bars
2009 White River Gravel Bars
2009 Surface Minus 2007 Surface
FEET
< -3.5
-3.5 to -2.5
-2.5 to -1.5
-1.5 to -0.5
-0.5 to 0.5
0.5 to 1.5
1.5 to 2.5
2.5 to 3.5
> 3.5
Negative numbers indicate loss
Positive numbers indicate gain
Photo from February 2009
N
W
E
S
0
200
400
600
Feet
1 inch = 200 feet
\\dnrp1\projects\WLRD\09090\gravelbar_comparison.mxd KR

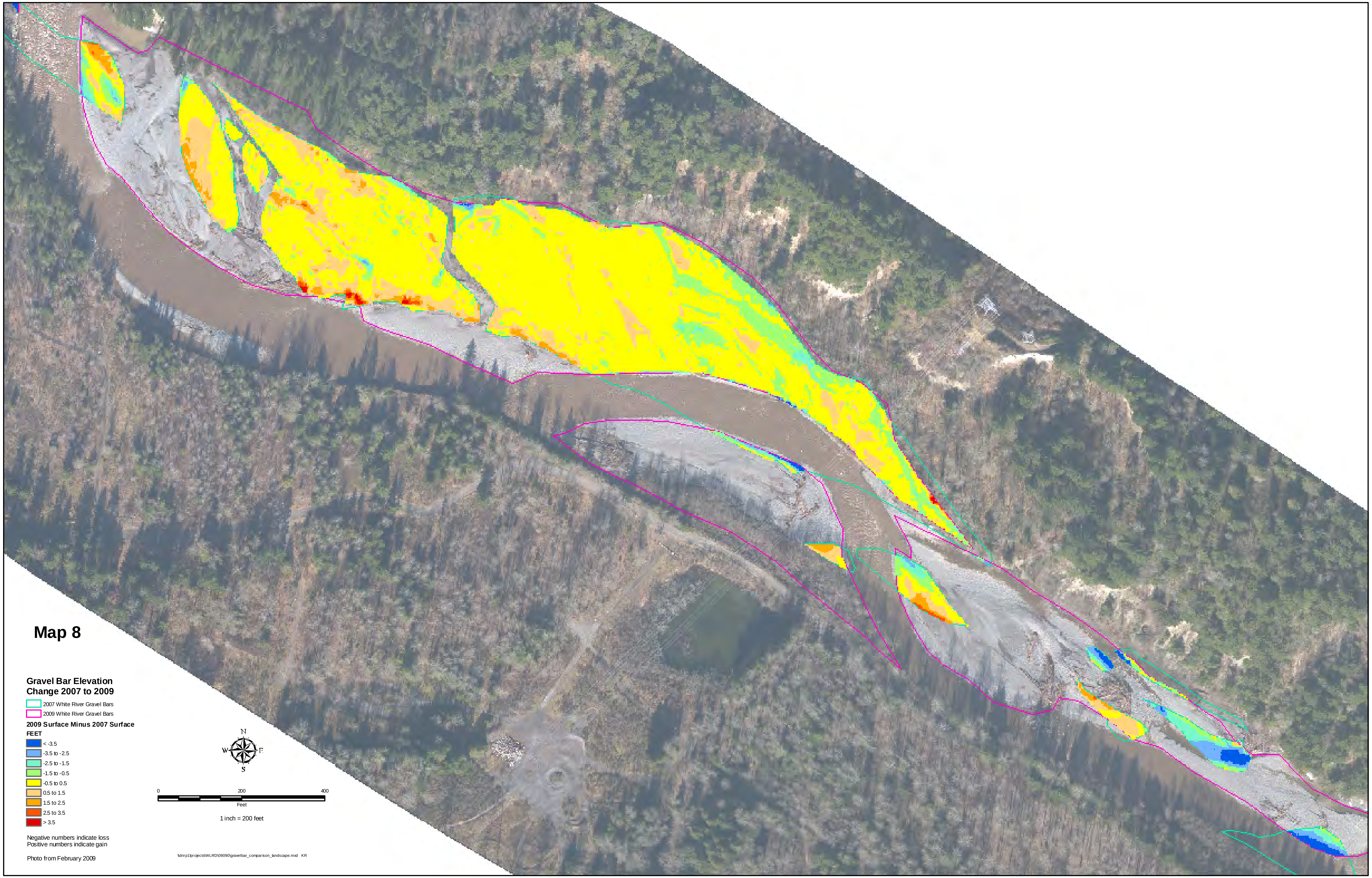

Map 3
N
W
E
S
0
200
400
Feet
1 inch = 200 feet
Gravel Bar Elevation Change 2007 to 2009
2007 White River Gravel Bars
2009 White River Gravel Bars
2009 Surface Minus 2007 Surface
FEET
< -3.5
-3.5 to -2.5
-2.5 to -1.5
-1.5 to -0.5
-0.5 to 0.5
0.5 to 1.5
1.5 to 2.5
2.5 to 3.5
> 3.5
Negative numbers indicate loss
Positive numbers indicate gain
Photo from February 2009
\\dnrp1\projects\WLRD\09090\gravelbar_comparison_landscape.mxd KR


Map 4
N
W
E
S
0
200
400
Feet
1 inch = 200 feet
Gravel Bar Elevation Change 2007 to 2009
2007 White River Gravel Bars
2009 White River Gravel Bars
2009 Surface Minus 2007 Surface
FEET
< -3.5
-3.5 to -2.5
-2.5 to -1.5
-1.5 to -0.5
-0.5 to 0.5
0.5 to 1.5
1.5 to 2.5
2.5 to 3.5
> 3.5
Negative numbers indicate loss
Positive numbers indicate gain
Photo from February 2009
\\dnrp1\projects\WLRD\09090\gravelbar_comparison_landscape.mxd KR

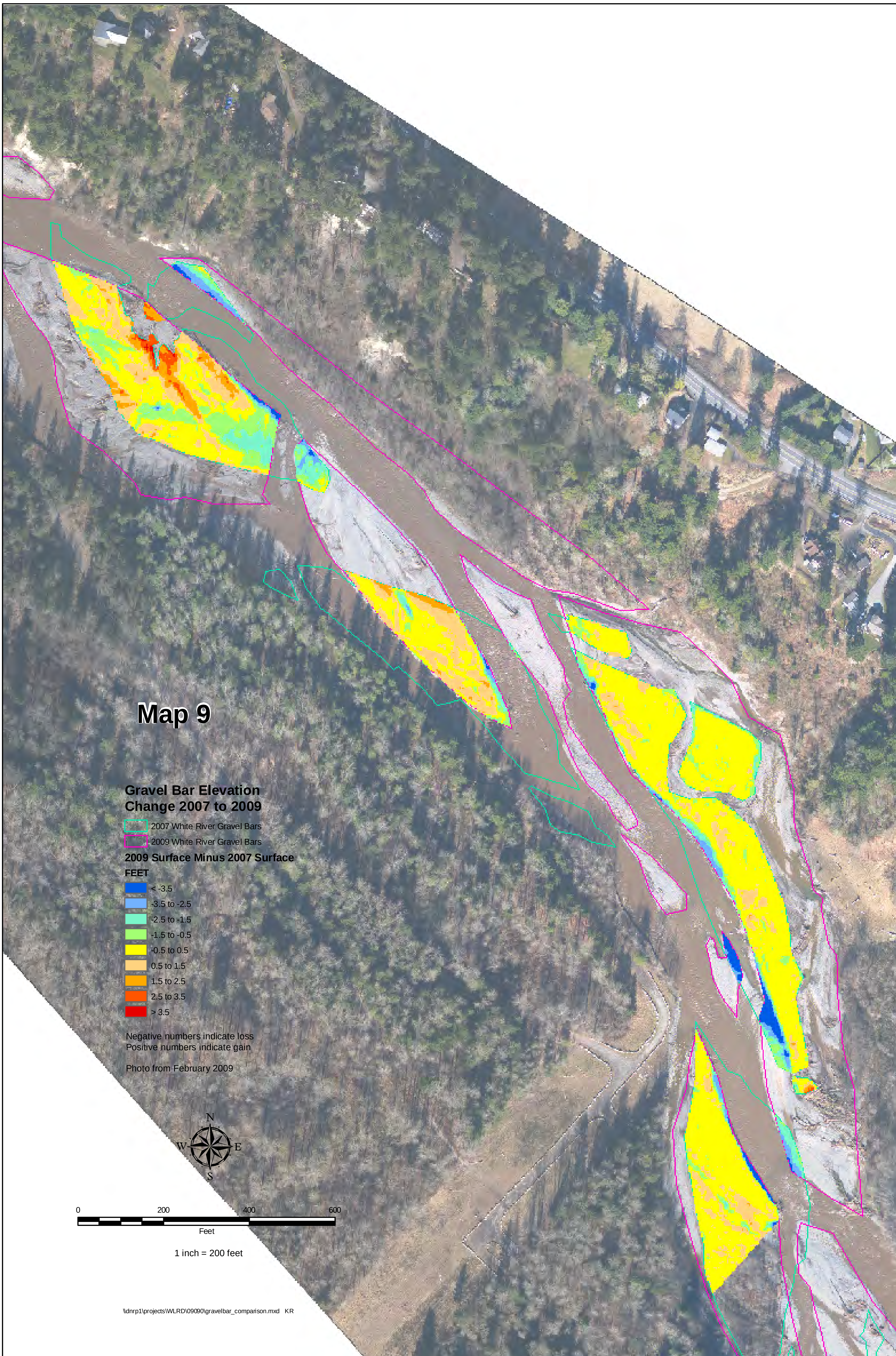

Map 5
Gravel Bar Elevation Change 2007 to 2009
2007 White River Gravel Bars
2009 White River Gravel Bars
2009 Surface Minus 2007 Surface
FEET
< -3.5
-3.5 to -2.5
-2.5 to -1.5
-1.5 to -0.5
-0.5 to 0.5
0.5 to 1.5
1.5 to 2.5
2.5 to 3.5
> 3.5
Negative numbers indicate loss
Positive numbers indicate gain
Photo from February 2009
N
W
E
S
0
200
400
Feet
1 inch = 200 feet
\\dnrp1\projects\WLRD\09090\gravelbar_comparison_landscape.mxd KR


Map 6
Gravel Bar Elevation Change 2007 to 2009
2007 White River Gravel Bars
2009 White River Gravel Bars
2009 Surface Minus 2007 Surface
FEET
< -3.5
-3.5 to -2.5
-2.5 to -1.5
-1.5 to -0.5
-0.5 to 0.5
0.5 to 1.5
1.5 to 2.5
2.5 to 3.5
> 3.5
Negative numbers indicate loss
Positive numbers indicate gain
Photo from February 2009
N
W
E
S
0
200
400
600
Feet
1 inch = 200 feet
\\dnrp1\projects\WLRD\09090\gravelbar_comparison.mxd KR


Map 7
Gravel Bar Elevation Change 2007 to 2009
2007 White River Gravel Bars
2009 White River Gravel Bars
2009 Surface Minus 2007 Surface
FEET
< -3.5
-3.5 to -2.5
-2.5 to -1.5
-1.5 to -0.5
-0.5 to 0.5
0.5 to 1.5
1.5 to 2.5
2.5 to 3.5
> 3.5
Negative numbers indicate loss
Positive numbers indicate gain
Photo from February 2009
N
W
E
S
0
200
400
Feet
1 inch = 200 feet
\\dnrp1\projects\WLRD\09090\gravelbar_comparison_landscape.mxd KR

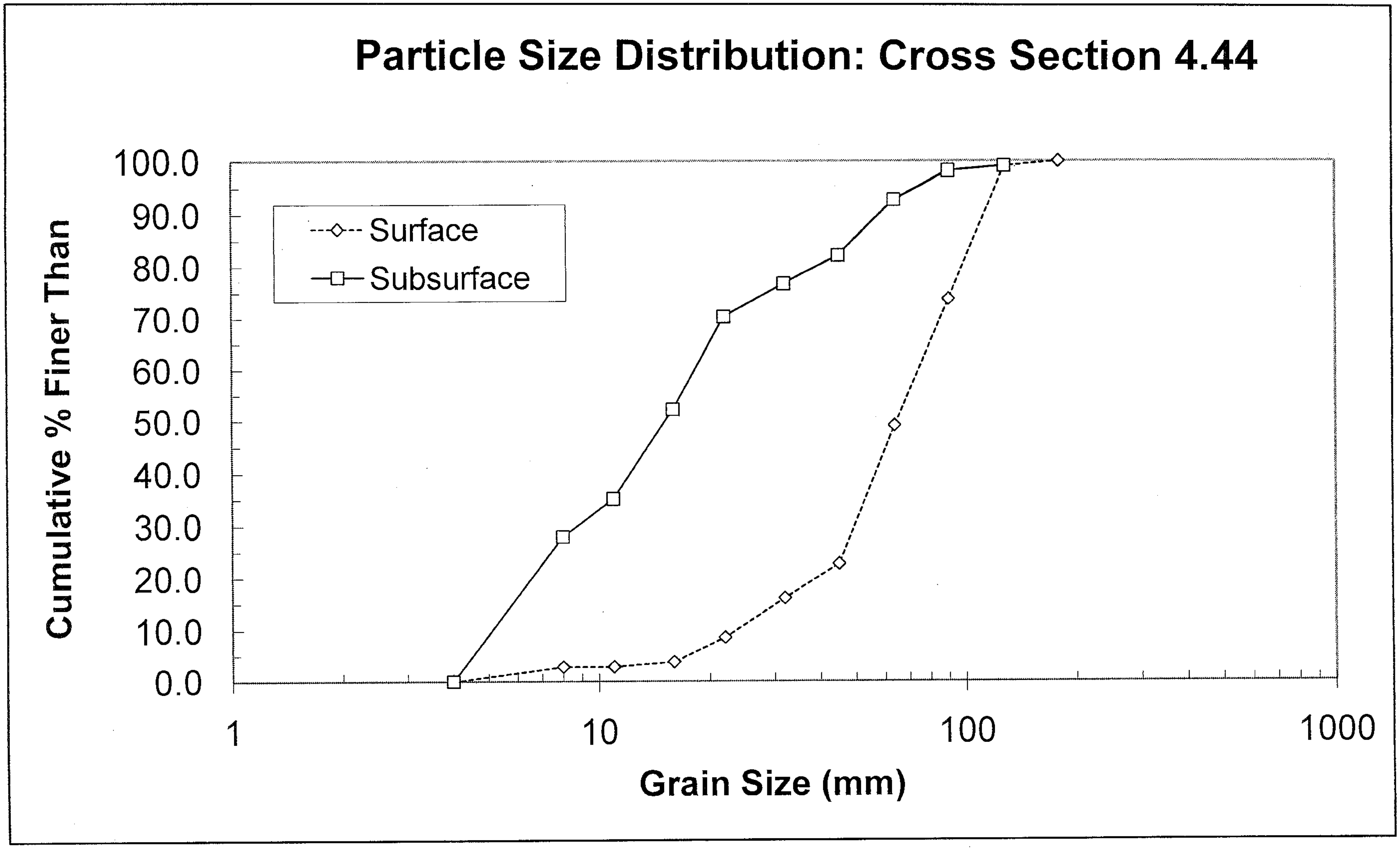


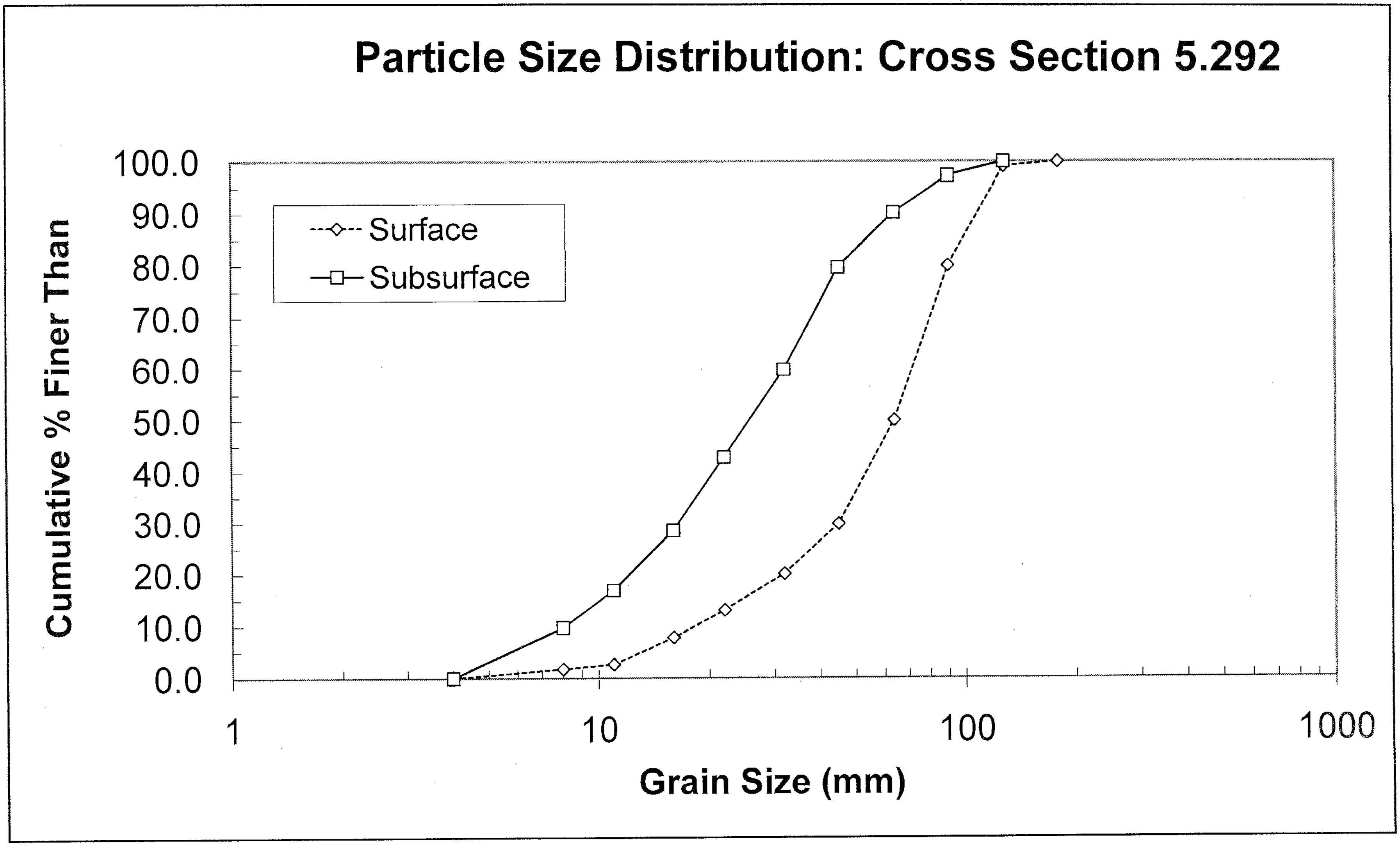
Map 8
Gravel Bar Elevation Change 2007 to 2009
2007 White River Gravel Bars
2009 White River Gravel Bars
2009 Surface Minus 2007 Surface
FEET
< -3.5
-3.5 to -2.5
-2.5 to -1.5
-1.5 to -0.5
-0.5 to 0.5
0.5 to 1.5
1.5 to 2.5
2.5 to 3.5
> 3.5
Negative numbers indicate loss
Positive numbers indicate gain
Photo from February 2009
N
W
E
S
0
200
400
Feet
1 inch = 200 feet
\\dnrp1\projects\WLRD\09090\gravelbar_comparison_landscape.mxd KR

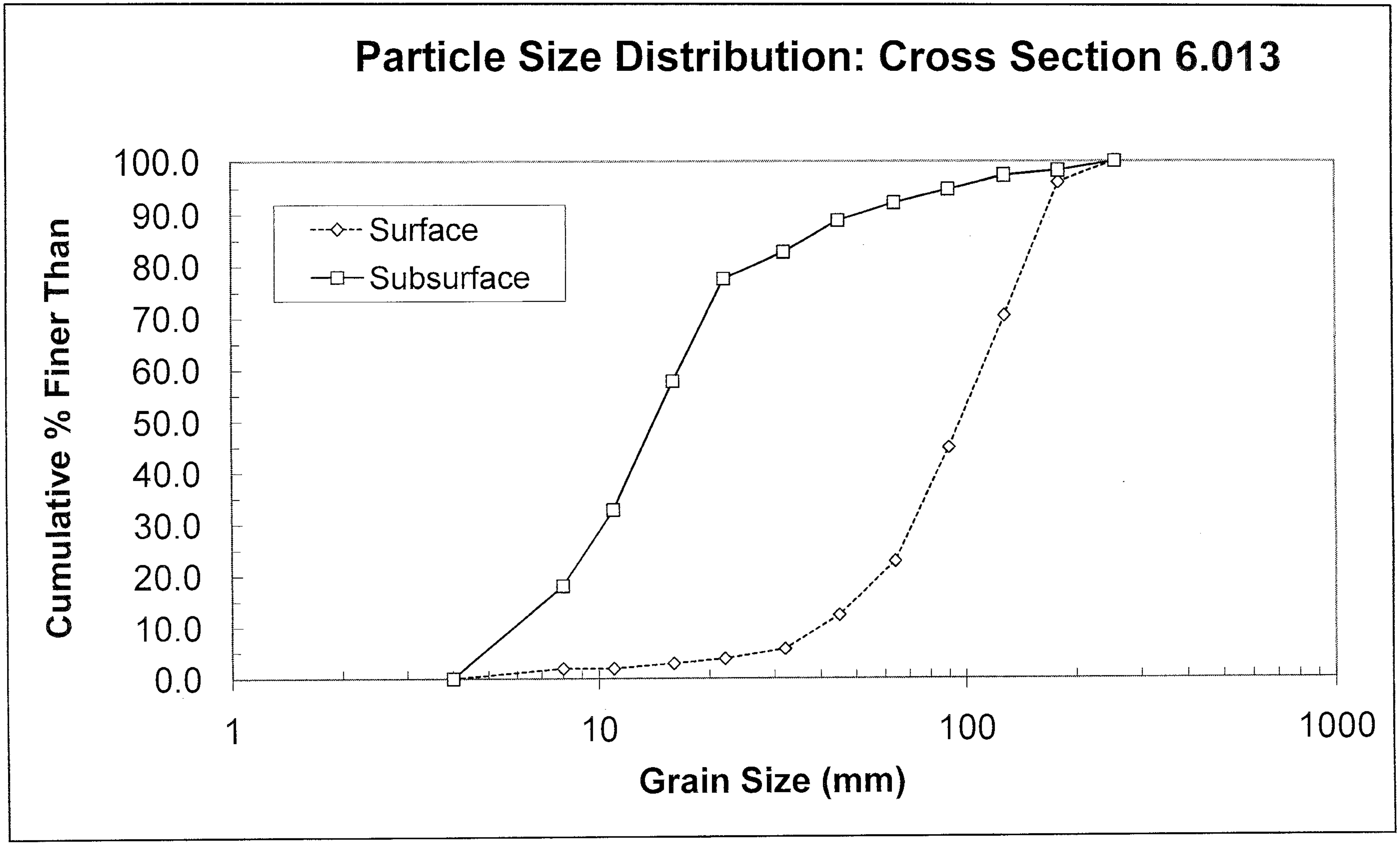

Map 9
Gravel Bar Elevation Change 2007 to 2009
2007 White River Gravel Bars
2009 White River Gravel Bars
2009 Surface Minus 2007 Surface
FEET
< -3.5
-3.5 to -2.5
-2.5 to -1.5
-1.5 to -0.5
-0.5 to 0.5
0.5 to 1.5
1.5 to 2.5
2.5 to 3.5
> 3.5
Negative numbers indicate loss
Positive numbers indicate gain
Photo from February 2009
N
W
E
S
0
200
400
600
Feet
1 inch = 200 feet
\\dnrp1\projects\WLRD\09090\gravelbar_comparison.mxd KR

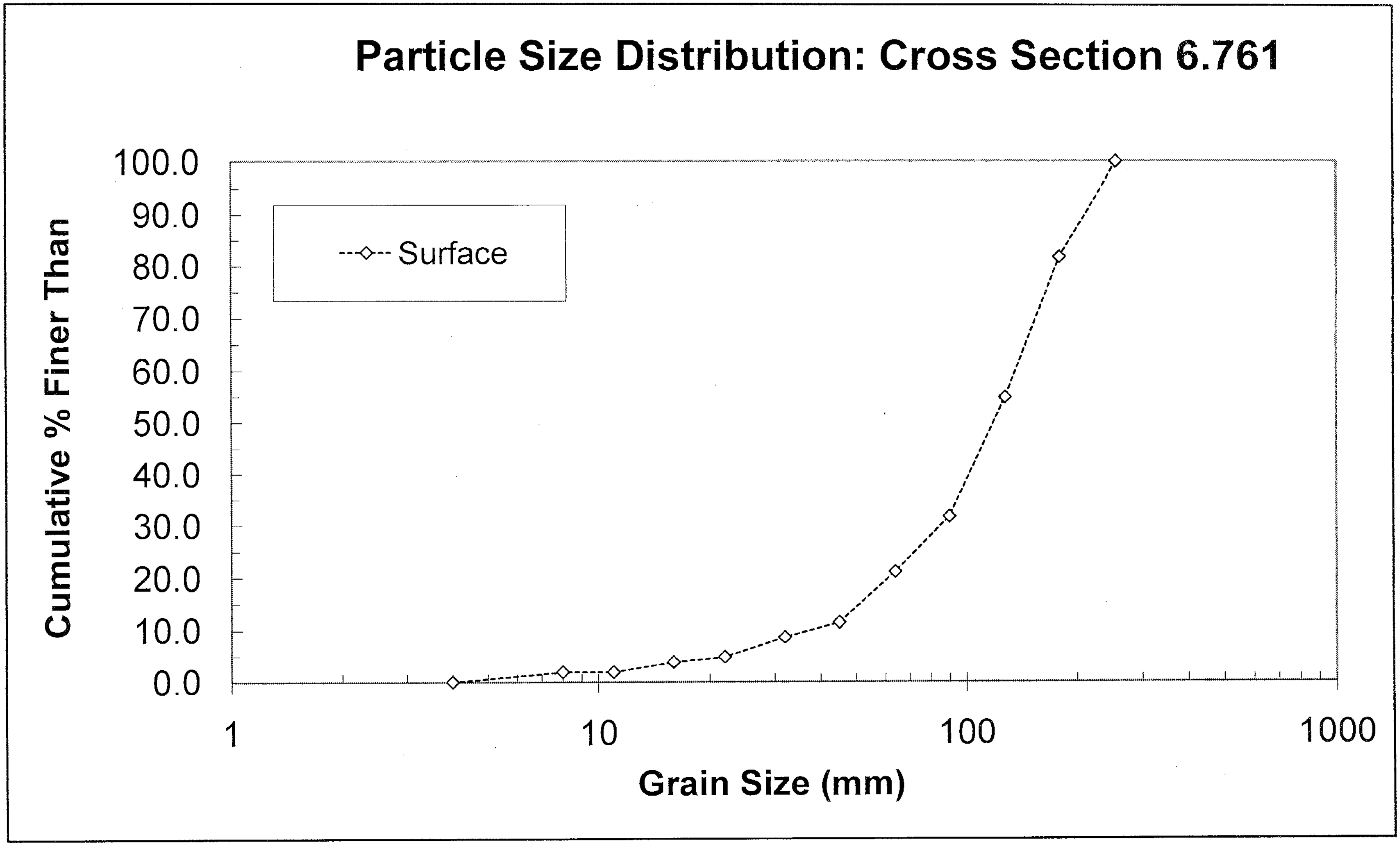
APPENDIX G

White River Pebble Count Data

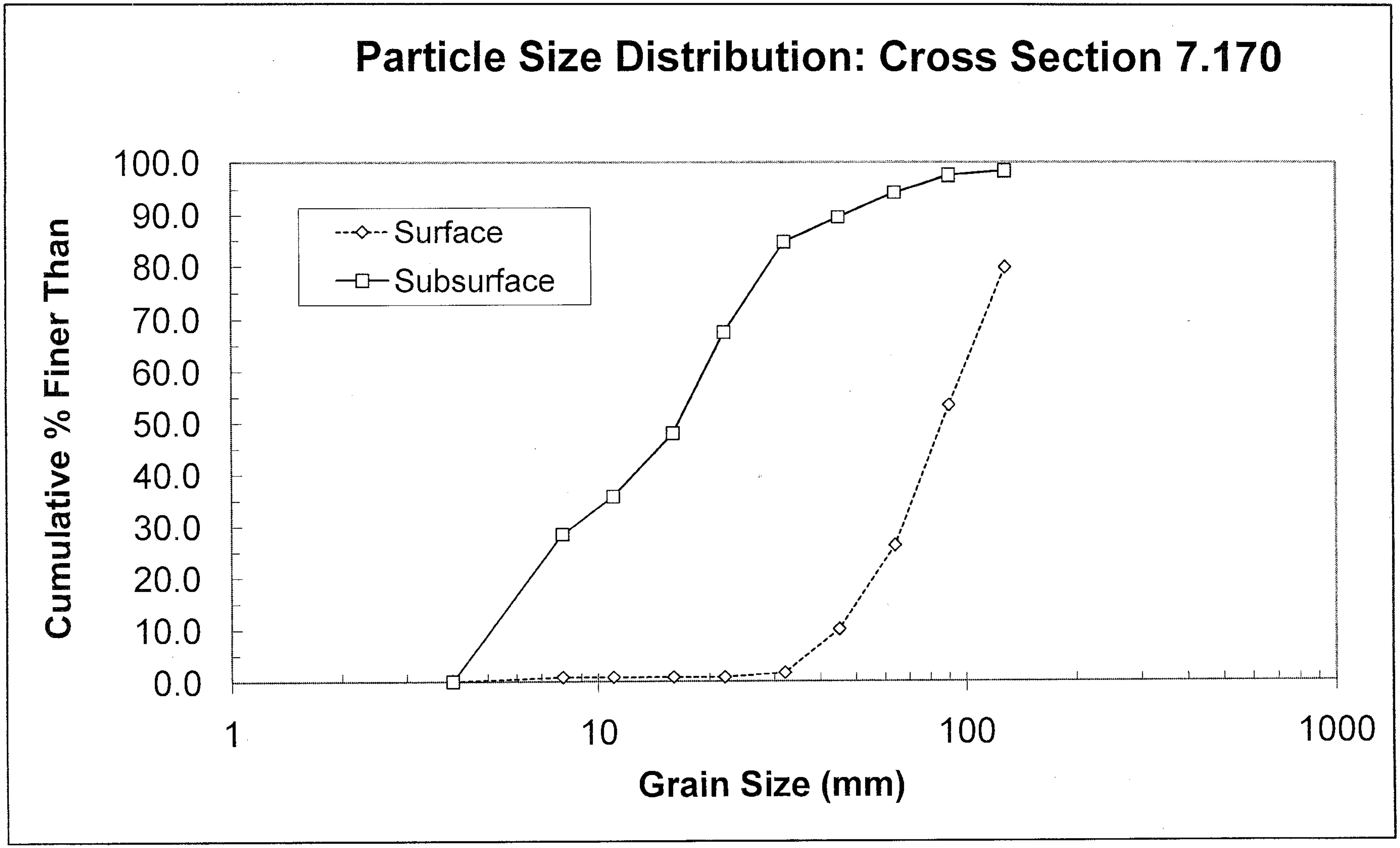

Particle Size Distribution: Cross Section 4.44
Cumulative % Finer Than
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Surface
Subsurface
1
10
100
1000
Grain Size (mm)

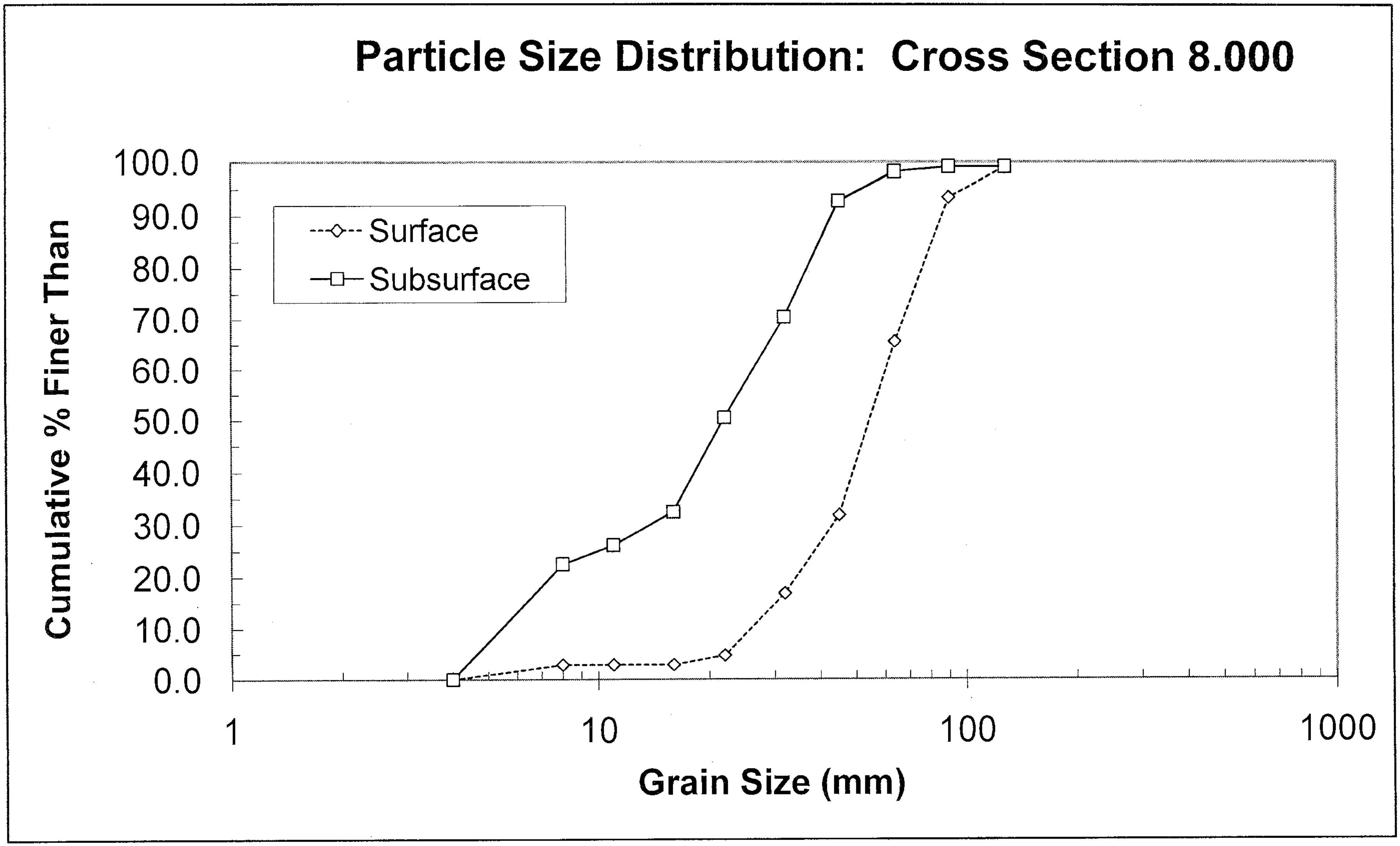

Particle Size Distribution: Cross Section 5.292
Surface
Subsurface
Cumulative % Finer Than
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1
10
100
1000
Grain Size (mm)

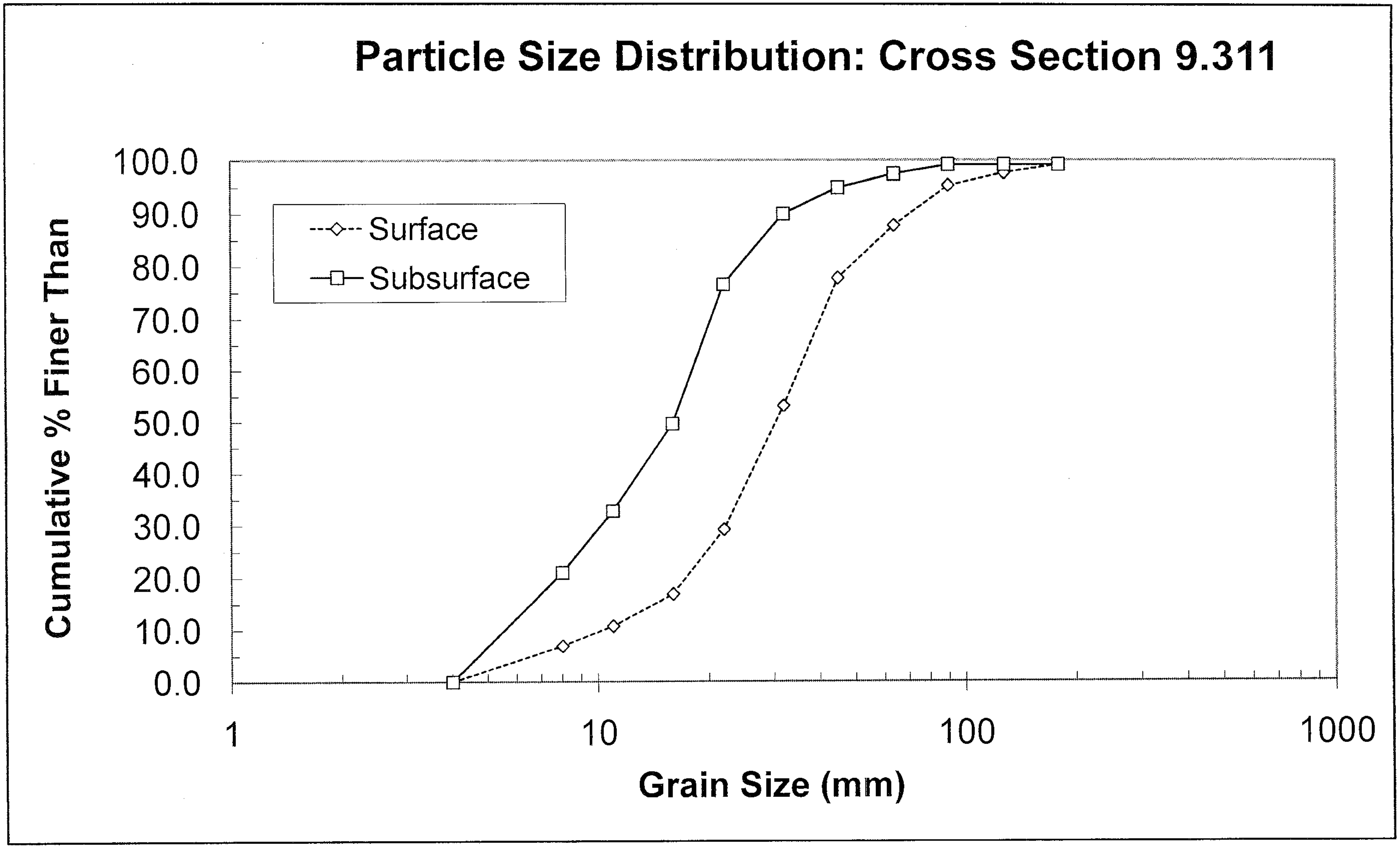

Particle Size Distribution: Cross Section 6.013
Cumulative % Finer Than
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Surface
Subsurface
1
10
100
1000
Grain Size (mm)

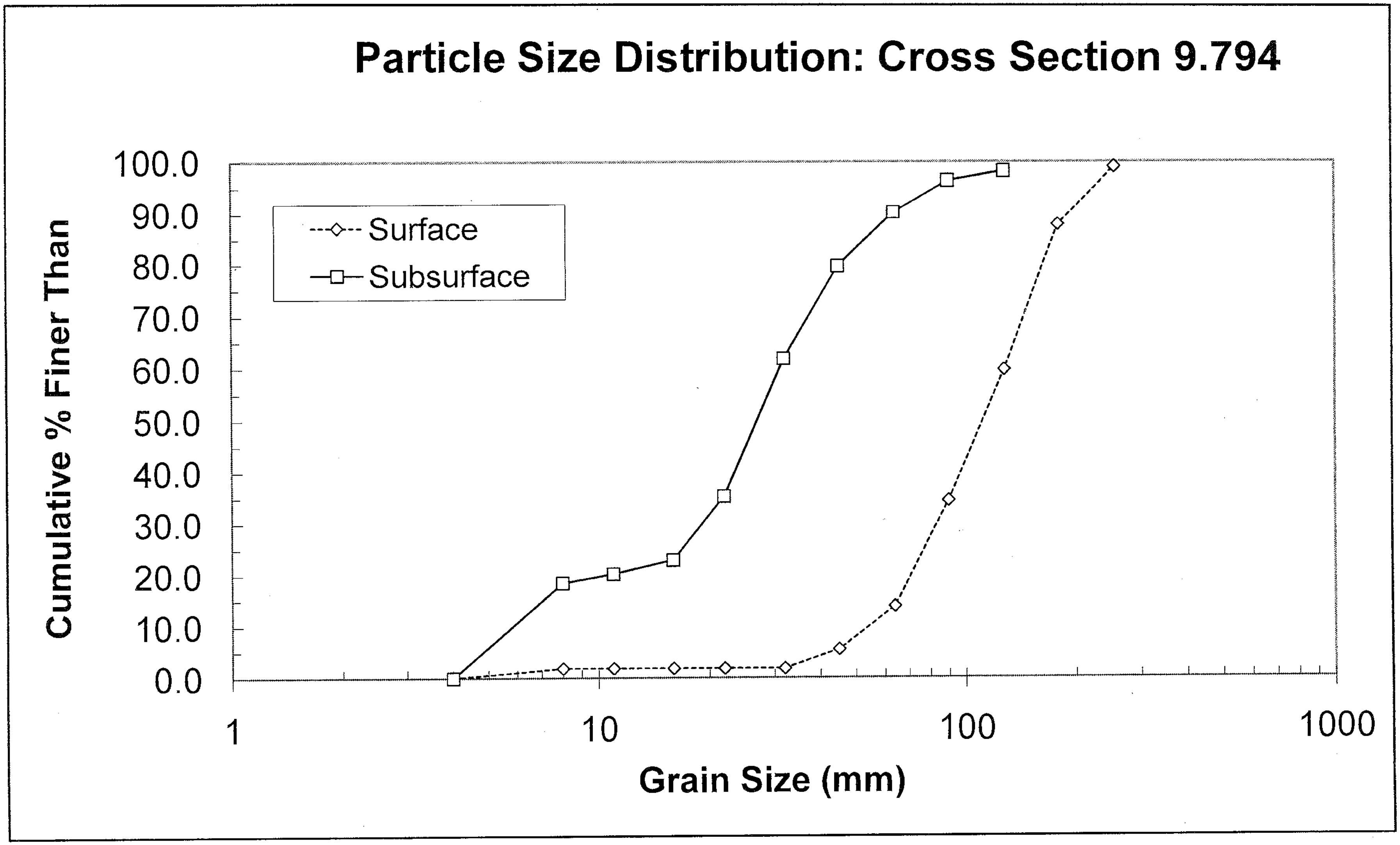


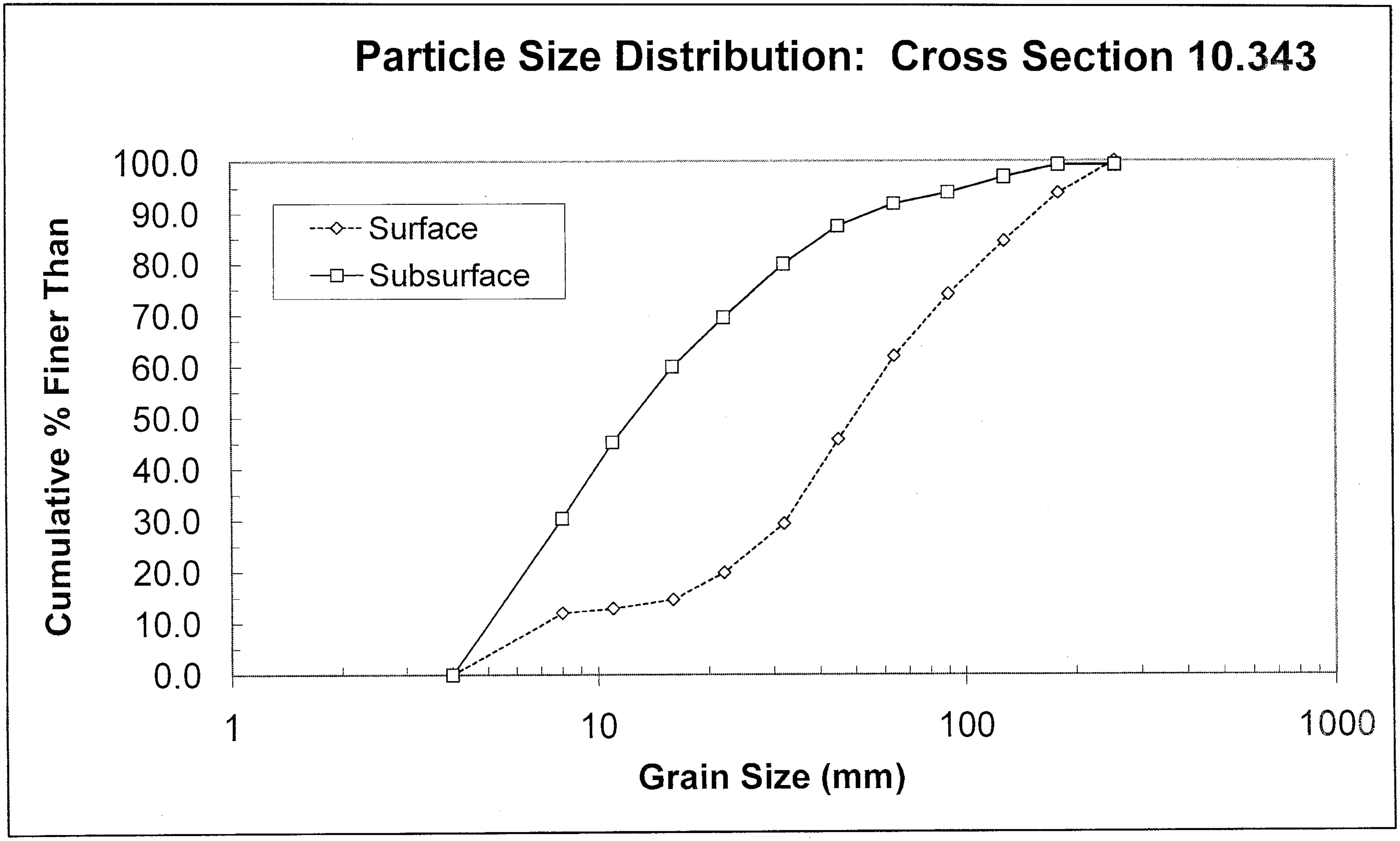
Particle Size Distribution: Cross Section 6.761
Cumulative % Finer Than
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Surface
1
10
100
1000
Grain Size (mm)


Particle Size Distribution: Cross Section 7.170
Cumulative % Finer Than
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Surface
Subsurface
1
10
100
1000
Grain Size (mm)


Particle Size Distribution: Cross Section 8.000
Surface
Subsurface
Cumulative % Finer Than
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1
10
100
1000
Grain Size (mm)


Particle Size Distribution: Cross Section 9.311
Cumulative % Finer Than
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Surface
Subsurface
1
10
100
1000
Grain Size (mm)


Particle Size Distribution: Cross Section 9.794
Surface
Subsurface
Cumulative % Finer Than
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1
10
100
1000
Grain Size (mm)



Particle Size Distribution: Cross Section 10.343
Cumulative % Finer Than
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Surface
Subsurface
1
10
100
1000
Grain Size (mm)

Pebble Count Form

CREEK: White

NAME: Sediment Trends GPS # u/s 4.5

DATE: 8/17/09 X-SECTION #: 4.44

RB / LB

U/S:

D/S:

Photo #

Photo # of substrate

SURFACE: X

SUBSURFACE:

psi = ln(mm)/ln(2)

Goldsmith, Barton
T. Butler

LB = left bank

RB = right bank

Clasts
170
185
165
160
180
170
~~170~~ e per T.B.
175

mm (<=)	SAND	~~4.0~~	~~5.7~~	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096
psi	< 2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12
count		< 8																				
%																						

Herrera Environmental Consultants - White River Sediment Trends - Project No. 08-04059-013

Pebble Count Form

CREEK: White Rv. | RB / LB | Photo # | Photo # of substrate | SURFACE: | SUBSURFACE: | psi = ln(mm)/ln(2)

NAME: Sediment Trends GPS # 4.5 | U/S: | J. Goldsmith | LB = left bank

DATE: 8/17/09 X-SECTION #: 4.44 | D/S: | T. Butler, C. Barton | RB = right bank

25-30% Sand

mm (<=)	SAND	~~4.0~~	5.7	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096
psi	< 2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12
count		<8																				
%																						

Herrera Environmental Consultants - White River Sediment Trends - Project No. 08-04059-013

08.04059.013 (CMB photos)

Pebble Count Form CREEK:

NAME: White River GPS # XS 5.292

DATE: July 30, '09 X-SECTION #: 5.292

RB / LB | U/S: | D/S:

Photo #: 2501 | Photo # of substrate:

SURFACE: (circled) J. Goldsmith, Butler, Barton | SUBSURFACE: | psi = ln(mm)/ln(2) | LB = left bank (circled) | RB = right bank

25																						25
24															7 clasts (med diameter)							24
23																150						23
22																150						22
21																130						21
20																115						20
19																130						19
18																155						18
17																150						17
16																						16
15																						15
14																						14
13																						13
12																						12
11																						11
10																						10
9																						9
8																						8
7										||||												7
6										卌												6
5									|||	卌	||											5
4									卌	卌	卌											4
3								|	卌	卌	卌											3
2					|	|	|||	卌	卌	卌	卌											2
1			||	|	卌	卌	卌	卌	卌	卌	卌	|										1
mm (<=)	SAND	~~4.0~~	~~5.7~~	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096	
psi	< 2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	
count		<8																					
%																							

Herrera Environmental Consultants - White River Sediment Trends - Project No. 08-04059-013

08.04059.013 CMB

Pebble Count Form CREEK:

NAME: White River GPS # XS 5.292

DATE: July 30, 09 X-SECTION #: 5.292

RB / LB			Photo #	Photo # of substrate	SURFACE:		SUBSURFACE:		psi = ln(mm)/ln(2)
U/S:			250		T. Butler				LB = left bank
D/S:					Goldsmith, Barton				RB = right bank

25																							25
24																							24
23																							23
22																							22
21																							21
20																							20
19																							19
18																							18
17																							17
16																							16
15																							15
14																							14
13																							13
12																							12
11																							11
10																							10
9																							9
8																							8
7																							7
6																							6
5																							5
4																							4
3																							3
2																							2
1																							1
mm (<=)	SAND	~~4.0~~	5.7	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096	
psi	< 2	~~2~~	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	
count		<8																					
%																							

Herrera Environmental Consultants - White River Sediment Trends - Project No. 08-04059-013

08.04059.013

Pebble Count Form CREEK:

NAME: White River GPS # 6.013

DATE: July 30 2009 X-SECTION #: 6.013

RB / LB | U/S: | D/S: | Photo # term Bottle | Photo # of substrate | SURFACE: | SUBSURFACE: | psi = ln(mm)/ln(2)

LB = left bank
RB = right bank

24														7 Clasts									24
23															230								23
22															220								22
21															240								21
20															200								20
19															215								19
18															230								18
17															200								17
6										|||	||												6
5									|||	||||	卌												5
4									卌	卌	卌												4
3								|	卌	卌	卌												3
2							||	卌	卌	卌	卌												2
1			|||		|	|	||	卌	卌	卌	卌	卌	||||										1
mm (<=)	SAND	4.0	5.7	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096	
psi	< 2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	
count		28																					
%																							

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08.04059.013

Pebble Count Form CREEK:

NAME: White River GPS # 6.013

DATE: July 30, 2008 X-SECTION #: 6.013

RB / LB			Photo #	Photo # of substrate	SURFACE:		SUBSURFACE: (circled)		psi = ln(mm)/ln(2)
U/S:			See T. Butler		T. Butler				LB = left bank
D/S:					Goldsmith / Barton				RB = right bank (circled)

25																							25
24																							24
23																							23
22																							22
21																							21
20																							20
19																							19
18																							18
17																							17
16																							16
15																							15
14																							14
13																							13
12																							12
11																							11
10																							10
9																							9
8																							8
7																							7
6																							6
5																							5
4																							4
3																							3
2																							2
1																							1
mm (<=)	SAND	4.0	[illegible]	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096	
psi	< 2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	
count			28																				
%																							

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<surface only>

Pebble Count Form

CREEK: White River

NAME: Sediment Trends

GPS #: Nat LWD upstream

DATE:

X-SECTION #: 6.761

RB / LB — U/S: — D/S:

Photo #

Photo # of substrate: CMB

SURFACE: X — SUBSURFACE:

J. Goldsmith, C. Barton, T Butter

psi = ln(mm)/ln(2)

(LB) = left bank

RB = right bank

mm (<=)	SAND	4.0	5.7	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096
psi	< 2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12
tally			|| 9		||	|	||||	|||	𝍸 𝍸	𝍸 𝍸 |	𝍸 𝍸 𝍸 𝍸 ||||	𝍸 𝍸 𝍸 𝍸 𝍸 |||	𝍸 𝍸 𝍸 ||||			Clasts: 220, 260, 200, 210, 220, 230, 230						
count		<8																				
%																						

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1 @ 220mm, 1 @ 230, 1 @ 230 ~ biggest clast sizes

Pebble Count Form CREEK: White R. | RB / LB | Photo # | Photo # of substrate | SURFACE: X | SUBSURFACE: | psi = ln(mm)/ln(2)

NAME: Mary Strauser GPS # | U/S: | LB = left bank

DATE: 7/1/09 X-SECTION #: 7.170 | D/S: | RB = right bank

25																							25
24																Largest Clasts							24
23																		200					23
22																		220					22
21																		170					21
20																		120					20
19																		280					19
18																		250					18
17																		170					17
16																		190					16
15																		190					15
14																							14
13																							13
12																							12
11																							11
10																							10
9																							9
8																							8
7																							7
6																							6
5																							5
4																							4
3																							3
2																							2
1																							1
mm (<=)	~~SAND~~	~~4.0~~	~~5.7~~ <8	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096	
psi	< 2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	
count			1				1	10	19	32	31	14	10										
%																							

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Pebble Count Form CREEK: White

NAME: Strazer, McCarthy GPS # Pebble count

DATE: July 1, 2009 X-SECTION #: 7.170

RB / LB			Photo #	Photo # of substrate	SURFACE:		SUBSURFACE: X	psi = ln(mm)/ln(2)
U/S:								LB = left bank
D/S:								RB = right bank

25																						25
24																						24
23																						23
22																						22
21																						21
20																						20
19																						19
18																						18
17																						17
16																						16
15																						15
14																						14
13																						13
12																						12
11																						11
10																						10
9																						9
8																						8
7			卌																			7
6			卌																			6
5			卌			||||	|															5
4			卌			卌	卌															4
3			卌		卌	卌	卌															3
2			卌	||||	卌	卌	卌	|	|													2
1			卌	卌	||||	卌	卌	卌	卌	||||	|	||											1
mm (<=)	SAND	~~4.0~~	5.7	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096	
psi	< 2	2 (<8)	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	
count																							
%																							

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→ U/S 7,958

Pebble Count Form

NAME: Mary Strazer	CREEK: White R.	RB / LB	Photo #	Photo # of substrate	SURFACE: X
DATE: 6/30/09	GPS #	U/S:			SUBSURFACE:
	X-SECTION #: 8.0	D/S:			psi = ln(mm)/ln(2)

LB = left bank

RB = right bank

Largest 7: 128, 250, 180, 300, 180, 290, 200, 160, 180

mm (<=)	SAND	4.0	5.7	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096
psi	<2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12
count																						
%																						

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Pebble Count Form

CREEK: White R.
NAME: Mary Strazer
DATE: 6/30/09
GPS #
X-SECTION #: 8.0 (U/S 7.958)

RB / LB			Photo #	Photo # of substrate	SURFACE:		SUBSURFACE:	X	psi = ln(mm)/ln(2)
U/S:									LB = left bank
D/S:									RB = right bank

mm (<=)	SAND	4.0	5.7	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096
psi	< 2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12
count																						
%																						

Herrera Environmental Consultants - White River Sediment Trends - Project No. 08-04059-013

Pebble Count Form	CREEK: White R.	RB / LB	LB		Photo #	Photo # of substrate	SURFACE:		SUBSURFACE:	X	psi = ln(mm)/ln(2)
NAME: MJS, JG, Terry Butler	GPS # 9.3/1	U/S:				759-60					LB = left bank
DATE: 6/30	X-SECTION #: 9.3/1	D/S:									RB = right bank

25																						25
24																						24
23																						23
22																						22
21																						21
20																						20
19																						19
18																						18
17																						17
16																						16
15																						15
14																						14
13																						13
12																						12
11																						11
10																						10
9																						9
8																						8
7																						7
6																						6
5																						5
4																						4
3																						3
2																						2
1																						1
mm (<=)	SAND	~~4.0~~	5.7	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096
psi	< 2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12
count																						
%																						

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Pebble Count Form

CREEK: White R. | RB / LB | Photo # | Photo # of substrate | SURFACE: X | SUBSURFACE: | psi = ln(mm)/ln(2)

NAME: MJS + JG | GPS # | U/S: | 57-58 | LB = left bank

DATE: 6/30/09 | X-SECTION #: 9.31A | D/S: | RB = right bank

25															160								25
24															190								24
23															160								23
22															120								22
21															180	largest pieces							21
20															210								20
19															210								19
18															180								18
17															200								17
16																							16
15																							15
14																							14
13																							13
12																							12
11																							11
10																							10
9																							9
8																							8
7																							7
6																							6
5																							5
4																							4
3																							3
2																							2
1		20																					1
mm (<=)	~~SAND~~	~~4.0~~	~~5.7~~	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096	
psi	< 2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	
count																							
%																							

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Pebble Count #2

Pebble Count Form	CREEK: WHITE R	RB / LB			Photo #	Photo # of substrate	SURFACE:		SUBSURFACE: X	psi = ln(mm)/ln(2)
NAME: BUTLER/GOLDSMITH, BARRIGA	GPS #	U/S:								LB = left bank
DATE: 6/26/09	X-SECTION #: 9.794	D/S:								RB = right bank

25																						25
24															SURFACE							24
23																						23
22														LARGEST 7 CLASTS								22
21														350	270							21
20														270	240							20
19														195	210							19
18														230								18
17																						17
16																						16
15																						15
14																						14
13																						13
12																						12
11																						11
10																						10
9																						9
8																						8
7																						7
6							卌															6
5			|				卌															5
4			卌				卌	卌														4
3			卌			||||	卌	卌	||													3
2			卌			卌	卌	卌	卌	||												2
1			卌	||	|||	卌	卌	卌	卌	卌	||	||										1
mm (<=)	SAND	4.0	5.7	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096	
psi	< 2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	
count																							
%																							

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all sand ≈ 28%

Pebble Count #2

Pebble Count Form CREEK: WHITE R

NAME: BUTLER, GOLDSMITH, BAKER GPS #

DATE: 6/25/09 X-SECTION #: 9.794

RB / LB			Photo #	Photo # of substrate	SURFACE: X	SUBSURFACE:	psi = ln(mm)/ln(2)
U/S:							LB = left bank
D/S:							RB = right bank

25																							25
24																							24
23																							23
22																							22
21																							21
20																							20
19																							19
18																							18
17																							17
16																							16
15																							15
14																							14
13																							13
12																							12
11																							11
10																							10
9																							9
8																							8
7																							7
6											II	~~IIII~~											6
5										II	~~IIII~~	~~IIII~~											5
4										~~IIII~~	~~IIII~~	~~IIII~~											4
3										~~IIII~~	~~IIII~~	~~IIII~~	II										3
2									IIII	~~IIII~~	~~IIII~~	~~IIII~~	~~IIII~~										2
1			II					IIII	~~IIII~~	~~IIII~~	~~IIII~~	~~IIII~~	~~IIII~~	I									1
mm (<=)	~~SAND~~	~~4.0~~	5.7	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096	
psi	< 2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	
count																							
%																							

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Pebble Count # 1

Pebble Count Form Goldsmith CREEK: White River	RB / LB			Photo #	Photo # of substrate	SURFACE: X	SUBSURFACE:	psi = ln(mm)/ln(2)
NAME: Barton / Butler GPS #	U/S:					mid-channel bar		LB = left bank
DATE: 6/25/09 X-SECTION #: 10,343	D/S:							RB = right bank

25																							25
24																							24
23																							23
22																							22
21																							21
20																							20
19																							19
18																							18
17																							17
16																							16
15																							15
14																							14
13																							13
12																							12
11																							11
10																							10
9																							9
8																							8
7																							7
6																							6
5																							5
4																															4
3												卌	卌																		3
2			卌					卌	卌	卌	卌				卌													2
1			卌						卌	卌	卌	卌	卌	卌	卌	卌										1
mm (<=)	~~SAND~~	~~4.0~~ <8	5.7	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096		
psi	< 2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12		
count																								
%																								

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mm of Largest Pieces
270
185
265
320
210
260
200

Pebble Count #1 20-30% Sand Content

Pebble Count Form Goldsmith CREEK: White River	RB / LB			Photo #	Photo # of substrate	SURFACE:	SUBSURFACE: X	psi = ln(mm)/ln(2)
NAME: Barton / Butler GPS #	U/S:					mid-channel bar		LB = left bank
DATE: 6/25/09 X-SECTION #: 10343	D/S:							RB = right bank

25																						25
24																						24
23																						23
22																						22
21																						21
20																						20
19																						19
18																						18
17																						17
16																						16
15																						15
14																						14
13																						13
12																						12
11																						11
10																						10
9			|																			9
8			||||/																			8
7			||||/																			7
6			||||/																			6
5			||||/																			5
4			||||/	||||/	||||/																	4
3			||||/	||||/	||||/	|||																3
2			||||/	||||/	||||/	||||/	||||	||||/	|														2
1			||||/	||||/	||||/	||||/	||||/	||||/	||||/	|||	||||	|||												1
mm (<=)	SAND	~~4.0~~	~~5.7~~ ≤8	8.0	11.3	16.0	22.6	32.0	45.3	64.0	90.5	128.0	181.0	256.0	362.0	512.0	724.1	1024.0	1448	2048	2896	4096	
psi	< 2	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	
count																							
%																							

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APPENDIX H

White River Large Woody Debris Analysis
Tables and Graphs

Table H-1. White River Study Area Stable Large Wood Accumulations.

Reach	X-S	Stable Wood		2007 LWD	2009 LWD	Change in Area Between 2007 - 2009 (m)
		Id	Area (m)	Area (m)	Area (m)	
1	5.041	1	2,689	3,454	2,689	-765
1	5.041	2	6,226	2,829	6,226	3,397
1	5.621	3	1,921	1,041	1,921	879
1	5.621	4	1,837	938	1,837	899
1	6.326	5	3,478	2,760	3,478	718
2	6.569	6	3,838	299	3,838	3,540
2	6.569	7	4,490	4,093	4,490	397
2	6.761	8	4,534	5,609	4,534	-1,074
2	6.761	9	905	488	905	417
2	7.252	10	1,302	746	1,302	556
2	7.252	11	1,496	1,972	1,496	-476
5	9.477	12	2,292	1,026	2,292	1,266
5	9.477	13	1,196	1,165	1,196	31
5	9.477	14	1,795	1,304	1,795	491
5	9.477	15	12,104	1,712	12,104	10,391
5	10.065	16	1,786	586	1,786	1,200
5	10.596	17 (ELJ)	263	263	263	0
William's Site		18 (ELJ)	3,796	526	3,796	3,270
William's Site		19 (ELJ)	702	603	702	99

Table H-2. White River Study Area 2007 and 2009 Large Wood Accumulations.

2007 LWD				2009 LWD			
Id	Area (ft^2)	Area (m)	Volume (m^3)	Id	Area (ft^2)	Area (m)	Volume (m^3)
4	3,949	1,204	361	4	2,102	641	192
5	1,922	586	176	6	3,774	1,150	345
6	5,618	1,712	514	7	3,388	1,033	310
7	4,277	1,304	391	8	15,508	4,727	1,418
8	3,823	1,165	350	9	7,320	2,231	669
9	3,367	1,026	308	10	3,020	920	276
10	995	303	91	11	4,633	1,412	424
11	998	304	91	12	1,297	395	119
12	868	265	79	13	15,222	4,640	1,392
13	245	75	22	14	2,359	719	216
14	6,471	1,972	592	15	5,859	1,786	536
15	2,448	746	224	16	9,854	3,003	901
16	1,600	488	146	17	8,863	2,701	810
17	18,402	5,609	1,683	18	1,828	557	167
18	13,430	4,093	1,228	19	9,728	2,965	890
19	979	299	90	20	7,305	2,227	668
20	9,056	2,760	828	21	869	265	79
21	3,078	938	281	22	39,710	12,104	3,631
22	3,416	1,041	312	23	9,813	2,991	897
23	768	234	70	24	1,590	485	145
24	1,338	408	122	25	2,071	631	189
25	1,154	352	106	26	771	235	71
26	9,283	2,829	849	27	7,521	2,292	688
27	11,333	3,454	1,036	28	2,373	723	217
				29	475	145	43
				30	786	240	72
				31	1,645	501	150
				32	2,313	705	211
				33	1,740	530	159
				34	742	226	68
				35	2,259	689	207
				36	6,651	2,027	608
				37	3,882	1,183	355
				38	2,044	623	187
				39	4,909	1,496	449
				40	4,272	1,302	391
				41	17,846	5,439	1,632
				42	455	139	42
				43	3,895	1,187	356
				44	427	130	39
				45	567	173	52
				46	14,732	4,490	1,347
				47	12,592	3,838	1,151
				48	3,294	1,004	301
				49	1,435	437	131
				50	11,411	3,478	1,043
				51	2,894	882	265
				52	6,027	1,837	551
				53	6,301	1,921	576
				54	2,933	894	268
				55	1,580	481	144
				56	316	96	29
				57	377	115	34
				58	2,485	758	227
				59	1,434	437	131
				60	20,427	6,226	1,868
				61	8,823	2,689	807
				62	4,194	1,278	384
				63	1,247	380	114

Total Wood:	9,950	2007 Total Volume (m3)	32,173	2009 Total Volume (m3)
	100.3	Volume (m3) per 100 m/channel	324.4	Volume (m3) per 100 m/channel

Channel Length:	6.16	miles
	32,524.80	feet
	9,916.10	meter
	99.16	100 meter segements in Study Reach

Table H-3. White River Study Area Stable Wood Accumulations.

Study Area Reach	Number of 2007 LWD Accumulations	Number of 2009 LWD Accumulations	Number of Stable Large Wood Accumulations
1	8	16	5
2	8	11	6
3	0	1	0
4	2	7	0
5	6	24	5
Totals	24	59	16

*Williams site ELJs, and stable wood outside of study area are not included.

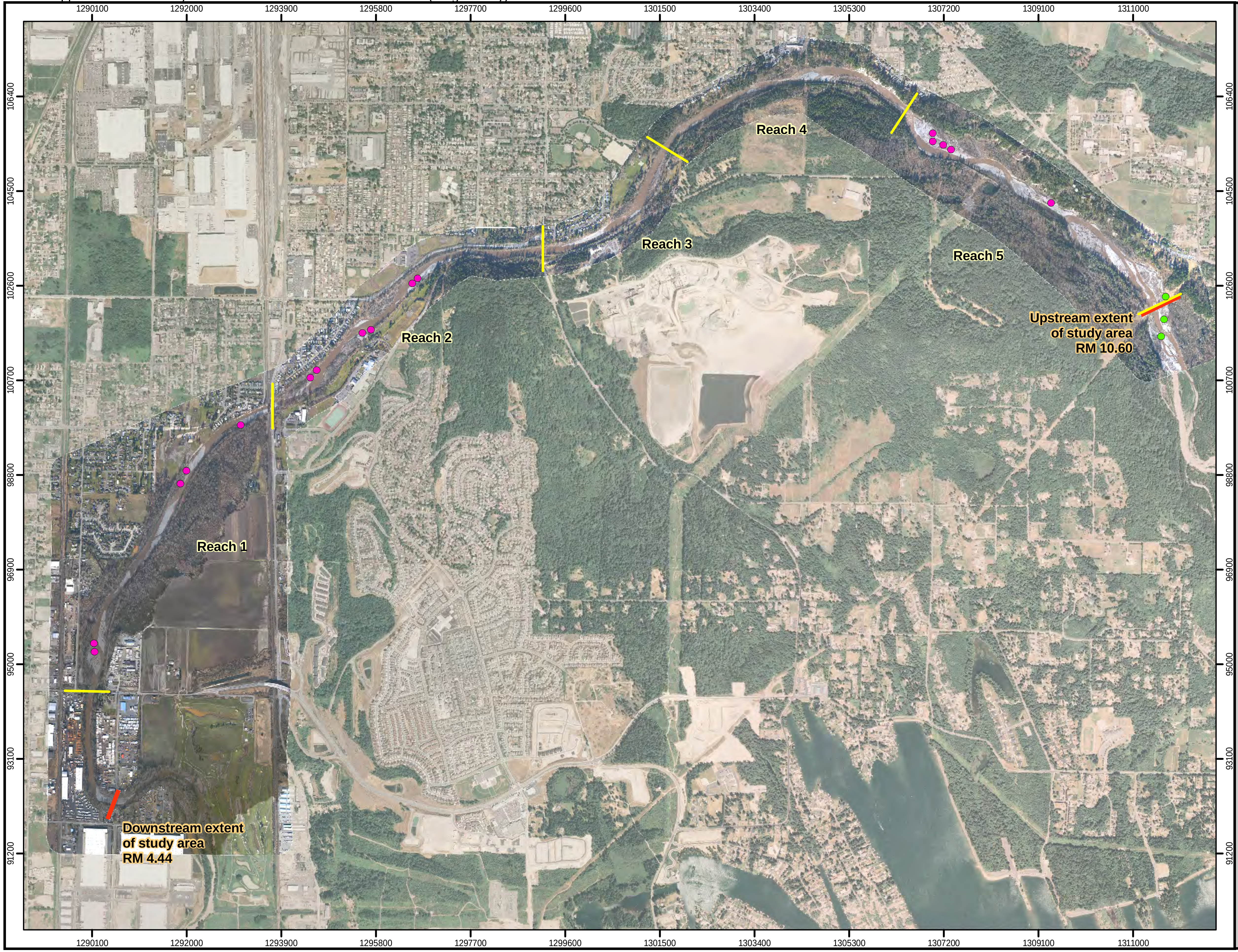

Figure H-1.
White River sediment trends study area stable large wood.

Legend

- Stable wood
- Williams ELJ (n=3)
- Reach break
- Study area

N

0 950 1,900 3,800 Feet

HERRERA ENVIRONMENTAL CONSULTANTS

Coordinates: NAD83 Washington StatePlane North (feet)
Aerial Photo: King County (2009)

Produced By: GIS (rdr)
Project: K:\Projects\08-04059-013\Project\stable_large_wood_accumulations.mxd

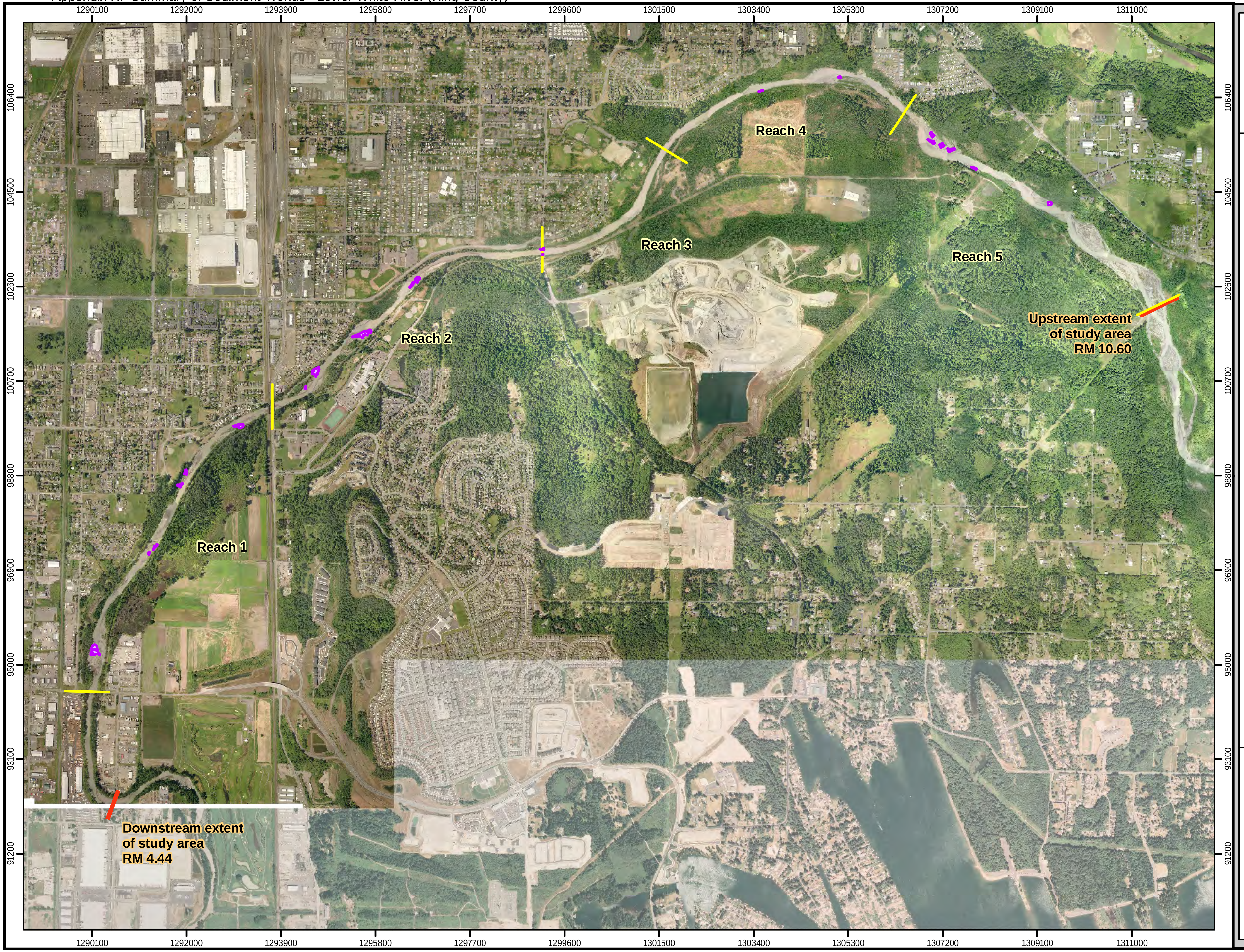

Figure H-2.
White River sediment trends study area 2007 large wood.

Legend

- Large woody debris
- Reach break
- Study area

N

0 950 1,900 3,800 Feet

HERRERA ENVIRONMENTAL CONSULTANTS

Coordinates: NAD83 Washington StatePlane North (feet)
Aerial Photo: King County (2007)

Produced By: GIS (rdr)
Project: K:\Projects\08-04059-013\Project\large_woody_debris_2007.mxd

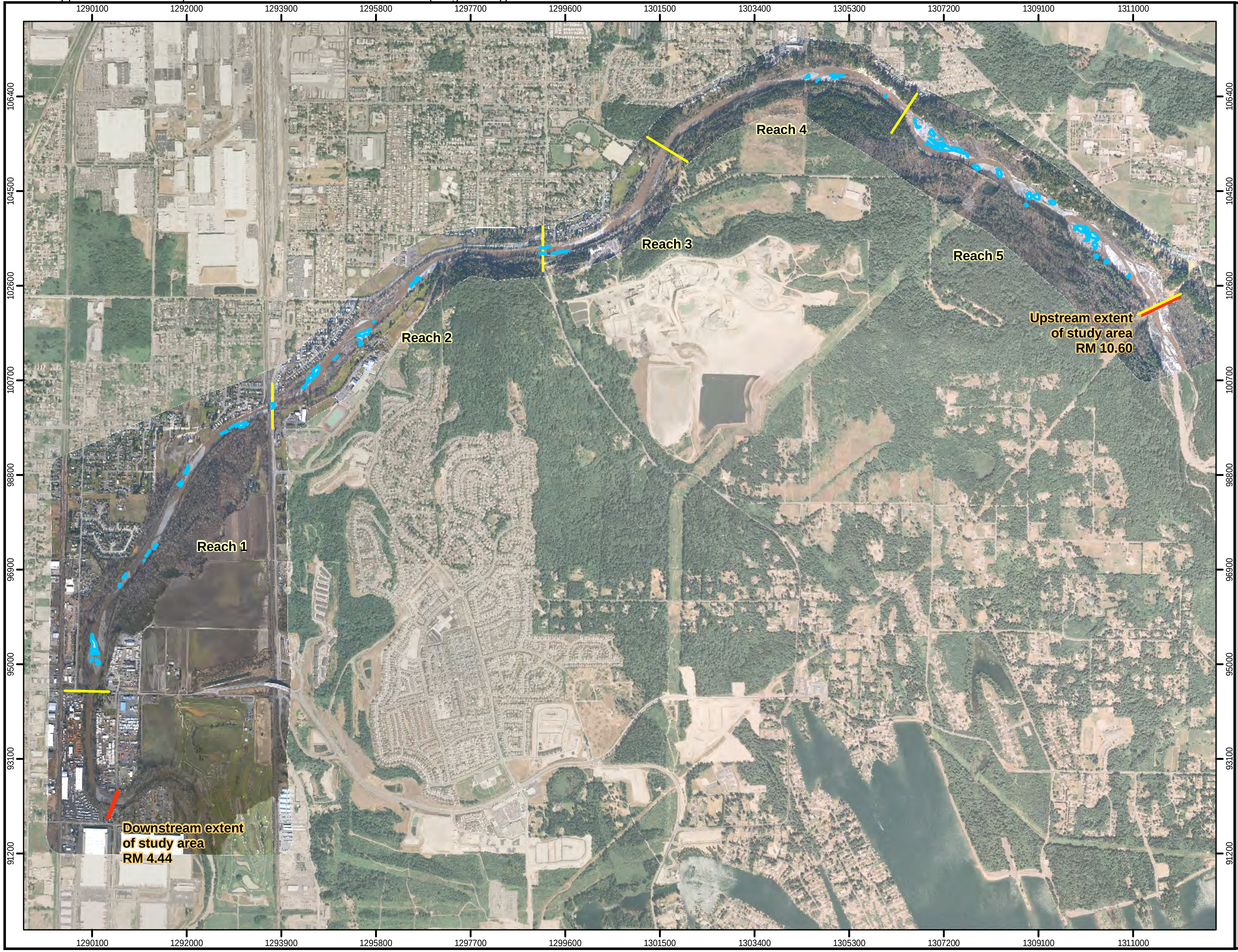

Figure H-3.
White River sediment trends study area 2009 large wood.

Legend

- Large woody debris
- Reach break
- Study area

N

0 950 1,900 3,800 Feet

HERRERA
ENVIRONMENTAL CONSULTANTS

Coordinates: NAD83 Washington StatePlane North (feet)
Aerial Photo: King County (2009)

Produced By: GIS (rdr)
Project: K:\Projects\08-04059-013\Project\large_woody_debris_2009.mxd