Draft Summary of Lower White River In-Channel Sediment Monitoring Data through 2011

Technical Memo

October 8, 2012

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King County
Department of
Natural Resources and Parks
Water and Land Resources Division

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1. Introduction

This document presents the results of the 2011 in-channel monitoring of sediment levels in the Lower White River from approximate River Mile (RM) 4.4 to RM 10.6. It was prepared by King County staff in the Department of Natural Resources and Parks (DNRP), River and Floodplain Management Section (RFMS), consistent with the provisions of the 2006 King County Flood Hazard Reduction Plan.

1.1. Purpose

The purpose of this report is to summarize the most recent information on in-channel sediment levels and hydraulic response in the Lower White River for use in King County's ongoing sediment management program and flood hazard reduction efforts. The 2011 survey data on in-channel sediment levels are compared to similar data from 2009 and previous time periods to document changes and characterize trends in the in-channel sediment levels of the Lower White River. The 2011 in-channel sediment levels also are used in a hydraulic model to calculate resulting hydraulic response of flood water levels. The 2011 hydraulic model results are compared to similar previous hydraulic analyses to characterize changes in flood water levels in this part of the White River.

1.2. Background

The monitoring area in this report includes the Lower White River from RM 10.6 downstream to RM 4.4. In this area, the Lower White River flows through portions of the Muckleshoot Indian Reservation, Cities of Auburn, Pacific and Sumner, and crosses from King County into Pierce County (**Figure 1**). This river monitoring area is at the downstream end of a 464 square mile basin with its headwaters on Mt. Rainier, and is located where the river exits the White River canyon and flows down the White River alluvial fan. This natural geographic setting, and a long history of river engineering that has altered the channel dramatically, have had a major influence on the sediment transport and deposition trends in this part of the White River to this day. Basin-scale influences and Lower White River sediment trends, from the early 1900s through 2009, are described in detail by Herrera (2010) and Czuba et al. (2010). Relevant information and data from those reports are provided here for context.

2. Methods

2.1. Sediment

The primary method of monitoring the in-channel changes in sediment levels in this area was the 2011 resurvey of 52 existing river channel cross sections between RM 4.44 and RM 10.596, though this monitoring report focuses on cross sections from RM 4.978 (near the 8th Street East Bridge)

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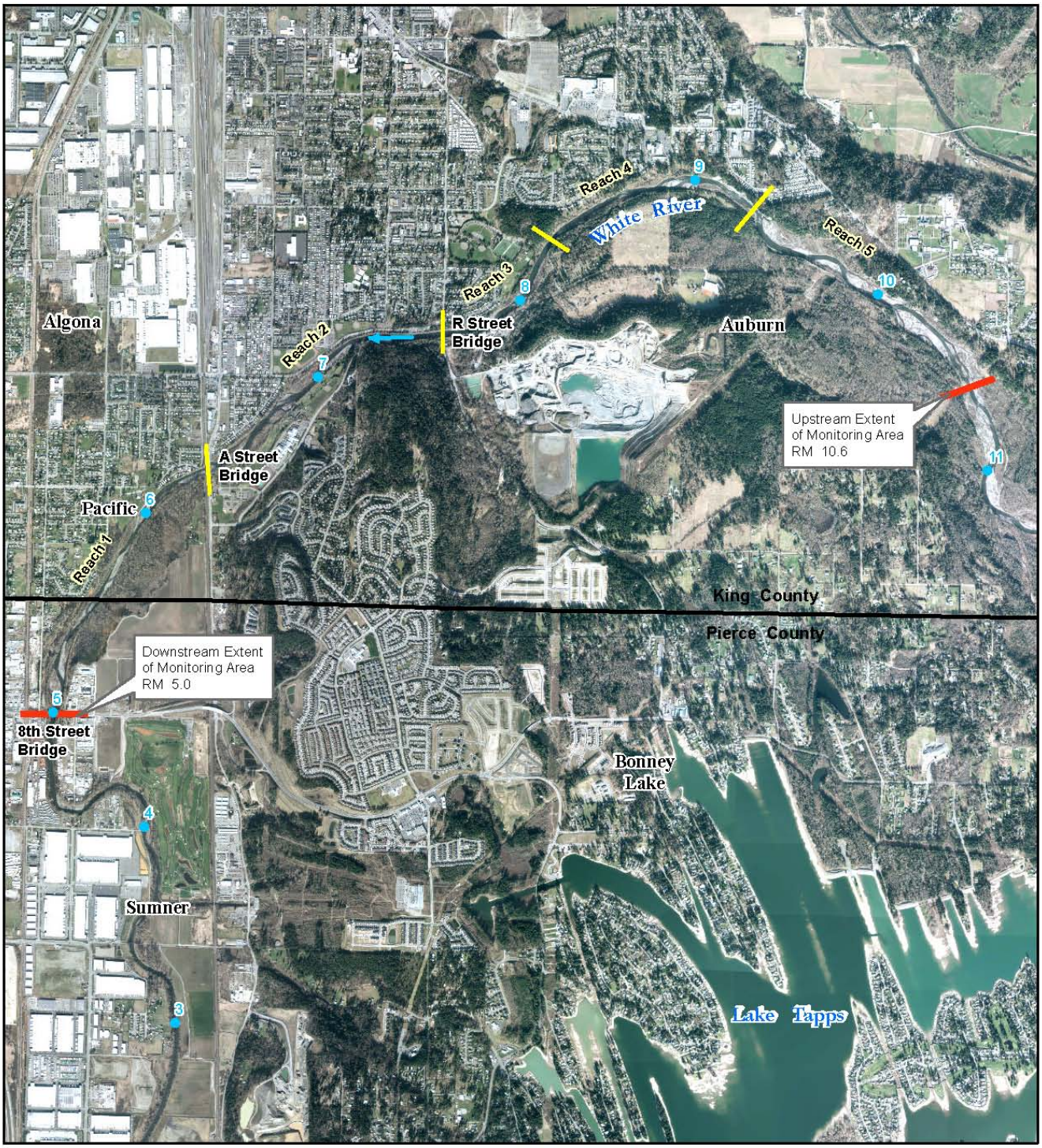

Figure 1: Lower White River Channel Monitoring Area Vicinity Map

Photo From 2010

Legend

- River Mile
- Study Area
- Reach Break
- County Boundary

0 2,000 4,000 6,000
Feet

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to RM 10.596. In addition, there were ten new cross sections added within this monitoring area as part of the 2011 survey, which will be resurveyed in future monitoring efforts.

In this document, "in-channel" refers to the river channel from top of bank to opposite top of bank and does not include overbank areas on the floodplain or in adjacent wetlands. Comparison of survey data from all periods, including past monitoring intervals, focus on the same in-channel area to calculate the changes in sediment storage volume that occurred between survey dates.

For periods of time when there has been no sediment extraction, or dredging, from the channel, the calculated change in sediment volume is synonymous with either the net deposition or the net erosion. Dredging operations in the monitoring area part of this river are estimated to have ceased in approximately 1986, so the changes in sediment volume during the monitoring period of 1984 to 2001 is assumed to approximately equal net deposition (or erosion). For monitoring periods 2001 to 2007, 2007 to 2009, and 2009 to 2011 the change in storage is equal to net deposition or erosion. For monitoring periods of 1974 to 1984 and earlier, the change in sediment storage volume included effects of dredging, so the "changes in sediment volumes" reported for those periods do not accurately represent actual deposition volumes. Actual sediment deposition during those periods would equal the change in sediment volume plus extracted (dredged) volumes. Due to poorly kept records of sediment extraction volumes, actual deposition volumes in these earlier time periods are approximate at best. More information is provided in Herrera (2010 Appendix A). The term "change in sediment volumes" is used for periods during which dredging occurred rather than "volumes deposited."

The overall channel monitoring area from approximate RM 5 to RM 10.6 is split into the five individual river reaches of Herrera (2010), which are based primarily on channel gradient, channel confinement and channel planview pattern, and secondarily on constructed features such as bridges (**Table 1)**.

The 2011 underwater survey data were collected by boat in April 2011 using a combination of survey-grade Global Positioning System (GPS) equipment plus sonar. Out-of-water ground surface elevations were extracted from LiDAR data collected in April 2011. The two data sets were merged by King County to create full bank-to-bank cross sections. Changes in cross sectional area at each cross section were determined for 2009 to 2011. Volumetric changes in sediment were calculated by determining the changes in cross sectional area at each cross section, averaging the changes at two adjacent cross sections and multiplying by the distance between those cross sections. Calculations of changes from 2009 to 2011 at each cross section were aggregated into the five reaches or the full monitoring area for comparison to other time periods.

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Table 1: Lower White River reaches.

Reach Number	Downstream RM	Upstream RM	Length (RM)	Reach Name; Landmarks
1	4.978	6.326	1.35	Countyline Reach; 8th Str. E to BNSF/A Str. Bridges
2	6.326	7.716	1.39	Auburn Reach; BNSF/ A Street Bridges to R Street Bridge
3	7.716	8.269	0.55	R Street Bridge to Auburn Wall
4	8.269	9.311	1.04	Auburn Wall to RM 9.311
5	9.311	10.596	1.29	RM 9.311 to upstream end
All	4.978	10.596	5.62	Full monitoring area

The change in cross sectional area through time at each cross section was divided by the channel width at that location to yield a channel-averaged change in riverbed elevation. The average changes in riverbed elevations at each cross section were averaged to indicate an average change in riverbed elevation through each river reach.

The elevations of the out-of-water portions of gravel bar surfaces were compared graphically to depict changes in gravel bar top elevations from 2009 to 2011 using digital topographic data collected by LiDAR in both years. Because the exposed planview extent of gravel bars can change significantly between dates of data collection due to changes in bar size and location or to differences in flow levels at the time of LiDAR flights, the comparison of the two digital surfaces was not used to calculate volumetric changes. [This graphic will be included in the final memo.]

2.2. Hydraulics

The same surveyed channel cross sections used for in-channel sediment monitoring were used to create a 1-dimensional hydraulic model of 2011 existing channel conditions using HEC-RAS. These hydraulic modeling results of computed 2011 channel conditions were compared to corresponding 2009 HEC-RAS hydraulic model results to indicate hydraulic response to in-channel sediment changes over the intervening two-year period. The primary hydraulically modeled parameters compared from 2009 and 2011 are water surface elevations and channel conveyance capacity. The only difference between the hydraulic models from 2009 to 2011 was the channel geometries, meant to represent in-channel sediment changes. Hydraulic variables such as the Manning's n roughness coefficient were not changed between model years.

All of the hydraulic modeling of 2009 and 2011 existing conditions was done using a feature in the HEC-RAS program that artificially keeps flow in the channel even if water levels would be high enough to overtop the riverbanks. This is done by insertion of an infinitely tall, frictionless barrier to overtopping flow at the top of each riverbank at every river cross section (referred to as "Raised Levees" in HEC-RAS). This approach was taken to focus the evaluation only on the effects of in-channel changes due to sedimentation or erosion and also to simplify the modeling process by eliminating the need to model splits in flood flows. The insertion into the hydraulic model of the frictionless, tall artificial walls at the top of every bank results in the modeled water

surface elevations of flows that occur above the top of the riverbank being overstated to some undetermined degree. This approach focuses on the open channel flow that would be contained by the existing top of riverbank or levee and does not include any detailed analysis of the more complex hydraulics around bridges. Channel conveyance capacity at the bridges in this monitoring area was not characterized in this analysis.

3. Results

3.1. Sediment

The locations of the 62 cross sections surveyed in 2011 are shown in **Figure A-1 of Appendix A**. Cross section views [will be provided in the final version of this memo] to show the 62 cross sections the surveyed in 2011 plotted in comparison to those cross sections surveyed in previous years in **Appendix A**. The changes from 2009 to 2011 in cross sectional area, riverbed elevations, and the rates of change at each cross section, for each river reach and for the full monitoring area are summarized in Table A-1 in **Appendix A**.

Survey results at the three cross sections downstream of the 8th Street East Bridge to RM 4.44 are not included in the reach-scale analyses of this document or in Herrera (2010), because only the cross section at RM 4.44 has been surveyed consistently and the distance between it and RM 4.978 is too large to represent reach-scale changes adequately. These three individual cross sections [also will be plotted in Appendix A in the final version of this memo].

3.1.1. Full monitoring area (RM 5 to RM 10.6)

In-channel sediment changes in the full monitoring area of RM 5 to RM 10.6 from 2009 to 2011 are summarized in **Table 2** along with data from other time periods since 1969 for historical context. In the full channel monitoring area of 5.6 river miles, there was a total net deposition of about 13,400 cubic yards during the 2009 to 2011 period. That total net deposition volume is about 10 percent of the total net deposition (136,700 cu yd) that occurred during 2007 to 2009. Area-wide changes in sediment volume are normalized to a rate per distance (cu yd/year/RM) in the fifth column of **Table 2,** where it can be seen that there was a relatively low rate of sediment deposition in 2009 to 2011 (1,300 cu yd/yr/RM) when compared to other non-dredging periods. The 2009 to 2011 average rate of change in riverbed elevation (0.05 feet/year) also is relatively minor compared to that of 2007 to 2009 (0.22 feet/year) and other periods.

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Table 2: Lower White River sediment trends over the full monitoring area through different time periods. The length of the full monitoring reach is 5.6 river miles in all periods except 1984-2001 and 2001-2007, when it was 4.1 river miles (RM 5 to RM 9.1).

Time period	Number of Years	Net Change in Sediment Volume (cu yd)	Average Rate of Change (cu yd/yr)	Average Rate of Change per Distance (cy/yr/RM)	Average Change in Riverbed Elevation (feet)	Average Rate of Change in Riverbed Elevation (ft/yr)
1969-1974	5	7,600	1,500	300	-0.09	-0.02
1974-1984	10	-773,400	-77,300	-14,400	-2.32	-0.23
1984-2001	17	240,500	14,100	3,400	0.81	0.05
2001-2007	6	135,100	22,500	5,400	0.48	0.08
2007-2009	2	136,700	68,400	12,800	0.44	0.22
2009-2011	2	13,400	6,700	1,300	0.11	0.05
1969-2011	42	-240,100	-5,700	-1,100	-0.16	0.00
1984-2011	27	525,700	19,500	3,600	0.64	0.02

Values for the full monitoring area through the various time periods in **Table 2** are plotted for the net change in sediment volume (**Figure 2**), rate of change in sediment volume per distance (**Figure 3**), change in average riverbed elevation (**Figure 4**), and rate of change in average riverbed elevation (**Figure 5**). When the plotted parameters are absolute values, as in **Figure 2** (cu yds) and **Figure 4** (feet), the period from 1974 to 1984, when there was widespread dredging, and from 1984 to 2001, in a period of deposition subsequent to dredging, are prominent. When the plotted parameters are rates of change, as in **Figure 3** (cu yds/yr/RM) and **Figure 5** (feet/year), the 2007 to 2009 period stands out along with 1974 to 1984. Changes in sediment volumes and the rates of change in sediment volumes for the full monitoring area during 2009 to 2011 are relatively minor when compared to other individual periods and the longer-term, mostly post-dredging period of 1984 to 2001.

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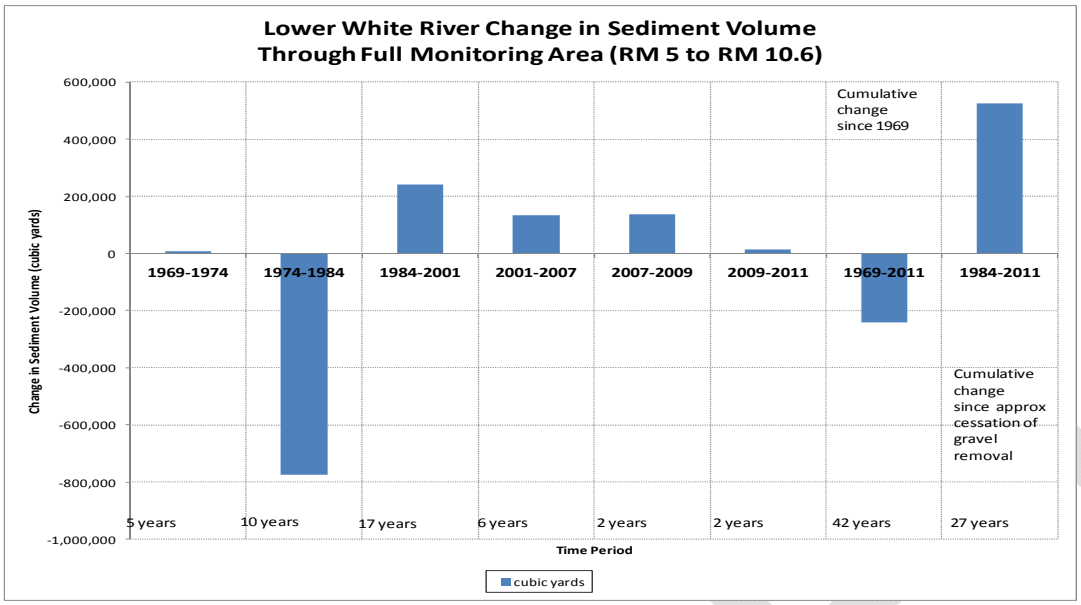

Figure 2: Lower White River change in sediment volume through the full monitoring area (RM 5 to RM 10.6).

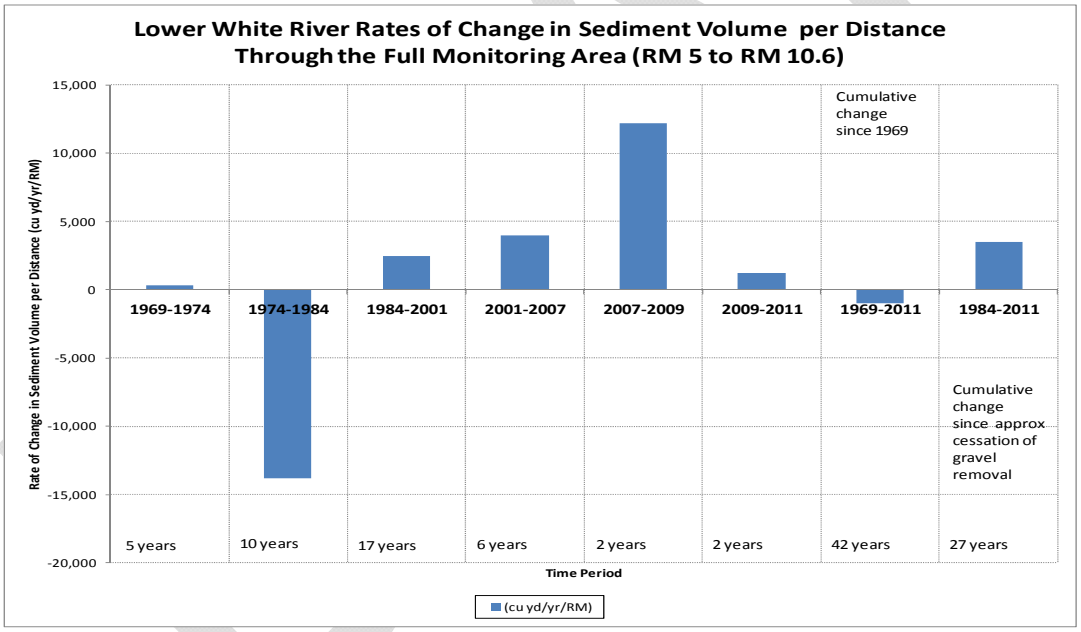

Figure 3: Lower White River rates of change in sediment volume per distance, through the full monitoring area (RM 5 to RM 10.6).

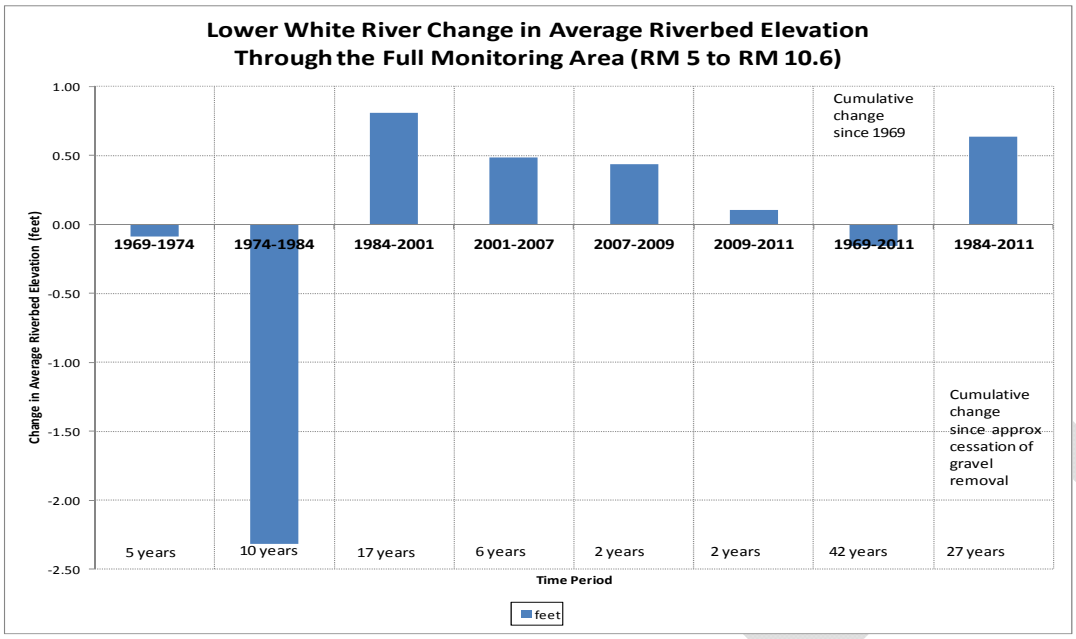

Figure 4: Lower White River change in average riverbed elevation through the full monitoring area (RM 5 to RM 10.6).

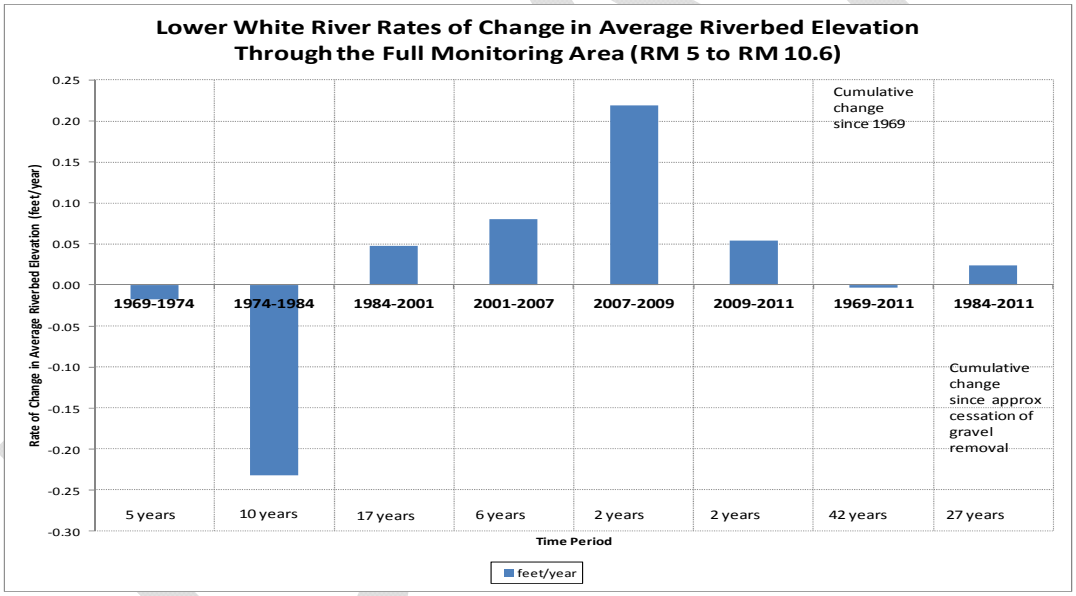

Figure 5: Lower White River rates of change in average riverbed elevation through the full monitoring area (RM 5 to RM 10.6).

3.1.2. River reaches

Comparisons of the full monitoring area are informative for historical context, but conditions can vary widely within the full monitoring area as indicated by the results calculated for the five river reaches. For example, the total net deposition through the full monitoring area from 2009 to 2011 (13,400 cu yds; **Table 2**) is a combined result of almost 24,000 cubic yards deposited in Reach 1; 5,000 cubic yards in Reach 2; about 1,300 cubic yards in Reach 3 and a combined net erosion of almost 17,000 cubic yards in Reaches 4 and 5 (**Table 3** and **Figure 6**).

Table 3: Lower White River changes in sediment volume, 1969 through 2011.

Time Period	River Reach No.	River Reach Brief description	Change in Sediment Volume (cu yd)	Average Rate of Change (cy/yr)	Average Rate of Change per Distance (cy/yr/RM)	Average Change in River Bed Elevation (feet)	Average Rate of Change in River Bed Elevation (ft/yr)
1969-1974	1	~8th Str to BNRR/A Str Br	38,400	7,700	5,800	0.6	0.1
	2	A Str to R Str	35,500	7,100	5,900	0.6	0.1
	3	R Str to RM 8.3	-700	-100	-200	0.0	0.0
	4	RM 8.3 to RM 9.3	16,600	3,300	3,200	0.4	0.1
	5	RM 9.3 to RM 10.6	-82,200	-16,400	-12,800	-1.0	-0.2
		Total	**7,600**	**1,500**	**300**	**-0.1**	**0.0**
1974-1984	1	~8th Str to BNRR/A Str Br	-85,100	-8,500	-6,400	-2.0	-0.2
	2	BNRR/A Str to R Str	-334,100	-33,400	-27,800	-4.3	-0.4
	3	R Str to RM 8.3	-70,800	-7,100	-12,800	-1.8	-0.2
	4	RM 8.3 to RM 9.3	-99,600	-10,000	-9,600	-2.8	-0.3
	5	RM 9.3 to RM 10.6	-183,800	-18,400	-14,300	-1.3	-0.1
		Total	**-773,400**	**-77,300**	**-13,800**	**-2.3**	**-0.2**
1984-2001	1	~8th Str to BNRR/A Str Br	101,600	6,000	4,500	2.3	0.1
	2	BNRR/A Str to R Str	189,800	11,200	9,300	1.7	0.1
	3	R Str to RM 8.3	-9,700	-600	-1,100	-0.9	-0.1
	4	RM 8.3 to RM 9.3	-41,200	-2,400	-2,300	-1.2	-0.1
	5	RM 9.3 to RM 10.6	NA	NA			
		Total	**240,500**	**14,100**	**2,500**	**0.8**	**0.0**
2001-2007	1	~8th Str to BNRR/A Str Br	110,100	18,400	13,800	1.4	0.2
	2	BNRR/A Str to R Str	39,000	6,500	5,400	0.6	0.1
	3	R Str to RM 8.3	-2,300	-400	-700	-0.3	-0.1
	4	RM 8.3 to RM 9.3	-11,700	-2,000	-1,900	-0.4	-0.1
	5	RM 9.3 to RM 10.6	N/A	N/A			
		Total	**135,100**	**22,500**	**4,000**	**0.5**	**0.1**
2007-2009	1	~8th Str to BNRR/A Str Br	65,000	32,500	24,300	0.9	0.4
	2	BNRR/A Str to R Str	40,300	20,200	16,800	0.5	0.3
	3	R Str to RM 8.3	-2,000	-1,000	-1,800	-0.1	-0.1
	4	RM 8.3 to RM 9.3	7,600	3,800	3,600	0.6	0.3
	5	RM 9.3 to RM 10.6	25,800	12,900	10,000	0.1	0.1
		Total	**136,700**	**68,400**	**12,200**	**0.4**	**0.2**
2009-2011	1	~8th Str to BNRR/A Str Br	23,800	11,900	8,900	0.5	0.2
	2	BNRR/A Str to R Str	5,000	2,500	2,100	0.1	0.1
	3	R Str to RM 8.3	1,300	700	1,300	-0.1	0.0
	4	RM 8.3 to RM 9.3	-8,100	-4,100	-3,900	-0.2	-0.1
	5	RM 9.3 to RM 10.6	-8,600	-4,300	-3,300	0.0	0.0
		Total	**13,400**	**6,700**	**1,200**	**0.1**	**0.1**
1969-2011	1	~8th Str to BNRR/A Str Br	253,800	6,000	4,500	0.8	0.0
	2	BNRR/A Str to R Str	-24,500	-600	-500	-0.2	0.0
	3	R Str to RM 8.3	-84,200	-2,000	-3,600	-0.8	0.0
	4	RM 8.3 to RM 9.3	-136,400	-3,200	-3,100	-1.1	0.0
	5	RM 9.3 to RM 10.6	-248,800	-5,900	-4,600	-0.4	0.0
		Total	**-240,100**	**-5,700**	**-1,000**	**-0.2**	**0.0**
1984-2011	1	~8th Str to BNRR/A Str Br	300,500	11,100	8,300	1.9	0.1
	2	BNRR/A Str to R Str	274,100	10,200	8,500	1.2	0.0
	3	R Str to RM 8.3	-12,700	-500	-900	-0.6	0.0
	4	RM 8.3 to RM 9.3	-53,400	-2,000	-1,900	-0.8	0.0
	5	RM 9.3 to RM 10.6	17,200	600	500	0.0	0.0
		Total	**525,700**	**19,500**	**3,500**	**0.6**	**0.0**

Length, in River Miles	Reach No.	Lower White River Reach, per Sediment Trends Study (Herrera 2010)
1.338	1	Near 8th Str (RM 4.978) to BNRR/A Str Bridges (RM 6.326)
1.203	2	BNRR/A Str Bridges (RM 6.390) to R Str (RM 7.716)
0.553	3	R Str (RM 7.716) to RM 8.269
1.042	4	RM 8.269 to RM 9.311
1.285	5	RM 9.311 to RM 10.596
5.618	All	Total

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Some reach-scale changes in sediment volume characteristics appear to persist through the different periods (**Figure 6**). Reaches 1 and 2 are depositional during all periods other than 1974 to 1984 (when much dredging occurred). Changes in Reaches 3, 4 and 5 vary through the individual time periods and typically are of lesser magnitude than in Reaches 1 and 2. These general characteristics carry through to the rates of change in sediment volumes (**Figure 7**), where the highest rates of deposition occur in Reaches 1 and 2 in 2007 to 2009.

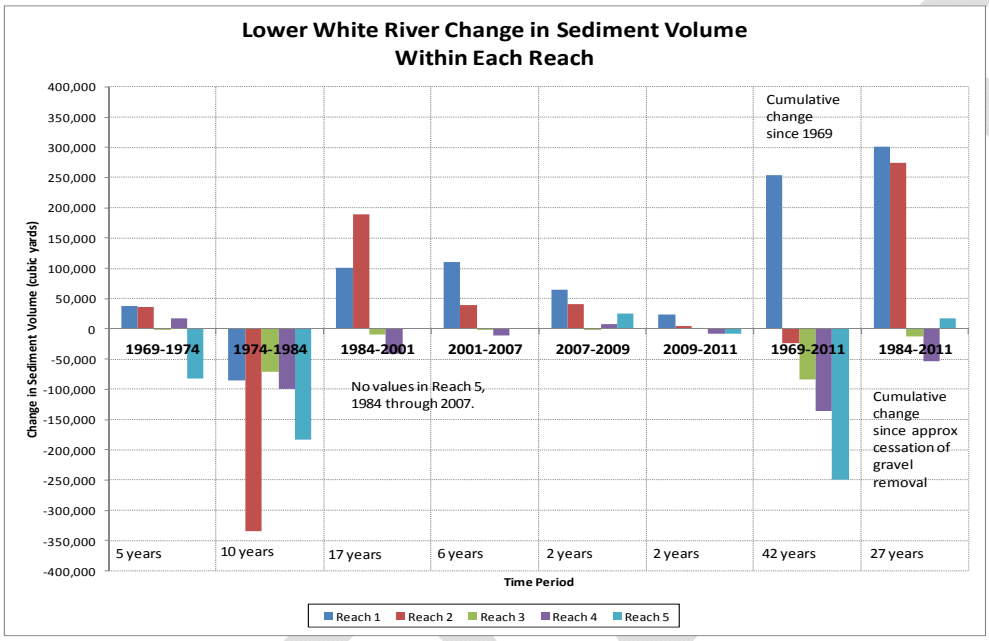

Figure 6: Lower White River change in sediment volume within each reach.

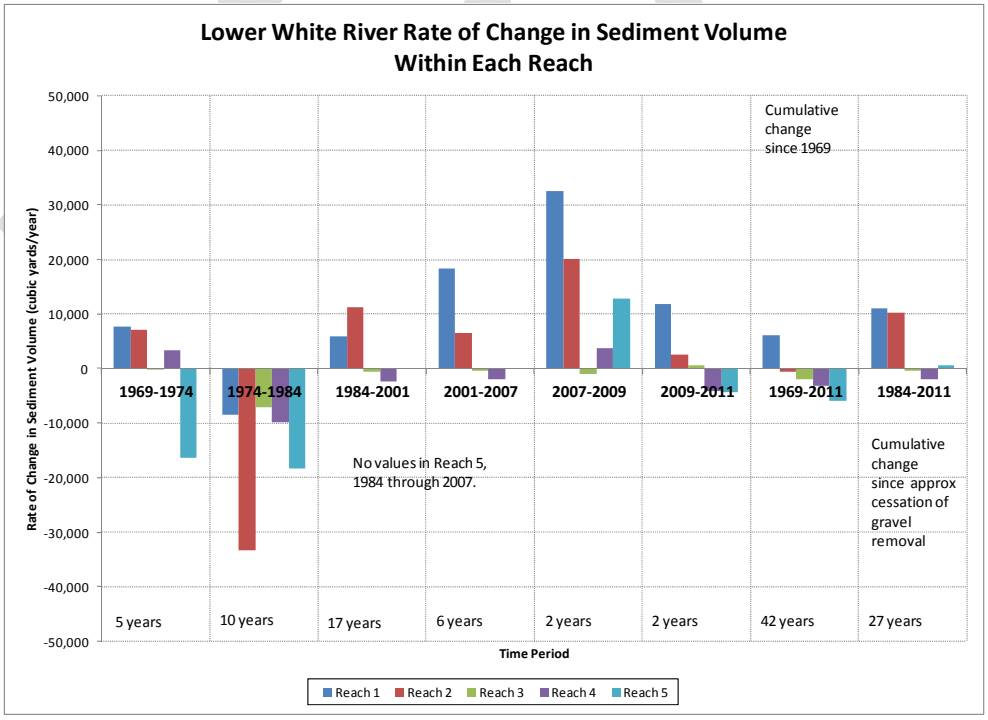

Figure 7: Lower White River rate of change in sediment volume within each reach.

The 1984-2011 deposition rates in Reaches 1 and 2 can be considered to represent a long-term average rate occurring since approximate cessation of gravel removal, at about 11,000 cy/yr in Reach 1 and 10,000 cy/yr in Reach 2. A summary of volumes deposited in each of these two reaches from 2001 through 2011 (Table 2) indicates a shorter-term net deposition rate of 20,000 cy/yr in Reach 1 and 6,000 cy/yr in Reach 2.

The changes in average riverbed elevation at each cross section, summed for each river reach through the individual time periods, indicate large decreases in Reaches 1 and 2 (e.g., negative 1 to negative 4 feet) during the 1974 to 1984 period when much dredging occurred, and relatively large increases in Reaches 1 and 2 (e.g., more than 1.5 feet) during the 1984 to 2001 period (**Figure 8**). Normalization to a rate of change in average riverbed elevation (**Figure 9)** dampens

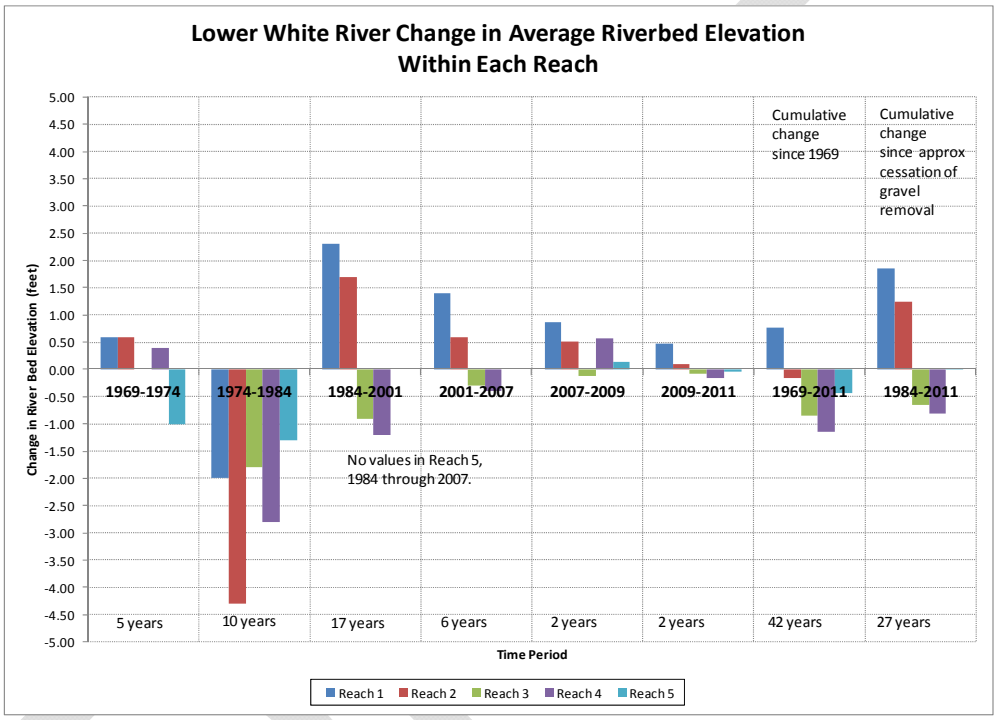

Figure 8: Lower White River change in average riverbed elevation within each reach.

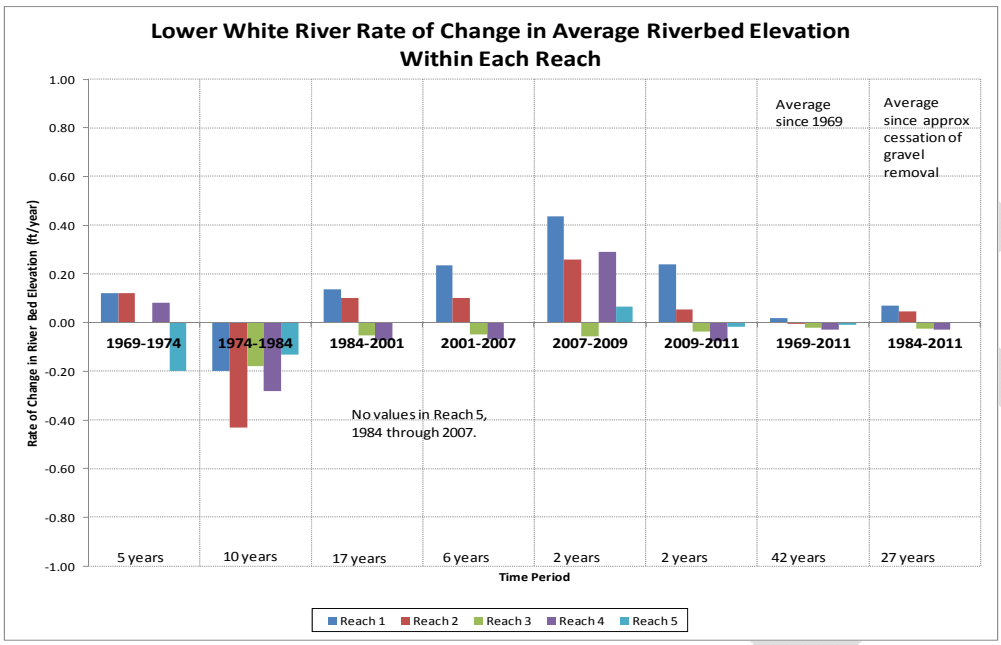

Figure 9: Lower White River rate of change in average riverbed elevation within each reach.

some of the larger variations and reveals relatively large negative rates in all five river reaches in 1974 to 1984 and equally large positive rates of change in three of the five river reaches during the 2007 to 2009 period.

3.1.3. Variations within river reaches

Changes from 2009 to 2011 in average riverbed elevation at each cross section reveal the variability of sediment deposition and erosion within the individual river reaches through the full monitoring area (**Figure 10**). There was a net increase in average riverbed elevation of about one-half foot or more at most of the cross sections in Reach 1, with an increase of more than 1.5 feet at RM 5.517. Field observations corroborate apparent increases in the mid-channel gravel bar at and near RM 5.517. The majority of cross sections in Reach 2 also showed increased average riverbed elevations, but none exceeded one-half foot. During this same period, Reaches 3, 4 and 5 each had a majority of cross sections that showed net erosion, and almost all vertical changes, positive or negative, did not exceed one-half foot at a cross section.

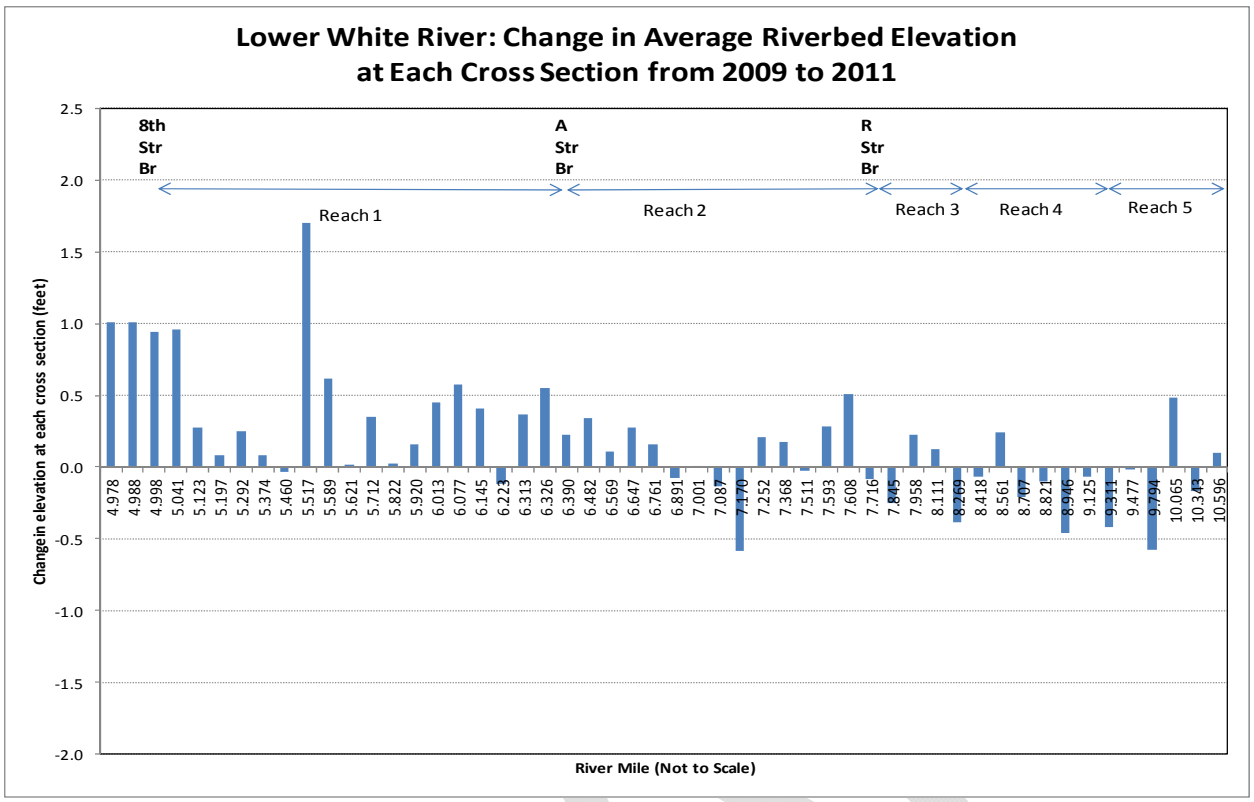

Figure 10: Lower White River change in average riverbed elevation at each cross section from 2009 to 2011.

A comparison of the rate of change in average riverbed elevation at each cross section through all individual periods (**Figure 11)** suggests generally similar patterns to the changes in elevation during 2009 to 2011 **(Figure 10)** in all periods except 1974 to 1984. All non-dredging periods show positive rates of change at almost every cross section in Reaches 1 and 2, with variability in Reaches 3, 4 and 5. Magnitudes of the rate of change within each time period typically are largest in Reaches 1 and 2. The rate of change in average riverbed elevation is negative or zero at all cross sections during 1974 to 1984, when much dredging occurred in this part of the White River. **Figure 11** updates Figure 8 of Herrera (2010) to include the 2009 to 2011 period.

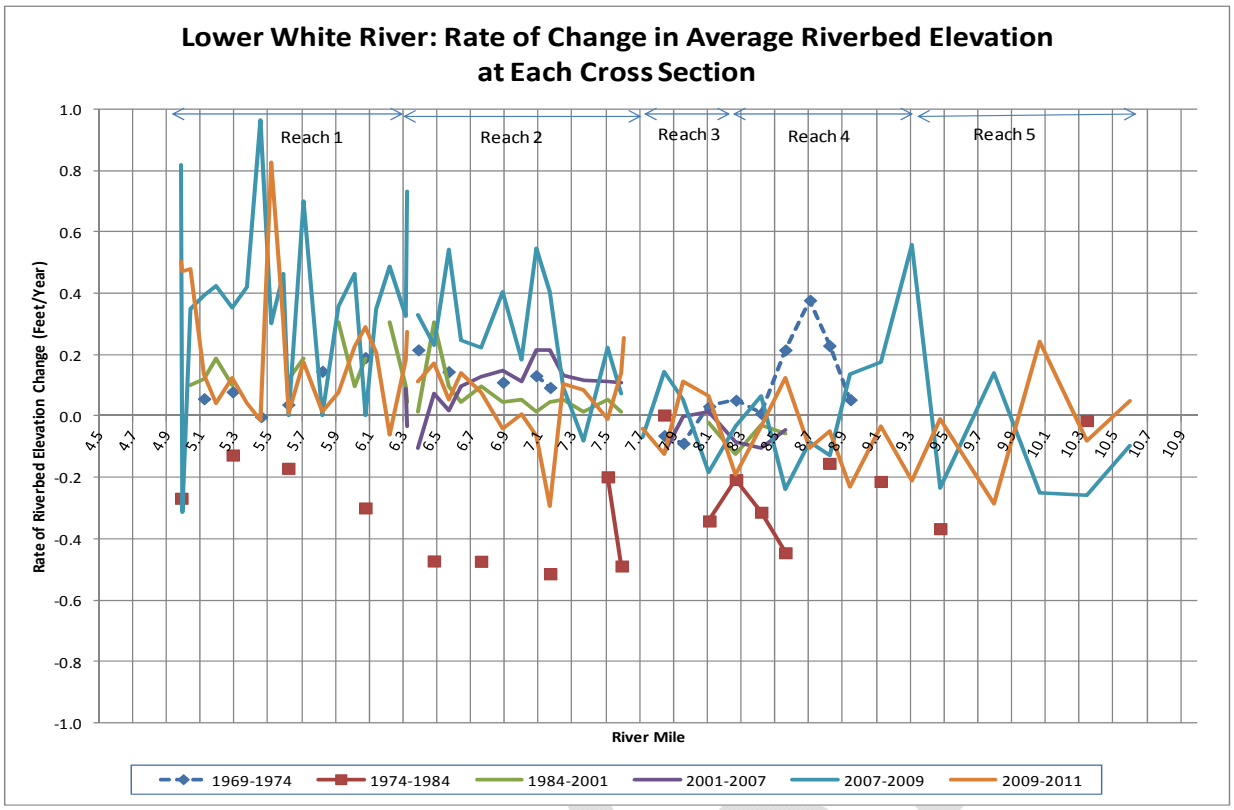

Figure 11: Lower White River rate of change in average riverbed elevation at each cross section through various time periods.

Profile views of thalweg elevations are plotted in Figure 12 from several years since the 1970s through 2011. The generally lower thalweg elevations during 1984 probably result from extensive channel dredging that occurred in the 1970s and 1980s. While subsequent deposition has increased thalweg elevation in Reaches 1 and 2, more recent thalweg elevations appear to have remained relatively lower in areas upstream of R Street.

The changes in thalweg elevations from 2009 to 2011 (Figure 13) shows variability through the full monitoring area, with fluctuations as great as five feet divergence (positive or negative). Large changes in thalweg elevations may result from local scour or infilling. The change in average riverbed elevation from 2009 to 2011 (Figure 13), which is a metric that considers change in elevation across the full cross section, shows similar trend and direction as thalweg changes but with less dramatic fluctuations.

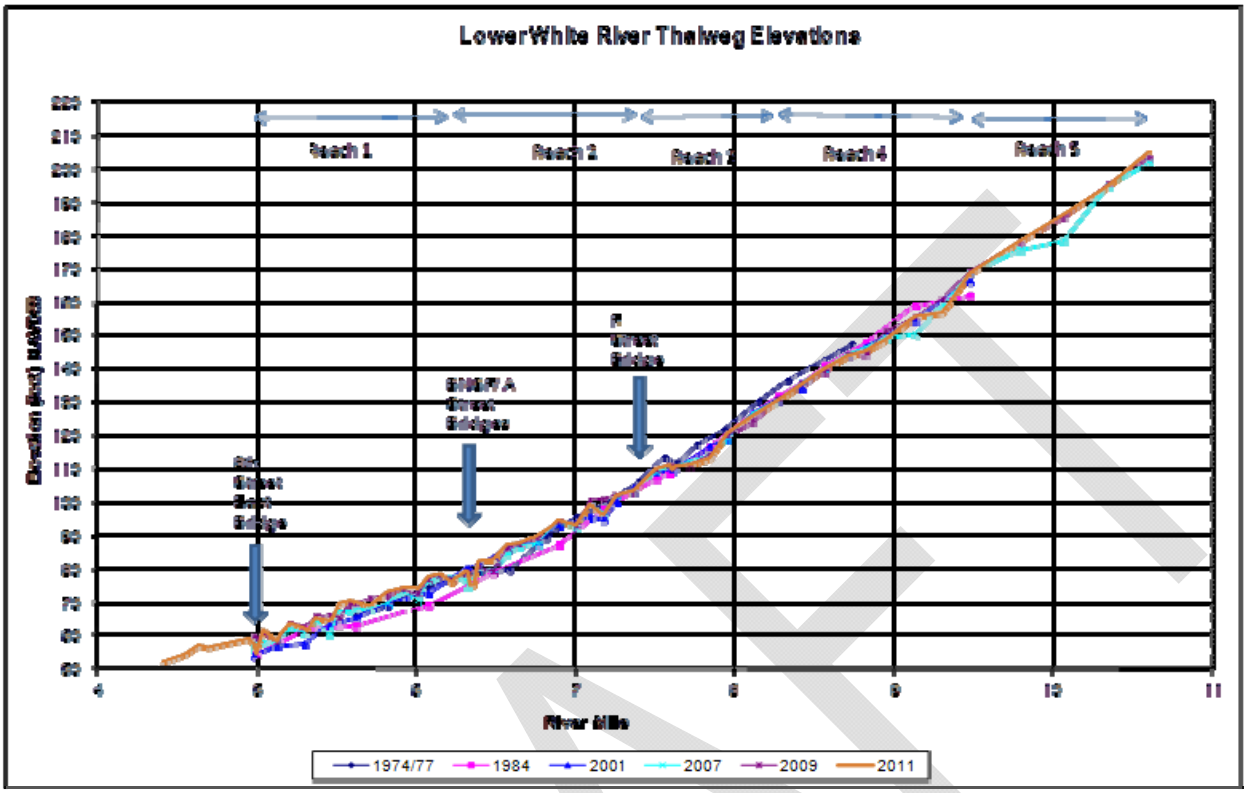

Figure 12: Lower White River thalweg elevation profiles during several years.

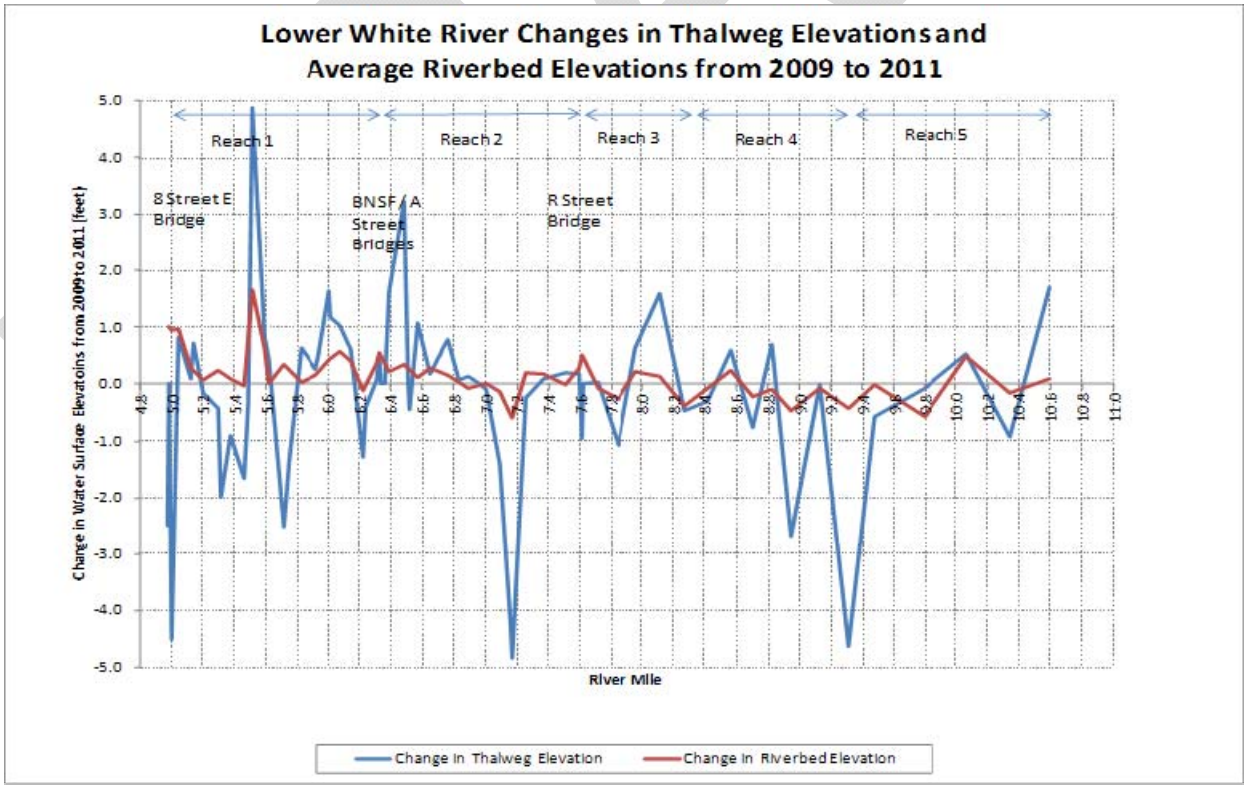

Figure 13: Change in Lower White River thalweg elevations and average riverbed elevations from 2009 to 2011.

With other factors such as channel gradient and channel confinement mostly fixed through this monitoring area, sediment transport and deposition is largely determined by river flows. Both magnitude and duration of flows above a threshold of motion for coarse sediment (which moves as bedload) is important in the Lower White River. Initiation of motion calculations indicate that bedload transport begins at about 3,500 to 4,000 cfs in Reach 1 (Herrera 2010), which is consistent with results of bedload sampling conducted at R Street (Czuba et al. 2011). The peak flow during the 2009 to 2011 monitoring period occurred in January 2011 at about 7,500 cfs, which is not large by historic standards. However, flows during that event remained above 4,000 cfs for about 12 days.

[The final memo may include more information on recent flow discharges in the Lower White River that have occurred during the periods of channel monitoring.]

3.2. Hydraulics

This section summarizes 2011 hydraulic conditions in the Lower White River from RM 5 to RM 10.6 as computed in a HEC-RAS model using the 2011 surveyed cross sections to represent the 2011 channel geometry. These hydraulically modeled 2011 conditions are compared to 2009 channel conditions hydraulically modeled in HEC-RAS. Field observations are reported in addition to modeled results regarding channel conveyance capacity.

3.2.1. Changes in modeled Water Surface Elevations from 2009 to 2011

An overview of the changes from 2009 to 2011 in modeled Water Surface Elevations (WSELs) through the full monitoring area is illustrated in profile view of the modeled WSELs at 9,000 cfs (**Figures 14A, B and C**). A discharge of 9,000 cfs is about a 2-year event which stays within the riverbanks throughout most of the monitoring area. The largest increases from 2009 to 2011 in modeled WSELs were evident in Reach 1 (**Figure 14A**), with lesser such increases in Reach 2 (**Figure 14B**), and minor increases or decreases in modeled WSELs in Reaches 3, 4 and 5 (**Figures 14 C**). Note different scales in **Figures 14A, B and C**.

[More example HEC-RAS output may be included in the final version of this memo.]

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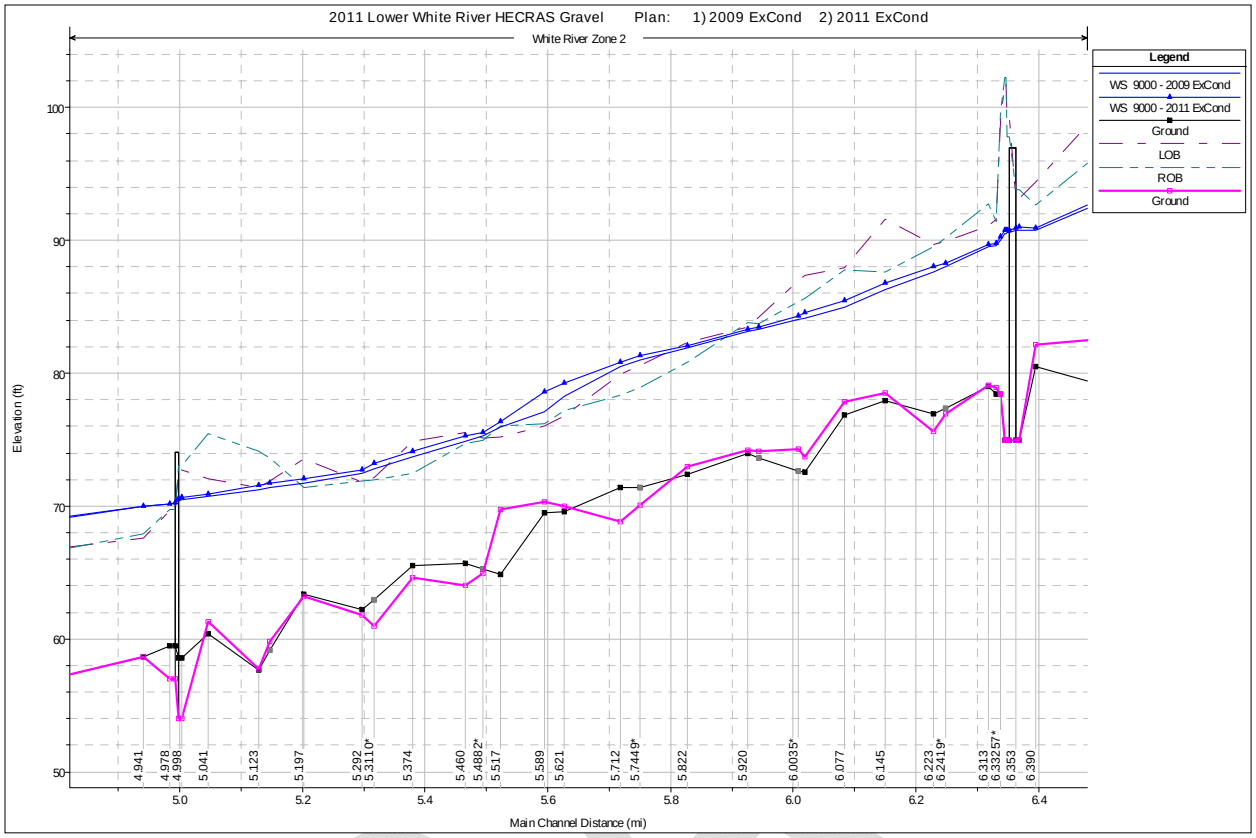

Figure 14 A: Lower White River modeled water surface elevations for 2009 and 2011 existing conditions; Reach 1, from near 8th Street E (RM 4.978) to BNSF (RM 6.326) and A Street Bridges. Flow is from right to left.

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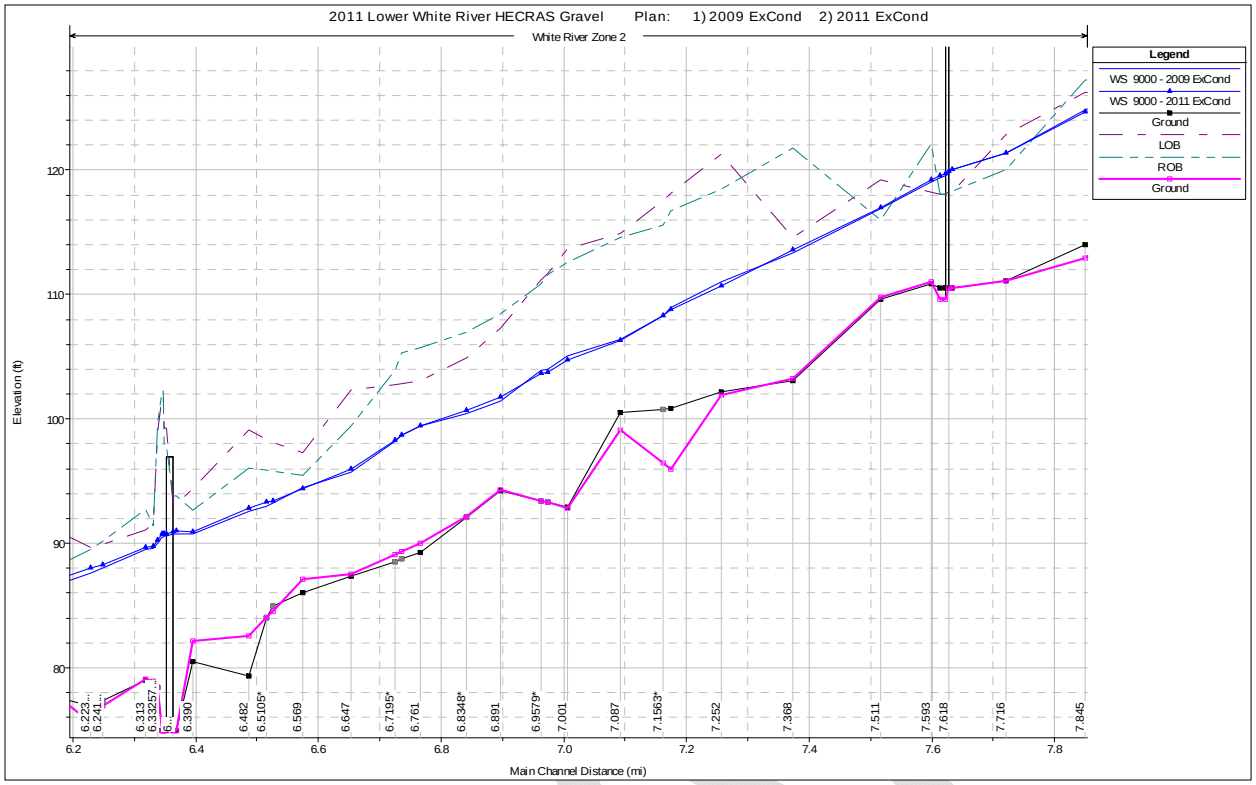

Figure 14B: Lower White River modeled water surface elevations for 2009 and 2011 existing conditions; Reach 2, from BNSF (RM 6.326) and A Street Bridges to R Street Bridge (RM 7.716). Flow is from right to left.

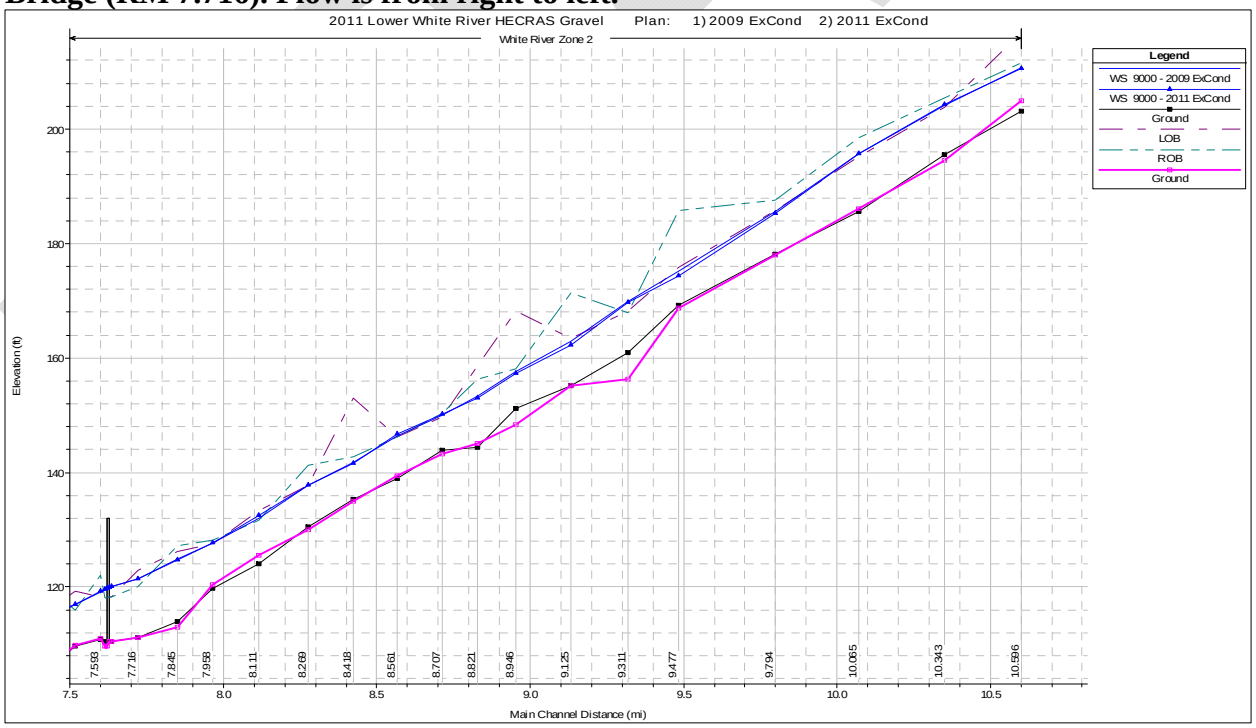

Figure 14C: Lower White River modeled water surface elevations for 2009 and 2011 existing conditions; Reaches 3, 4 and 5 from R Street Bridge (RM 7.716) to upstream end of monitoring area at RM 10.596. Flow is from right to left.

The same general pattern of changes in water surface elevations (WSELs) from 2009 to 2011 described above for the 9,000 cfs flow is evident over a range of flows from 5,000 cfs to 15,500 cfs (**Figure 15; Table 4**). The mean change in modeled WSELs from 2009 to 2011 for each reach can be used to represent general changes through the full monitoring area (**Table 4**): the Reach 1 mean change was 0.3 feet at most of the modeled flows; Reach 2 mean change was 0.1 feet at most of the modeled flows; Reach 3 mean change was 0.1 feet at most of the modeled flows; Reach 4 mean change was negative 0.1 feet at most of the modeled flows; Reach 5 mean change was negative 0.3 feet at most of the modeled flows.

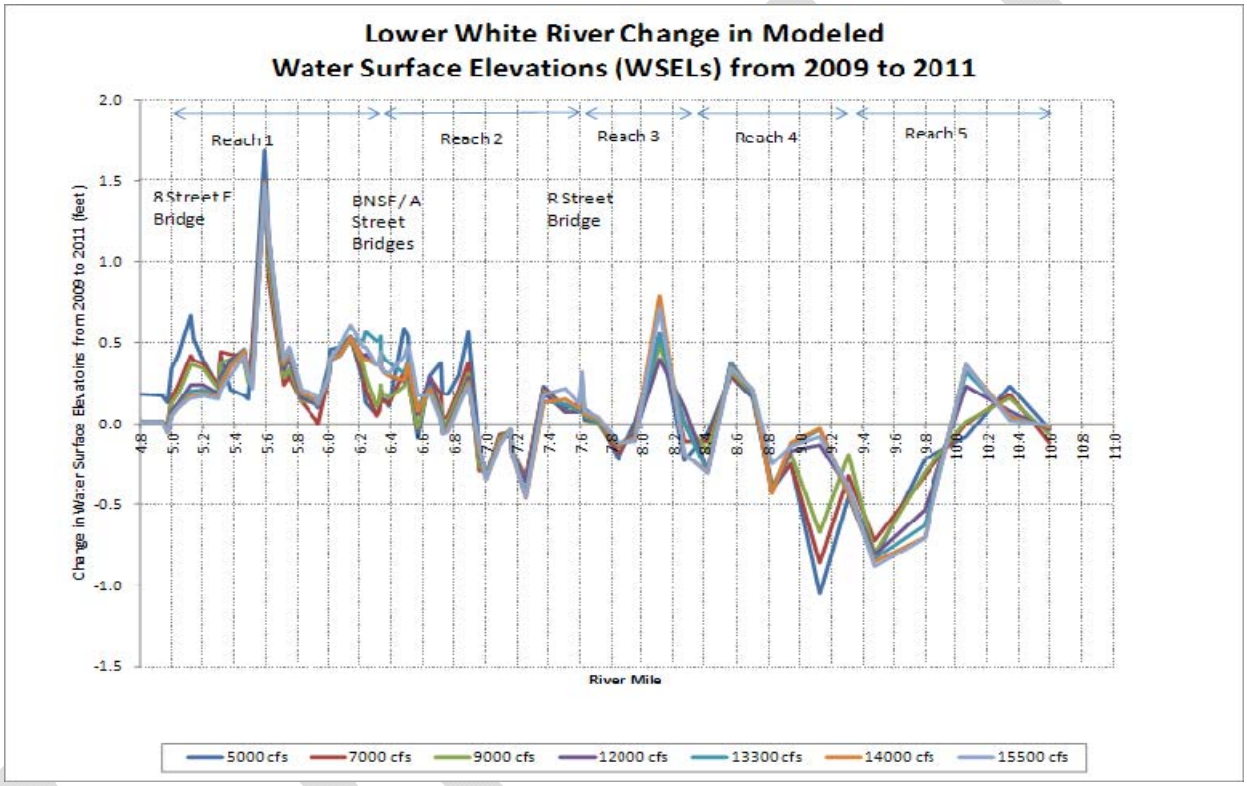

Figure 15: Changes from 2009 to 2011 in modeled water surface elevations through a range of flows.

Table 4: Summary statistics on changes from 2009 to 2011 in Lower White River modeled water surface elevations.

River Reach	Summary Statistic	5,000 cfs (feet)	7,000 cfs (feet)	9,000 cfs (feet)	12,000 cfs (feet)	14,000 cfs (feet)	15,500 cfs (feet)
Reach 1	Maximum	1.7	1.5	1.5	1.5	1.5	1.5
	Minimum	0.1	0.0	0.0	-0.1	-0.1	-0.1
	Mean	0.4	0.3	0.3	0.4	0.3	0.4
	Median	0.3	0.3	0.3	0.3	0.3	0.3
	Std Dev	0.3	0.3	0.3	0.3	0.3	0.3
Reach 2	Maximum	0.6	0.4	0.3	0.3	0.4	0.5
	Minimum	-0.3	-0.3	-0.4	-0.4	-0.5	-0.5
	Mean	0.1	0.1	0.0	0.1	0.1	0.1
	Median	0.1	0.1	0.1	0.1	0.1	0.1
	Std Dev	0.3	0.2	0.2	0.2	0.2	0.3
Reach 3	Maximum	0.6	0.6	0.5	0.4	0.8	0.7
	Minimum	-0.2	-0.2	-0.2	-0.1	-0.2	-0.2
	Mean	0.0	0.0	0.1	0.1	0.1	0.1
	Median	0.0	0.0	0.0	0.0	0.0	0.0
	Std Dev	0.3	0.3	0.2	0.2	0.4	0.3
Reach 4	Maximum	0.3	0.3	0.3	0.4	0.3	0.3
	Minimum	-1.1	-0.9	-0.7	-0.4	-0.4	-0.3
	Mean	-0.2	-0.2	-0.2	-0.1	-0.1	0.0
	Median	-0.2	-0.2	-0.2	-0.1	-0.1	-0.1
	Std Dev	0.5	0.4	0.4	0.3	0.3	0.3
Reach 5	Maximum	0.2	0.2	0.2	0.2	0.4	0.4
	Minimum	-0.8	-0.7	-0.8	-0.8	-0.9	-0.9
	Mean	-0.2	-0.2	-0.2	-0.2	-0.3	-0.3
	Median	-0.2	-0.2	-0.1	-0.2	-0.2	-0.2
	Std Dev	0.4	0.3	0.3	0.4	0.5	0.5

While there is variability in the changes in modeled water surface elevations as indicated by the maximum and minimum changes summarized in **Table 4** and the values at each cross section plotted in **Figure 15**, a general pattern of changes appears as follows. Most changes in modeled WSELs from 2009 to 2011 in Reach 1 range from zero to an increase of one-half foot, with larger increases or decreases at a few cross sections. Changes in Reach 2 showed more variability, with notable decreases at RM 7.001 through RM 7.252. Changes in the short Reach 3 showed much variability, with marked increases at RM 8.111. Reaches 4 and 5 had more cross sections showing decreases, some approaching one foot, though there is much variability. The magnitude and direction of the modeled changes in WSELs at each cross section are mostly consistent through the range of modeled flows.

These reach-scale descriptions of changes in modeled WSELs are generally similar to observed patterns of reach-scale changes in sediment deposition (**Figure 6**) and in the average riverbed elevations (**Figure 8**). A comparison of the 2009 to 2011 mean change in riverbed elevations for each reach (from **Table 3**) to the 2009 to 2011 mean change in modeled WSEL at 9,000 cfs for

each reach (from **Table 4**) also suggests a general similarity of these two parameters on the reach scale during the 2009 to 2011 period (**Figure 16**).

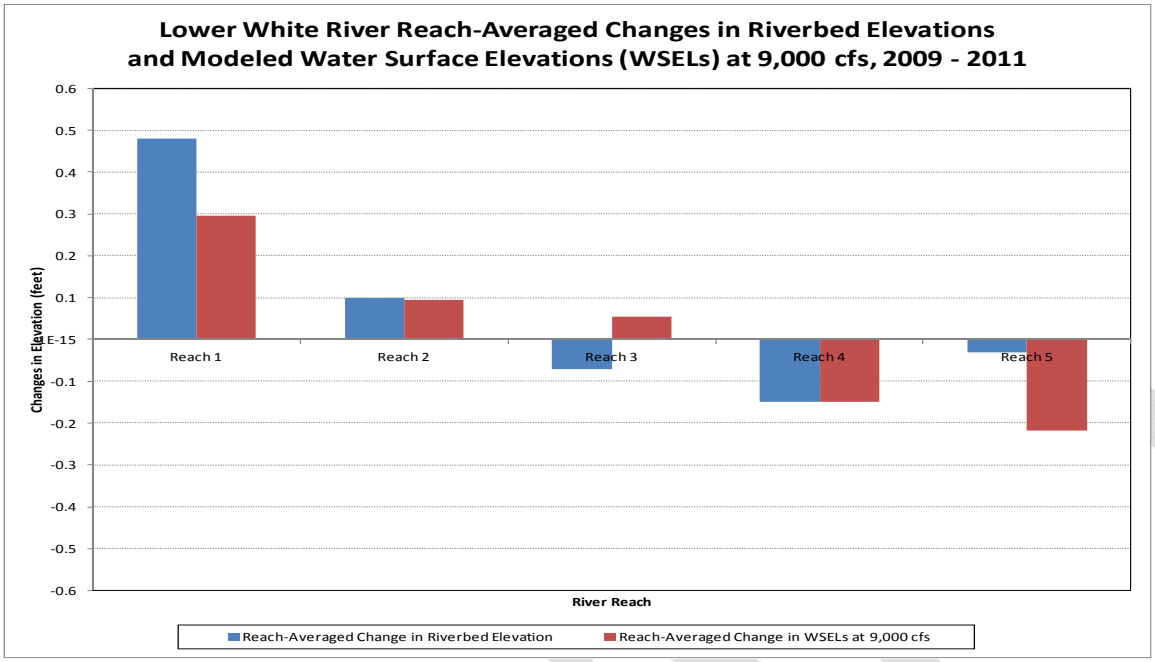

Figure 16: Reach-averaged changes from 2009 to 2011 in riverbed elevations and modeled water surface elevations at 9,000 cfs.

Comparing changes in these same two parameters from 2009 to 2011 at each cross section provides more detail on spatial variations within the river reaches through the full monitoring area (**Figure 17**). There appears to be a relatively close correspondence between changes in average riverbed elevations and in modeled water surface elevations in this time period. The pattern and direction of changes are the same at most cross sections, with the changes in modeled WSELs typically occurring 0.1 to 0.2 river miles upstream of the sediment changes. It is consistent with hydraulic principles that water surface responses to channel changes would manifest in the upstream direction in the subcritical flow regime that occurs in this part of the White River.

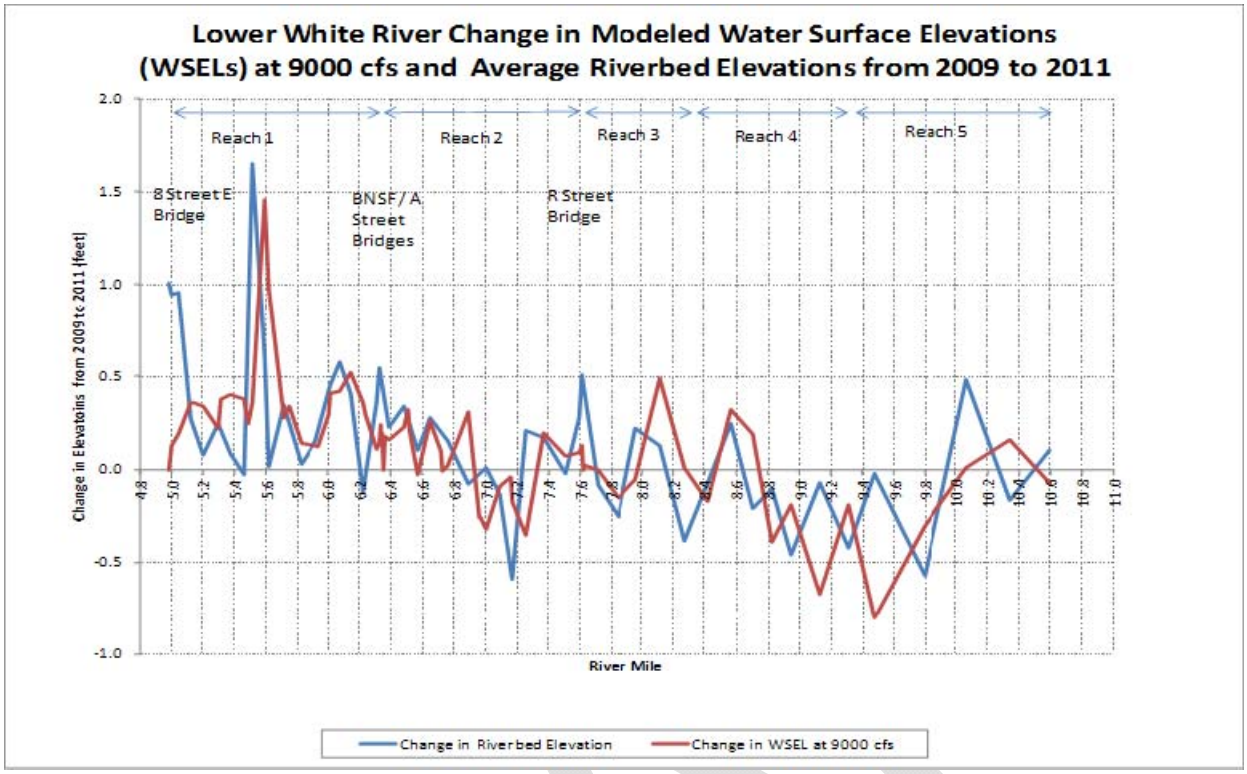

Figure 17: Changes from 2009 to 2011 in average riverbed elevations and modeled water surface elevations at 9000 cfs.

3.2.2. Channel conveyance capacity in 2009 and 2011

3.2.2.1. Modeled channel conveyance capacity

Channel conveyance capacity is defined in this document as the flow that a channel can convey within its existing channel banks without overtopping. Specifically, it is the maximum flow that is just contained by the lower of the two riverbanks at any given location or cross section. However, if channel conveyance capacity is exceeded, this definition states only that overbank flow has occurred and does not provide information on the significance of the overtopping in the affected overbank area. Overtopping flows may occur into undeveloped floodplain or wetland areas without consequence to structures or human habitation. Channel conveyance capacities were extracted from HEC-RAS hydraulic modeling of 2009 and 2011 channel geometries.

The maximum modeled flow was 15,500 cfs (a 100-year flood). Hydraulic model results indicate that the White River channel conveyance capacity in both 2009 and 2011 equals or exceeds 15,500 cfs from RM 6.647 to RM 10.596, so **Figure 18** only depicts channel conveyance capacity up to R Street at RM 7.6. In addition, there are about seven cross section locations from RM 6.647 to RM 4.978 where modeled channel conveyance capacity equals or exceeds 15,500 cfs in both years. At almost all other cross section locations in Reach 1 and the downstream part of Reach 2, the 2009 channel conveyance capacity was less than 15,500 cfs and the 2011 channel conveyance capacity decreased relative to 2009 (**Figure 18**). The greatest decrease in modeled channel conveyance capacity during this time period was approximately 2,000 cfs, which occurred near RM 5.6. The resulting 2011 modeled channel conveyance

capacity is less than 5,000 cfs at RM 5.589. The modeled channel conveyance capacity decreased by about 1,000 cfs in the area of RM 6.1 to RM 6.3, with a resulting 2011 channel conveyance capacity of about 11,000 cfs at RM 6.145.

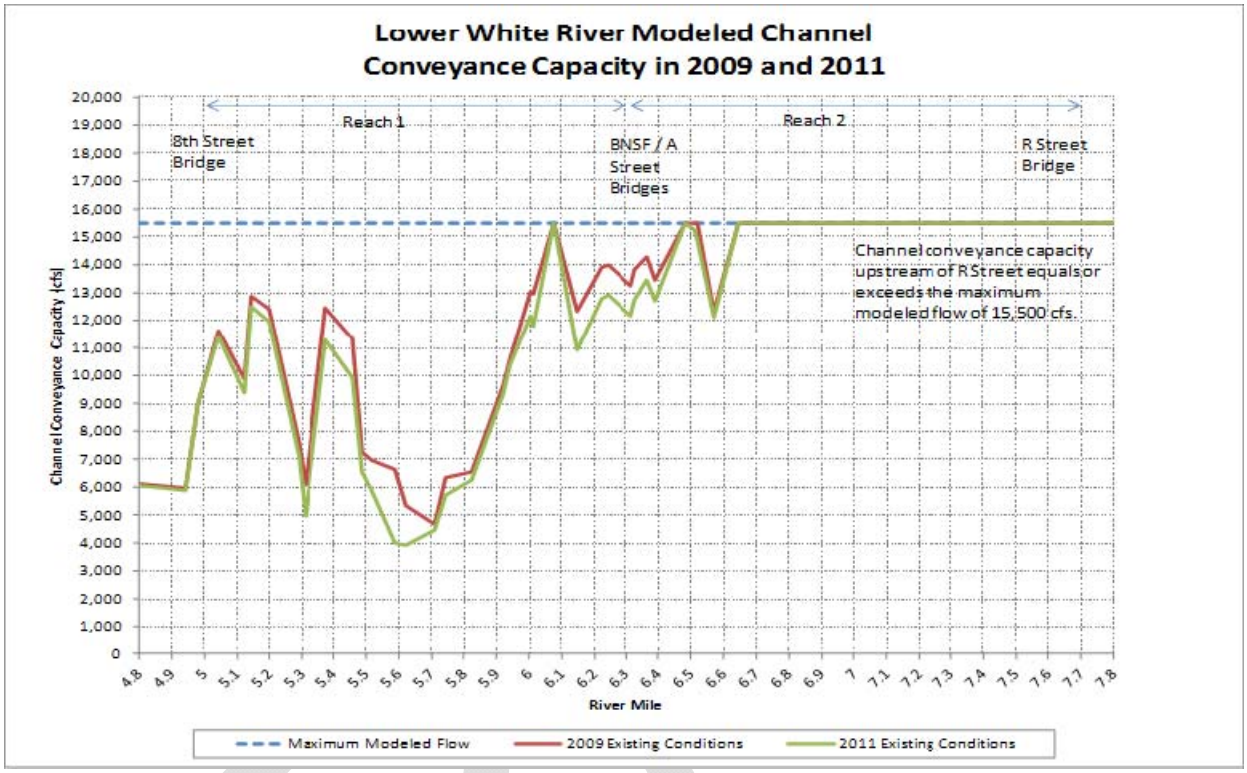

Figure 18: Lower White River modeled channel conveyance capacity in 2009 and 2011.

Channel monitoring and hydraulic modeling indicates a consistent decrease of channel conveyance capacity of as much as 2,000 cfs in the monitoring area during the 2009 to 2011 period. These channel capacities also are much less than Lower White River channel conveyance capacities in periods past. The 1984 channel capacity between the 8th Street East Bridge (RM 5) to RM 10.6 equaled or exceeded 19,000 cfs, except at approximate RM 5.2 where it was about 11,000 cfs (Prych 1988). These 1984 channel capacity would have reflected conditions at the end of a period of much dredging, and there has been containment of a number of floods ranging from 14,000 cfs to 15,000 cfs in the late 1980s and 1990s. Original channel design capacity of the Lower White River through this monitoring reach was 25,000 cfs.

3.2.2.2 Field observations

Field observations indicated that during the period of summer 2009 to summer 2011, flows would overtop the left bank near RM 5.6, the physical county line, at discharges of about 2,000 cfs and greater. These observed overtopping flows are less than the hydraulically modeled 2011 channel conveyance capacity of about 4,000 cfs at RM 5.589 and RM 5.621 in **Figure 18**. The difference may be due to the observed overtopping occurring between hydraulic model cross sections. In about September 2011, the levee top elevation in this area was raised by about one

foot as a result of maintenance work by Pierce County. Subsequent field observations indicate that overtopping of the levee in this area now occurs at flows of about 3,500 cfs and greater.

4. Discussion

Although there was net sediment deposition through the full monitoring area during 2009 to 2011, most deposition occurred in Reach 1, with net erosion occurring in Reaches 4 and 5. Net changes in sediment storage in Reaches 2 through 4 were less than the long-term (1984-2011) averages and the net deposition rate in Reach 1 was essentially the same as the long-term average. The relatively minor changes in sediment levels observed in this period likely result from the relatively minor flow events. However, even with minor peak flows, deposition continues in Reach 1 with locally marked increases in sediment levels and modeled water surface elevations continue near the county line. The duration of flows above threshold of motion for bedload transport appears to be equally important as the magnitude of the peak discharge with regard to sediment deposition in Reach 1.

[More discussion may be added to the final version of this memo.]

5. Summary and conclusions

- Channel monitoring data indicate continued net sediment accumulation in the Lower White River through the full monitoring area (RM 5 to RM 10.6) from 2009 to 2011.
- The total net deposition from 2009 to 2011 within the full monitoring area was about 10 percent of the total net deposition in the same area from 2007 to 2009.
- The 2009 to 2011 general patterns of sediment deposition or erosion in the five river reaches (within the full monitoring area) appear similar to long-term trends: Reach 1 is depositional and the Reach 1 exhibits the greatest volumes and rates of sediment deposition; Reach 2 has less net deposition than Reach 1 and generally with more deposition in its downstream part; Reach 3 showed little net deposition, which is consistent with its longer-term general characteristic as a transport reach; Reaches 4, and 5 exhibit variability throughout, with net erosion during this monitoring period.
- The Reach 1 rate of sediment deposition from 2009 to 2011 of approx 11,000 cubic yards per year essentially is identical to the long-term average Reach 1 deposition rate from 1984 through 2011.
- The shorter-term average annual deposition rate from 2001 through 2011 in Reach 1 is about 20,000 cubic yards per year.
- Ongoing sediment deposition occurred during 2009 to 2011 in Reach 1 even though the peak flow in this period (7,500 cfs) was not a large flood event. It appears that sustained discharges of 4,000 cfs and greater continue to transport sediment into Reach 1, where it deposits.
- Increases in modeled water surface elevations follow similar patterns of net deposition through the five river reaches.
- The modeled channel conveyance capacity continued to decrease during 2009 to 2011 in Reach 1. The modeled channel conveyance capacity in the upstream part of Reach 2 and in all of Reaches 3, 4 and 5 continues to equal or exceed 15,500 cfs (a 100-year flood).

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- The monitoring of in-channel sediment levels and the monitoring of resulting hydraulic responses, where the only parameter that was modified from 2009 to 2011 was the channel geometry (i.e., changes in sediment levels) indicate that increases in water surface elevations and decreases in channel conveyance capacity are attributable to ongoing sedimentation in the monitoring area. This finding applies primarily to Reach 1 (RM 5 to RM 6.3).
- Because increased flood water surface elevations and decreased channel capacity are taken to indicate increases in flood hazard, it appropriate to consider sediment management actions in the affected areas (King County 2006). This finding applies primarily to Reach 1. Sediment management actions may include longer-term actions such as elevation or acquisition and removal of at-risk structures, levee setback and floodplain reconnection projects, or shorter-term remedies such as installation of temporary flood barriers or gravel removal.

6. References

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Appendix A

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Table A-1: Lower White River changes in sediment volume, 2009 to 2011.

PROVISIONAL DATA - SUBJECT TO CHANGE

HECRAS River Station	HECRAS Distance between cross sections (feet)	Change in area at each cross section (sq ft)	AVERAGE change in area at adjacent cross sections 2009 to 2011 (sq ft)	Change in volume betw adjacent cross sections (cu yd)	AVERAGE ANNUAL rate of Change (cu yd/year)	Channel Width using edges of change in xs area (ft)	Vertical Change at each xsection 2009 to 2011 (ft)
4.978	0	161				160	1.0
8th St Br							
4.988	53	161	161	315	158	160	1.0
4.998	104	192	177	680	340	203	0.9
5.041	227	316	254	2138	1069	330	1.0
5.123	434	110	213	3430	1715	402	0.3
5.197	390	37	74	1065	532	455	0.1
5.292	504	59	48	895	448	238	0.2
5.374	431	21	40	638	319	252	0.1
5.460	453	-6	7	122	61	211	0.0
5.517	303	352	173	1939	970	213	1.7
5.589	380	141	246	3467	1734	229	0.6
5.621	167	4	72	448	224	218	0.0
5.712	483	81	42	758	379	232	0.3
5.822	582	7	44	942	471	244	0.0
5.920	516	40	23	448	224	259	0.2
6.013	488	102	71	1280	640	224	0.5
6.077	342	135	118	1495	748	233	0.6
6.145	356	101	118	1550	775	245	0.4
6.223	413	-24	39	590	295	197	-0.1
6.313	477	60	18	324	162	164	0.4
6.326	65	88	74	173	89	160	0.5
Bridges							
6.390	337.92	47	67	844	422	208	0.2
6.482	485	98	73	1305	653	289	0.3
6.569	462	44	71	1214	607	411	0.1
6.647	409	88	66	998	499	316	0.3
6.761	605	54	71	1593	797	349	0.2
6.891	687	-25	15	369	184	316	-0.1
7.001	580	2	-11	-245	-122	270	0.0
7.087	456	-32	-15	-253	-127	242	-0.1
7.170	435	-127	-80	-1282	-641	216	-0.6
7.252	436	30	-48	-780	-390	146	0.2
7.368	610	20	25	569	285	118	0.2
7.511	757	-3	9	245	123	127	0.0
7.593	434	37	17	277	139	133	0.3
7.608	79	83	60	175	88	163	0.5
R Str Bridge							
7.716	649	-13	35	835	417	165	-0.1
7.845	683	-43	-28	-717	-359	173	-0.3
7.958	597	58	7	157	78	260	0.2
8.111	808	38	48	1432	716	300	0.1
8.269	837	-64	-13	-408	-204	169	-0.4
8.418	785	-12	-38	-1115	-558	182	-0.1
8.561	756	55	21	599	300	225	0.2
8.707	766	-45	5	148	74	212	-0.2
8.821	608	-13	-29	-640	-320	122	-0.1
8.946	662	-152	-82	-2020	-1010	332	-0.5
9.125	945	-17	-85	-2970	-1485	254	-0.1
9.311	983	-96	-57	-2064	-1032	228	-0.4
9.477	872	-13	-54	-1755	-878	646	0.0
9.794	1677	-203	-108	-6683	-3342	354	-0.6
10.065	1430	137	-33	-1732	-866	284	0.5
10.343	1469	-66	36	1931	966	403	-0.2
10.596	1331	51	-8	-372	-186	500	0.1

Length (R Miles)	Sub Reach Boundaries	VOLUME (cu yd)	RATE (cu yd/yr)	Average Width (ft)	Average Vert. Change (ft)
1.338	RM 4.978 to BNRR/A Str Br (RM 6.326)	22,700	11,350	239	0.5
1.390	BNSF/A (RM 6.326) to R Str (RM 7.716)	5,000	2,500	236	0.1
0.553	R Str (RM 7.716) to RM 8.269	1,300	650	213	-0.1
1.042	RM 8.269 to RM 9.311	-8,100	-4,050	222	-0.2
1.285	RM 9.311 to RM 10.596	-8,600	-4,300	437	0.0
5.608	Total for Entire Study Reach	12,400	6,200		

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Figure A-1: Lower White River 2011 Cross Sections

Reach 1

2011 Aerial Photo Along River

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King County

Legend

- 2011 Cross Sections
- Reach Boundary
- Monitoring Area

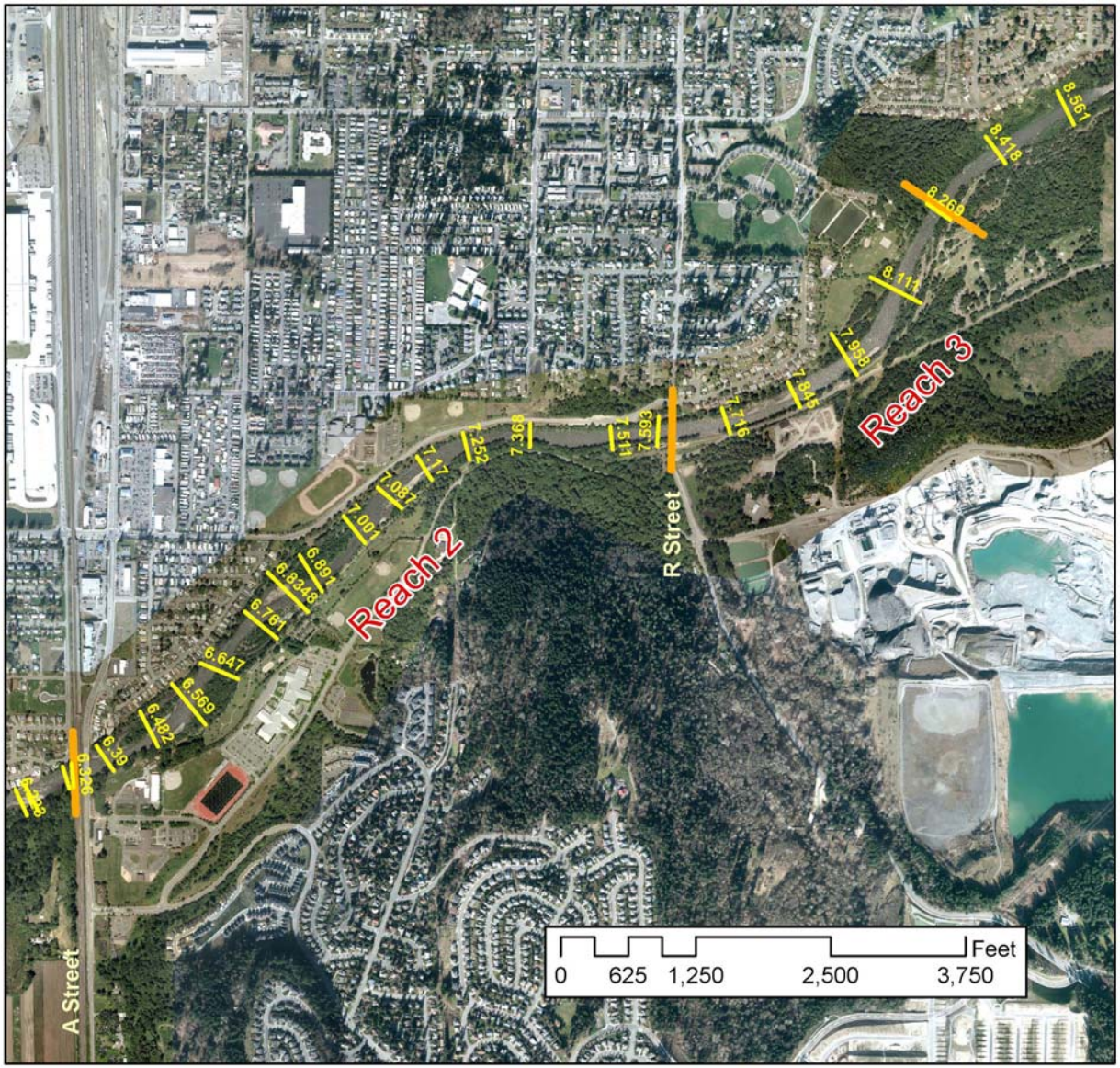

Figure A-1: Lower White River 2011 Cross Sections

Reach 2 and 3

2011 Aerial Photo Along River

N

King County

Legend

- 2011 Cross Sections
- Reach Boundary
- Monitoring Area

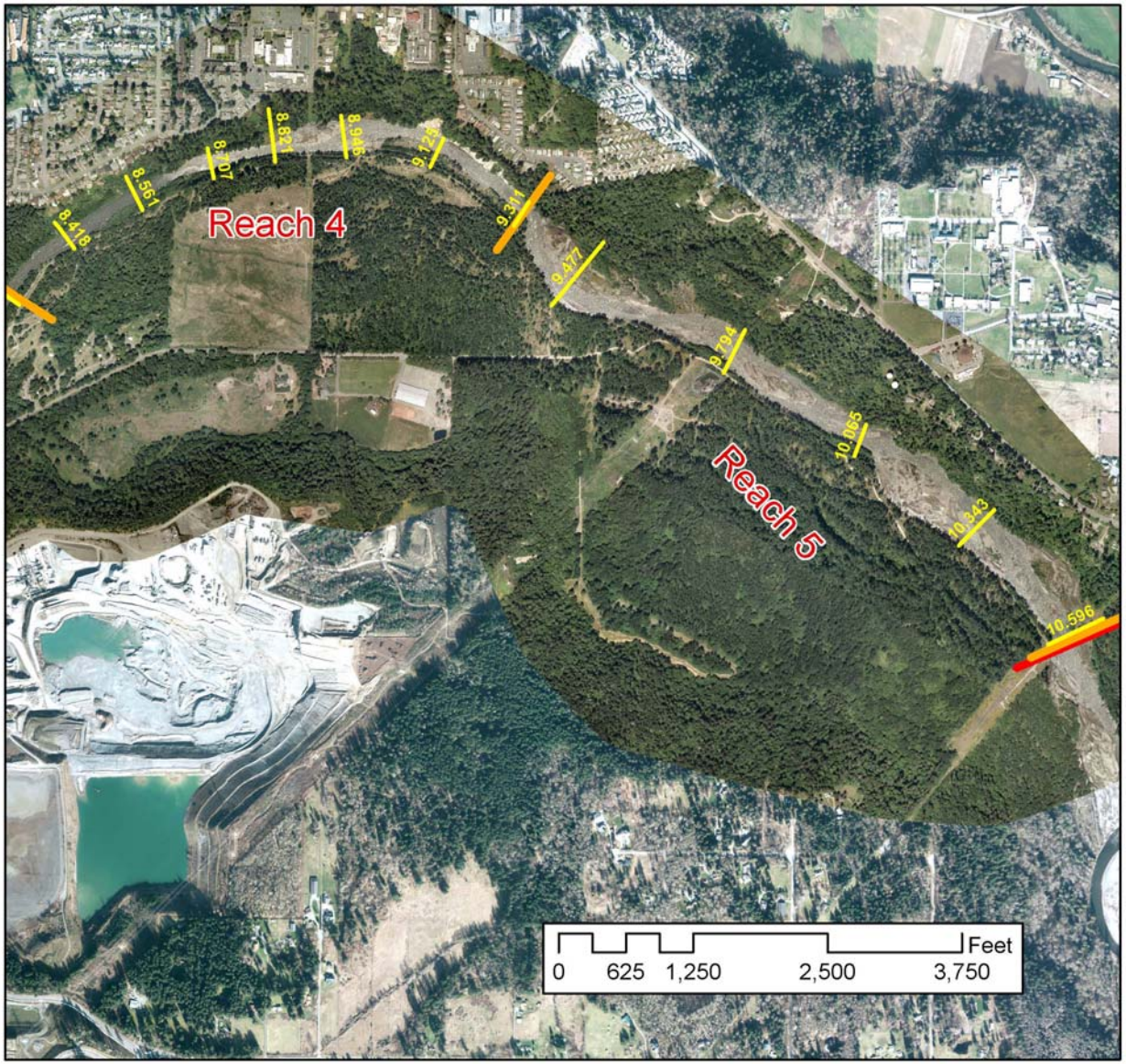

Figure A-1: Lower White River 2011 Cross Sections

Reach 4 and 5

2011 Aerial Photo Along River

N

King County

Legend

- 2011 Cross Sections
- Reach Boundary
- Monitoring Area