Draft evaluation of gravel removal in the Lower White River 2011

Technical Memo

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Natural Resources and Parks
Water and Land Resources Division

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1. Introduction

1.1. Background

The White River has its headwaters on Mt. Rainier and its mouth at the confluence with the Puyallup River. Between headwaters and mouth, the White River flows through a relatively young geologic landscape that erodible formations composed of glacial drift and mudflow deposits. In its lower reaches near the City of Auburn, the river exits the White River canyon and flows down its alluvial fan with ever-decreasing channel gradient. This setting makes the White River a sediment-rich river basin with consistently high sediment loads supplied in upstream areas and middle reaches, and a Lower White River is naturally predisposed to sediment deposition. In addition, a long history of channel engineering has channelized and confined the Lower White River (e.g., Herrera 2010; Czuba et al. 2010), likely increasing vertical rates of sedimentation by preventing overbank deposition during most frequent flood events.

King County has established a sediment monitoring program that periodically collects data in the Lower White River to measure elevations of the in-channel sediment levels and their effects on flood water elevations. This monitoring effort is conducted as part of the sediment management program described in the King County Flood Hazard Management Plan (King County 2006) so as to inform consideration of potential flood management actions. Lower White River channel monitoring by King County is coordinated with the City of Auburn and their channel monitoring efforts within city limits.

The King County sediment monitoring area includes the Lower White River from River Mile (RM) 5.0 to RM 10.6 (**Figure 1**). Surveyed data on in-channel sediment levels are collected approximately every two years, though they may be collected more or less frequently depending on river flows. Channel monitoring data and relevant historic information collected through 2009 was presented in a Summary of Sediment Trends (Herrera 2010). Changes during the 2009 to 2011 period, plus relevant data from previous periods, are summarized in the Lower White River 2011 channel monitoring summary (King County 2012d).

The 2011 channel monitoring summary identified continued sedimentation in parts of the Lower White River monitoring area, primarily in the Lower White River between the BNSF/A Street Bridges (RM 6.3) and the 8th Street E Bridge (RM 5.0), which is referred to as Reach 1. Hydraulic modeling in the same summary document identified increases in flood water surface elevations and decreases in the channel conveyance capacity during the same period also in Reach 1. Such changes are taken to indicate increasing flood hazard that is attributable to ongoing sedimentation (King County 2012d).

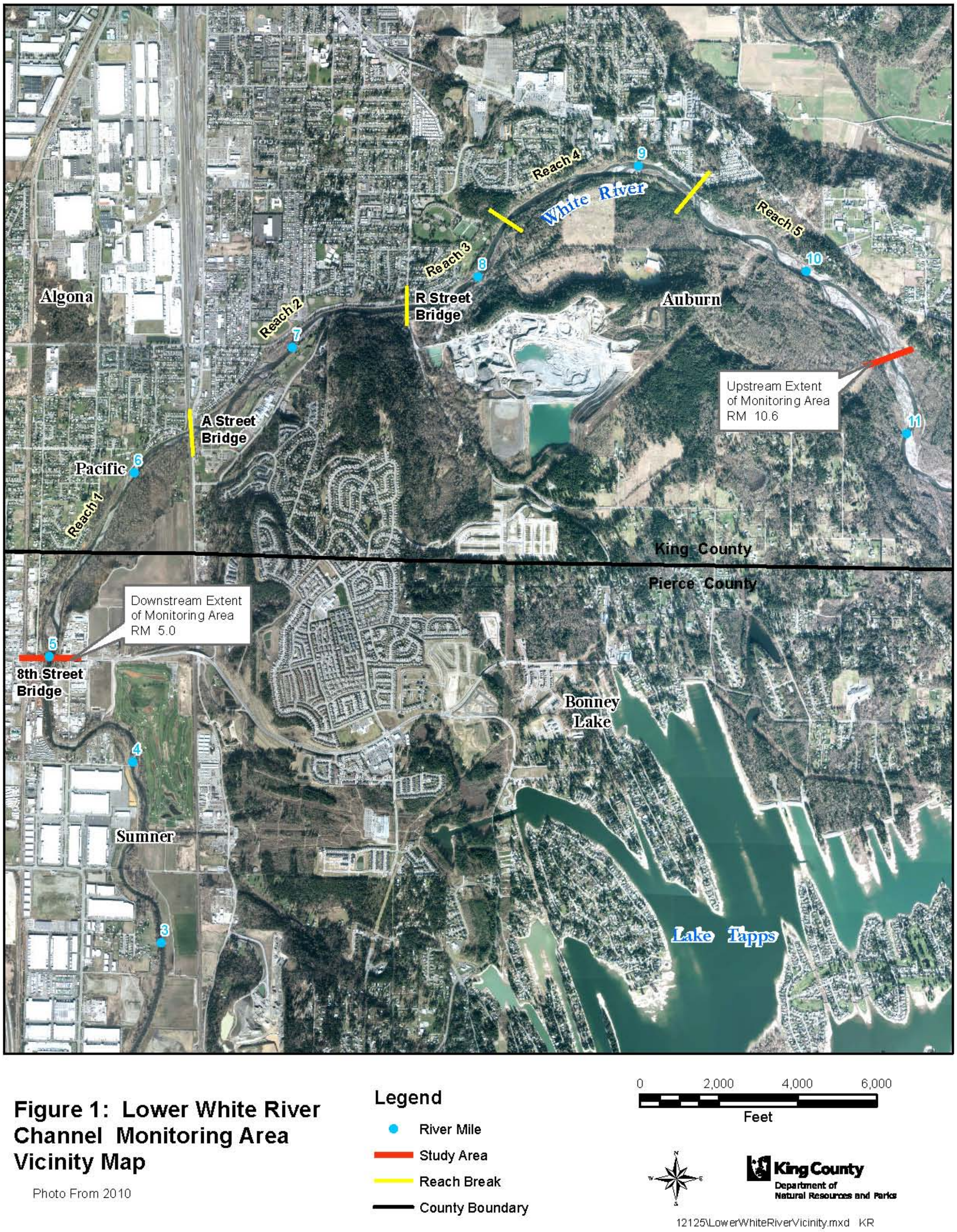

Figure 1: Lower White River Channel Monitoring Area Vicinity Map

Photo From 2010

The 2011 channel monitoring summary therefore concluded that it is appropriate to consider sediment management actions in the affected area, actions which may include levee removal and setback, acquisition and removal of at-risk structures, installation of temporary flood barriers and gravel removal or some combination thereof (King County 2007). Some of these actions have already been taken, some actions are under analysis and design and some actions are under consideration.

1.2. Purpose

The purpose of this analysis is to evaluate the effectiveness of gravel removal as a flood hazard reduction strategy along the Lower White River. This evaluation focuses primarily on the channel between 8th Street East Bridge and the BNSF/A Street Bridges (RM 5 to RM 6.3; Reach 1) but also considers the channel from A Street to R Street (RM 6.3 to RM 7.6; Reach 2).

Gravel removal scenarios are evaluated against the specific flood reduction objective of containing a flow of 15,500 cfs within existing riverbanks or levees. A flow of 15,500 cfs is equal to the 100-year flood as calculated using data to date. The Countyline Levee Setback Project, now being designed, has identified containment of the 15,500 cfs plus 3 feet of freeboard as its target design flow. Evaluation of gravel removal scenarios in their effectiveness in containing 15,500 cfs allows comparison of these two different types of flood hazard reduction strategies.

This document evaluates only the effectiveness of hypothetical gravel removal scenarios, primarily by hydraulic modeling. This analysis does not include evaluation of potential adverse environmental impacts, necessary mitigation of impacts, analysis of alternatives, or likely permitting requirements of any gravel removal operation in the Lower White River. Modeling and evaluation of these gravel removal scenarios does not indicate an intent to conduct gravel removal. Consideration of potential flood hazard and flood risk reduction alternatives, including gravel removal, is consistent with the King County Flood Hazard Management Plan (King County 2006).

2. Methods

2.1. Hydraulic modeling of gravel removal

The effectiveness of gravel removal in flood hazard reduction was evaluated by hydraulic modeling of gravel removal scenarios using the HEC-RAS program, which is a 1-dimensional steady state hydraulic model. A few different gravel removal scenarios were identified in order to evaluate the relative effectiveness of a range of gravel removal configurations. The gravel removal scenarios were created by modifying the 2011 existing conditions channel cross sections in order to represent channel geometries as if gravel extraction had occurred. The hydraulic response to the gravel removal scenarios are compared to the 2011 existing conditions, as well as to the identified gravel removal objective of containing 15,500 cfs.

All of the hydraulic modeling of gravel removal scenarios 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 so as to focus the evaluation only on the in-channel hydraulic effects due to gravel removal and also to simplify the modeling process by eliminating the need to represent flow splits in overbank areas. Therefore, this evaluation is best used to compare the effectiveness of the different gravel removal scenarios relative to each other, rather than to focus on absolute changes that may result from the different scenarios. 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 actually would occur above the top of the riverbank being overstated to some undetermined degree.

To further focus the evaluation on the effect of in-channel changes due to simulated gravel removal, the hydraulic roughness coefficient (Manning’s ‘n’ value) for the gravel removal scenarios was not changed from hydraulic roughness coefficient for existing conditions.

The effectiveness of each gravel removal scenarios as a flood reduction strategy is evaluated based primarily on its success in establishing or maintaining a channel conveyance capacity of 15,500 cfs. Channel conveyance capacity, as used here, is the flow discharge that just stays within the channel based on the top of bank elevation at the lower of the two riverbanks at any given location. This information was extracted from HEC-RAS at each channel cross section. 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 is not characterized in this analysis.

The sediment volumes that would be extracted were calculated for each scenario. The estimated number of years that the flood reduction benefits of gravel removal would persist, or their longevity, was estimated for each scenario simply by dividing the excavation volume of that scenario by a representative average annual rate of sediment deposition. Average annual deposition rates are available from the channel monitoring program. In addition, planning-level cost estimates were calculated for each gravel removal scenario based on established unit rate values based on experience with similar capital projects. These cost estimates also are based on the estimated excavation volume of each scenario.

2.2. Gravel removal scenarios

Gravel removal was simulated by four gravel bar scalping scenarios and one dredging scenario. Gravel bar scalping includes excavation that occurs only on parts of gravel bars located above the water surface. Dredging can excavate above and below the water, across the full channel width, to variable depths and along whatever river length is deemed appropriate to the objective.

The Washington Administrative Code (WAC 220-110-140) identifies specific criteria that must be met for gravel bar scalping, including but not limited to the following. The WAC states that an "excavation line" must be established along a gravel bar, below which gravel removal may not occur, although the WAC does not specify the methods by which to establish the excavation line. Also, the upstream end of the gravel bar must be left undisturbed in place (as a hydraulic control). And excavation must leave gravel bar surfaces that slope upward at a 2 percent gradient away from the river toward the bank (to avoid fish stranding). These criteria were used in configuring the four bar scalping scenarios.

The excavation line for bar scalping scenarios was established at approximately one half foot above the low flow water surface elevation. Flow rates on the White River are controlled by flow releases from Mud Mountain Dam and during summer months are regulated to a minimum of 500 cfs. A flow of 500 cfs was assumed to be the low flow for this evaluation and the low flow water surface elevations at each cross section was determined by the hydraulic model. Gravel removal scenarios were configured to excavate no lower than one half foot above the low flow elevation and the excavation surface sloped at 2 percent upward from the river channel and from existing side channels.

Two of the bar scalping scenarios were configured to not remove gravel from the upstream third of the gravel bar. Two of the bar scalping scenarios were configured to remove gravel from the entire gravel bar. While gravel bar scalping from the entire gravel bar is inconsistent with WAC provisions and might not be permitted, these scenarios were included in order to illustrate a maximum effect possible from gravel removal by bar scalping.

A dredging scenario was included because the hydraulic modeling results indicate that none of the bar scalping scenarios would meet the objective of containing 15,500 cfs. A dredge scenario could be configured specifically to accomplish that objective. In so doing, it also would illustrate the amount and extent of excavation necessary to accomplish that objective. In addition, dredging was conducted historically not only to maintain existing Lower White River channel capacity (e.g., Herrera 2010 Appendix A), but dredging also essentially created the Lower White River of today by enlarging, straightening and channelizing the smaller channel(s) of the Stuck River so as to accommodate the diversion of the White River in circa 1914. The dredging scenario is configured with excavated side slopes of 3Horizontal:1Vertical so as to avoid destabilizing existing riverbanks and levees.

The gravel removal scenarios are described below and their general characteristics are summarized in **Table 1**. A schematic cross section view in **Figure 2** depicts a typical gravel bar scalping scenario and dredging scenario evaluated in this analysis. The gravel bars that these gravel removal scenarios would affect are numbered sequentially upstream from the 8th Street East Bridge, plus one named gravel bar downstream, as identified in subsequent figures.

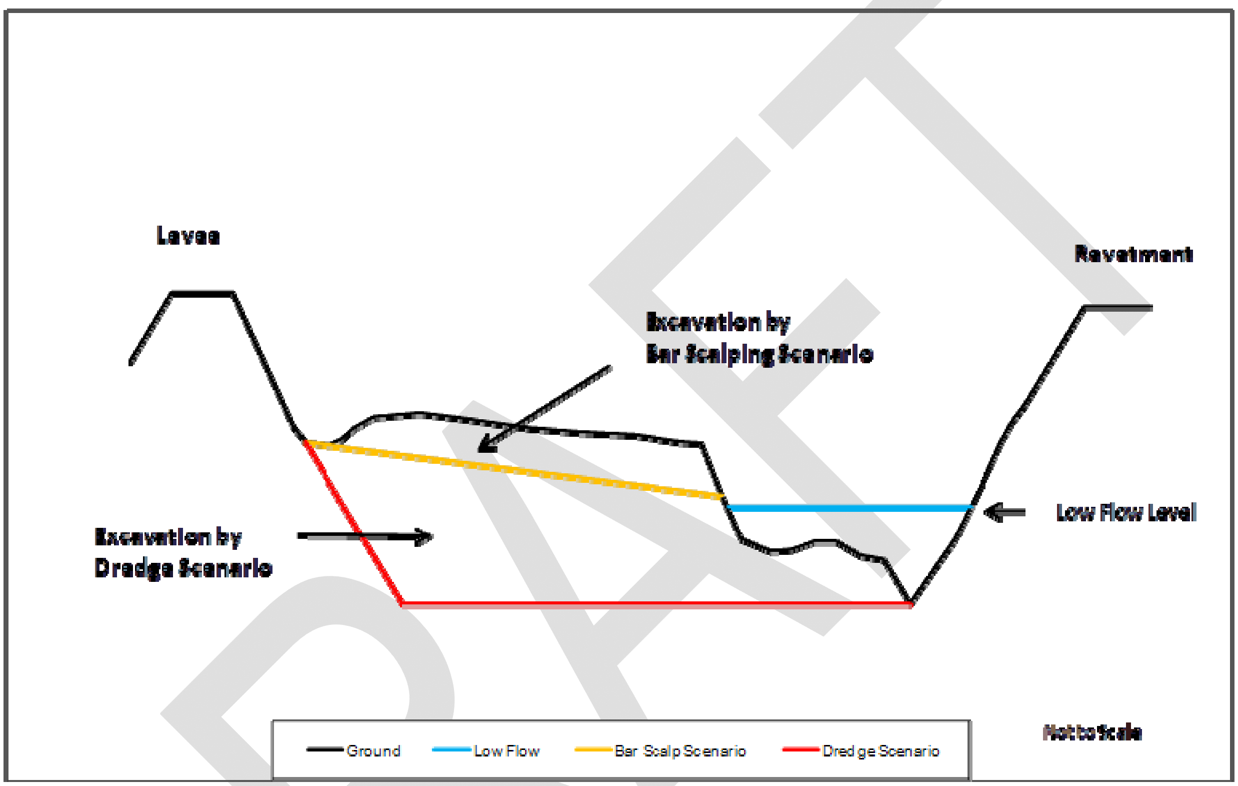

Figure 2: Schematic cross section view of gravel removal scenarios.

Bar Scalp Scenario 1 would affect the RCI bar (RM 4.5) plus gravel bars 1 through 10, except gravel bar 3 (**Figure 3**). Bar Scalp Scenario 1 would leave the upstream third of the gravel bars intact and remove gravel only from the downstream two-thirds of the bar. This scenario would remove gravel from elevations on the bar starting at one-half foot above the low flow water surface elevation and would excavate through areas that now support woody vegetation. Bar Scalp Scenario 1 would remove approximately 37,000 cubic yards of sediment.

Bar Scalp Scenario 2 would affect gravel bars 1, 2, 4, and 5 (**Figure 4**). Bar Scalp Scenario 2 also would leave the upstream one third of the bar intact and start excavation at approximately one half foot above the low flow elevation. This scenario would not excavate through areas that now support woody vegetation. Bar Scalp Scenario 2 would remove approximately 20,000 cubic yards of sediment.

Bar Scalp Scenario 3 would affect gravel bars 1 through 10 plus the RCI bar (**Figure 5**). This scenario would remove gravel from the entire gravel bar including the upstream third, and would start excavation at about one-half foot above the low flow elevation. Bar Scalp Scenario 4 would excavate through areas with woody vegetation. This scenario would result in removal of approximately 77,000 cubic yards.

Bar Scalp Scenario 4 would affect gravel bars 1, 2, and 3 (**Figure 6**). This scenario would remove gravel from the entire gravel bar including the upstream third, start excavation at about one-half foot above the low flow elevation, and would excavate through areas with woody vegetation. Bar Scalp Scenario 4 would remove approximately 18,000 cubic yards.

The **Dredge Scenario** would excavate above and below the water surface to varying depths across the full width of the channel, subject to the provision that excavated side slopes be no steeper than 3H:1V. The length of affected channel was dictated by the objective of containing 15,500 cfs from 8th Street E to BNSF/A Street Bridges. Because the hydraulic effects of channel conditions are manifested in the upstream direction in the subcritical flow regime that exists in this part of the Lower White River, the simulation of dredging was started downstream of the 8th Street East Bridge (Reach 1). A Dredge Scenario that would meet the 15,500 cfs containment objective would excavate in-channel sediment from approximately RM 4.0, downstream of the RCI bar, upstream to RM 6.36 at the BNSF Bridge (**Figure 7**). The Dredge Scenario would excavate about 580,000 cubic yards.

Table 1: Lower White River gravel removal scenarios, based on 2011 existing conditions.

Bar Scalping Scenario Number	Brief Description	Excavation line's height above low flow elevation	Excavate upstream third of bar?	Excavate through woody vege?	Gravel Bars or River Distances Affected
1	Scalp the downstream 2/3 of the bar to a half foot above low flow.	Half foot	No	Yes	1, 2, 4, 5, 6, 7, 8, 9, 10 and RCI bar
2	Scalp the downstream 2/3 of the bar to a half foot above low flow. Retain wood vegetation.	Half foot	No	No	1, 2, 3, 4, 5, 6
3	Scalp the entire bar to a half foot above low flow. Do so on all gravel bars.	Half foot	Yes	Yes	1 through 10 and RCI bar
4	Scalp the entire bar to a half foot above low flow. Do so on gravel bars 1, 2 and 3.	Half foot	Yes	Yes	1, 2, 3
N/A	Dredge the full width of the channel from downstream of RCI bar (RM 4.5) to BNSF/ A Street Bridges (RM 6.3)	Excavation would occur above and below water and depth would vary	Yes	Yes	All gravel bars and full channel width from RM 4.5 to RM 6.3

Other gravel removal scenarios than those described above also may be evaluated in the final version of this memo. In addition, modifications to the hydraulic parameters in existing scenarios, such as the hydraulic roughness coefficient may be revised in subsequent hydraulic analyses. Hydraulic analysis of gravel removal scenarios is a work in progress the time of this draft technical memo. More information and findings may be available in the final version of this memo. Also, if gravel removal for flood reduction purposes actually were to be pursued, more detailed analyses of its effects and effectiveness than were conducted for this evaluation would be necessary.

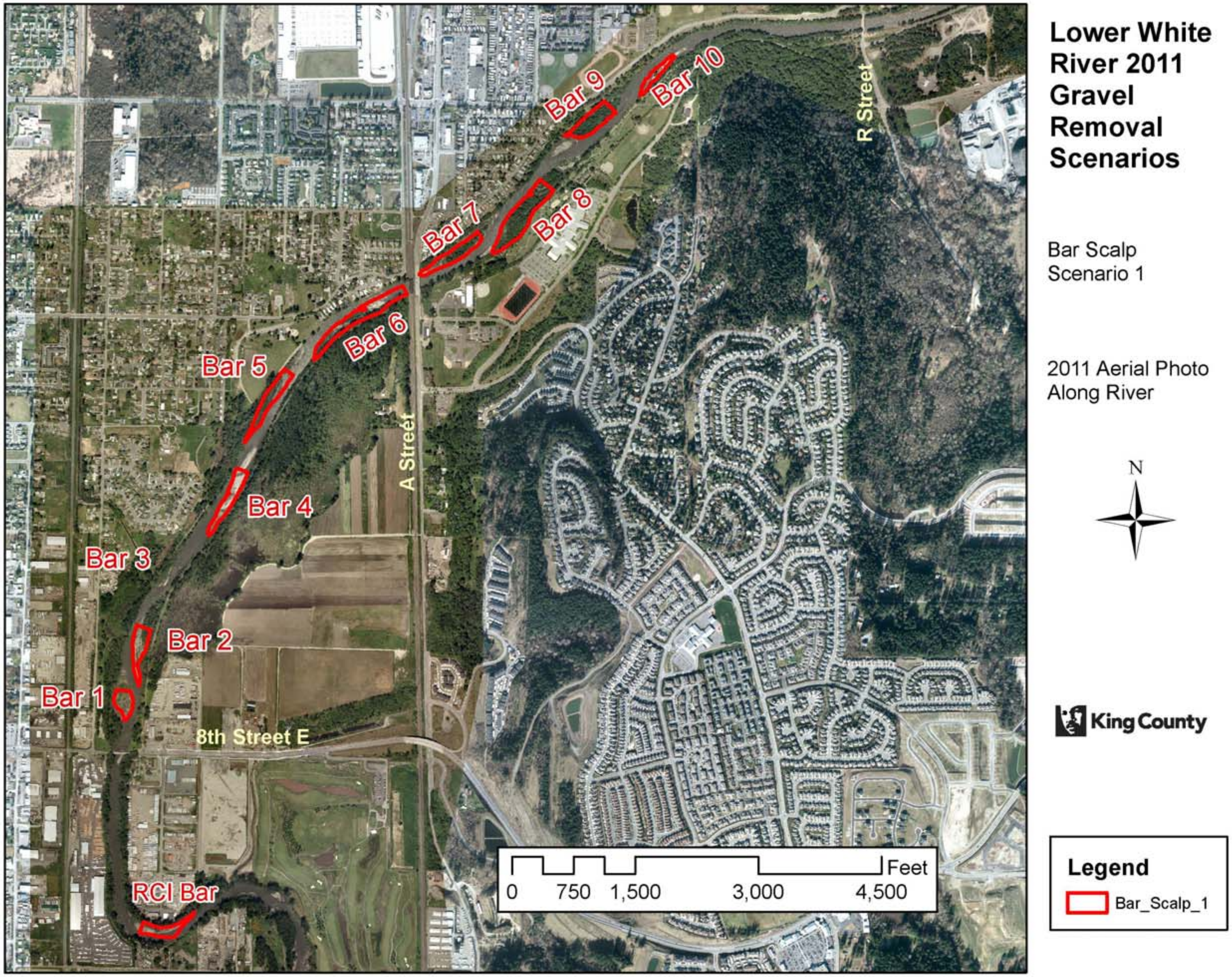

Figure 3: Lower White River 2011 Bar Scalp Scenario 1, schematic plan view aerial map.

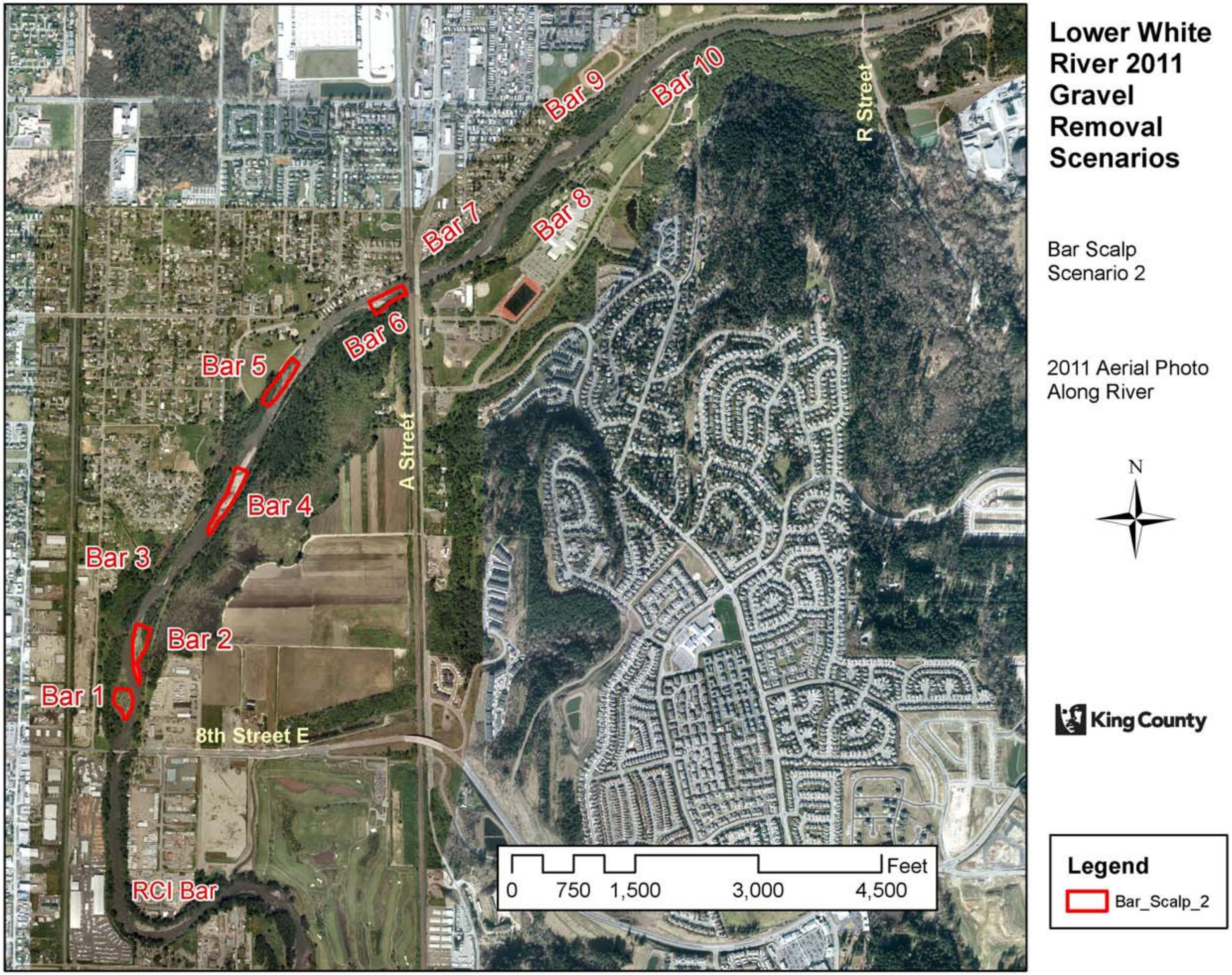

Figure 4: Lower White River 2011 Bar Scalp Scenario 2, schematic plan view aerial map.

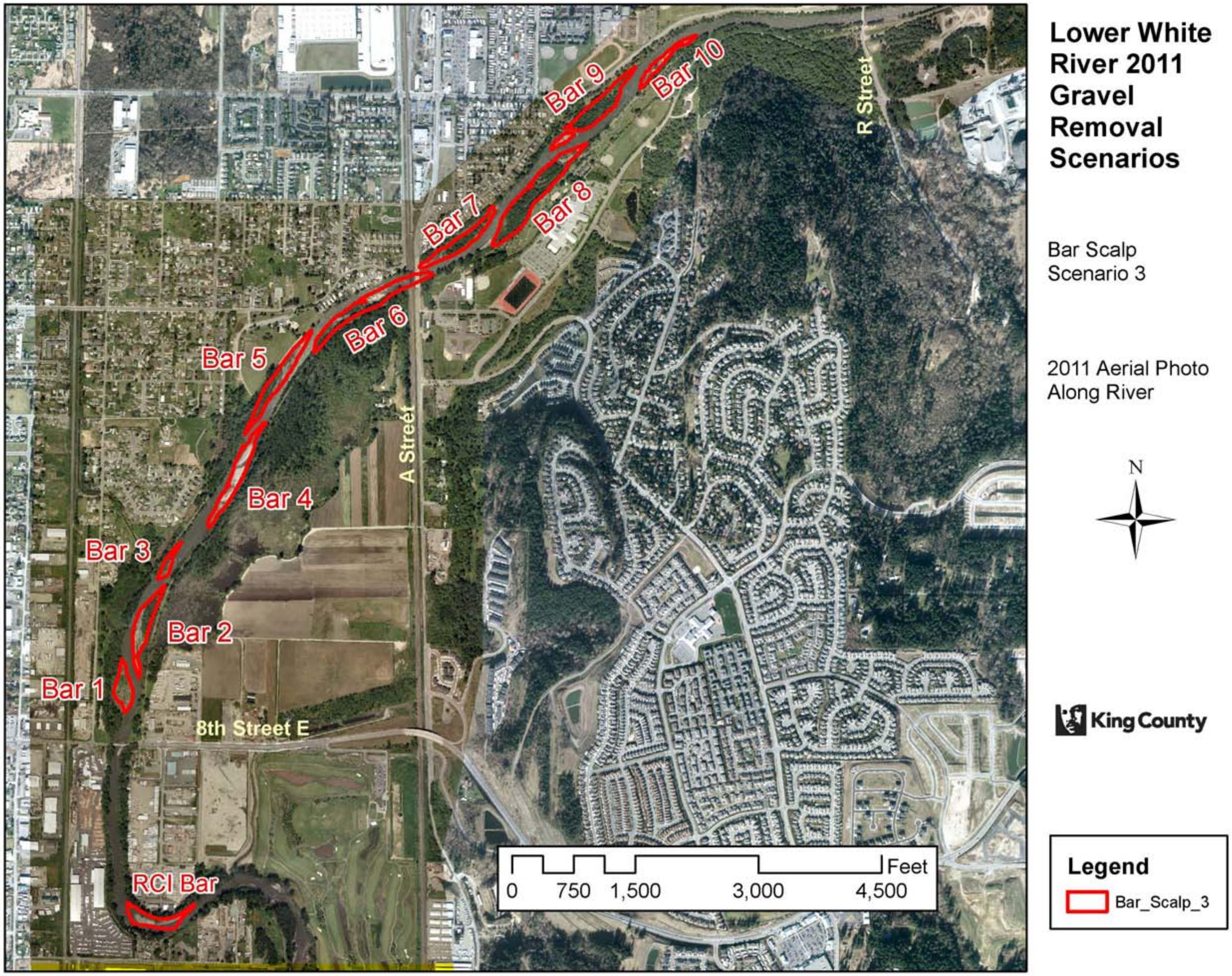

Figure 5: Lower White River 2011 Bar Scalp Scenario 3, schematic plan view aerial map.

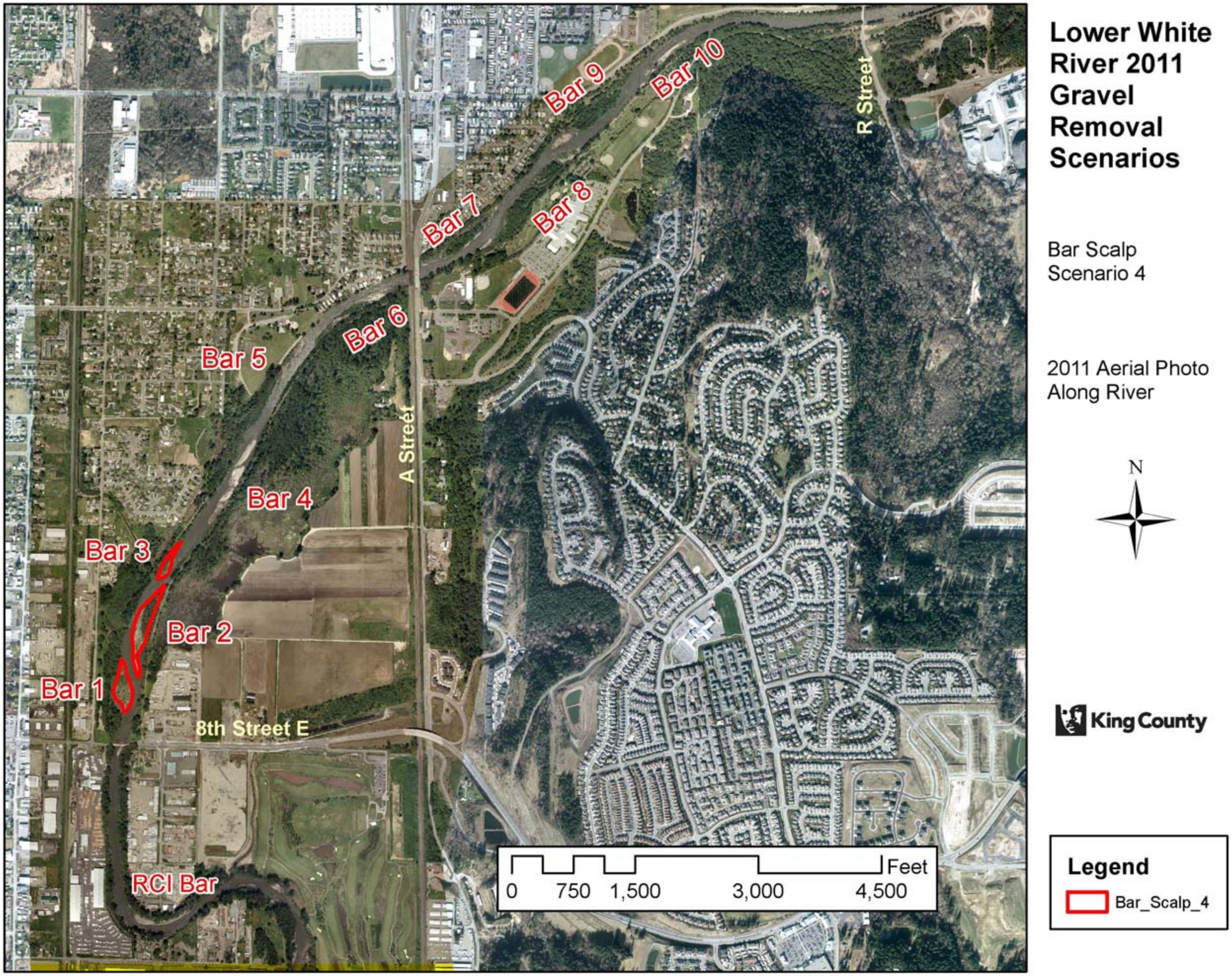

Figure 6: Lower White River 2011 Bar Scalp Scenario 4, schematic plan view aerial map.

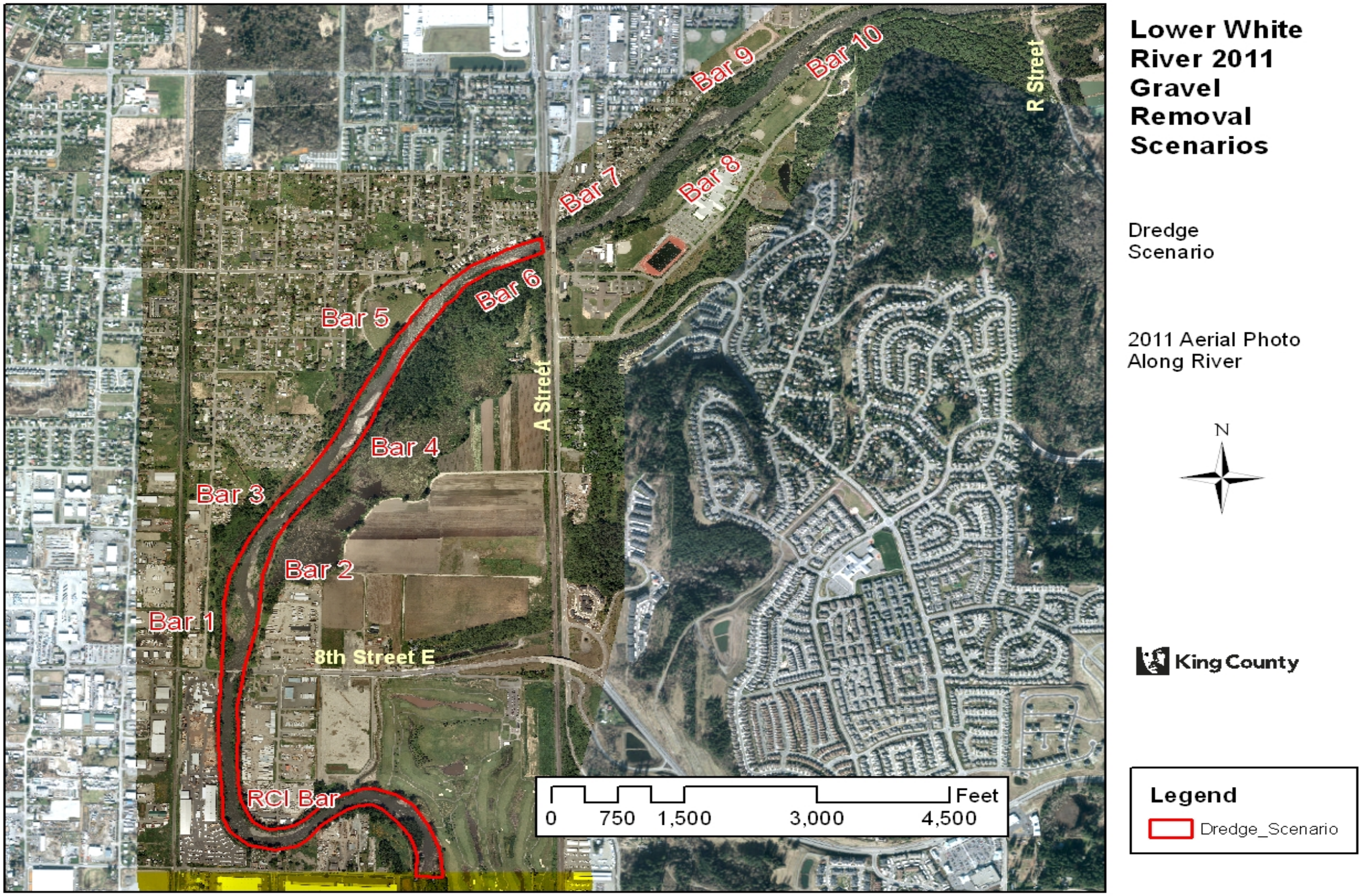

Figure 7: Lower White River 2011 Dredge Scenario, schematic plan view aerial map.

3. Results

3.1. Effect of gravel removal on water surface elevations

The four bar scalping scenarios would decrease the water surface elevations during a flood of 15,500 cfs by varying amounts and differently through the length of Reach 1 and 2. Bar Scalp Scenario 3 would scalp the full length of every gravel bar in Reaches 1 and 2, plus the RCI bar. With its largest excavation volume and greatest areal extent, this scenario would have the greatest effect of all bar scalp scenarios on water surface elevations (**Table 2**). Bar Scalp Scenario 3 would decrease the 15,500 cfs water surface elevations by as much as 0.7 feet at RM 6.313 (in Reach 1) and as much as 1.2 feet at RM 7.001 (in Reach 2).

Bar Scalp Scenario 1 would excavate nine of the ten gravel bars in Reaches 1 and 2 plus the RCI bar, but only remove gravel from the downstream two-thirds of each bar. Bar Scalp Scenario 1 therefore is about as extensive as Scalp 3, but would result in lesser decreases in the 15,500 cfs water surfaces, e.g., about one-half of a foot in Reach 1 and about one foot in Reach 2.

Bar Scalp Scenario 2 would not excavate on the upstream third of the bar and would avoid excavation where woody vegetation now exists, and therefore would affect five of the six gravel bars in Reach 1. This scenario would result as much as a half foot decrease in water surface elevations in Reach 1 (similar in magnitude to the decreases from Bar Scalp 1). The effect of Scalp 2 diminishes to zero not far into Reach 2 upstream of A Street.

Bar Scalp Scenario 4 would extract only from gravel bars 1, 2 and 3, though it would do so along the entire gravel bar. It would result in minor and localized decreases in water surface elevations, i.e., a maximum decrease of about 0.2 feet between RM 5.3 and RM 5.3 (near Bars 1, 2 and 3).

The effect of the most extensive and largest bar scalping scenario, Bar Scalp Scenario 3, on water surface elevations during a 15,500 cfs flood is shown in profile view in **Figure 8** and in cross section views at selected locations in **Figure 9** and **Figure 10**. The effect of Bar Scalp Scenarios 1, 2 and 4 may equal these examples in a few locations but more typically would be less than is shown in these examples. Throughout Reaches 1 and 2, the general effect of the bar scalping scenarios water surface elevations would be to approximately match the increases in water surface elevations that occurred under existing conditions from 2009 to 2011 (**Table 2**). **Table 2** data are depicted in **Figure 11**.

Table 2: Changes in Lower White River water surface elevations from 2009 Existing Conditions to 2011 Existing Conditions and from 2011 Existing Conditions to each of four Bar Scalping scenarios and the Dredge Scenario, during a 15,500 cfs flood.

River Mile	From 2009 to 2011 Existing Conditions (feet)	Going from 2011 Existing Conditions to each of the following scenarios: Bar Scalp Scenario 1 (feet)	Bar Scalp Scenario 2 (feet)	Bar Scalp Scenario 3 (feet)	Bar Scalp Scenario 4 (feet)	Dredge Scenario (feet)
3.941		0.0	0.0	0.0	0.0	0.0
4.017		0.0	0.0	0.0	0.0	-0.1
4.173		0.0	0.0	0.0	0.0	-0.7
4.406		0.0	0.0	0.0	0.0	-1.0
4.531		-0.1	0.0	-0.1	0.0	-1.3
4.5607		-0.2	0.0	-0.2	0.0	-1.3
4.5687		-0.2	0.0	-0.2	0.0	-1.3
4.629		-0.2	0.0	-0.3	0.0	-1.5
4.692		-0.2	0.0	-0.2	0.0	-1.9
4.715		-0.1	0.0	-0.2	0.0	-2.2
4.941		-0.1	0.0	-0.1	0.0	-2.9
4.978	-0.1	-0.1	0.0	-0.1	0.0	-2.8
8th Street Bridge						
4.998	0.0	-0.1	0.0	-0.1	0.0	-3.1
5.041	0.1	-0.1	0.0	-0.1	0.0	-3.4
5.123	0.2	-0.1	0.0	-0.1	0.0	-3.4
5.142	0.2	-0.1	-0.1	-0.1	0.0	-3.5
5.197	0.2	-0.1	0.0	-0.2	-0.1	-3.6
5.292	0.1	-0.1	-0.1	-0.2	-0.1	-3.7
5.311	0.2	-0.2	-0.1	-0.2	-0.2	-3.8
5.374	0.3	-0.2	-0.1	-0.3	-0.3	-4.2
5.46	0.4	-0.1	0.0	-0.3	-0.2	-4.5
5.4882	0.3	-0.1	0.0	-0.2	-0.2	-4.1
5.517	0.2	0.0	0.0	-0.3	-0.2	-4.3
5.589	1.5	-0.1	-0.1	-0.1	0.0	-4.9
5.621	1.2	-0.1	-0.1	-0.1	0.0	-4.8
5.712	0.4	-0.5	-0.5	-0.5	0.0	-5.0
5.7449	0.5	-0.6	-0.6	-0.5	0.0	-5.0
5.822	0.2	-0.4	-0.4	-0.5	0.0	-4.5
5.92	0.2	-0.5	-0.2	-0.5	0.0	-3.3
5.939	0.1	-0.4	-0.1	-0.5	0.0	-3.1
6.0035	0.3	-0.3	-0.2	-0.4	0.0	-3.0
6.013	0.4	-0.3	-0.3	-0.4	0.0	-3.0
6.077	0.5	-0.2	-0.2	-0.5	0.0	-4.0
6.145	0.6	-0.2	-0.1	-0.4	0.0	-2.5
6.223	0.5	-0.3	-0.1	-0.4	0.0	-2.6
6.2419	0.5	-0.4	0.1	-0.5	0.0	-3.0
6.313	0.4	-0.6	-0.4	-0.7	0.0	-4.3
6.326	0.4	-0.8	-0.5	-0.6	0.0	-3.9
BNSF/ A Street Bridges						

Table 2, continued: Changes in Lower White River water surface elevations from 2009 Existing Conditions to 2011 Existing Conditions and from 2011 Existing Conditions to each of four Bar Scalping scenarios and the Dredge Scenario, during a 15,500 cfs flood.

		Going from 2011 Existing Conditions to each of the following scenarios:				
River Mile	From 2009 to 2011 Existing Conditions (feet)	Bar Scalp Scenario 1 (feet)	Bar Scalp Scenario 2 (feet)	Bar Scalp Scenario 3 (feet)	Bar Scalp Scenario 4 (feet)	Dredge Scenario (feet)
BNSF/ A Street Bridges						
6.390	0.3	-0.3	-0.3	-0.6	0.0	-1.7
6.482	0.4	-0.6	-0.2	-0.8	0.0	-0.8
6.5105	0.5	-0.7	-0.2	-0.8	0.0	-0.7
6.5204	0.5	-0.8	-0.2	-0.8	0.0	-0.6
6.569	0.2	-0.5	-0.1	-0.8	0.0	-0.4
6.647	0.2	-0.4	0.0	-0.6	0.0	-0.1
6.7195	0.0	-0.7	0.0	-0.7	0.0	0.0
6.7309	-0.1	-1.0	0.0	-0.8	0.0	0.0
6.761	0.0	-0.4	0.0	-0.8	0.0	0.0
6.8348	0.1	-0.2	0.0	-0.6	0.0	0.0
6.891	0.2	-0.1	0.0	-0.5	0.0	0.0
6.9579	-0.1	-0.9	0.0	-1.0	0.0	0.0
6.9673	-0.2	-1.1	0.0	-0.9	0.0	0.0
7.001	-0.3	0.0	0.0	-1.2	0.0	0.0
7.087	-0.1	0.0	0.0	-0.9	0.0	0.0
7.1563	0.0	-0.2	0.0	-0.2	0.0	0.0
7.17	-0.2	-0.5	0.0	-0.3	0.0	0.0
7.252	-0.5	-0.1	0.0	-0.4	0.0	0.0
7.368	0.2	0.0	0.0	0.0	0.0	0.0
7.511	0.2	0.0	0.0	0.0	0.0	0.0
7.593	0.1	0.0	0.0	0.0	0.0	0.0
7.608	0.3	0.0	0.0	0.0	0.0	0.0
R Street Bridge						

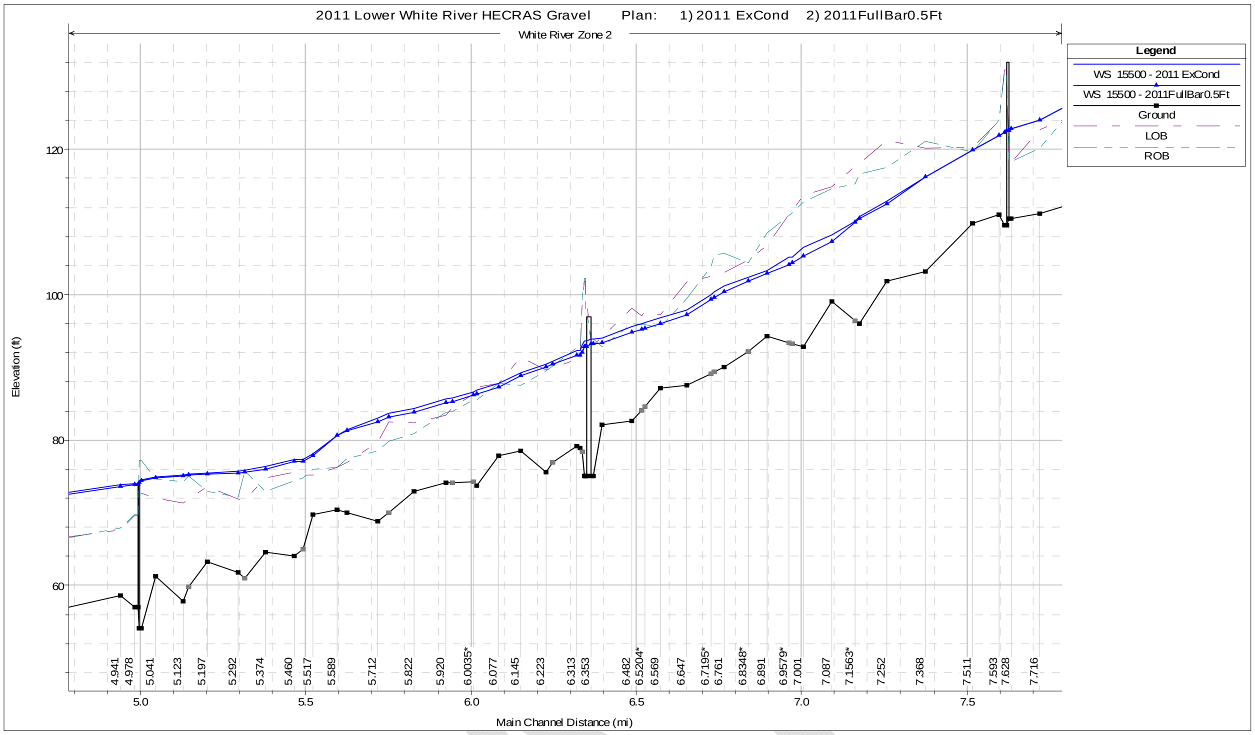

Figure 8: Profile view of Lower White River water surface elevations between R Street Bridge and 8th Street East Bridge during a 15,500 cfs flood under 2011 Existing Conditions and Bar Scalp Scenario 3. Flow is from right to left.

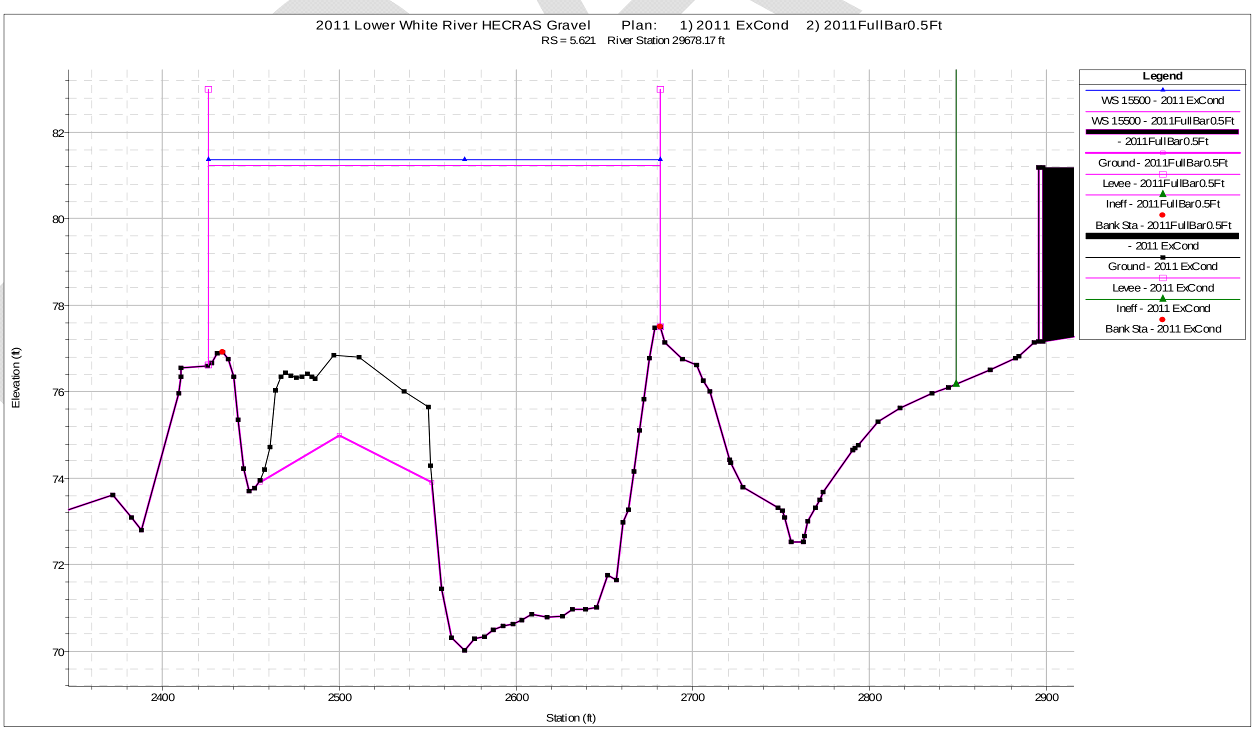

Figure 9: Cross section view of Lower White River water surface elevations at RM 5.621 (adjacent to White River Estates, Pacific) during a 15,500 cfs flood under 2011 Existing Conditions and Bar Scalp Scenario 3.

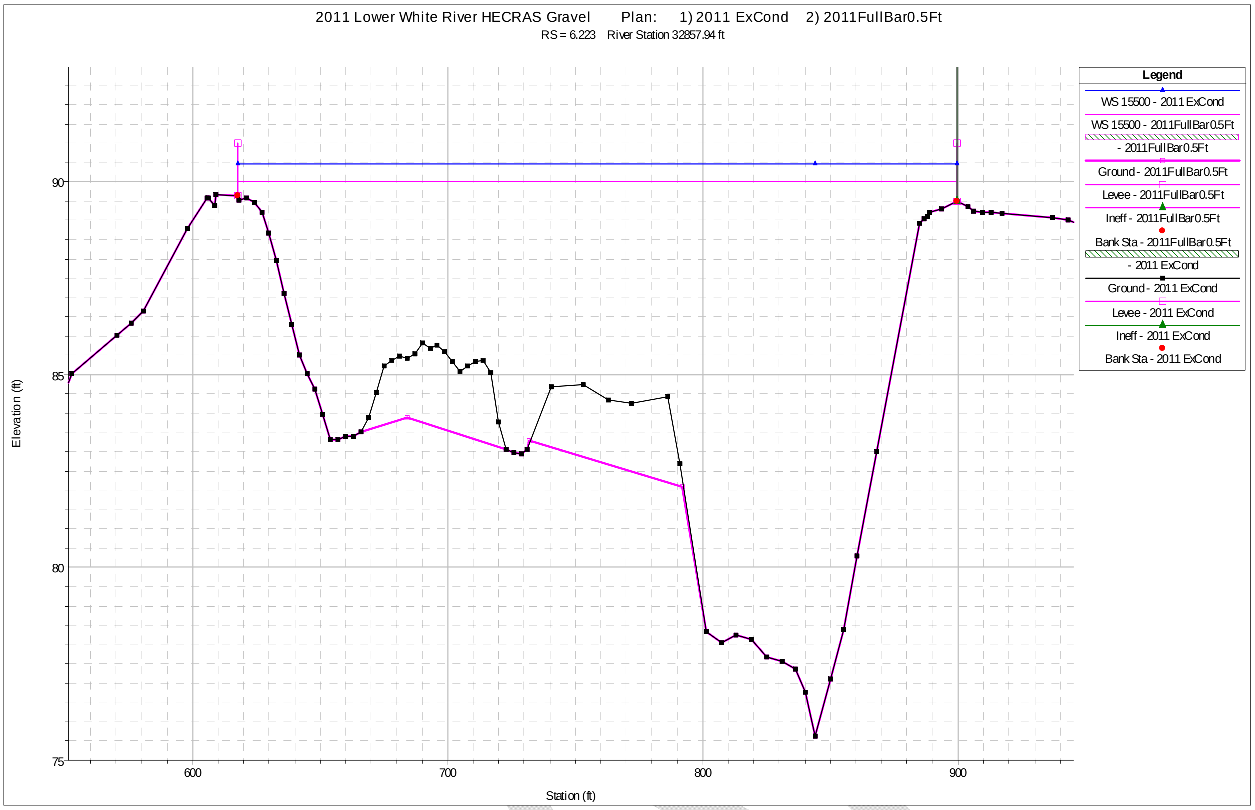

Figure 10: Cross section view of Lower White River water surface elevation at RM 6.223 (adjacent to 3rd Place South) during a 15,500 cfs flood under 2011 Existing Conditions and Bar Scalp Scenario 3.

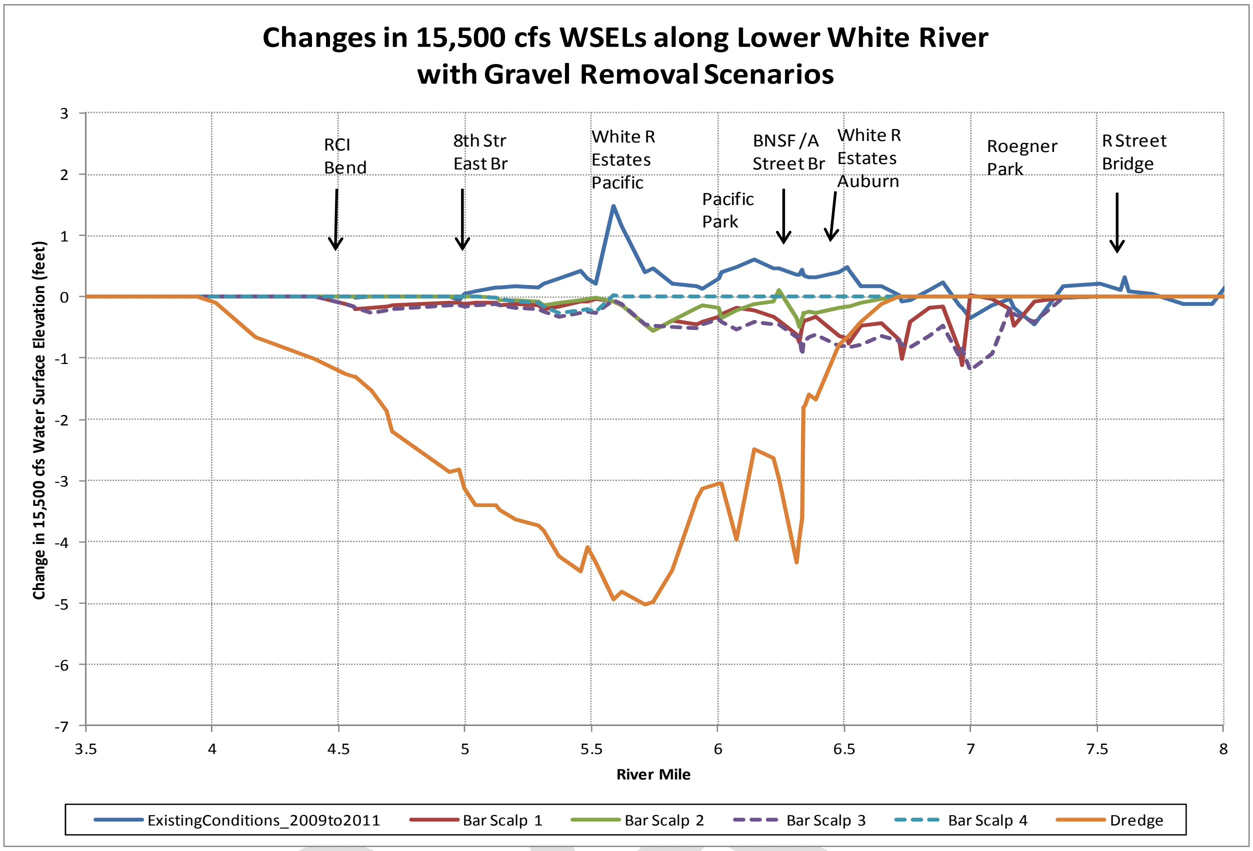

Figure 11: Change in Lower White River water surface elevations from 2009 Existing Conditions to 2011 Existing Conditions and from 2011 Existing Conditions to each of four Bar Scalping Scenarios and the Dredge Scenario.

The Dredge Scenario would result in decreases in the 15,500 cfs water surfaces of as much as 5 feet, e.g., at RM 5.712 (**Table 2**). Effects of the dredge scenario would vary through the area of analysis, but generally would decrease water surfaces during a 15,500 cfs flood by 3 to 5 feet between the 8th Street East Bridge and the BNSF/A Bridges. The effect of the Dredge Scenario would diminish upstream of A Street to no change in water surface elevations at about RM 6.7. The effect of the Dredge Scenario on water surface elevations during a 15,500 cfs flood is shown in profile view in **Figure 12** and in cross section view at selected locations in **Figure 13** and **Figure 14**.

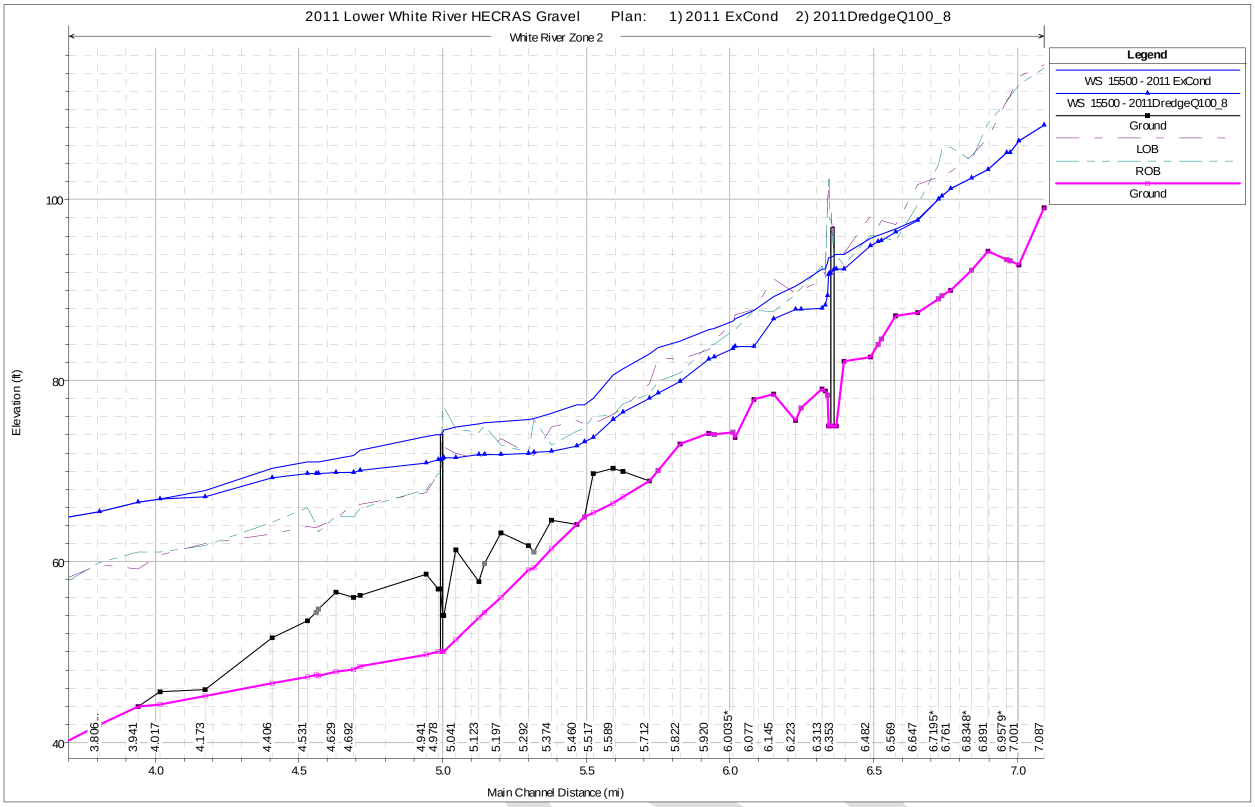

Figure 12: Profile view of Lower White River water surface elevation from approx RM 6.7, upstream of R Street Bridge to approx RM 3.9, well downstream of the 8th Street East Bridge, during a 15,500 cfs flood under 2011 Existing Conditions and Bar Scalp Scenario.

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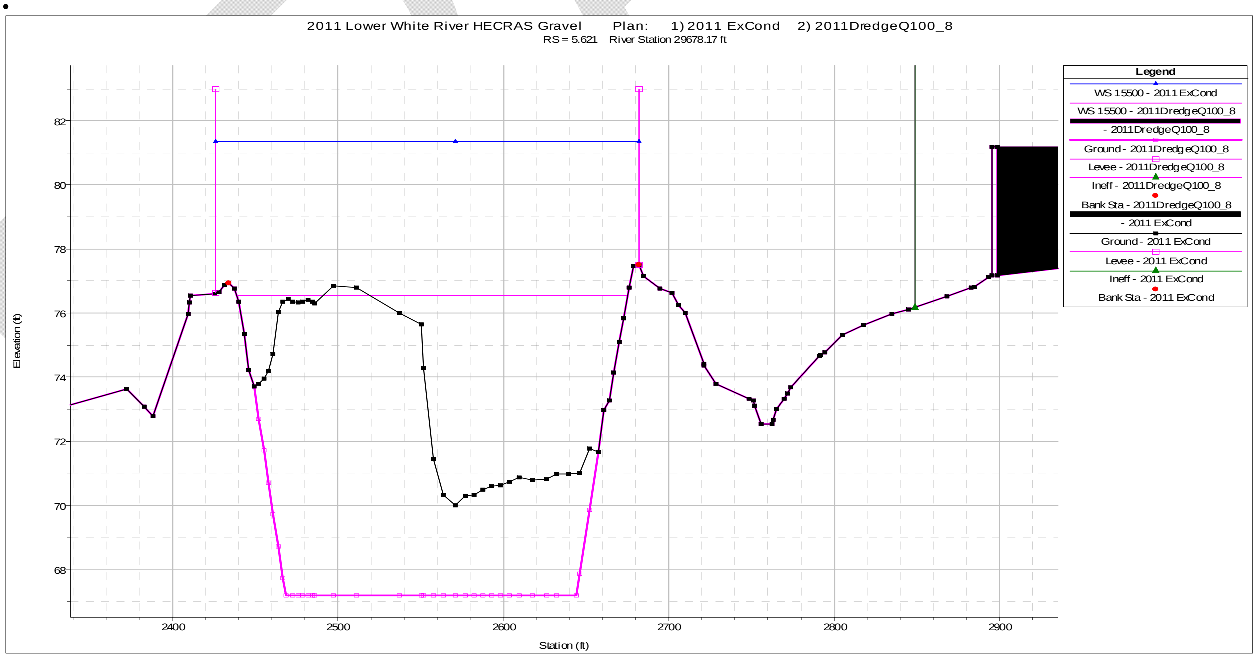

Figure 13: Cross section view of Lower White River water surface elevations at RM 5.621 (adjacent to White River Estates, Pacific, during a 15,500 cfs flood under 2011 Existing Conditions and the Dredge Scenario.

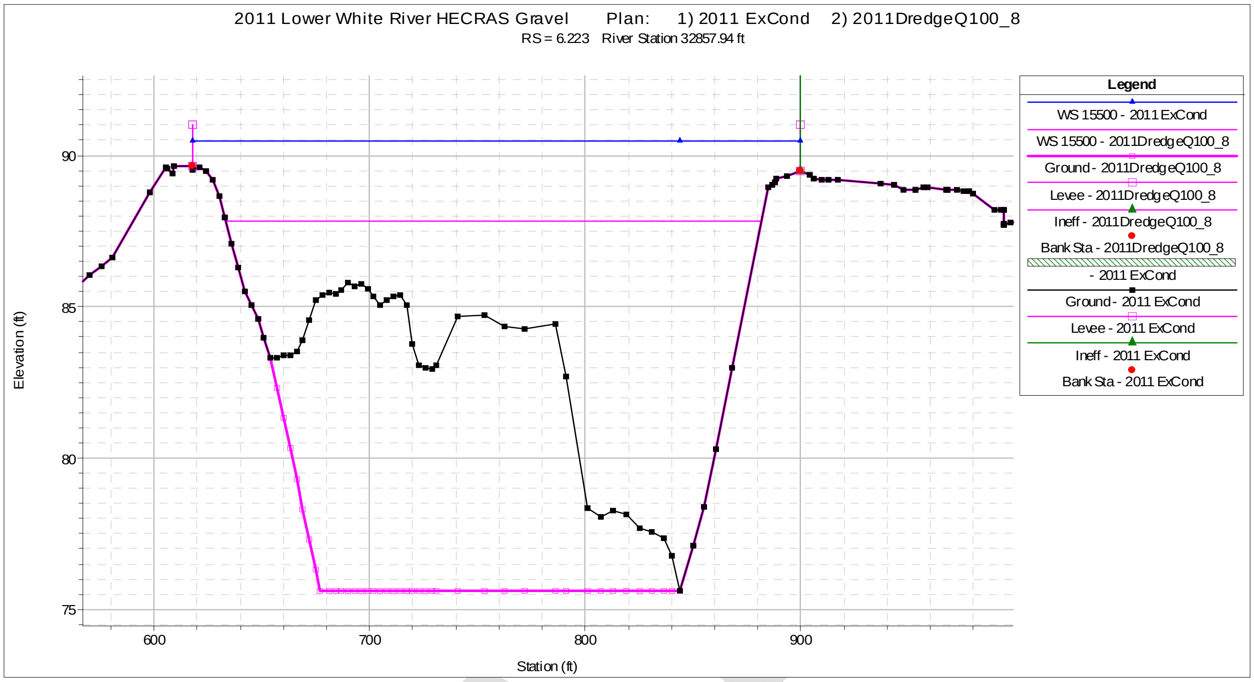

Figure 14: Cross section view of Lower White River water surface elevations at RM 6.223 (adjacent to 3rd Place South) during a 15,500 cfs flood under 2011 Existing Conditions and the Dredge Scenario.

[Other example plots from HEC-RAS modeling showing effect of gravel removal scenarios on water surface elevations may be provided in the final version of this document.]

3.2. Effect of gravel removal on channel conveyance capacity

The channel conveyance capacity, i.e., the maximum flow that is contained by the (lower) riverbank at any given location, was determined for 2009 and for 2011 existing conditions from RM 5 to RM 10.6 in the Lower White River 2011 channel monitoring summary (King County 2012d). Using the same methods, channel conveyance capacity was identified in this analysis at every channel cross section for each of the gravel removal scenarios. 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.

Results of this analysis are shown in **Figure 15**. The maximum modeled flow was 15,500 cfs, so that is the greatest channel capacity that was identified specifically. The channel conveyance capacity under both 2009 and 2011 existing conditions equals or exceeds 15,500 cfs from about RM 6.7 (along Roegner Park) and upstream. For that reason and because no gravel removal scenario would affect gravel bars upstream of about RM 7, **Figure 15** does not extend upstream of R Street Bridge at RM 7.6.

The bar scalping scenarios would result in relatively minor increases in channel capacity between RM 5 and RM 7 relative to 2011 existing conditions. The channel conveyance capacity resulting from the largest and most extensive bar scalp scenario, Bar Scalp 3, would be as follows at various locations through Reach 1: about12,500 cfs near the Potelco property (RM 3.7); about 4,000 cfs to 5,000 cfs along White River Estates Pacific (RM 5.4 to 5.7); a range of 9,000 cfs to 13,000 cfs along Pacific Park (RM 5.9 to 6.1); a range of about 12,000 cfs to 14,000 cfs along 3rd Place South (RM 6.15 to RM 6.3). In general, these channel conveyance capacities resulting from Scalp Scenario 3 would increase the channel conveyance capacity above the 2011 existing conditions to approximately match that of 2009 existing conditions from 8th Street East Bridge to the BNSF/A Street Bridges (RM 5 to RM 6.3). Scalp Scenario 3 would increase channel conveyance capacity to greater than that in 2009 from RM 6.3 to RM 6.7.

Scalp Scenarios 1, 2 and 4, with lesser excavation volumes and extent than Scalp Scenario 3, would be less effective at increasing channel conveyance capacity. None of the bar scalping scenarios would increase the channel conveyance capacity to anywhere close to 15,500 cfs between RM 5 and RM 6.7, unless the existing capacity was already very close to 15,500 cfs.

The Dredge Scenario would result in a channel conveyance capacity that equals or exceeds 15,500 cfs at almost every location between the 8th Street East Bridge and the BNSF/A Street Bridges (Reach 1). The channel conveyance capacity with the Dredge Scenario would match the 2011 existing conditions upstream of A Street, including approximately 12,000 cfs at RM 6.57**.** There would be a steady decrease in channel conveyance capacity downstream of 8th Street East with the Dredge Scenario to where it would match existing conditions near RM 4.0 at the downstream end of this scenario.

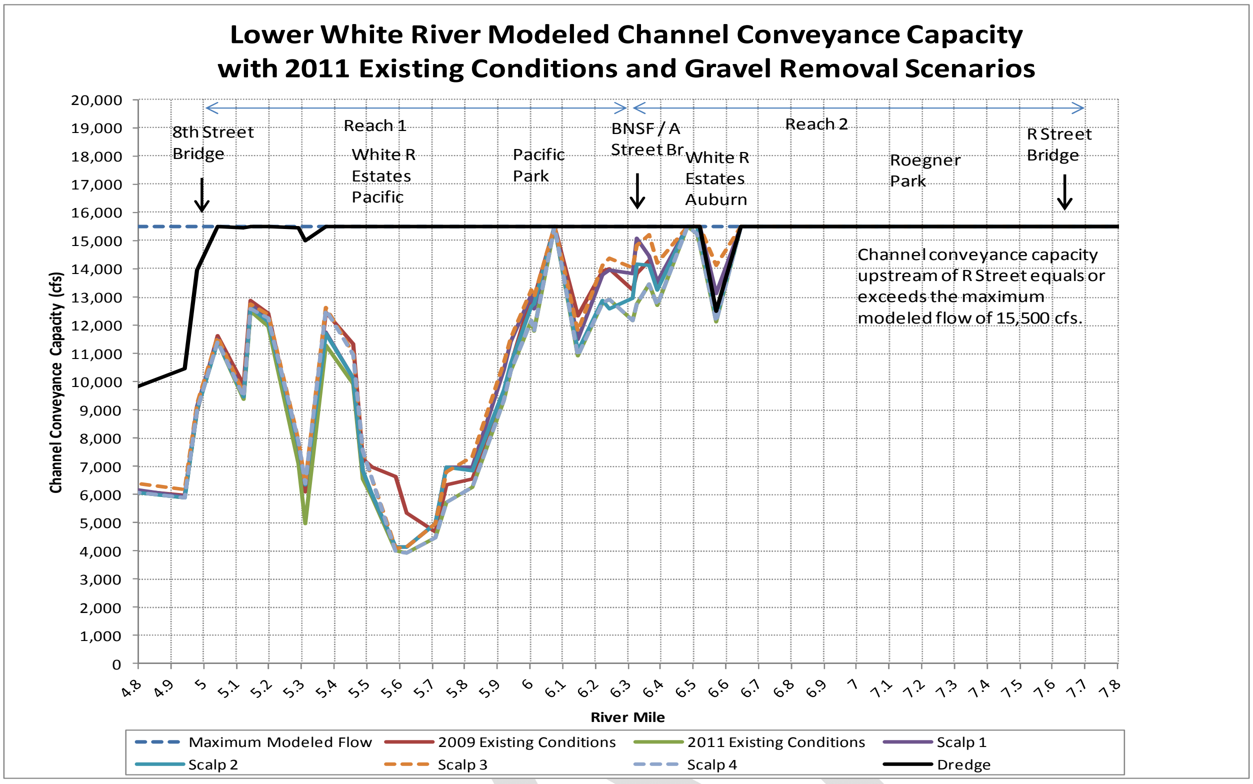

Figure 15: Channel conveyance capacity in Lower White River water surface elevations during a 15,500 cfs flood for the 2009 Existing Conditions, 2011 Existing Conditions, Bar Scalp Scenarios 1,2,3 and 4 and the Dredge Scenario.

3.3. Estimated costs and longevity of gravel removal scenarios

Planning-level costs of implementing the gravel removal scenarios were estimated based on unit cost values experienced by King County in similar capital projects. The costs include a number of components including construction costs for mobilization as well as sediment excavation and disposal. The unit cost used for these construction components was $35/cy yd. Other components necessary to prepare and conduct gravel removal would include planning and design, construction management, mitigation and monitoring. For the combination of all components to conduct gravel removal, the total estimated unit cost was $70/cy yd.

The estimated longevity of flood reduction benefits of a gravel removal scenario is calculated as the excavation volume divided by a representative sediment deposition rate. Two values were used to calculate the estimated longevity. One value represents a longer-term average deposition rate from 1984 through 2011, approx 13,000 cy/yr; the other value represents a shorter-term rate of 2001 through 2011 at 20,000 cy/yr. Deposition rates were determined through ongoing channel monitoring (King County 2012d). This approach to estimating longevity is recognized to be based on simplifying assumptions about sediment transport and deposition. It is used to provide a general estimate of longevity and a means to compare the different scenarios.

Bar Scalp Scenario 3, the largest and most hydraulically effective scalp scenario, would have a total cost of about $5.4M and its flood reduction benefits would persist for about 4 to 6 years. The smaller bar scalping scenarios would cost from $1.3M to $2.6M and have flood reduction benefits that would persist for 1 to 3 years. The total cost of the dredge scenario would be about $40M. Its flood reduction benefits would persist for 29 to 45 years, depending on the assumption used.

Table 3: Estimated costs of Lower White River 2011 gravel removal scenarios and estimated longevity of flood hazard reduction benefits.

Gravel Removal Scenario	Estimated Excavation Volume (cu yds)	Estimated cost using $35/cy [A] ($M)	Estimated cost using $70/cy [B] ($M)	Estimated Longevity [C] using rate of 1984-2011 (years)	Estimated Longevity [D] using rate of 2001-2011 (years)
Bar Scalp Scenario 1	37,000	$1.3	$2.6	2.9	1.9
Bar Scalp Scenario 2	20,000	$0.7	$1.4	1.6	1.0
Bar Scalp Scenario 3	77,000	$2.7	$5.4	6.0	3.9
Bar Scalp Scenario 4	18,000	$0.6	$1.3	1.4	0.9
Dredge Scenario	580,000	$20.3	$40.6	45.0	29.1

Table 3 notes:
A: $35/cubic yard is the estimated cost of excavation and mobilization only.
B: $70/cubic yard is the estimated total cost, including planning, design, CMI, mitigation and monitoring plus all of [A].
C: Estimated longevity equals estimated excavation volume divided by 13,000 cubic yards/year, i.e., the rate of sediment deposition during 1984-2011.
D: Estimated longevity equals estimated excavation volume divided by 20,000 cubic yards/year, i.e., the rate of sediment deposition during 2001-2011.

In addition to the hydraulic modeling of hypothetical gravel removal scenarios, the quantities of deposition that have occurred through various time periods may inform analysis of sediment volumes that would need to be removed in order to contain certain flows, primarily in Reach 1 (Table 4). The amount of time that has lapsed since that monitoring period began is an inferred longevity of flood reduction benefits if that volume were excavated today.

For example, amount of sediment that has deposited in Reach 1 from 2007 to 2011 is about 89,000 cubic yards. As recently as January 2006, just before that period, a flow of 12,400 cfs occurred without adverse flooding in this river reach. This suggests that if about 89,000 cubic yards were excavated today it would provide containment of 12,400 cfs in Reach 1. Using the same unit costs and longevity calculations as above, this excavation would cost $6M and its flood reduction benefits would last about 4 years.

The monitoring information also provides a longer-term example. Approximately 349,000 cubic yards have deposited in Reach 1 between 1984 and 2011. In 1984, there was a channel conveyance capacity that equaled or exceeded 19,000 cfs at almost every location in Reach 1, i.e., between the 8th Street East Bridge and BNSF/A Street Bridges (Prych 1988). These 1984 channel capacity would have reflected conditions at or near the end of a period of much dredging from the mid-1970s to the mid-1980s. There was subsequent containment of a number of floods ranging from 14,000 cfs to 15,000 cfs in the late 1980s and 1990s. This information on historical channel management practices, the 1984 to 2011 monitoring data plus the 1980s to 1990s empirically demonstrated channel capacities suggests that sediment excavation from Reach 1 on the order of 350,000 cubic yards would be necessary to reestablish a channel capacity of 15,500 cfs. It should be noted that additional excavation than this volume, extending downstream of Reach 1, likely would be necessary because the hydraulic conditions at any given location are controlled by downstream channel conditions in the subcritical flow regime present in the Lower White River. (This is the likely reason that the excavation volume in the Dredge Scenario is so much larger than 350,000 cubic yards.)

This empirically based information is intended as a check on the analysis of hypothetical gravel removal scenarios. These volumes and the inferred longevities (**Table 4**) generally are consistent with the volumes and longevities found from analysis of gravel removal scenarios (**Table 3**).

Table 4: Lower White River Reach 1 deposition volumes and estimated costs and longevity of flood hazard reduction benefits if those volumes were excavated now.

Monitoring Perod or Example	Deposition Volume in Reach 1 only (cu yds)	Estimated cost to excavate @ $35/cy [A] ($M)	Estimated cost to excavate @ $70/cy [B] ($M)	Amount of time taken to actually deposit the volume, and therefore the inferred longevity if this volume were excavated now (in years).
2007-2011	89,000	$3.1	$6.2	4
Intermediate Example	140,000	$4.9	$9.8	approx 7
2001-2011	200,000	$7.0	$14.0	10
1984-2011	349,000	$12.2	$24.4	27

Table 4 notes:
A: $35/cubic yard is the estimated cost of excavation and mobilization only.
B: $70/cubic yard is the estimated total cost, including planning, design, CMI, mitigation and monitoring plus all of [A].

4. Discussion

The bar scalping scenarios would result in moderate decreases in the 15,500 cfs water surface elevations, but would not come close to reestablishing a channel capacity of 15,500 cfs throughout Reach 1. Through most of Reach 1 and 2, the bar scalping scenarios generally would result in water surface elevations and a channel capacity would approximately match those in 2009 existing conditions. Overall, these results indicate that gravel removal by any of the gravel bar scalping scenarios would be ineffective in achieving the stated objective of reestablishing a channel conveyance capacity of 15,500 cfs. Both the analyses of gravel removal scenarios and the empirically based examples suggest that if a channel conveyance capacity 15,500 cfs is to be achieved in Reach 1 of the Lower Whiter River by means of gravel removal, that gravel removal would need to be conducted as in-channel dredging.

5. Summary and conclusions

- The White River basin is a naturally sediment-rich setting and the Lower White River is an area naturally predisposed to sediment deposition, especially what is referred to as Reach 1 of the Lower White River, from the 8th Street East Bridge (RM 5.0) to the BNSF/A Bridges (RM 6.3).
- The Lower White River 2011 channel monitoring summary (King County 2012d) concluded that it is appropriate to consider gravel removal as a flood hazard reduction strategy in the Lower White River, primarily in Reach 1.
- The gravel bar scalping scenarios analyzed herein would result in various magnitudes and extents of decreases in the water surface elevations during a 15,500 cfs flood.
- Bar Scalp Scenario 3 would result in the largest decreases in the 15,500 cfs water surface elevations through the largest length of river channel, e.g. as much as 0.7 feet in Reach 1 and 1.2 feet in Reach 2. Aspects of Bar Scalp Scenario 3 are inconsistent with WAC provisions regarding gravel removal.
- Bar Scalp Scenario 1 would cover almost as great an extent as Scalp Scenario 3. It would result in about 0.5 foot decreases in the 15,500 cfs water surface elevations in Reach 1 and about a 1 foot decrease in Reach 2.
- Bar Scalp Scenario 2 would have similar results as Scalp Scenario 1 but only in Reach 1.
- Bar Scalp Scenario 4 would have only a minimal effect localized to the downstream end of Reach 1.
- In general, gravel removal by the bar scalping scenarios would result in decreasing the 15,500 cfs water surface elevation and increasing channel conveyance capacity to approximately match those observed under 2009 existing conditions.
- None of the four bar scalping scenarios would come close to increasing the channel conveyance capacity to 15,500 cfs in Reach 1, which was the identified as primary objective of any gravel removal scenario.
- The Dredge Scenario would result in decreases in the 15,500 cfs water surface elevations of about 5 feet in Reach 1. It would result in a channel conveyance capacity of 15,500 cfs at most locations within Reach 1.
- The estimated planning-level total cost of Bar Scalp Scenario 3 is $5.4M. The estimated amount of time that its flood hazard reduction benefits would persist (longevity) is about 4 to 6 years, depending on the assumption used.
- Costs of the other scalping scenarios range from $1.3M to $2.6M and their longevities are estimated at 1 to 3 years.
- The estimated planning-level total cost of the Dredge Scenario is about $40M. Its longevity is estimated at 29 to 45 years, depending on the assumption used.
- Quantities of sediment deposition, observed from channel monitoring, and inferred longevities of flood reduction benefits if those volumes were excavated today, generally are consistent with the volumes and longevities calculated for the gravel removal scenarios.
- The results of these analyses are provided to inform development of potential flood hazard and flood risk reduction strategies in the Lower White River, primarily Reach 1 of the monitoring area (8th Street East Bridge to the BNSF/A Street Bridges).

6. References

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