APPENDIX G

BRIDGE SEDIMENT REMOVAL GUIDELINES FOR AHTANUM & WIDE HOLLOW CREEKS

One of the major flood issues brought forth by the Committee and Staff in the development of this CFHMP is capacity of County and City road system bridges, and some private bridges, to convey flow during flood events such as the 10-, 25- and 100-year floods.

As described in Chapters 4, 7, and 8, the flat valley bottoms, the geologic tilting of the basins, and modification of the drainage network for irrigation/development, gives rise to relatively (compared to other basins) wide areas of flood inundation, and multiple interlacing shallow overflow paths. During flood events there is extensive interaction between the natural and modified drainage system, the irrigation distribution system, and the transportation system. The extent of these interactions are reflected in the recently completed 10 -, 25- year and 100-year floodplain maps.

In order to evaluate the flood management options for bridges on the Ahtanum and Wide Hollow Creeks, the Yakima Countywide Flood Control Zone District performed hydraulic analyses on the common bridge dimensions and channel characteristics in these two watersheds. From this exercise, sediment removal guidelines at bridges are determined then applied to seven example bridges where flooding problems exist. The revised (post-excavation) flood extents are also provided for the 10, 25 and 100-year flood maps. The analyses were performed using the HEC-RAS model, a public domain model developed over six decades by the US Army Corps of Engineers, and used in the development of the new FEMA maps for these watersheds.

This appendix focuses on the common condition of a narrow bridge over a small creek or combined creek and irrigation conveyance channel. Following the guidelines and application of the guidelines to seven example bridges, other scenarios are discussed.

BRIDGE HISTORY

Most of the bridges in the Ahtanum and Wide Hollow drainages were originally constructed by Yakima County, even though many are now within City limits through annexation. Many of those bridges date from the 1940s to the 1970s and are of similar design, width and depth regardless of where they are in the drainage network. It is unlikely that hydraulic capacity of the bridge relative to flood flows was examined as those flows were poorly defined. The FEMA and/or hydraulic code requirements for sizing of bridges to pass the 100 year flood did not exist until the 1980s.

For many years, State of Washington road standards classified “bridges” as spans 20 or more feet in length, “culverts” were classified as spans of 20 feet in length or smaller. “Bridge” construction qualified for state funding assistance, while “culverts” did not. In order to receive State assistance for bridge construction, many bridges were constructed at or near 20 feet in length. These funding categories had a major effect on the types of bridges constructed. Many of these bridges, especially in the more rural and western portions of the basin, have not been replaced and will not be replaced in the forseeable future. There is a subsequent “legacy” of numerous 20 foot span bridges that may exist well into the future, and need to be managed relative to flood conveyance capacity until they are replaced.

Bridge Channel Dimensions

Bridges have three major components; the deck, the abutments and the approaches. The bridge deck spans the stream channel and in this basin is generally elevated 5-8 feet above the stream bed. The bridge abutments support the bridge and generally have "footings" or a foundation for the bridge structure. The length of the bridge deck and the depth of footings determine the hydraulic flow capacity of the bridge. The approaches are composed of areas of fill on either side of the bridge which transition the road bed from the elevation of the adjacent floodplain to the elevation of the bridge deck. In most locations the road surface is elevated 1.5 to 3 feet above the natural ground surface. Since these floodplains are so broad and the flood overflow paths so extensive, the road and/or bridge approaches may cut off flood overflow paths in the floodplain, forcing all flow to pass underneath a bridge, or resulting in overtopping of the road at some distance from a bridge. For simplicity, the following bridge sediment removal guidelines will assume that the the road surface is level and only extend one hundred feet from the bridge.

BRIDGE HYDRAULICS IN THE AHTANUM AND WIDE HOLLOW DRAINAGES

The hydraulics of the stream channels and bridges in these basins, which occur in fine sediment deposits, behave in a manner known as "Sub-Critical flow"; that is to say, the behavior of the water flow is affected by what is downstream of a section rather than what is upstream of the section.

The capacity of a bridge is controlled by two constraints. The first constraint is the capacity of the channel downstream of the bridge. The capacity of this channel is determined by the geometry of the channel – a large channel with a lot of cross-section area caries a larger flow for the same gradient compared to one with smaller cross section. The roughness of the channel – is it lined with rounded gravels and rocks, or lined with grasses, shrubs, and trees – and the steepness of the channel are the other critical factors which affect the channel capacity. A high water surface downstream of the bridge, whether by elevated channel bottom or by reduced channel capacity restrains the water trying to flow through the bridge.

The second constraint controlling the flow through a bridge is the size and shape of the bridge opening itself. Only so much water will pass through a given size of bridge. Abutments, piers, & aprons will have a minor effect on the water flowing through the opening, but will cause head loss in water approaching the bridge. The amount of water which can pass through the bridge determines the height of water at the upstream face of the bridge.

Hydraulic behavior of the flow varies with differing depths of water surface on the upstream side of the bridge. Up to the point where the water surface impinges on the lower chord of the bridge, flow is classical "open channel", subject to the head losses of contraction from the abutments & piers. As flows approach the bridge, there will be a "funnel" effect, where depth of flow will be traded for velocity to get the flow through the bridge opening. This funnel effect will extend sideways, parallel to the bridge, as well as upstream.

Once the upstream water surface touches the bottom chord of the bridge, "Sluice Flow" occurs, so named because of the behavior of sluice gates. Flow passes under the bridge in a high-velocity condition, and exits the bridge, into the downstream channel, which may be like a stagnant pond, or a flowing channel. In either case, flow under the bridge is open channel.

If water level on the downstream face is impinging the bottom chord, or high enough, flow under the bridge operates under pressure flow, and the discharge behaves as though it were flowing in a pressurized water line. Water level on the upstream side of the bridge will rise to a depth sufficient to drive the flow through the bridge against the resistance o the bridge opening, bridge "pipe", and the water barrier on the other side. As the amount of flow increases, the water level on the upstream side of the bridge will rise until it overtops the bridge.

Water flowing over the top of the bridge flows as over a weir. Large increases in the flow quantity will produce relatively small amounts of rise in the upstream water. The road may be unpassable at this point.

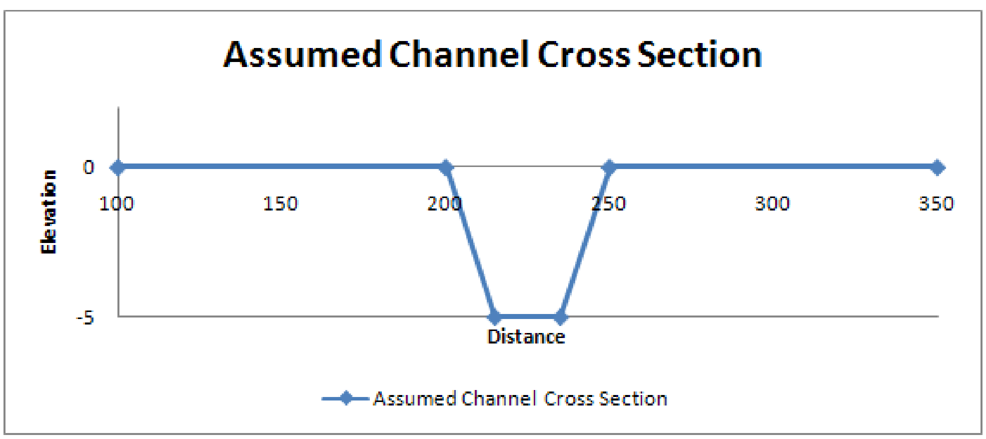
In summary, excavation upstream of a bridge will reduce water surface elevation and help prevent overtopping of the bridge, but will not fundamentally change bridge capacity. Excavation downstream of the bridge will reduce water surface downstream of the bridge and increase the overall capacity of the bridge to convey flood flows.

BRIDGE SEDIMENT REMOVAL GUIDELINES

Assumptions for Sediment Removal Guidelines

The first step of the analysis was to develop a set of "typical" stream channels and bridge dimensions entirely through the use of the HEC-RAS model. These entirely theoretical channel and bridge combinations will be referred to in this document as the "Guideline Streams".

Dimensions for the channel and the bridge were assumed as shown in Figure 1.



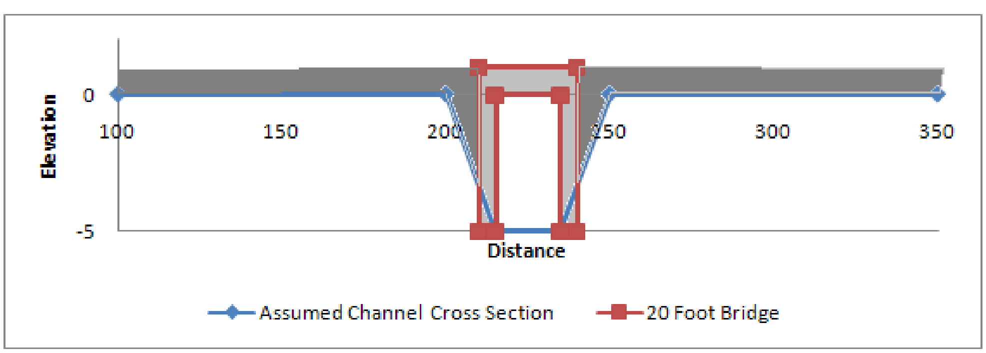


Figure 1 – Assumed channel and bridge cross sections

Guidelines for sediment removal were developed with these assumptions:

- Channel Dimensions - The stream channel dimensions were assumed to be a 20 foot channel bottom width and 3:1 side slopes. This channel width was a good representation of the average channels in the bridge locations. The channel dimensions and bridge layout are shown on Figure 1. As noted above, no flow is allowed over the bridge approaches. These “model” channels were simulated over the range of observed slopes though use of 3 different gradients, a 0.4% gradient typical of Wide Hollow Creek downstream of 16th Ave; and most of Bachelor and Hatton Creeks; a 0.7% gradient more typical of drainages in “hollows” such as lower Cottonwood, lower Shaw, Upper Wide Hollow, Bachelor and Hatton Creeks; and a steeper 0.95% channel typical of North and South Fork Ahtanum and upper reaches of Shaw, Wide Hollow, Pine Hollow and the flood channels that come off of Pine Mountain.
- Channel Roughness - A critical component in evaluation of the ability of the channel to convey water is the channel roughness coefficient or “Manning’s n”. For the initial state in these channels, the roughness was set to conditions obseved in these watersheds; a relatively high channel roughness coefficients of 0.07, reflecting the often extreme amounts of vegetation in the channels. The “Manning’s n” values was lowered in the area where sediment was removed to reflect a lower channel roughness, 0.04. Reductions in water surface elevations upstream and downstream of the bridges are therefore a reflection both of increased channel cross sectional area and increased channel conveyance due to decreased channel roughness.
- Bridge Dimensions - 20 feet wide 5 foot depth to footing (5 feet from the channel to the bottom chord of the bridge) was installed in the simulation to determine the effect of the bridge. Each gradient without a bridge in place was modeled over a range of flows (0-1600 cfs) to establish a baseline backwater profile.
- Upstream Excavation - The maximum amount of excavation occurs upstream of the bridge. in the excavated channel.Gradients higher than 2% would probably cause the development of headcuts upstream during even minor flood events.
- Downstream Excavation - The excavation gradient downstream was set at zero – i.e. a flat gradient downstream from the bridge face until the excavation comes into contact with the downstream channel. Sediment removal was modeled at 1 foot, 2 foot, 2.5 foot, and 3 foot depths, measured at the upstream bridge face. A profile of the typical excavation is shown in Figure 2.

Figure 2 shows the differing excavations shapes and dimensions upstream and downstream of the bridges in order to “daylight” the excavation, minimize excavations and optimize hydraulic conditions. More material is generated by excavation upstream, the initial upstream excavation results in a larger “cut” below existing ground surface.

Results for the excavations for the conditions with no bridge, and for the three bed profiles are shown in Figure 3. They are presented as water surface elevation at the upstream face of the bridge versus flow.

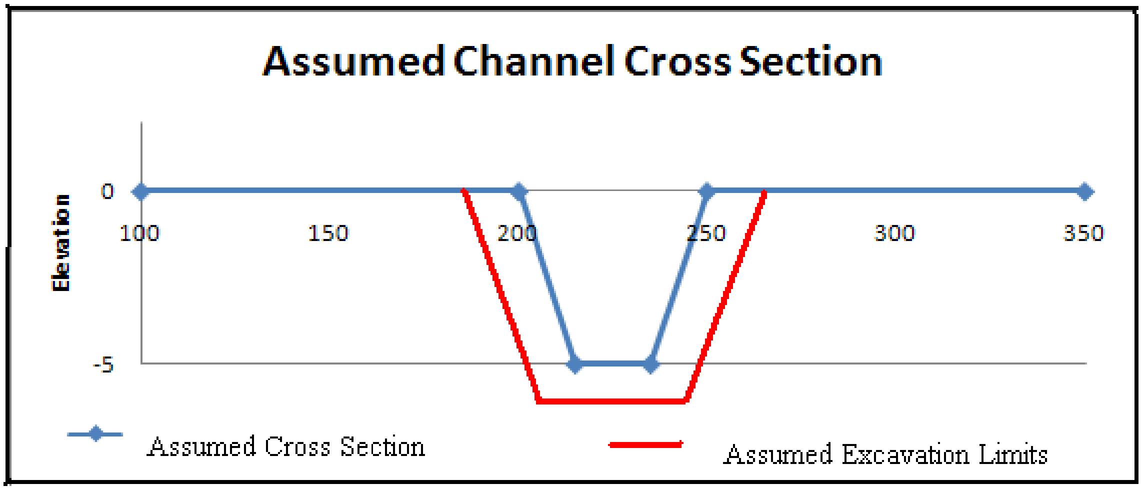
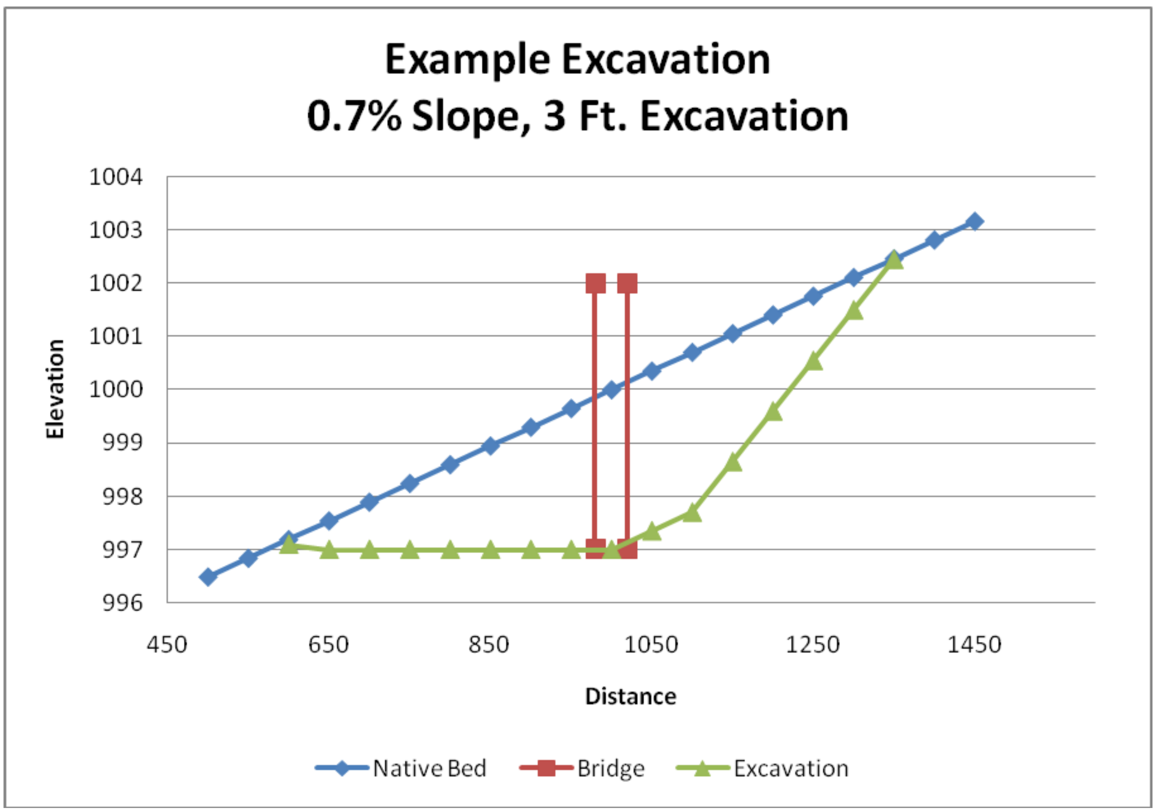
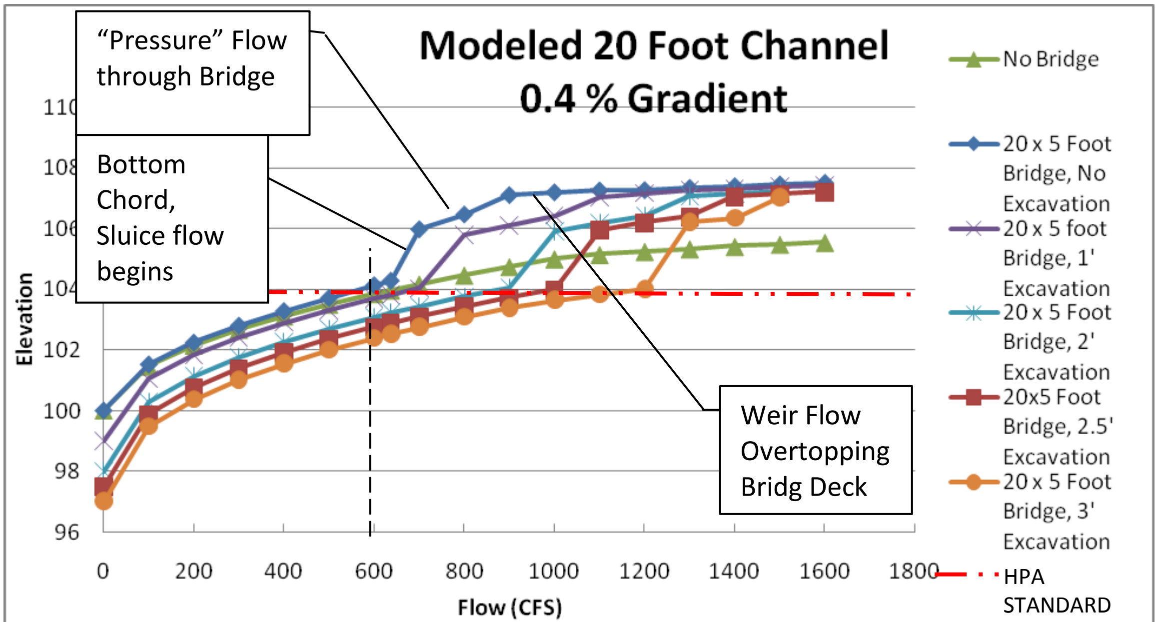


Figure 2 – Assumed excavation cross section and profile




Modeled 20 Foot Channel
0.4 % Gradient
"Pressure" Flow through Bridge
Bottom Chord, Sluice flow begins
Weir Flow Overtopping Bridg Deck
Elevation
Flow (CFS)
96
98
100
102
104
106
108
110
0
200
400
600
800
1000
1200
1400
1600
1800
No Bridge
20 x 5 Foot Bridge, No Excavation
20 x 5 foot Bridge, 1' Excavation
20 x 5 Foot Bridge, 2' Excavation
20x5 Foot Bridge, 2.5' Excavation
20 x 5 Foot Bridge, 3' Excavation
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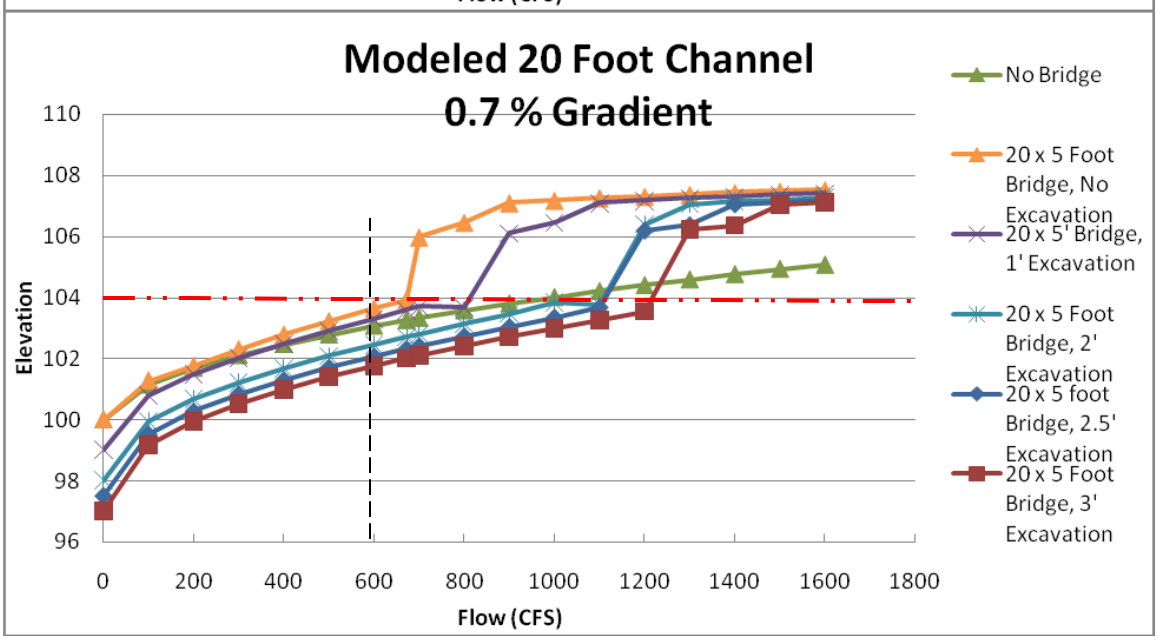

Modeled 20 Foot Channel
0.7 % Gradient
Elevation
Flow (CFS)
96
98
100
102
104
106
108
110
0
200
400
600
800
1000
1200
1400
1600
1800
No Bridge
20 x 5 Foot Bridge, No Excavation
20 x 5' Bridge, 1' Excavation
20 x 5 Foot Bridge, 2' Excavation
20 x 5 foot Bridge, 2.5' Excavation
20 x 5 Foot Bridge, 3' Excavation

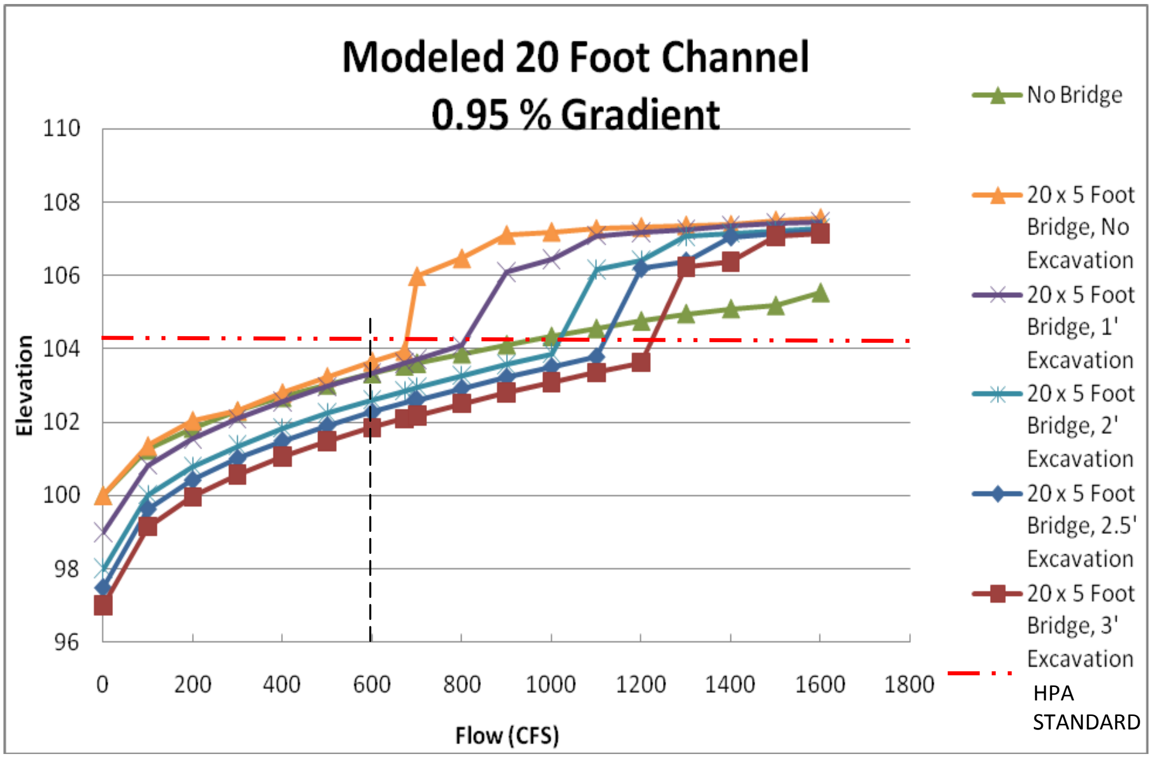


Figure 3 – Flow Conveyance Improvement versus excavation depth, 20 foot bridges.

For all gradients, the effect of the bridge relative to the no-bridge scenario begins at flows of 200 cfs or less, with minor rises in water elevation at the upstream face of the bridge until flows rise above 600 cfs. Just above 600 cfs a threshold is reached where the constriction in flow caused by the bridge triggers a change from normal flow to "sluice flow" through the bridge – ie. water surface slopes upstream of the bridge are very steep and water "dives" through the bridge. Past this point, relatively minor increases in flow cause the type of flow to shift again, to "pressure flow", which in turn causes the water level to rapidly rise and come into contact with the bridge chord and lower structure. Further increases in flow cause additional gradual rise as the increased pressure of the rising water upstream forces more water at higher velocity through the bridge opening.

Eventually, the bridge and adjacent roadway is overtopped and capacity is greatly supplemented by weir flow over the bridge deck and the water surface elevation levels off over a wide range of flows. When the bridge is overtopped, it becomes impassable to traffic. In general, streams with differing gradients showed a similar response to the bridge, only minor backwater effect (less than half a foot) until the flow reaches above 600 cfs, and these bridges are overtopped between 800 and 900 cfs.

Also shown on the graphs as HPA (Hyraulic Project Approval) is the current bridge standard from the Hydraulic Code, found at WAC 220-110-070, which states 2 criteria specific to the hydraulic capacity of the bridge:

1) *"The Bridge shall be constructed, according to the approved design, to pass the 100-year peak flow with consideration of debris likely to be encountered. Exception shall be granted if applicant provides hydrologic or other information that supports alternative design criteria", this criteria is usually interpreted in Eastern Washington to have at least one foot of clearance below the bridge at the 100 year flow;*

2) *"Abutments, piers, piling, sills, approach fills, etc., shall not constrict the flow so as to cause any appreciable increase (not to exceed .2 feet) in backwater elevation (calculated at the 100-year flood) or channel wide scour and shall be aligned to cause the least effect on the hydraulics of the watercourse."*

This elevation is shown as an aid in use of the graphics to better illustrate real-world design constraints. For the Guideline Streams, this criteria was not used in the development of the tables that show excavation distance and volume. This is because in these "artificial" streams, a 100 year flow value was not defined as a characteristic of a bridge or stream, this exercise was an initial attempt to look a bridge conveyance capacity.

Channel Gradient	Excavation Depth	Excavation Distance (ft.) from Upstream Face		Excavation Volume (cu. yd.)		Total Ex.
		Upstream	Downstream	Upstream	Downstream	
0.40%	1	200	250	296	248	544
	2	250	500	730	994	1724
	2.5	300	625	1204	1520	2724
	3	300	750	1318	2257	3575
0.70%	1	200	150	296	68	364
	2	300	300	832	495	1327
	2.5	300	350	1070	772	1842
	3	350	450	1479	1270	2749
0.95%	1	200	100	308	61	369
	2	300	200	832	341	1173
	2.5	350	250	1204	588	1792
	3	350	300	1475	847	2322

Table 1 – 20 foot channel bridge conveyance Excavation Volumes and Distances

Table 1 reveals that more excavation distance and quantity is required for lower gradient streams than for higher gradient streams. The above numbers can be graphed to evaluate the effectiveness of excavation distance or quantity to reductions in water elevations at different flows, and the 2 foot excavation is again most efective for the 0.4% and 0.7% gradients. The 0.95% gradient channel shows the greatest relative efficiency at the 1 foot excavation level, probably due to the higher channel velocities at this steeper gradient – i.e. relatively small increases in area have a large effect at higher velocities.

It appears from the graphs and model results that bridges of this dimension would meet the Hydraulic Code Standards without additional excavation for 100 year flows of less than 500 cfs for the 0.4% and 0.7% gradient streams, and less than 400 cfs for the 0.9% gradient streams.

Bridge Design Implications

Looking at these model characteristics, it became apparent that this analysis can also be used for a raw model for sizing or siting of bridges within the watershed. For example, if a 20 x 5 foot bridge could convey 500 cfs without backwater, then bridges of these dimensions could be appropriate for areas of the watershed where the 100 year flow is less than 500 cfs. Tables and maps presented in both the Wide Hollow and Ahtanum Hydrology Reports (Attachment A and Attachment B to this Appendix) can be used to determine the various parameters at various locations in these watersheds. For example, 100 year flows less than 500 cfs would include the tributaries of Wide Hollow Creek such as Wide Hollow and Cottonwood Creeks above their confluence, and Shaw Creek. In the Ahtanum System, all of Hatton Creek has 100 year flows below 500 cfs, as do several other overflow paths. Bridges located downstream of the Wide Hollow/Cottonwood confluence, such as the two bridges on Wide Hollow Road between 96th and 80th, would not convey the 100 year flow, or even the 50 year flow, without backwater under ideal, modeled conditions. Bridges of this dimension on the Bachelor Creek System in the Ahtanum, as well as on the mainstem Ahtanum, both of which have many bridges of this size, would also not convey the 100 year flood in conformance with the Hydraulic Code standards. All of the bridges, or roadways immediately adjacent to bridges, on Bachelor Creek become impassable at the 100 year flow, as do most of the bridges of this size and larger on mainstem Ahtanum Creek.

Effectiveness of Excavation

As the graphs above show, all of the excavation scenarios do improve the conveyance capacity of the bridges. It appears that all of the improvements are relatively consistent, with the 2 foot excavation allowing the greatest marginal level of improvement for quantity of flow without contact with the lower chord or overtopping for all gradients. The different stream gradients result in steepening of the curve once the bottom chord is contacted – given the same flow volumes the bridge will overtop sooner with higher gradients.

Effectiveness is also a function of the amount of excavation needed and the distance of channel that would be disturbed in order to achieve the hydraulic results above. Excavation itself has an economic cost, the variables include the cost of mobilizing equipment to the site or sites, the cost of excavation itself, and the cost of hauling and disposing of the material. Excavation of small amounts of material (less than 250 cubic yards) is very expensive due to the relatively high cost of mobilization for such a small amount. Excavation of larger quantities of the types of materials in stream channels can be estimated to be approximately $15 per cubic yard

The total length of channel disturbed has an effect on the environment, and the types of environmental impact may vary by location, which will affect both the time and likelihood of getting permits to perform the work. For instance, sediment removal in the upper Wide Hollow watershed would have minimal environmental effect on fish and wildlife, or water quality, as these channels are mostly dry outside of the irrigation season and are not considered high quality fish habitat. For this reason, permits for sediment removal in these can normally be secured, with minimal or no mitigation requirements. The same activities in the South Fork Ahtanum, however, would have impacts on fisheries and wildlife habitats as well as water quality, and may be difficult to get permitted or have very high mitigation requirements. In addition, the majority of the work, and access sites to perform the work, will occur on private lands, outside of public rights of way. Securing property owner permission and mitigating impacts to private lands may also significantly affect the project design, timeline and budget.

Summary – 20 Foot Bridges

This modeling exercise, when combined with the hydrology reports for the two basins, can be useful for sizing bridges, estimating when bridges will initiate backwater and nuisance flooding, and at what point they will be overtopped. Maintenance or conveyance improvement for existing bridges can also be evaluated, with the most efficient improvements in the range of 1-2 foot of excavation in the channel. Costs associated with such excavation at an estimated $15 per cubic yard for excavation would be in the range of $5,500 for higher gradient streams, to $26,000 for lower gradient streams, plus the cost of permitting, mitigation and landowner permission. These results are only applicable to idealized situations which may or may not occur in the watershed in the real world, and are likely most applicable to the construction or installation of new bridges or ongoing maintenance activities. Later in the appendix, excavations at existing bridges are shown to require an initial excavation much greater than estimated through this portion of the modeling exercise. This is often due to sediment stored upstream of bridges over periods that can extend up to 100 years in this basin.

The Effect of Increasing Bridge Span

The analysis was extended to 30 foot bridges occupying the same channel. As expected the results show that the longer spans lengthen the range of flows under "orifice flow", increase the flow required to develop significant backwater, and require less excavation to prevent bridge overtopping.

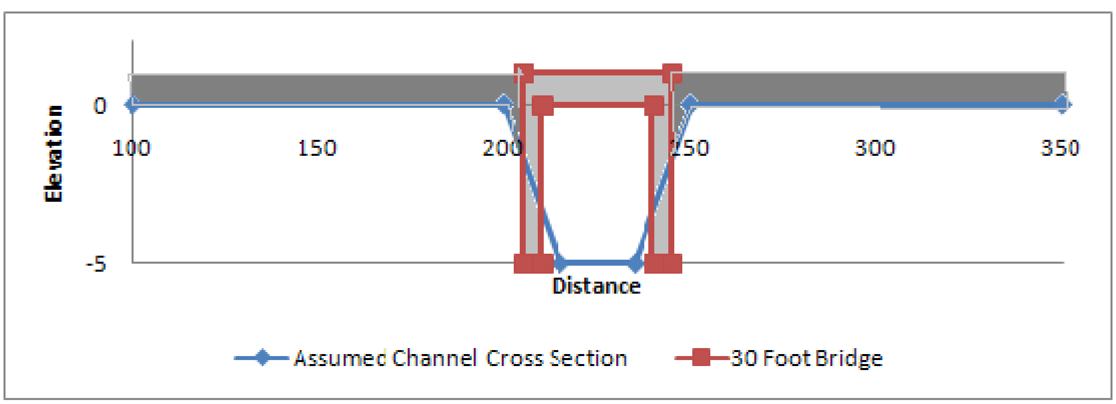
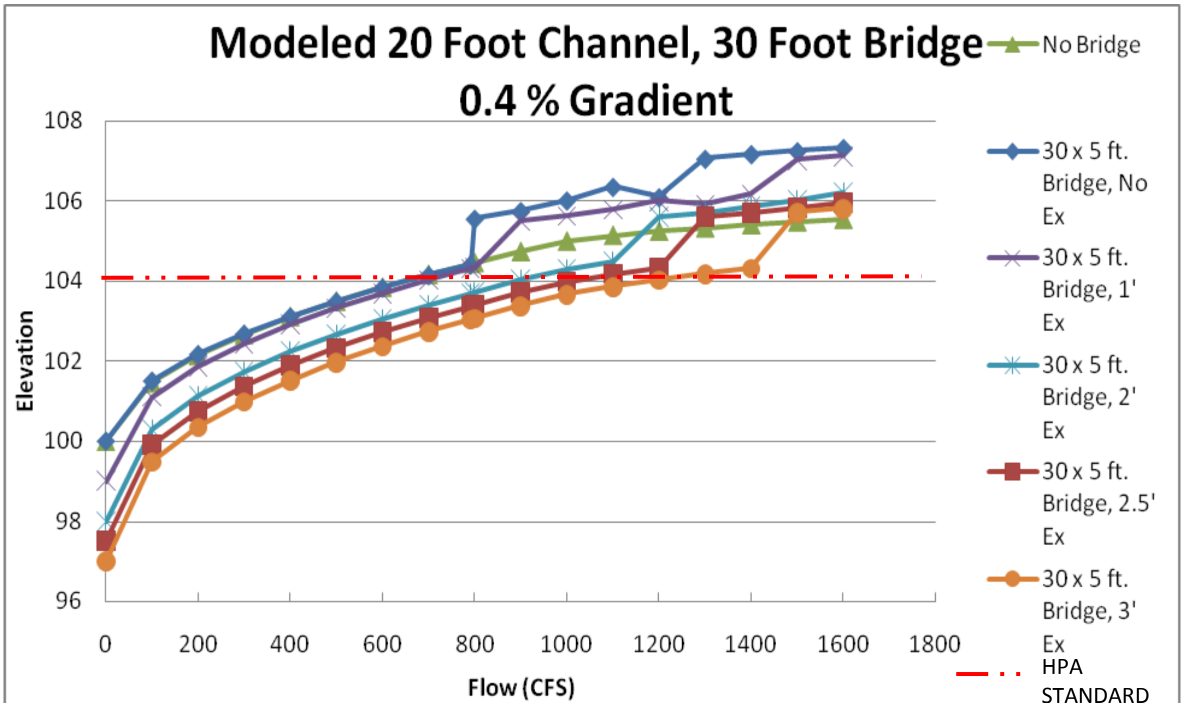
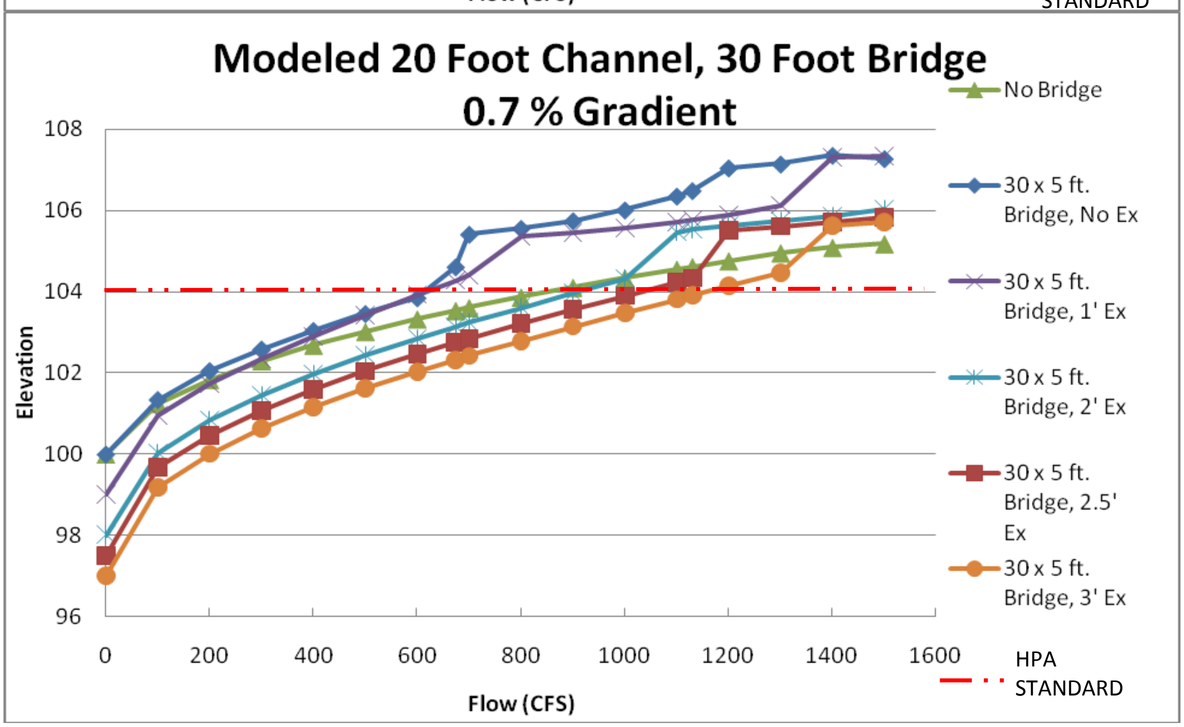


Figure 4 – Cross Section of a 30 foot bridge overlayed on assumed 20 foot channel. Note that the footings, and abutments lie outside of the active channel.


Modeled 20 Foot Channel, 30 Foot Bridge
0.4 % Gradient
Elevation
108
106
104
102
100
98
96
0
200
400
600
800
1000
1200
1400
1600
1800
Flow (CFS)
No Bridge
30 x 5 ft. Bridge, No Ex
30 x 5 ft. Bridge, 1' Ex
30 x 5 ft. Bridge, 2' Ex
30 x 5 ft. Bridge, 2.5' Ex
30 x 5 ft. Bridge, 3' Ex
HPA STANDARD


Modeled 20 Foot Channel, 30 Foot Bridge
0.7 % Gradient
Elevation
108
106
104
102
100
98
96
0
200
400
600
800
1000
1200
1400
1600
Flow (CFS)
No Bridge
30 x 5 ft. Bridge, No Ex
30 x 5 ft. Bridge, 1' Ex
30 x 5 ft. Bridge, 2' Ex
30 x 5 ft. Bridge, 2.5' Ex
30 x 5 ft. Bridge, 3' Ex
HPA STANDARD

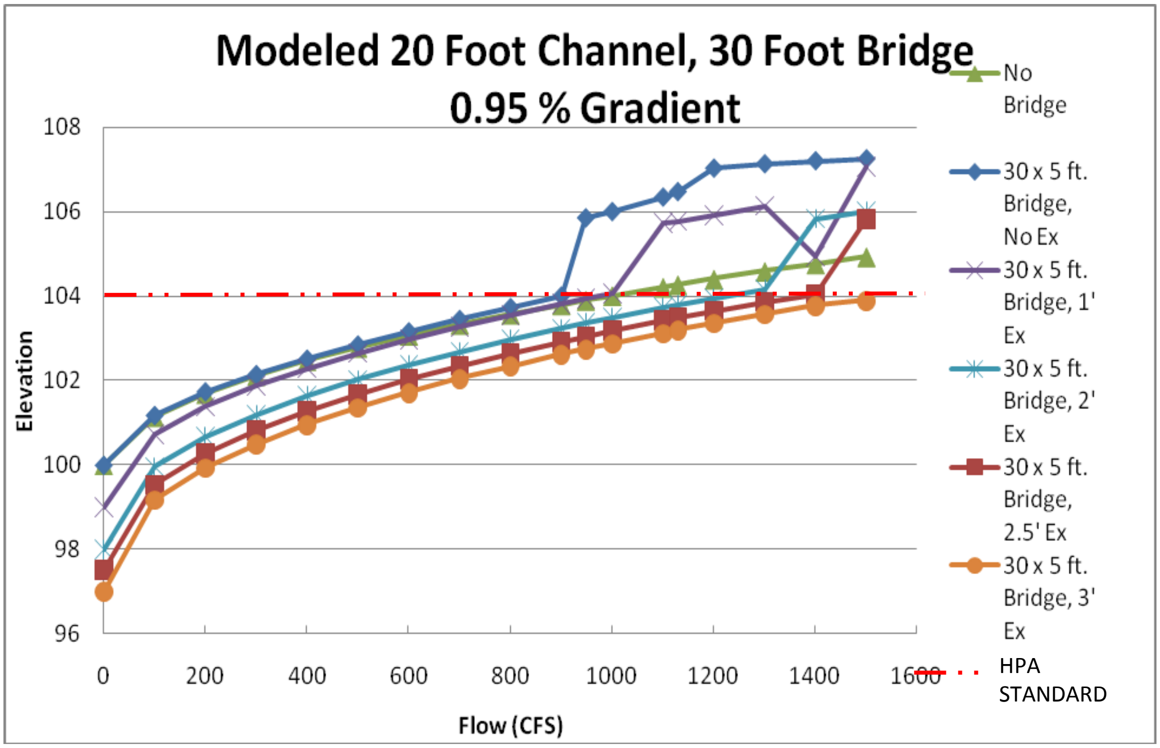
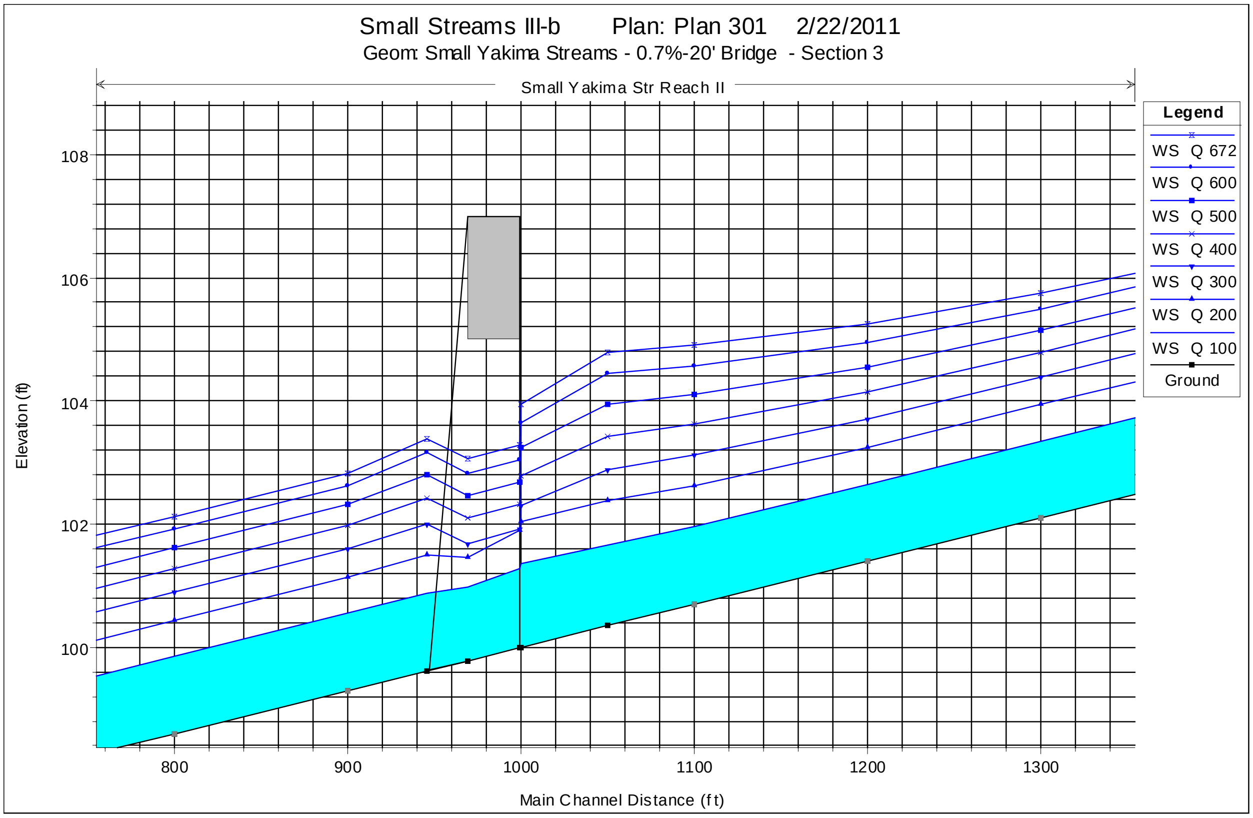
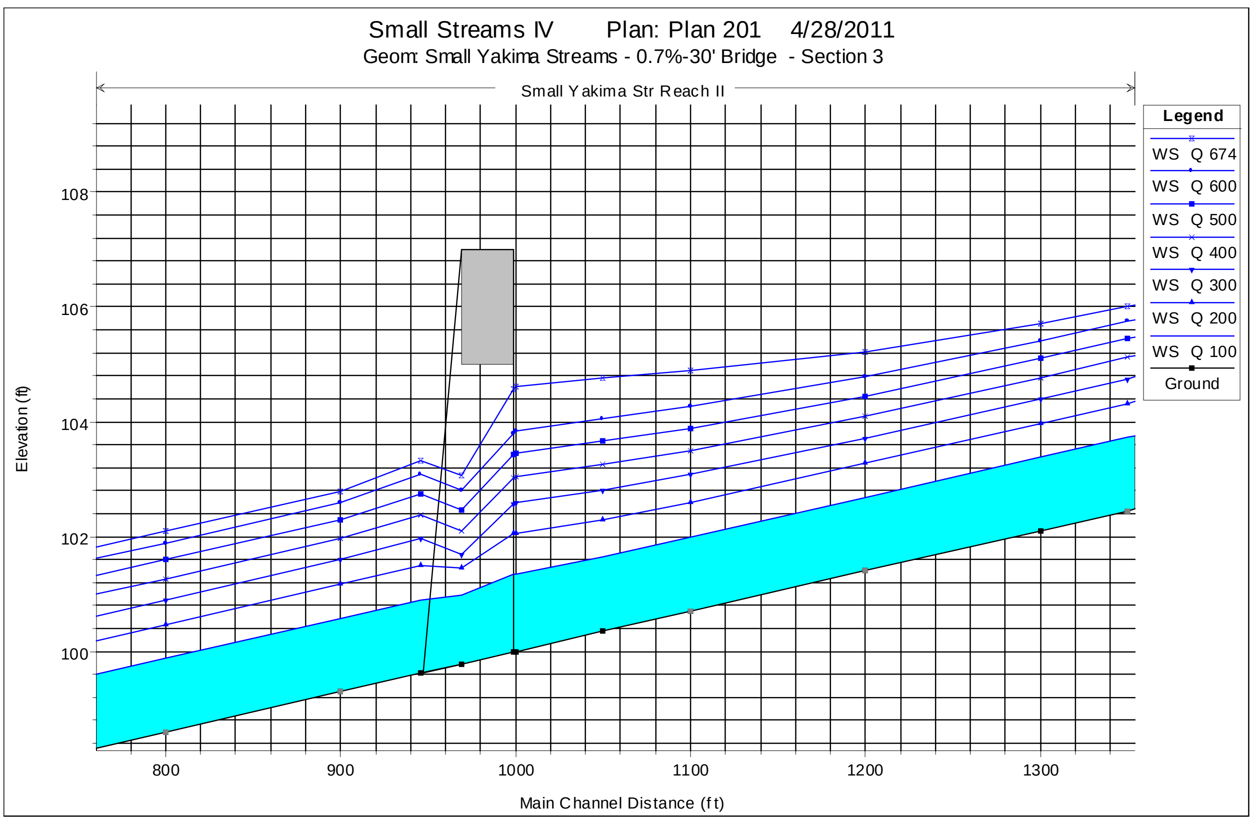


Figure 5 - Flow Conveyance Improvement for differing levels of excavation, 30 foot bridges.

The excavations volumes for the 30 foot bridges are identical to those shown for the 20 foot bridges in Table 1.

Figure 5 for the 0.7% gradient with a 30 foot bridge appears counterintuitive when compared to the same gradient with a 20 foot bridge. Backwater appears to begin sooner, and water surface elevations are higher for the longer bridge span. The reason for this is the different characteristics of the flow adjacent to the bridges, and where these water surface elevations are measured.





Figures 6 & 7 – Water Surface Profiles for 20 and 30 foot bridges at differing flow volumes.

The shapes of the profiles on the figures as water approaches the bridges are markedly different, especially at the upstream face of the bridge where this study is evaluating the effects. The 20 foot bridge acts as a flow constriction beginning at fairly low flows, and maximum water surface elevation occurs upstream of the structure, with water surface "diving" at the upstream bridge face . Flow approaches the 30 foot bridge in a much more laminar pattern, without "stacking" water upstream. This accounts for the misleading seeming worse performance of the 30 foot bridge versus the 20 foot bridge. In contrast water surface elevations 50 feet upstream of the bridge are generally significantly lower for the 30 foot bridge than the 20 foot bridge. All else being equal, shorter bridges will have a markedly higher water surface upstream from the bridge, and the greater energy sink above the structure will also further encourage the deposition of sediment over time.

CASE STUDIES

The Flood Control Zone District selected several bridges in the watersheds to examine the application of the guidelines to actual basin bridges. Bridges were selected based on previous examination or previous sediment removal, known problems for conveyance capacity, and to provide a representative sample of bridge sizes and stream gradients in these watersheds. Selected bridge are shown on Figure 8.

Bridge Case Study Location Map

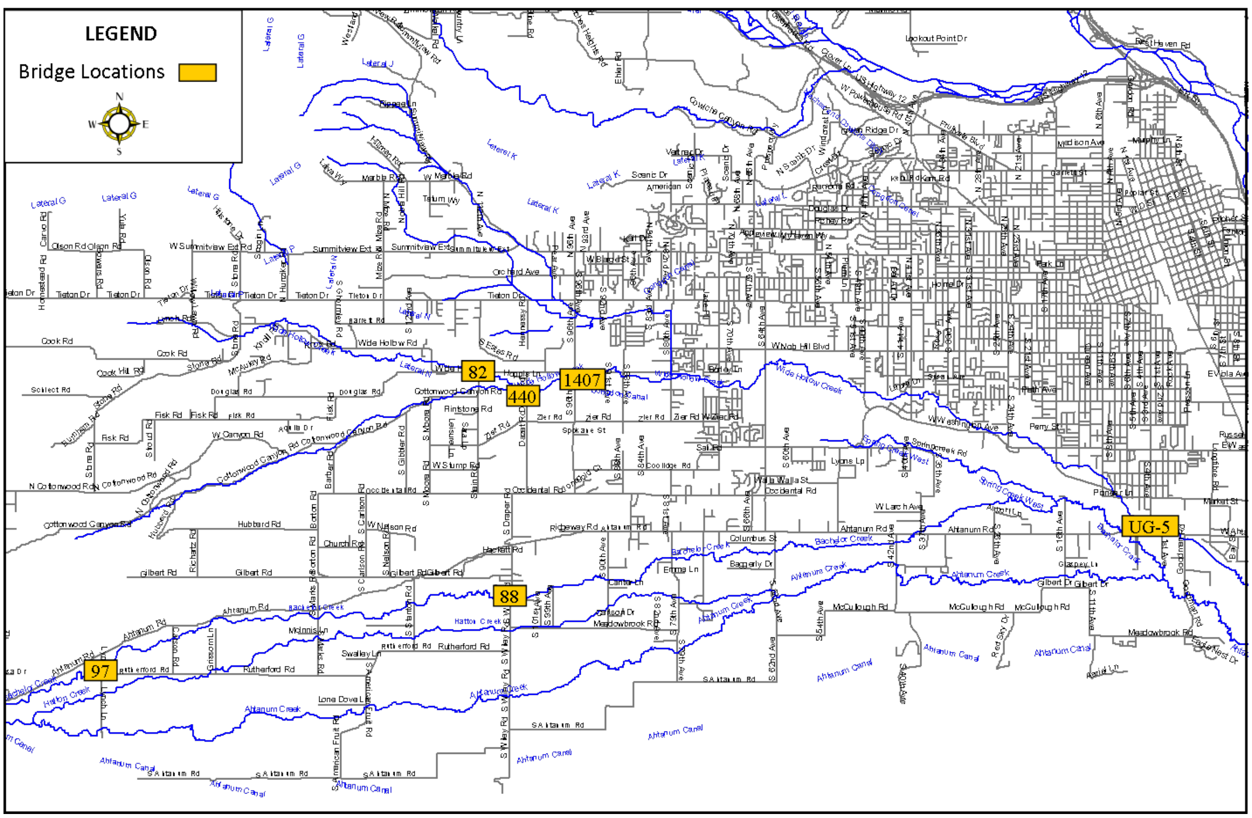


Figure 8 – Case Study Bridge Locations

The ability for the bridges to pass the 10-, 25-, and 100-yr flood flows at the upstream face are presented in Table 2.

Bridge Data				10 Yr Flood		25 YrFlood		100 Yr Flood	
Bridge #	Location	Width	Height	Q Total CFS	Q Bridge CFS	Q Total CFS	Q Bridge CFS	Q Total CFS	Q Bridge CFS
97	Bachelor Ck @ Lynch Lane	19.8	7.5'	510	451	890	310	1233	298
88	Bachelor Ck. @ S. Wiley Rd	20'	5'	422	179	541	202	888	243
146	Bachelor Creek @ 42nd.	21'	7'	418	418	621	621	881	418
440	Cottonwood Creek @ Dazet	27'	7'	179	179	262	262	411	411
82	Wide Hollow Ck @ Gromore	21'	9'	222	222	324	324	512	406
1407	Wide Hollow Ck @ 96th. Ave.	50'	10'	283	283	325	325	642	642
5	3rd & Wide Hollow – (Box Culvert)	6'	6'	343	343	498	498	778	625
121	3rd & Wide Hollow – (Bridge)	28'	10.5'						

Table 2 – Case Study Bridge Hydraulic Characteristics

Several of the bridges convey only a portion of the 100 (Bachelor at 42nd, Wide Hollow at Gromore, Wide Hollow @ 3rd Ave.) , and Bachelor Creek at Lynch Lane and at Wiley Road do not pass the 10 and 25 year flood. In these situations, either the channel capacity upstream or downstream of the bridge is low or the stream channel has been moved from the low point in the floodplain to a side hill to allow for irrigation. In either case water overtops the road where the bridge is located. It may also overtop at some distance from the bridge. In many cases water flows out into the floodplain and is routed into a new flood path.

Flooding Characteristics of Case Study Bridges

There is a marked difference between the volumes of excavated material estimated by applying the Sediment Removal Guidelines to Guideline Streams versus their application to the case studies, for several reasons shown below. The Guideline streams were modeled under the assumption of the location of a new bridge on a channel reach of uniform slope and shape, the case studies indicate that there are numerous conditions besides the capacity of the bridge which can contribute to flooding in the vicinity of the bridge. The case studies attempted to use excavation to provide passage of the 100-yr flood with one foot of freeboard below the bottom chord.

There are several reasons why flooding characteristics in the vicinity of a bridge may be different than conditions modeled in the "Guideline Streams" above.

- Low hydraulic capacity will cause the velocity upstream of a bridge to decrease, and water levels to increase, decreasing the amount of energy in the channel that can be used to convey sediment. If the stream is conveying bedload or washload sediment, this decrease in energy will cause sediment to settle out above the bridge. Over the long term, or even after a single long duration event, this sediment accumulation will act to reduce the conveyance capacity of the channel, and lead to more frequent out-of-bank flooding. Where sediment has accumulated upstream of the bridge bringing the stream to a lower overall gradient upstream of the bridge also generates significant volumes of excavation. Excavation depth upstream of the bridge may exceed the depth of excavation shown at the upstream bridge face where sediments have accumulated upstream. For example, Bachelor Creek at 42nd (which does not pass the 100 year flood and has experienced 3 100 year floods in its life) shows a 1 foot excavation upstream of the bridge face, but 30 feet upstream from the bridge in the area of sediment accumulation in the channel, excavation approaches or exceeds 4 feet below the existing channel, and continues at that depth for 400 feet upstream
- In many locations in the Wide Hollow Basin and on Bachelor and Hatton Creeks in the Ahtanum Basin, streams have been moved or otherwise altered to convey irrigation water. In some cases the stream has been moved from its natural position in the low point of the valley to the valley wall. This movement can increase the potential for sediment accumulation upstream of the bridge due to a lowering of stream gradient, and also lead to the formation of flood overflow paths that leave the creek well upstream of the bridge, but inundate roads in the vicinity of the bridge. In three locations (Wide Hollow at 3rd, 96th, and Gromore) additional sediment removal was modeled to reduce or eliminate flood overflow paths that begin upstream of the bridges. In another case, the bridge itself was modified as an irrigation diversion, which raised the bed of the creek and reduced conveyance capcity of the bridge, which in turn increase sediment accumulation upstream of the bridge.
- Additional excavation downstream may also be necessary to meet the objectives where downsteam conditions backwater through the bridge. The bridge downstream from Bachelor @ 42nd backwaters through the bridge, additional sediment removal was necessary at this location to reduce backwater from the downstream bridge. At Bridge #5 in Union Gap (Wide Hollow at 3rd Ave.) vegetation – a very dense stand of hybrid willow- combined with low gradient causes backwater through the larger bridge opening, expansion of the channel through excavation necessary to meet the flow objectives.
- In both watersheds, there are numerous locations that serve as flood overflow paths from other drainages. For example, calculation of bridge size for Bachelor or Hatton Creeks based on their watershed size would result in very low 100 year flow estimates. Bachelor Creek above the point where it becomes an overflow path for Ahtanum Creek only has a 100 year flow of 56 cfs, which these bridges can easily handle. But after flood overflows enter Bachelor Creek, the 100 year discharge is over 1100 cfs, which, for the

approximate 20 foot long bridges crossing the creek, will require a very large quantity of excavation to pass. Depending on the position in the watershed relative to flood overflow paths, adjacent bridges could have dramatically different flow characteristics and dramatically different excavation volumes to meet the 100 year conveyance with 1 foot of freeboard goal.

- For all of the reasons above, it is common to have flood overflow paths that begin at, or in some cases upstream of the backwater caused by the bridge. Excavation to prevent the development of these site-specific overflow channels during the 100 year event will also increase the amount of excavation modeled.

Table 3 below describes the flooding characteristics associated with each of the case study streams.

Bridge Data			Local and Watershed Conditions			
Bridge #	Location	US Sed	Relocated/ Perched/ Altered	DS Bridges or Constrictions	Flood Overflow Paths - Watershed	Flood Overflow Paths - Site
97	Bachelor Ck @ Lynch Lane	Y	Irrigation Channel	N	10,25,100	Residential
88	Bachelor Ck. @ S. Wiley Rd	Y	Irrigation Diversion	Diversion	10,25,100	School and Residential
146	Bachelor Creek @ 42nd.	Y	N	Bridges	10,25,100	Residential
440	Cottonwood Creek @ Dazet	Y	N	N	N	
84	Wide Hollow Ck @ Gromore	Y	Moved and Perched	Yes	N	
1407	Wide Hollow Ck @ 96th.	Y	Perched upstream of bridge	Y – Private Bridge	N	Rural
5	3rd & Wide Hollow – (Box Culvert)	Y	Moved and connected to Drain	Y – Vegetation/ Sediment choking channel	100	Commercial, Major Arterial
121	3rd & Wide Hollow – (Bridge)					

Table 3 – Bridge Flooding Characteristics

Case Study Excavation Quantities and Distance

The objective for these bridge excavations was to establish how much excavation would be required to meet the Hydraulic Code standards for these bridges – pass the 100 year flow with one foot of freeboard.

The general character of excavations for most of the case studies are similar to those used in the "Guideline Streams" – excavation upstream at a similar gradient to the channel, then tie into the existing stream at no greater than a 2% slope, excavation downstream at a zero percent gradient.

The required excavation volumes are shown in Table 4 below. It is important to note that these excavations represent passage of 100 year flow with freeboard and are not necessarily the recommended solution at each bridge. They are shown for direct comparison purposes on relative volumes and impacts by structure.

Comparion of these volumes to the anticipated "Guideline Streams" volumes, shown in Table 3 indicates highly variable conditions. In order to achieve this passage standard, excavation volumes, and to a lesser extent, excavation distance are considerably larger than that for the "Guideline Streams".

Bridge Data		Excavation (to Pass 100 yr flow)						
Bridge #	Location	Slope %	Depth at US Face	Distance (Feet) Stream	Up Down Stream	Quantity (Cu. Yd) Stream	Up Down Stream	Total
97	Bachelor Ck @ Lynch Lane	.095	3′	526	938	3877	3283	7160 (2322)
88	Bachelor Ck. @ S. Wiley Rd	.069	2′	362	661	864	440	1304 (1327)
146	Bachelor Creek @ 42nd.	0.69	1′	324	286	1412	1018	2430 (364)
440	Cottonwood Creek @ Dazet	0.73	1.5′	125	66	451	462	913 (740)
84	Wide Hollow Ck @ Gromore	0.93	1′	806	86	1962	204	2166 (369)
1407	Wide Hollow Ck @ 96th.	.071	1′	283	177	956	440	1396 (NA)
5	3rd & Wide Hollow – (Box Culvert)	.044	3′	225	809	2724	1630	4354 (3575)
121	3rd & Wide Hollow – (Bridge)							

Table 4 – Excavation Distance and Quantities for Case Study Streams. Total excavation quantities in parenthesis are estimated quantities from the Guideline Streams.

Bachelor Creek at Lynch Lane, Bridge #97

Much of the 10 (510 cfs), 25 (890 cfs) and 100 (1233 cfs) year flows in Bachelor Creek at this location have gone out of bank upstream and been routed into the floodplain north and south of the creek. Similar to other bridge locations in the Ahtanum, the topography of the valley bottom at this location is not level in cross section, numerous low ridges, running parallel to the stream, create sub floodplains and are the controlling feature determining flood paths. At this location, such a ridge separates Bachelor from Ahtanum, forming a separate flood path. Lynch Lane itself is at or only slightly above grade, allowing flood waters to overtop across a significant distance of the road, such as occurred in the 1974 and 1996 floods.

The bridge is at grade with the road, and provides little clearance between the stream bed and the bottom chord of the bridge. Even though the channel gradient at this location is relatively steep at almost 1%, the existing channel capacity is quite small relative to the 10, 25 or 100 year event. Under the modeled conditions in the guidelines (i.e. wide, trapezoidal approach and exit channel), this bridge could only handle about 6-700 cfs. The 25 and 100 year floods at this location exceed that value, indicating that the bridge design is undersized and large excavations will be required to meet these flow conditions.

Excavation to improve conveyance at this location to match the bridge opening of 19.8 feet significantly widens the existing channel upstream and downstream of the bridge, and combined with the depth of excavation (3') that is required to pass the 100 year flood, results in a very large amount of excavated material, 7,200 cubic yards. A slight majority of the excavation occurs in the channel upstream of the bridge, where the gradient is lower and the channel itself is much smaller than the Guideline Streams - only 12 feet in width. Excavation will result in a water velocity of 4 ½ to 10 ft/sec through the majority of the length of excavation of over 700 feet, with velocities up to 13 fps discharging from the bridge. Velocities of this magnitude normally(13 fps) would require a median bed particle size of over 12 inches (round rock) which does not occur at this location. Consequently, if this bridge were excavated to this degree, channel instability upstream, downstream, and through the bridge opening would be very high. If there was a desire to maintain channel stability at this location at the 100 year flow, riprap or other armor would likely be required.

As you can see in the graphics below, excavation does reduce the extent of floodplain upstream and downstream from the structure. The reduction is limited to removal of one house to the north of the creek from the 100 year floodplain. In this area, during large floods, Lynch Lane is flooded and impassable at this location, and floodwaters inundate and damage Rutherford Road. After sediment removal, Lynch Lane would be passable at this location (other crossings of Hatton and Ahtanum Creeks to t he south may be impassable) but the other flooding issues upstream and downstream of the bridge would be largely unaltered.

The amount of excavation is over 7,000 yards, the cost of this excavation plus armor to maintain channel stability would be about half or more of the cost of bridge replacement with a longer span (est at $180,000). At these levels of economic cost to improve conveyance at this structure, it would be difficult to generate a positive benefit/cost ratio for stream cleanout to a 100 year level at this structure.

The position of the bridge at the upper end of a broad overflow channel should also be taken into consideration. As the maps below show, this area is completely inundated during large flood events, and provides a large area for storage of floodwaters. Also, current conditions slow or regulate the release of floodwaters to more populous areas downstream. Improvement of conveyance at this location will make floodwaters travel downstream faster, and with more quantity, potentially causing higher flood hazards in more densely populated areas downstream.

Other alternatives, such as lengthening the bridge (i.e. additional span), only improving the conveyance to allow passage of the 10 year flow, or allowing this road to be unpassable during flood events, should be considered at this location. Also, raising of the road at this location, without improvements to the bridge is not recommended as the backwater from a raised road would likely cause water upstream to flow into Hatton Creek, which is even more undersized for flow conveyance than Bachelor Creek.

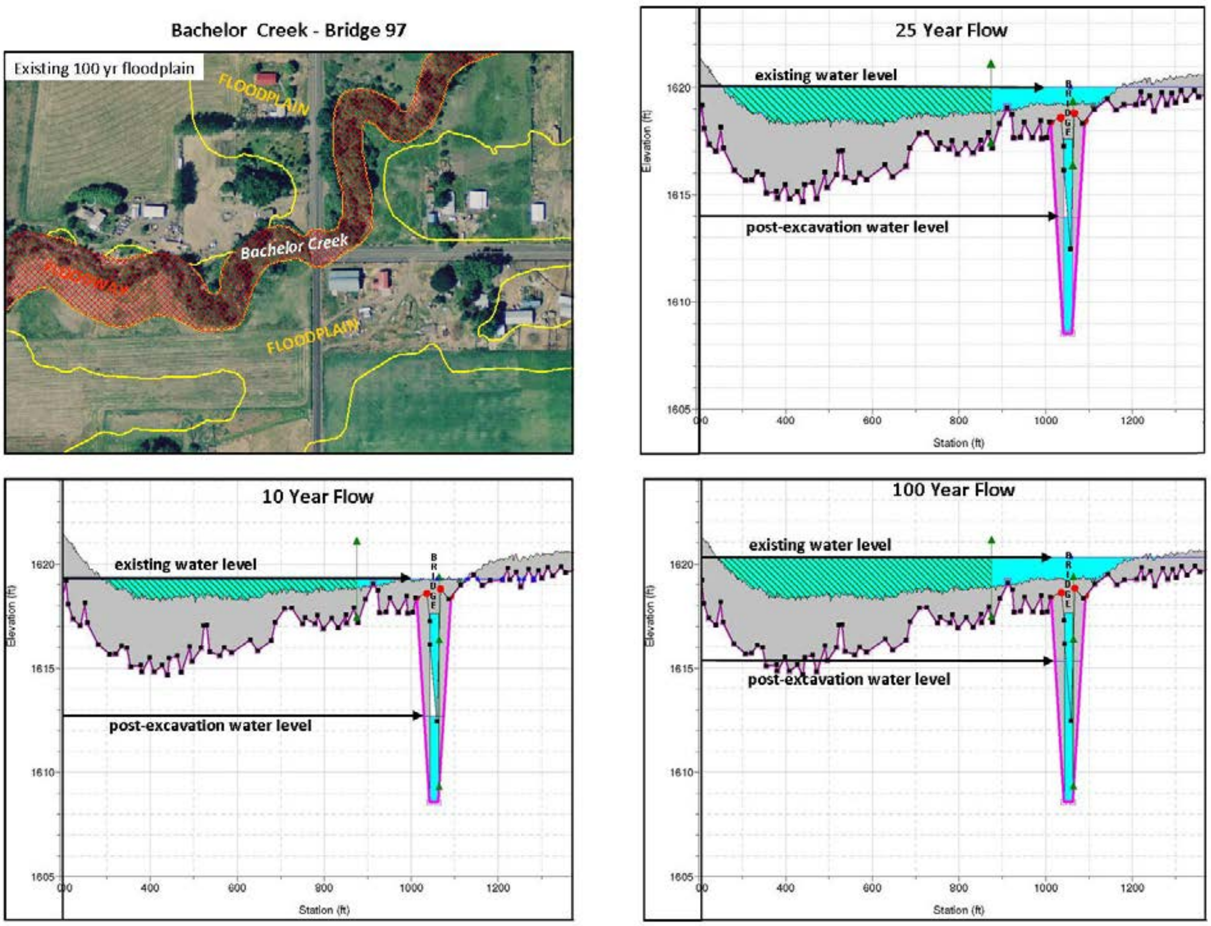


Figure 9 – Case Study Bridge 97 Profile

Bachelor Creek – Bridge 97

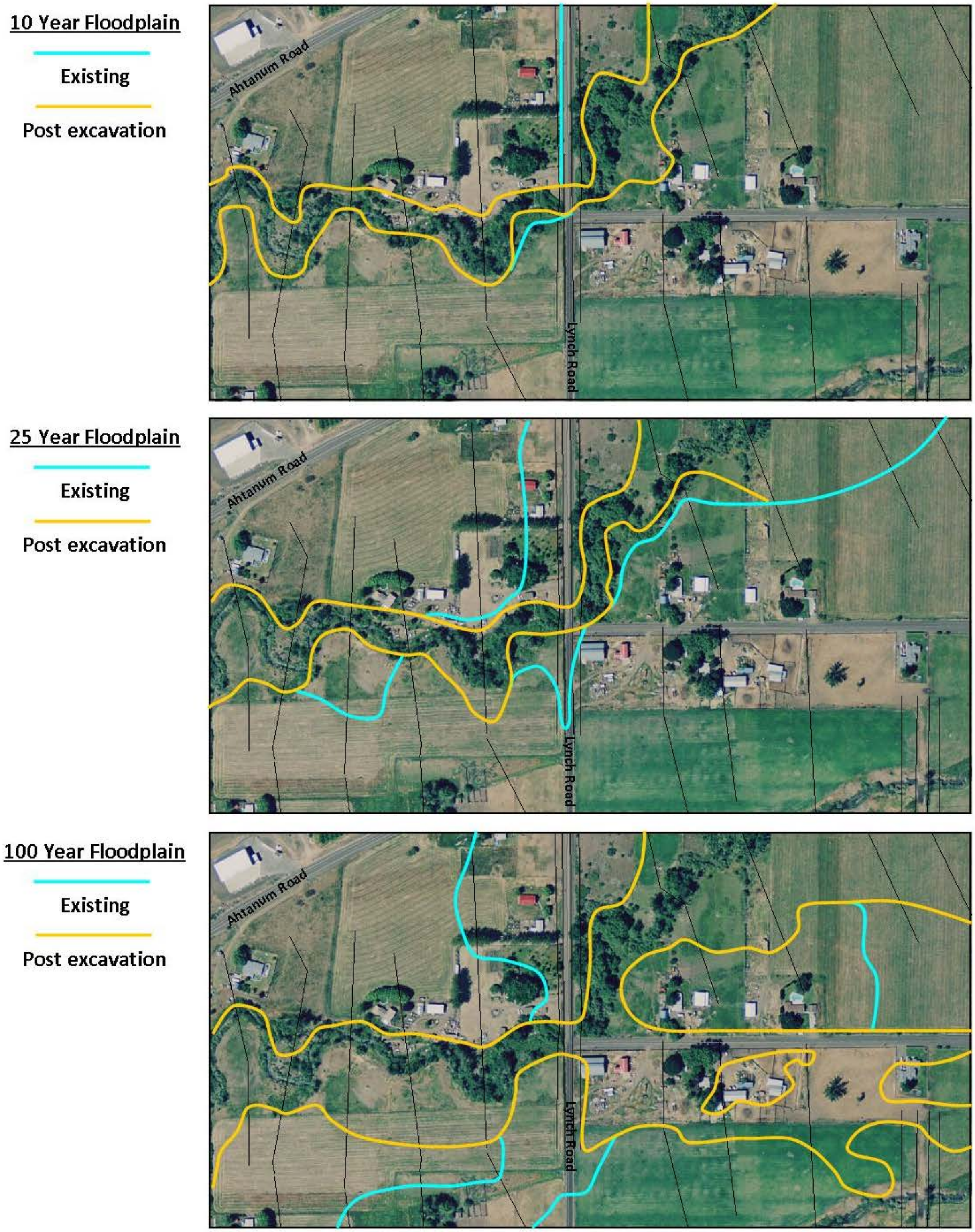


Figure 10 – Case Study Bridge 97 Floodplain

Bachelor Creek at S. Wiley Road, Bridge #88

This bridge also does not currently have conveyance capacity for the 10 (417 cfs), 25 (542 cfs) or 100 year flow of 868 cfs. Currently such flows would overtop the road to the north of the bridge location, and these floodwaters would continue to the north through the Ahtanum Elementary School toward the town of Ahtanum. This bridge was apparently modified to also serve as a check structure for irrigation – there is a concrete wall incorporated into the downstream abutment walls that "check" the stream up at this point. Currently, there is no irrigation diversion connected to Bachelor Creek in this vicinity, there is a screw gate on the north abutment wall, and an irrigation ditch in that location is visible on the 1947 air photos. Also, this bridge has already had some improvements in channel conveyance including vegetation removal and some limited excavation.

The channel at this location matches well with the modeled channel condition: channel slope of 0.69 %, channel width of approximately 20 feet , and the bridge is 20' long with 5' of depth to footing. Simulated excavation at this location removes the sediments that have accumulated behind this wall, and but more than half of the excavation occurs downstream to match gradient. This excavation totals 1,300 yards, almost exactly the estimated amount from the Guideline Streams above. Excavation at this bridge would require removal of the concrete wall to be effective, but with the wall removed, improvement in conveyance at this location would likely remain effective for many years into the future.

As the maps below show, removal of the sediment and the wall has a dramatic effect on floodplain extent in this location. This project would significantly reduce flood hazard to Ahtanum Elementary, located on the northwest corner of the bridge. This makes this this bridge probably the most cost-effective project of any of the case studies. Given that most of the other bridges on Bachelor Creek are also impassable during major flood events, this project could also provide significant emergency and flood route access in a relatively populated area.

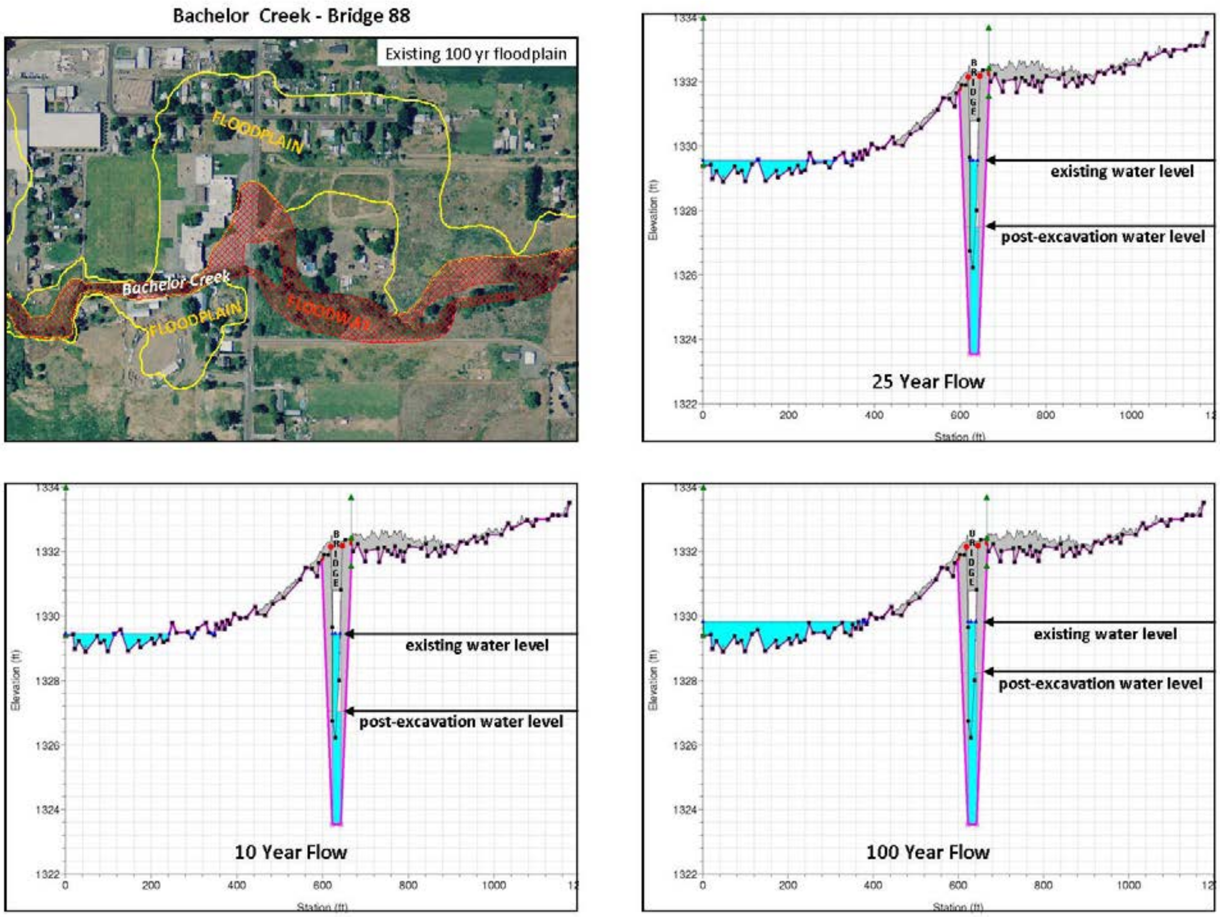


Figure 11 – Case Study Bridge 88 Profile

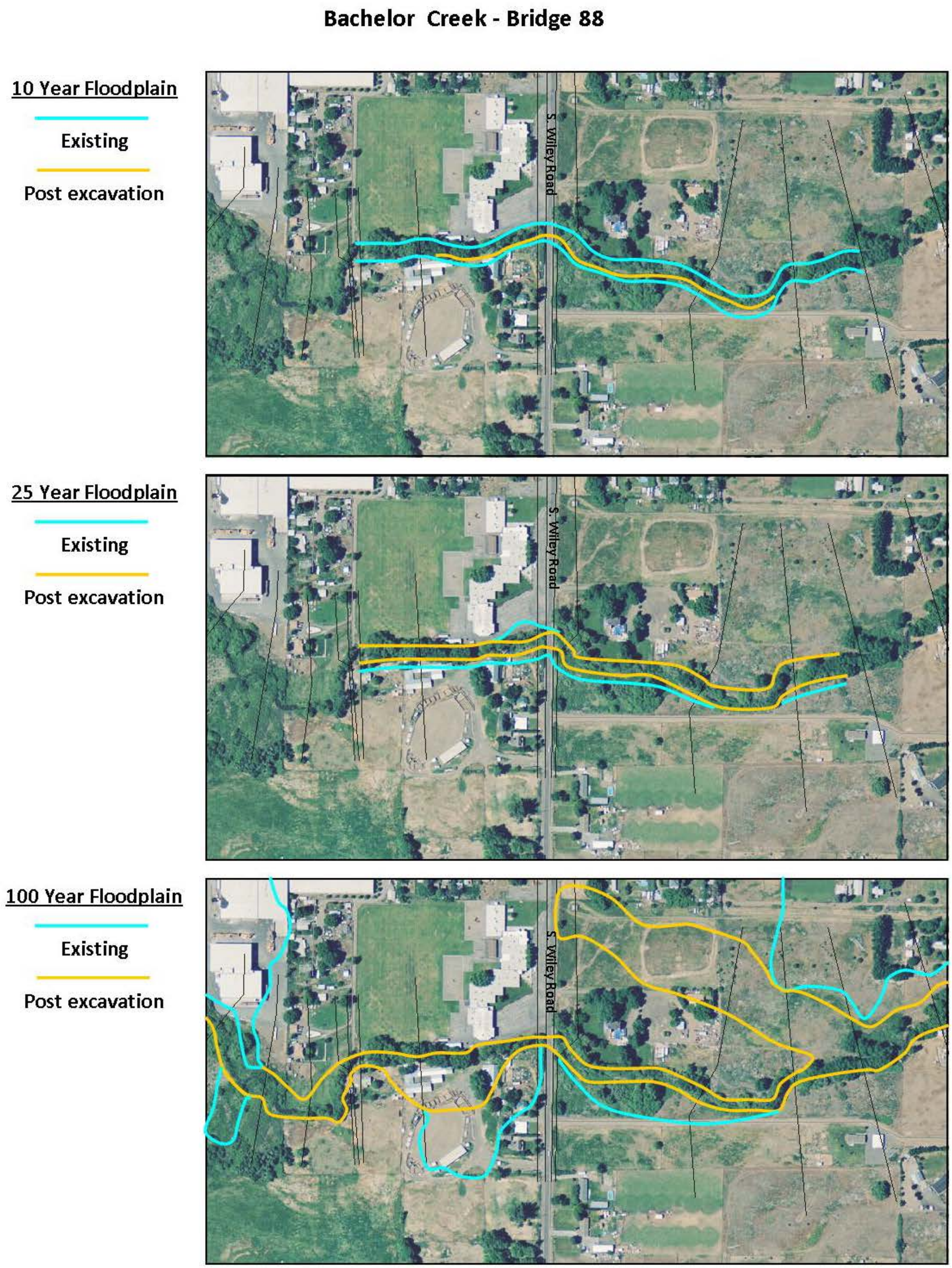


Figure 12 – Case Study Bridge 88 Floodplain

Bachelor Creek at S. 42nd Avenue, Bridge #146

This bridge is slightly larger than the modeled bridges, 21 feet long by 7 feet to the footings, and has a gradient of 0.73%. Simulations indicate that this bridge passes the 10 (363 cfs) and 25 (413 cfs) floods. The 100 year flow for Bachelor Creek just upstream of the bridge is 790 cfs, but the required conveyance to keep the bridge and road from being overtopped at the bridge location is 906 cfs in order to accomodate flows from the north (an overflow path along Ahtanum Road). This area was very complex to hydraulically model due to the numerous overflow paths at this location. Bachelor Creek and Ahtanum Creek at this location were modeled separately – as though there is no flow from one to the other. The modeled floodplains from these creeks abut each other in the FEMA model, and at the 100 year flow it is possible that water from Ahtanum Creek will actually flow north toward Bachelor, as occurred in the 1974 and 1996 flood. Therefore the 100 year flow at the bridge is likely this is an underestimation of what would be experienced if Ahtanum Creek was at a 100 year flow as well. Both these flow paths are along 42nd Avenue and enter the creek at right angles to the predominant flow in Bachelor Creek itself. These flow angles greatly decrease the efficiency of the bridge opening at high flows.

This bridge is also strongly influenced by the next downstream bridge which takes Bachelor Creek under Ahtanum Road, and that bridge is influenced by the next downstream bridge at S. 38th Avenue. At the 100 year flow, water backwaters from the 38th Avenue bridge, through the Ahtanum Road Bridge, and to the 42nd Avenue bridge. Back water from the Ahtanum Road bridge is especially severe because the angle of approach of Bachelor Creek to the bridge is greater than 90 degrees, and is probably underestimated by the hydraulic model. This severe backwater also causes sediments to accumulate in the channel between the two bridges, which reduces conveyance capacity in the channel and results in frequent out of bank flood events between the two bridges. Upstream of the 42nd Avenue bridge, significant amounts of sediment have accumulated in the combined backwater effect of the bridge, the backwater from the bridges below, and the reduced efficiency of the bridge from the converging overflow paths that join the creek at the upstream bridge face.

This bridge can be excavated to convey the 100 year flow by a 1 foot excavation at the bridge. This excavation removes a significant amount of accumulated sediments that have accumulated upstream of the bridge due to this bridges backwater, and downstream of the bridge due to backwater from downstream bridges. This produces a much larger removal volume of material than would be expected at this location based on the Guideline Streams – 2,430 cubic yards versus 359 cubic yards in the Guideline Streams. Due to large and deep deposits excavation upstream of the bridge exceeds 4 feet in depth for over 400 feet upstream of the bridge, generating over 1,400 cubic yards of excavation. Excavation downstream is an addional 1,018 cubic yards. Due to conditions at this location, the maintenance of conveyance through this bridge by excavation over the long term would likely require repeated, closely-timed excavations.

As shown on figure 14 the effect on the floodplains of the excavations is only significant at the 10 year flow levels. Adjacent floodplain extent is mostly maintained at higher flows, especially the 100 year flows due to the multiple overflow paths that meet at this location. Sediment removal at this bridge may not be cost effective due to the flow overflow paths and influences from adjacent bridges downstream. The high volume of removals indicate a problematic reach without easy solutions and the need for larger bridges. Replacement of bridges at this location to improve conveyance would require not only replacement of this bridge with a longer bridge to reduce the effect of the flood overflow paths, but also replacement of two bridges downstream. Flood control projects currently under development on Ahtanum Creek at 42nd may also mitigate flows which historically have approached from the south, from Ahtanum Creek.

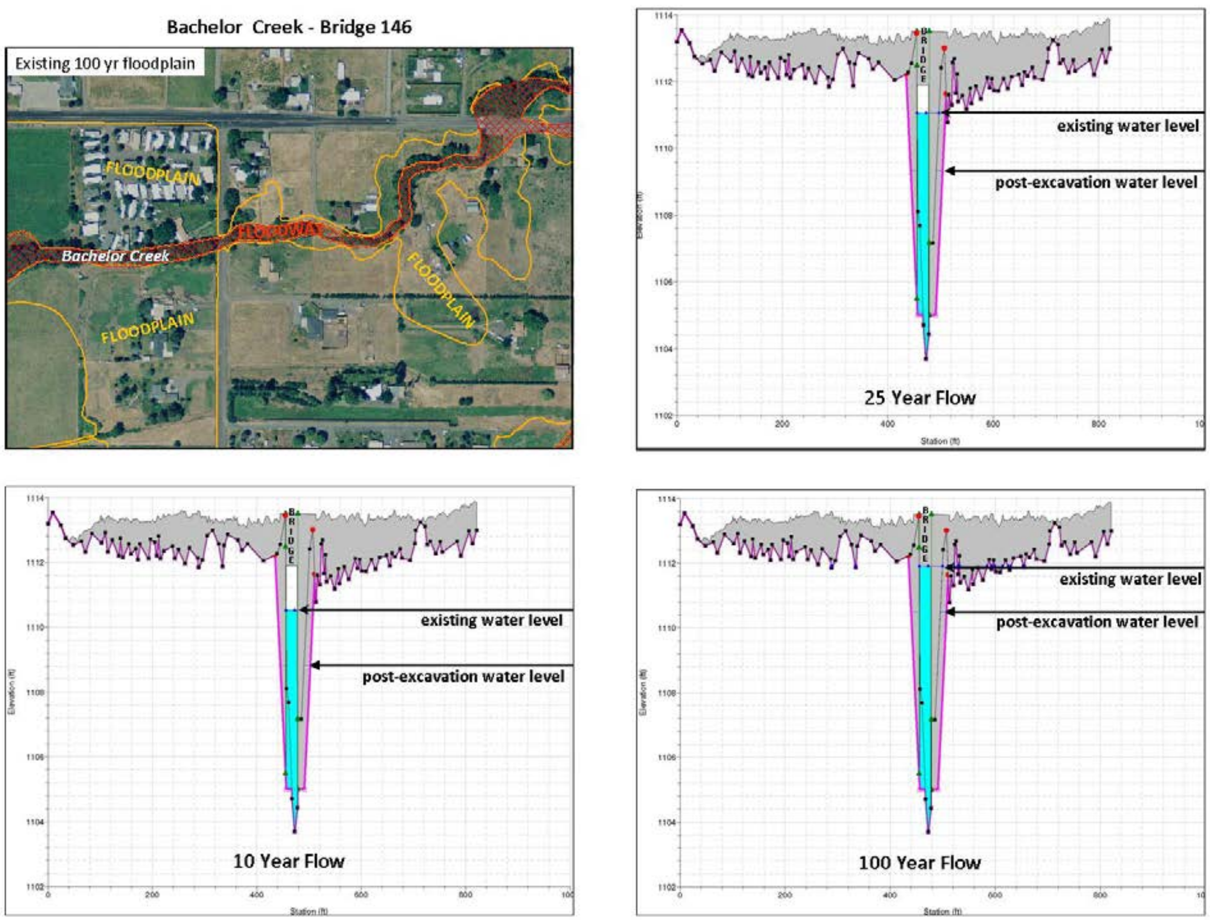


Figure 13 – Case Study Bridge 146 Profile

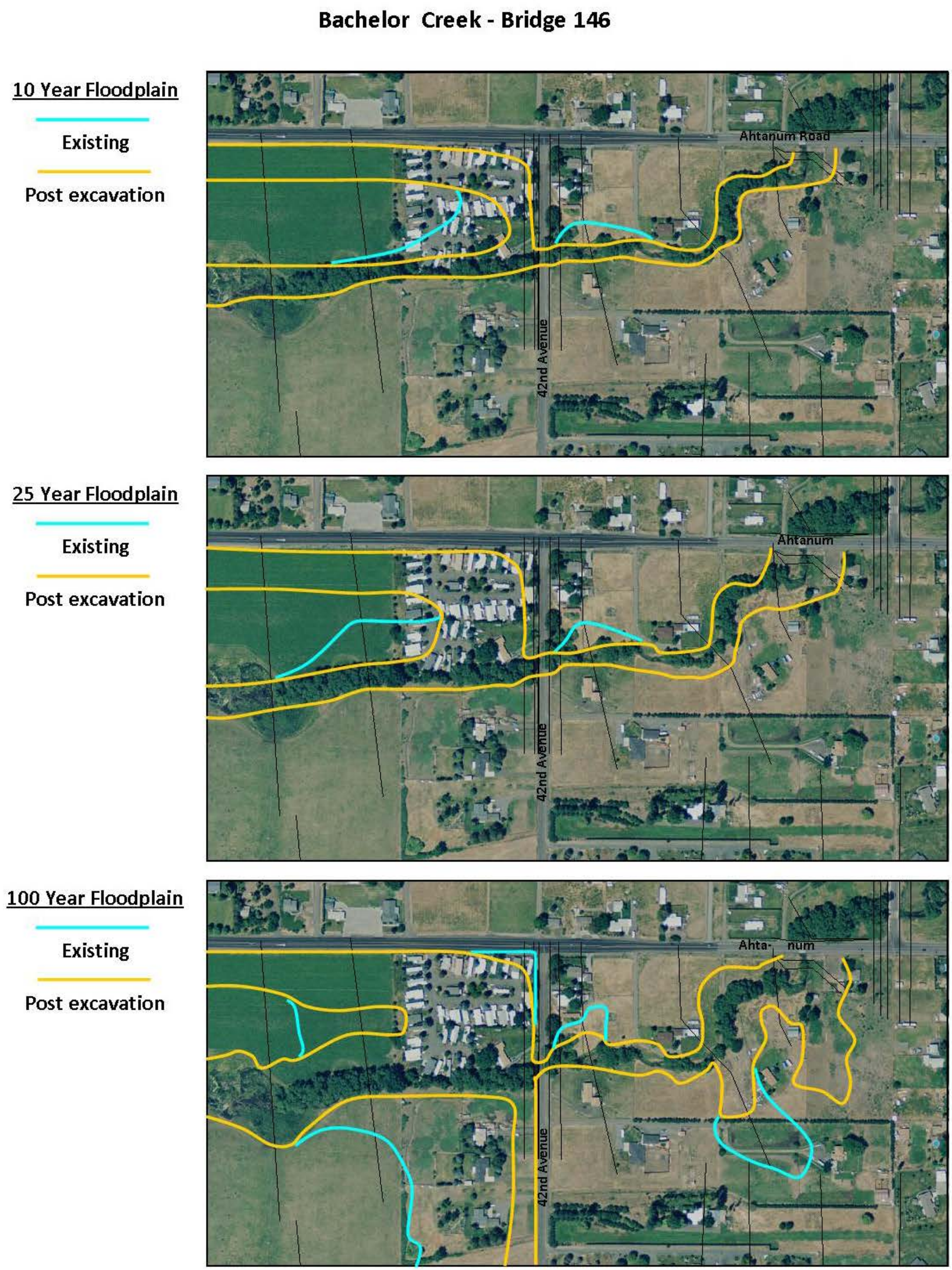


Figure 14 – Case Study Bridge 146 Floodplain

Cottonwood Creek at Dazet Road, Bridge #440

This bridge is 27 feet long with a depth of 7 feet to the footings, and channel width is approximately 18 feet, with a local stream gradient of 0.93%. The 100 year flow is 411 cfs, which, based on the modeled stream results, should be conveyed by a structure of this size. This channel has had some recent stream channel maintenance conducted near the bridge in 2009.

To convey the 100 year flow, the simulated channel was excavated to a depth of 1.5 feet. Total excavation volume was 1,135 cubic yards and estimated excavation from the guideline modeled stream would be on the order of 770 cubic yards. 700 cubic yards of the excavation at this site occurs downstream of the bridge, which is mostly composed of organic mucks and silts. There are some stands of Hybrid Willow upstream and downstream of the bridge, which act to trap sediment and generate large amounts of leaf and small woody material, but the infestation at this location is much less severe than at locations downstream.

The excavation is effective at reducing floodplain extent, especially for the 10 year flood and a house is removed from the 100 year floodplain at that flow as well. Localized bridge excavation for maintenance of channel capacity at this site may be a viable alternative – there are cooperative landowners, relatively good access and biological value of the stream at this point is low, so permit and mitigation requirements would be low as well.

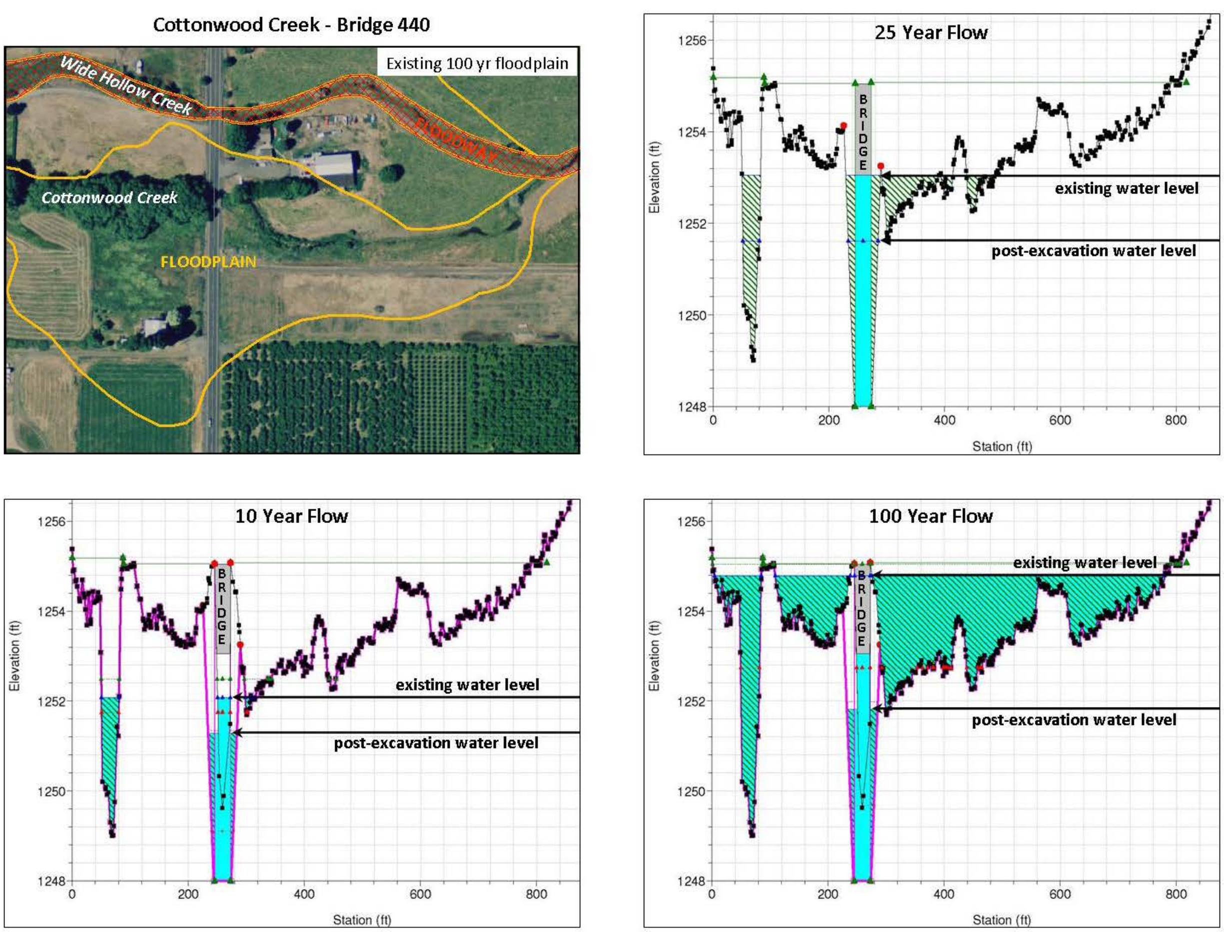


Figure 15 – Case Study Bridge 440 Profile

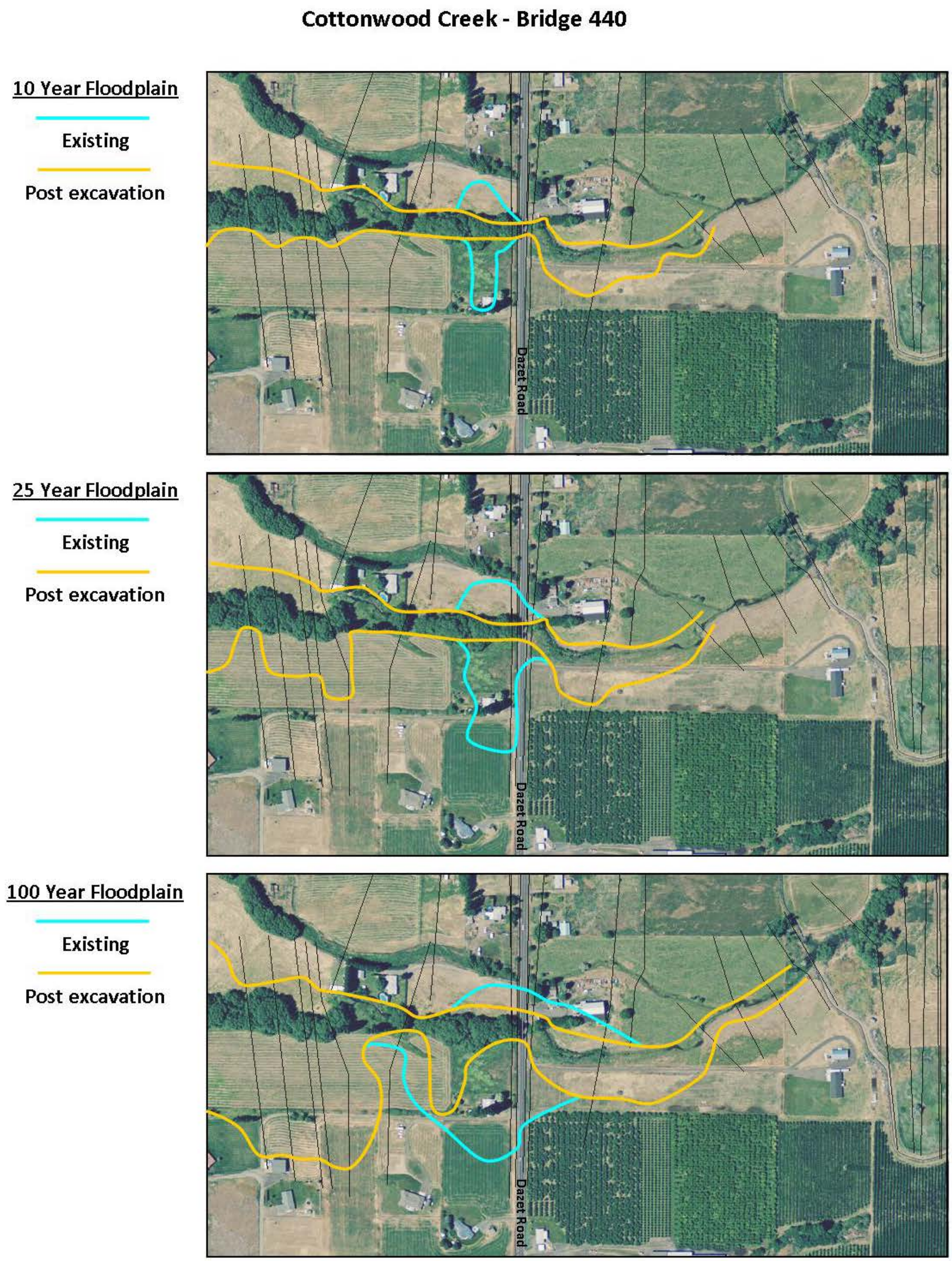


Figure 16 – Case Study Bridge 440 Floodplain

Wide Hollow Creek at Gromore, Bridge #82
This bridge is 21 feet long with a 9 foot depth to footing. The 100 year flow at this location is 512 cfs, which should easily be conveyed by this structure under normal conditions. Overall channel gradient at this location is 1%, but there is a grade break at the bridge, the stream has a steeper gradient (2%) immediately upstream of the bridge for 150 feet, then flattens to a 0.7% gradient. Downstream the gradient is 0.7% as well. Examination of the early USGS maps (1908) which date from before the development of large scale irrigation in this location, indicate that the stream channel has been moved slightly to the North, but still in the natural floodplain of the stream. In this case, moving of the creek was probably coincident with construction of Wide Hollow Road or the Yakima Valley Transportation Company (trolley) line in 1910, shortly after the USGS maps were printed. A small levee exists on the east (left) bank that ties into the elevated Wide Hollow Road prism. This levee appears to cut off a small portion (0.8 acres) of the prior natural floodplain of the creek and forces overbank flow near the bridge through the bridge opening.

The consequences of moving the stream are flattening of the stream gradient, which eventually must be recovered at some point in the stream drainage network, and exposing the lowlands where the creek or floodplain was to flood hazard when the creek overflows. In either case, the current stream location is "perched" on the north side of the valley, and some of the gradient "lost' when the stream was moved. This loss is made up just downstream of the current bridge at Gromore. Sediment accumulation would be expected in the area where gradient has been reduced; where the gradient is made up, erosion would be expected. This is also reflected in the estimated quantities of excavation; very little material is removed downstream of the bridge due to the existing erosion of the bed at that location.

The current model shows the 100 year flow goes out of bank in the low gradient portion of the channel upstream of the bridge and crosses Wide Hollow Road on its way to the valley bottom. Upstream of the bridge and levee, another flow path breaks off and heads east, flowing around the levee and then entering the historic floodplain adjacent to Wide Hollow Road, eventually opertopping Wide Hollow Road. Excavation at this location was modeled to contain all of these flow paths under the bridge, and prevent overtopping of Wide Hollow Road upstream and downstream of the bridge. Consequently, at this bridge, excavation upstream was continued until these overflow paths were contained in the channel, resulting in a large quantity of excavation upstream.

Guideline Streams Total excavation at this bridge for that derived depth of one foot was 2,166 cubic yards, with over 1,900 cubic yards of excavation occurring upstream of the bridge. The excavation widens and regrades the stream for a distance of 800 feet upstream. The modeled stream removal guidelines would indicate that this depth of excavation would generate 386 cubic yards. Likely this amount of excavation is composed of sediments that have accumulated over time plus native material that was left in place when the Creek was moved. This large amount of material removal would likely be a single occurrence. If the use of excavation to maintain flow conveyance at this site is continued into the future, subsequent entries would likely remove much smaller quantities of material.

This excavation has perhaps the largest effect on the 100 year flood of any of the case studies. This is achieved by reducing flows to overflow paths on the north and south side of the creek. On the other hand, reduction of flood extent at the 10 and 25 year floods is relatively minor.

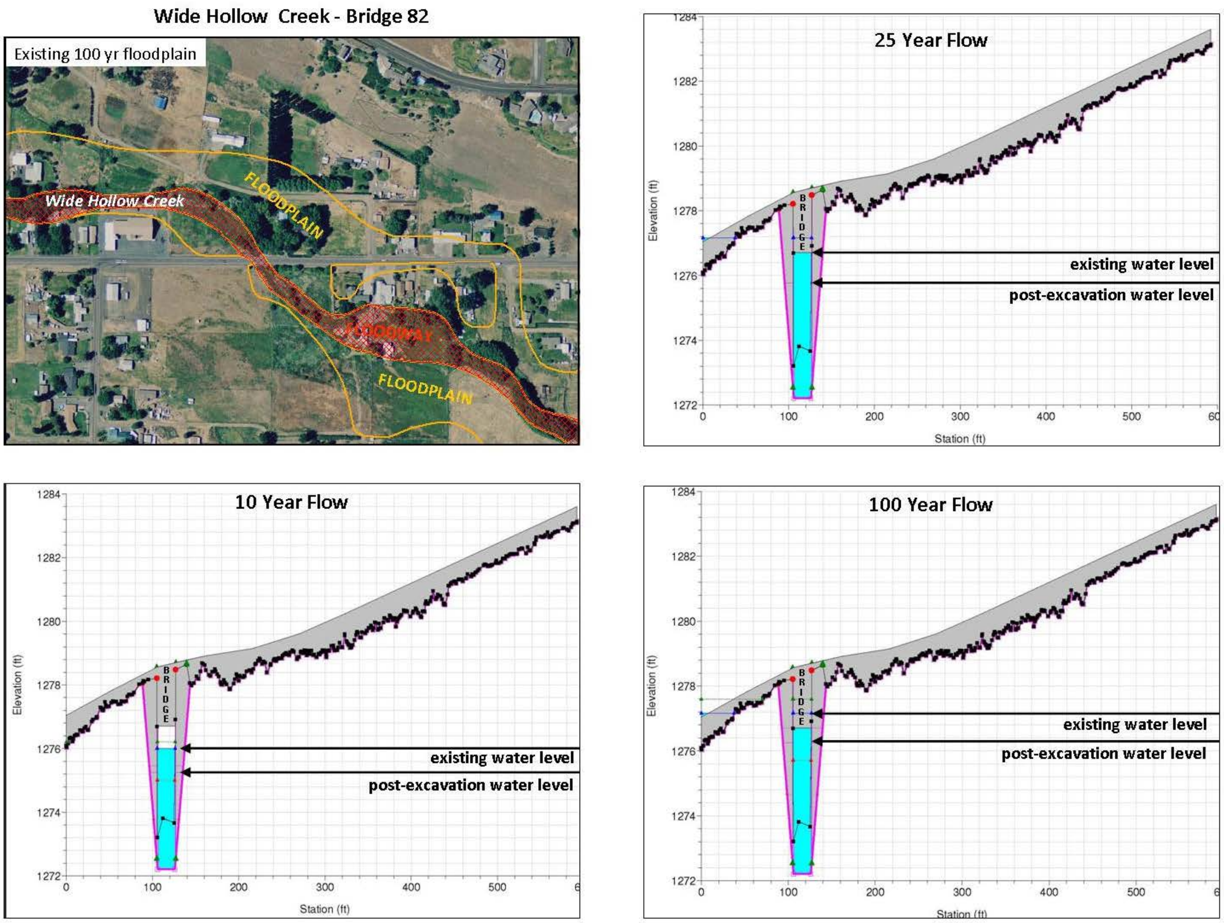


Figure 18 – Case Study Bridge 82 Profile

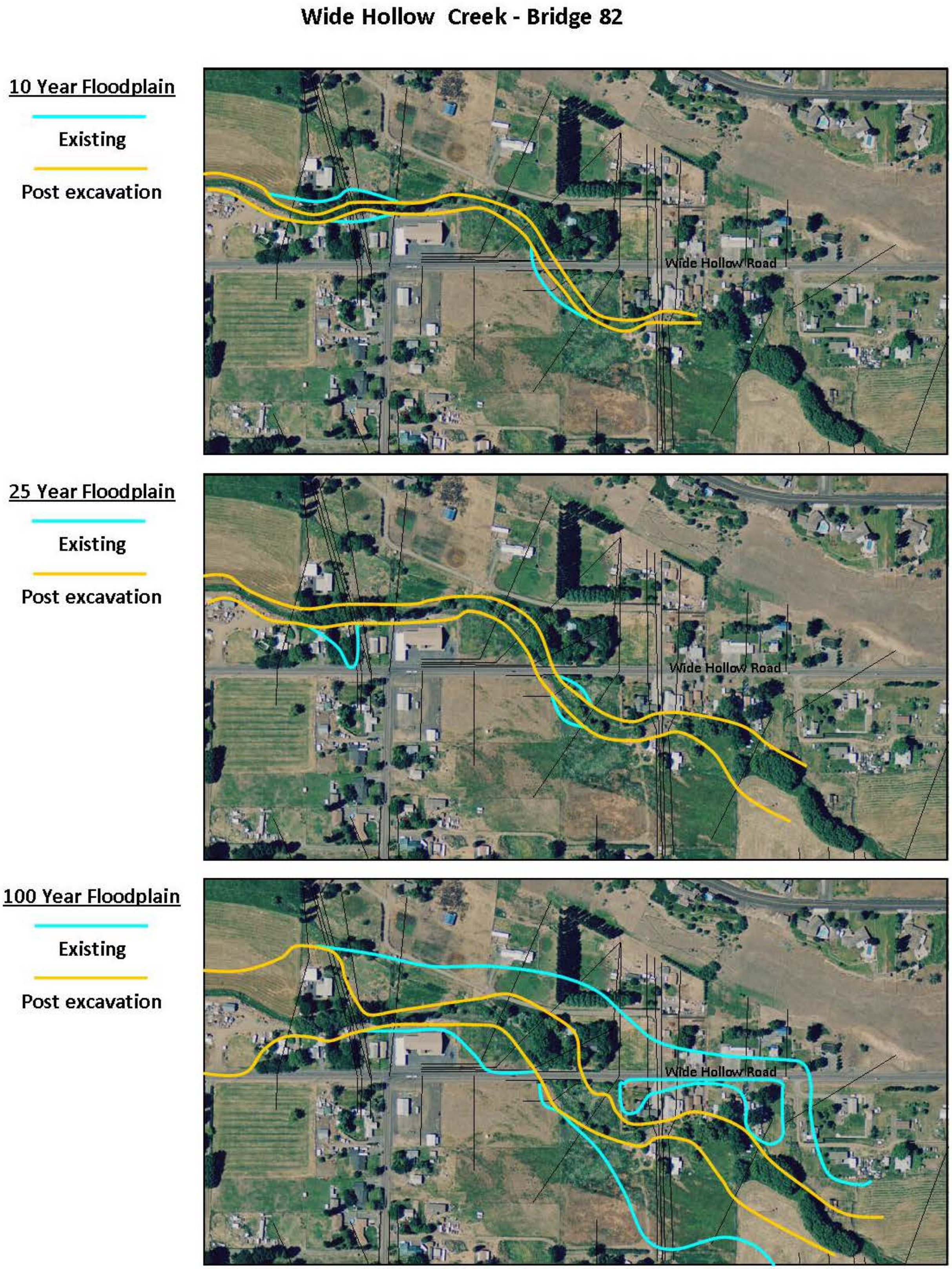


Figure 19 – Case Study Bridge 82 Floodplain

Wide Hollow Creek at 96th Avenue , Bridge #1407
This bridge is much larger than the previous bridges in the study, 50 feet long with a 10 foot depth of footing. This bridge was recently constructed in 2007. Prior to construction of this bridge, there was no road or road fill at this location. Hydraulic models employed at the time indicated that a significant amount of flow exited the channel upstream of the proposed bridge and flowed to the south. The new bridge was designed to pass the 100 year flow, then estimated as 579 cfs. Culverts were also installed in the road in the center of the overflow path, and the combined capacity of the culverts and bridge during the 100 year discharge is 700 cfs.

The revised estimated 100 year flow is 642 cfs, the 10 year flow is 283 cfs, and the 25 year 411 cfs. The bridge design did meet the HPA standards for clearance and backwater, although these standards apply only to the Creek itself, and not the overflow areas south of the bridge. The overflow area to the south of the creek, west of the road, did see an increase of approximately 0.3 feet in elevation of the 100 year flood due to the effect of the road and the surcharge (water surface above the culvert) required to meet the culvert's design capacity. The area to the south, east of the road saw a decrease in both flood elevation and floodplain extent after road construction. This bridge also has had excavation work already performed in 2008, with the intent of reducing nuisance flooding, and reducing flood elevations in the field to the south. This excavation consisted of by removing a berm and large tree that separated the area adjacent to the bridge from the floodplain to the south, removal of woody debris from the stream channel, and 60 cubic yards of excavation outside the channel to create a new side channel and improve the "approach" of the stream to the bridge opening.

In current condition following the recent excavation the modelshows that the 100 year flow will not overtop 96th Avenue, barring blockages during an event. However, excavation of the channel was modeled to further reduce nuisance flooding. The depth of excavation was 1 foot, generating a quantity of excavation of 1,396 cubic yards, while the guidelines estimate less than 386 cubic yards of excavation for this slope of 0.7%. This is attributed to the removal of over 900 yards of material from 300 foot stretch just upstream of the bridge, where the channel has been constricted by a dense growth of hybrid willows, and the channel had aggraded prior to the bridge construction. This was due to a fence line that acted as a check dam in the creek. Likely a good percentage of the excavated material would be roots and stems of trees. Excavation is effective at reducing flood overflow to the south of the creek during the 25 and 100 year events. The profile of excavation from the model shows a significant decrease is water surface elevation at the 100 year flow for a 400 feet upstream. At these high flows, the next (private) bridge downstream becomes a constriction and is overtopped, which limits the effectiveness of the excavation at the 100 year flow.

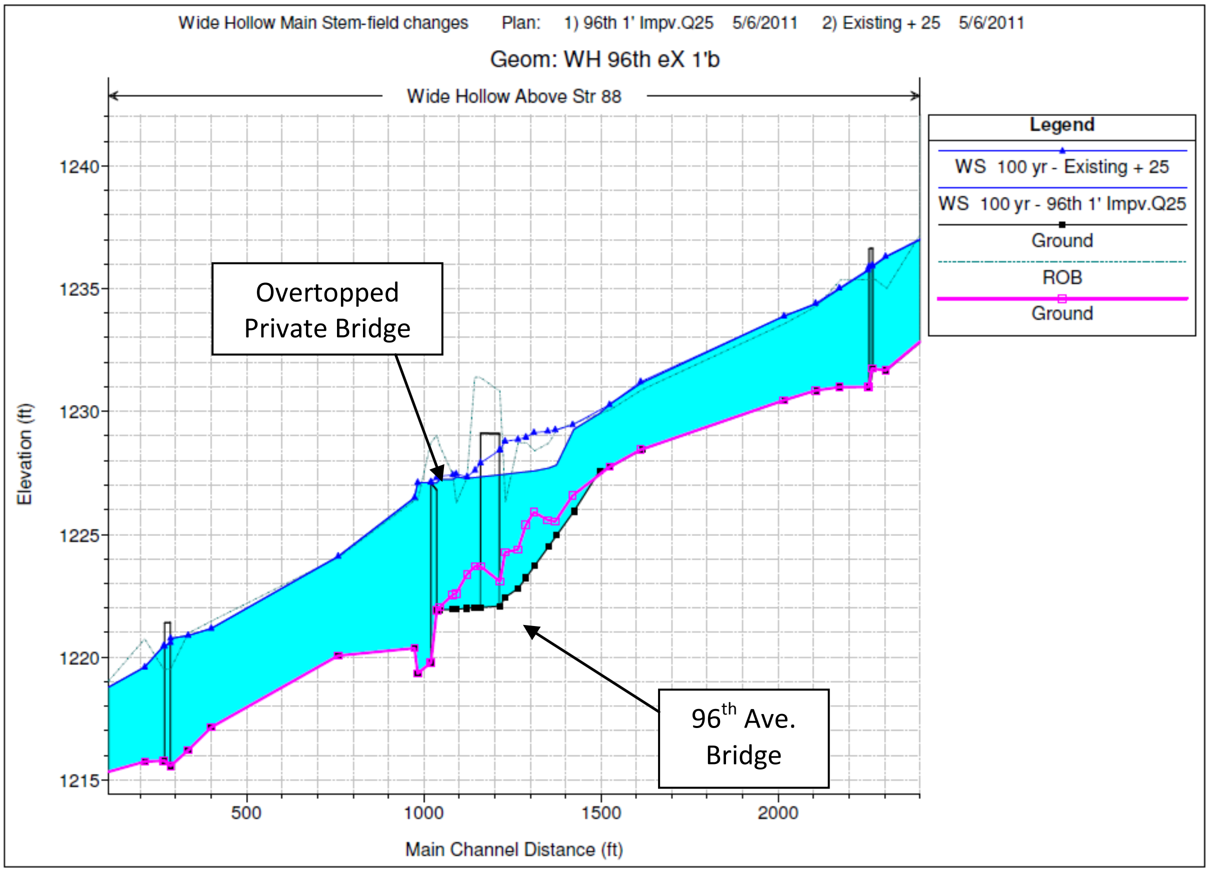


Figure 20 – Bridge Profile

This area has a moderate habitat value, and the impact of this degree of vegetative loss would likely have to be mitigated. The landowner has been cooperative thus far in allowing channel excavation and some tree removal on his property.

This bridge serves as an example of the types of effects on flood elevations that new bridge and road construction and pre-existing channel conditions may have in the real world. The construction of the bridge did not, and was not designed to, improve flow conveyance in this section of the creek, or reduce the extent of the floodplain. Nor did installation of the bridge trigger consideration of improvements to the stream channel outside of the new right-of-way. To optimize conveyance at this location, such steps would have been necessary, but were not then, and are not now, typically undertaken during the design of a new bridge.

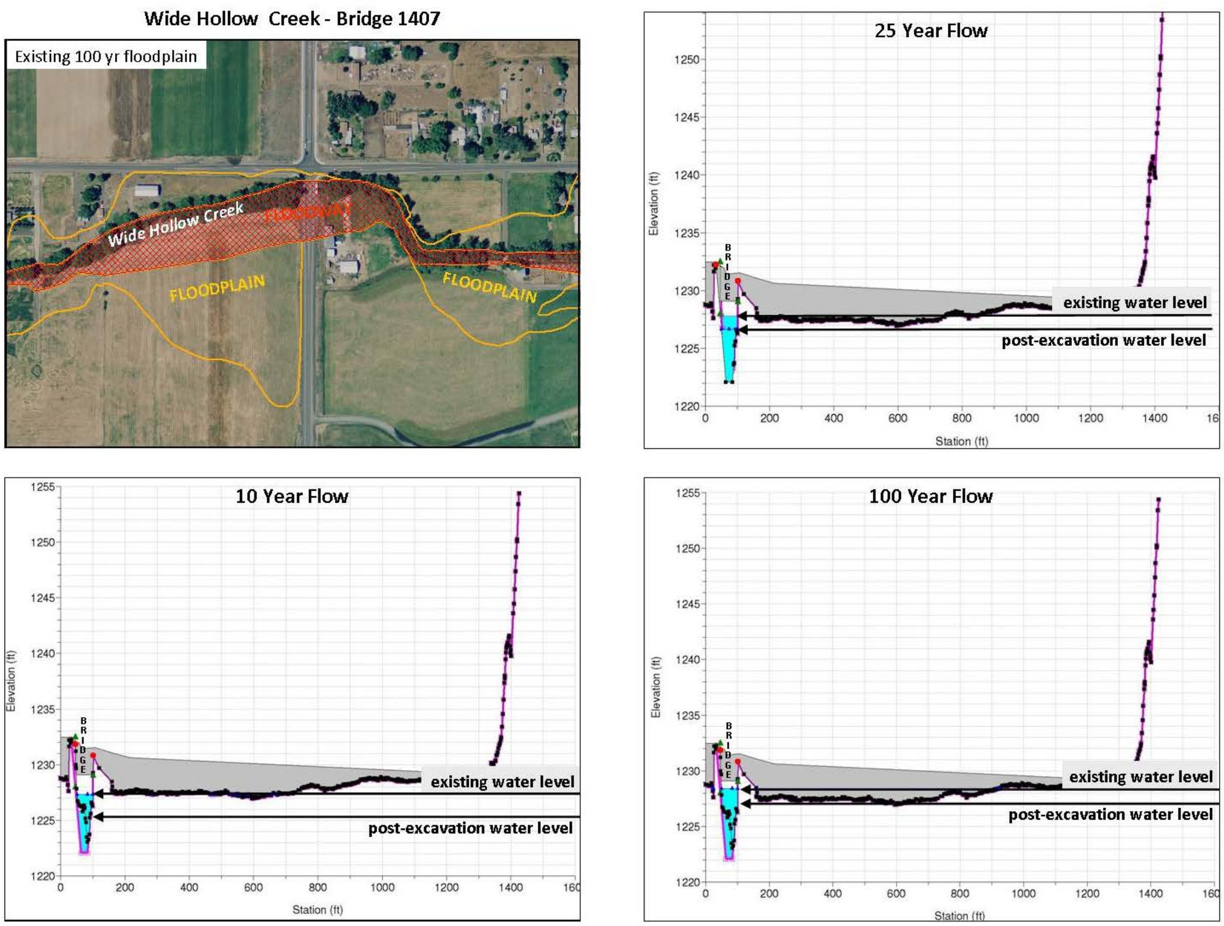


Figure 21 – Case Study Bridge 1407 Profile

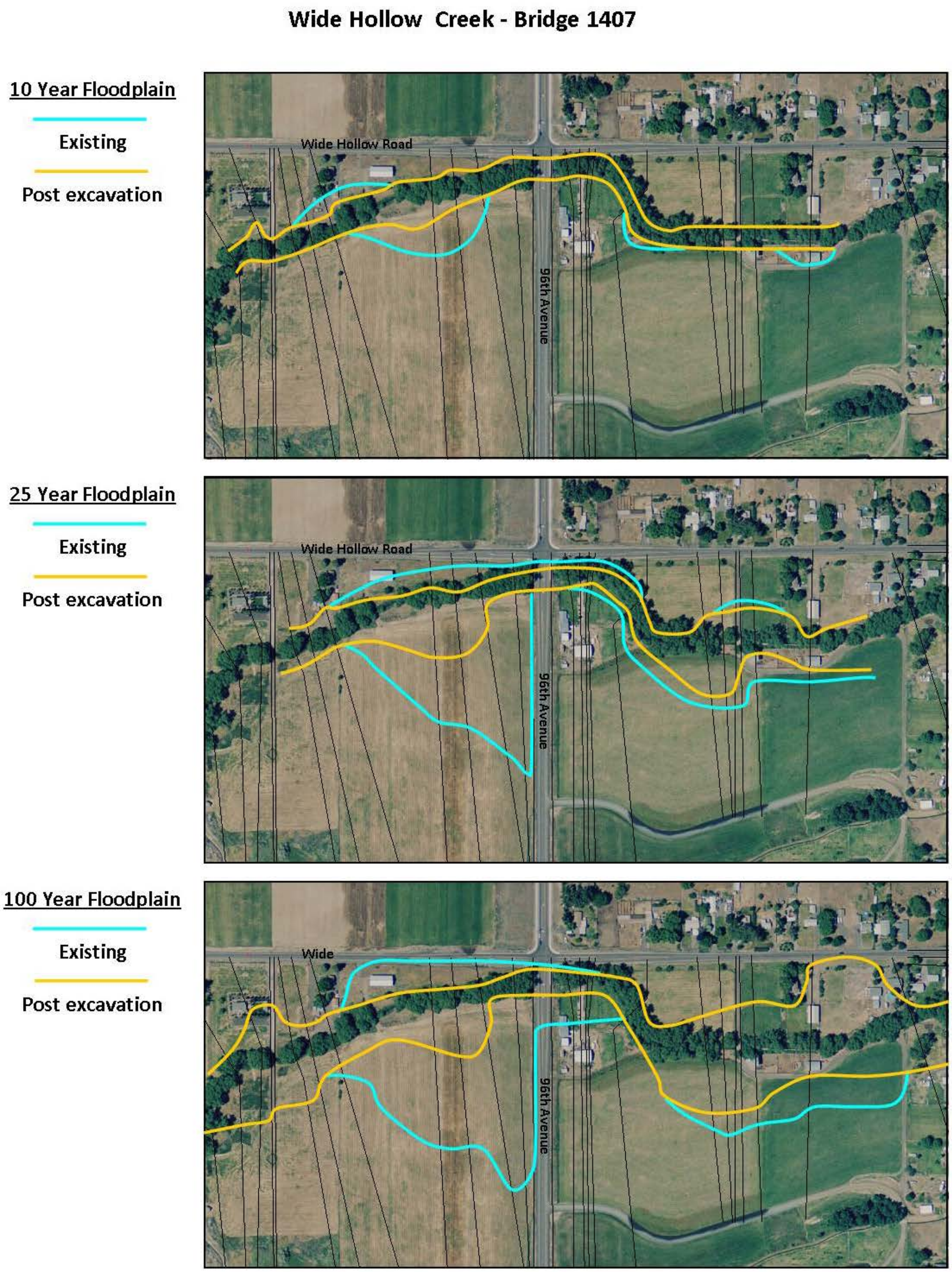


Figure 22 – Case Study Bridge 1407 Floodplain

Wide Hollow Creek at 3rd Avenue, Union Gap #5

This crossing of 3rd Avenue in the City of Union Gap is a combination of two culverts and a bridge, separated by about 200 feet. From examination of the air photos, old maps, and road plans, it appears that prior to construction of Drainage Improvement District (DID) #24 Broadway lateral, the creek ran directly under the 3rd (Broadway) Avenue at the location of the existing bridge. The 1914 construction drawings for DID #24 show that the newly installed outfall for the DID discharged to Wide Hollow Creek upstream of the bridge, and the Creek channel had been moved north to the outfall location, causing the realigned channel to flow along the road for 200 feet upstream of the bridge opening. The crossing remained in this configuration until 1997, when 3rd Ave was reconstructed and the culvert and a channel downstream of the culvert were added. Both DID 24 and an additional groundwater drain constructed in 1997 currently outfall into this culvert.

The culverts are 6′ x 6′ boxes, and the bridge has a 28.5′ span and a 10′ depth of footing. Gradient through the structures is 0.44%. The 100 year flow at this location is 775 cfs, and the new FEMA maps show that the bridge is overtopped during this flow. The 10 year flow is 343, and the 25 year, 498 cfs. The maps also show that the flow upstream of the bridge goes out of bank and flows to the south to Ahtanum Road, and flows across 3rd Avenue. The hydraulic simulations for the Guideline Streams indicate that the bridge alone should be able to convey the 100 year flow under normal conditions. Model results indicate that in its current condition, this crossing can barely pass the 25 year flow (498 cfs) which does come into contact with the lower bridge chord. This modeled condition does reflect conditions that have been observed in the field for these types of flows.

This crossing has been in place for over 100 years, the bridge location has not changed, but the alignment of the stream channel upstream has shifted, which must have reduced the gradient of the channel and caused significant backwater during floods. Both of these changes would have favored sediment deposition in the channel and floodplain. Downstream of the culverts, where material was removed in 1997, the channel is open and drains well for approximately 350 feet. Downstream of the bridge and the remainder of the creek after the new channel confluence, the creek is clogged with a severe infestation of hybrid willows which grow on the banks and in the stream channel itself, with large accumulations of downed tree stems and trunks also blocking the channel. This and other similar areas of Wide Hollow Creek have been given a very high channel roughness (Manning's) that limit the flow conveyance of the channel itself. Since most of the conveyance capacity of this crossing is through the bridge opening, this high channel roughness (in combination with the adverse angle of approach to the bridge), especially downstream of the bridge, does not allow the bridge to meet or even get close to design conveyance capacity.

Modeled excavation at this location was 3 feet at both the bridge and culvert. Total excavation was estimated at 4,354 cubic yards, 2,724 of which occurred downstream. Total distance of excavation was 1,034 feet, the distance of excavation are the most of any of the bridges examined.

After excavation, the bridge does convey the 100 year flow without overtopping, and the water surface elevation of the 10 year flood was lowered by only .4 feet. Upsteam backwater was substantially reduced, but floodwater sill exits the channel upstream of the bridge, travels south to Ahtanum Road, and floods across 3rd Avenue at the 100 (55 cfs across 3rd Avenue) year flow.

This crossing configuration, in combination with low gradient and downstream conditions, render this crossing very inefficient. Excavation of the channel does not fundamentally change the configuration or roughness conditions in the channel beyond the limits of excavation upstream or downstream. The need at this location is to address conveyance capacity of the channel itself upstream and downstream from the bridges. Downstream actions would need to continue for at least 2,000 feet until the stream crosses underneath Ahtanum Road and the adjacent Goodman Road Bridges. Upstream, the overflow channel that routes water south of the bridge has multiple exits from the channel, increasing the distance of excavation upstream is unlikely to prevent the formation of this overflow channel. The effectiveness of excavation at this point would also likely be short lived unless the stream itself is managed to discourage the re-establishment of hybrid willow stands. This type of management would likely include revegetation and control of hybrid willow regeneration into the forseeable future.

This is significant in that both the low gradient and high infestation of hybrid willows are common in lower Wide Hollow and Ahtanum Creek. New road crossings in both these creeks, which are in an urban or urbanizing area of the watershed, should be carefully planned or avoided if possible where these vegetative conditions are expected to continue into the future.

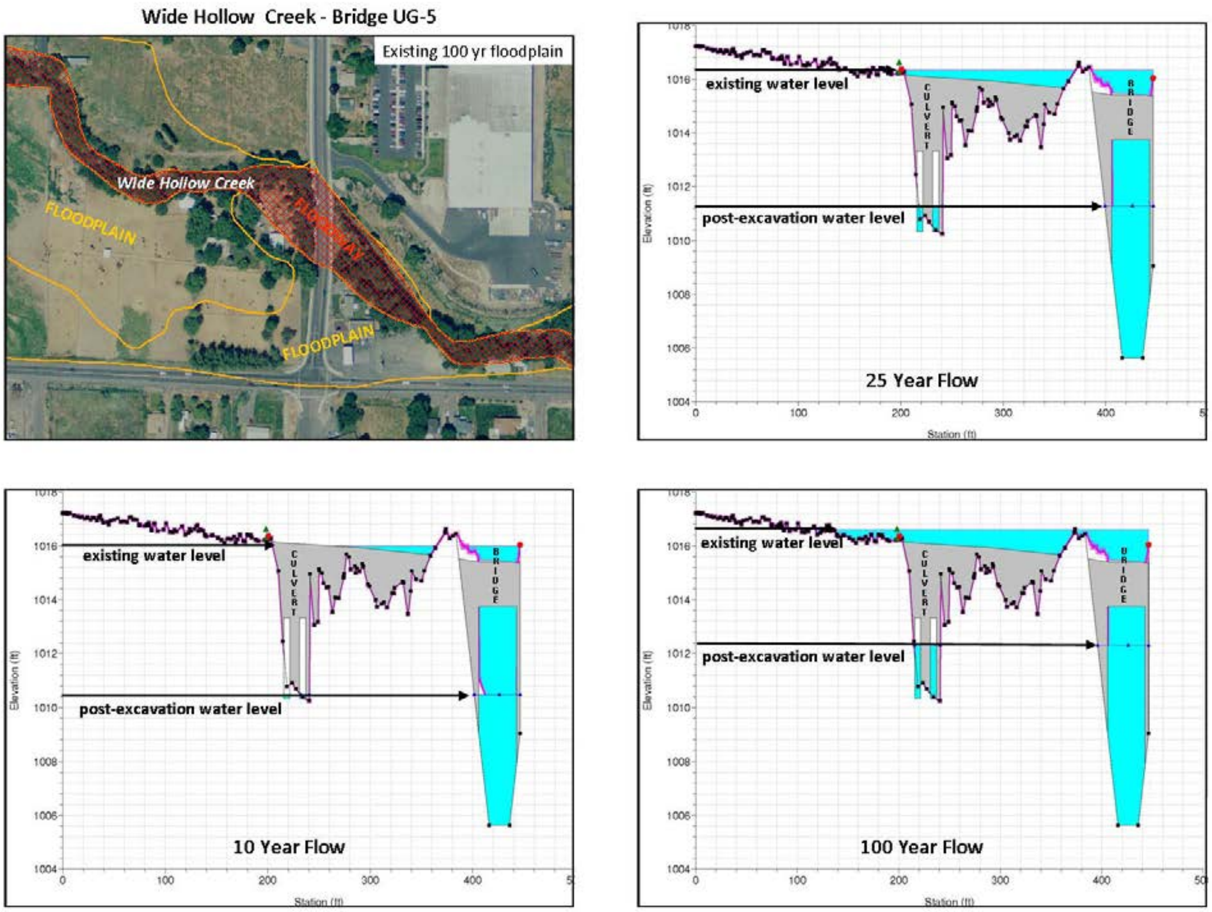


Figure 23 – Case Study Bridge UG-5 Profile

Wide Hollow Creek - Bridge UG 5

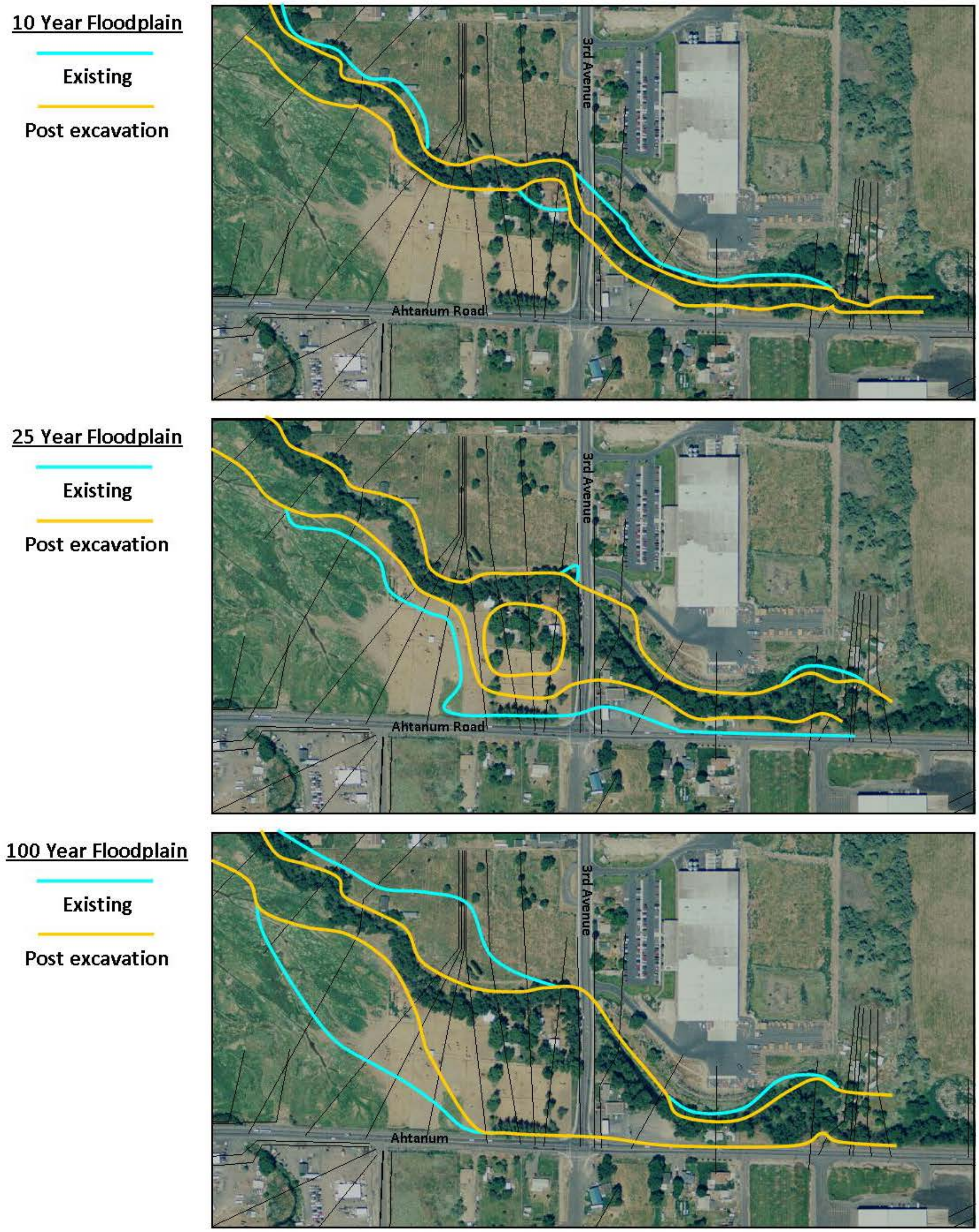


Figure 24 – Case Study Bridge UG-5 Floodplain

Summary – Flooding Characteristics at Bridges, Causal Factors and Sediment Removal Effectivness

Flooding characteristics of the bridges examined in this report indicate that many bridges in these watersheds are locations where floodwaters can be expected to go out of bank during major and minor flood events. Examination of the 10 and 25 year flood maps indicate that increased flood stage and the formation of flood overflow paths upstream from bridges is a common occurrence in these watersheds as well.

The quantities of sediment and distances of excavation to pass the 100 year flow in the "guideline" and "case study" streams are significant in terms of cost and environmental effect. Undertaking a program to improve the conveyance capacity of bridges or reducing the frequency of flooding upstream of bridges would not be a simple exercise of excavation directly adjacent to and underneath bridges.

The causal factors for the flooding characteristics at bridges are many. When bridge openings lack sufficient width or depth to convey a given flow without constricting, backwater occurs. Flood waters upstream increase in elevation and decrease in velocity , while velocities through the bridge opening increase. There are two effects: localized scour within the bridge opening and sediment deposition of fines upstream of the bridge due to slower velocities. Over a sufficiently long period of time with large sediment loads and no floods to "flush" the bridge opening or maintenance program to remove accumulated sediments, the sediment deposition results in further throttling of the bridge flow capacity.

The case studies show that bridges may also be influenced by conditions downstream of the bridge such as lack of channel capacity, vegetative encroachment, undersized bridges, irrigation diversions or severe channel bends. These conditions may require additional excavation, reworking of infrastructure, alteration of channel alignment or other measures to increase the capacity of the existing bridge.

Other conditions upstream of the a bridge can also "limit" the effectiveness of a bridge. If the channel upstream of the bridge is higher than the surrounding floodplain, or if the channel has been moved from the low point in the floodplain to the edge of the valley or onto the valley wall, flow in the channel may never reach the bridge. Excavation of the channel in these situations does not increase capacity of the bridge, it maintains conveyance capacity of the channel so floodwaters will reach the bridge. It is not unusual in these watersheds for channels to be perched or altered. In these situations, such as the Wide Hollow at Gromore bridge, excavation of material will improve the overall function of the bridge by altering the channel to have a more even gradient through the structure. The problem to be solved in these areas lies more with the conditions and location of the channel in the vicinity of the bridge, and if there are no plans to relocate the stream or relieve flood flows by other means (such as the proposed Shaw Creek bypass) an essentially one-time excavation entry of large scale may be the only way to achieve conveyance of the 100 year flow.

Sediment Management Recommendations

Sediment removal to maintain and achieve 100 year conveyance capacity may be appropriate in most situations in Upper Wide Hollow Creek, and based on estimated flows, many bridges on Hatton Creek. In other areas, such as most of the bridges on Bachelor Creek and Wide Hollow below the Cottonwood/Wide Hollow confluence, removal of sediment to pass the 100 year flow could result in with a relatively high cost and little benefit to reduction of flood hazard or maintenance of access during flood events. For example, excavation and haul of 7,160 cubic yards at Bachelor Creek on Lynch Lane, would cost an estimated $107,400, plus the cost of mitigation and likely the cost of armoring the channel to prevent un-forecasted channel change and protect the bridge footings. A new, 50 foot bridge at this location would cost approximately $180,000 . Even a new bridge at this location would only solve one aspect of a severe road access limitations and road damage in this area. Similar expense at the 3rd Avenue crossing would be incurred, although a bridge at this location would be more expensive due to the wider traveling lanes required on this high standard urban major collector. At locations such as this, excavation or channel improvement along with bridge replacement should be considered

In other locations, such as Bachelor Creek at 42nd Avenue. excavation is expensive, and repeated entries are likely. Examination of adjacent structures, whether they be road, bridges, or irrigation diversions, to improve both flow and sediment conveyance through the reach should be considered. At 42 nd, replacement of the Ahtanum Road Bridge downstream would likely be more cost effective over the long term, and is recommended in the CFHMP. Bachelor Creek at Wiley Road is an example where irrigation infrastructure attached to the bridge itself severely limits conveyance capacity of the bridge, and could be removed at little cost for the benefit in conveyance.

For the current bridges in these watersheds, it may be more appropriate to manage for a lower standard of conveyance than the 100-year flood for several reasons.

- First, the most benefit per amount of excavation occurs where nuisance flooding results in frequent repeated damage to the road or other major structures. To maximize benefits, the new 10 and 25 year flood maps should be used to determine where the most frequent damage occurs and concentrate on rectifying those areas and minimizing new structures in areas with high frequency flooding.
- Second, it is unlikely that there is funding available or economic justification to retrofit all existing bridges in these watersheds.
- Third, in areas such as Bachelor Creek at Lynch Lane, large improvements to the conveyance capacity of the creek, beyond what was present naturally before the bridge induced deposition have the potential to reduce upper watershed areas of flood storage during major events. Retention of areas that naturally act as flood storage or natural flood overflow paths during major events should be a consideration when deciding on bridge conveyance improvements or replacement.
- Fourth, many of these streams have been relocated, straightened, or modified for irrigation purposes and are “perched”. At these locations during the 100 year flood, adjacent areas to these perched channels will likely be flooded regardless of the

conveyance capacity of a bridge. Flood frequency in areas adjacent to these perched channels is very high, and where improvement of conveyance through bridges can reduce high frequency flooding in these perched channels, it is probably of high benefit.

The case studies show that 15 foot easements at bridges are insufficient to manage the sediment depositions created by the obstructions. It would be preferable also to provide bridges that fully span the channel and channel side slopes to avoid producing acceleration and deposition.

Attachment A – Ahtanum Hydrology Study

Final Hydrology Data Table as entered into the Ahtanum Creek HEC-RAS Model for the 10 yr-100 yr events

	River Reach	RS	10 Yr	25 Yr	50 Yr	100 Yr
1	Ahtanum above Bachelor	147510	950	1390	1750	2250
2	Ahtanum above Bachelor	117365	950	1390	1750	2250
3	Ahtanum above Bachelor	116925	941	1349	1741	2195
4	Ahtanum above Bachelor	116591	925	1362	1726	2152
5	Ahtanum above Bachelor	115363	925	1361	1722	2140
6	Ahtanum above Bachelor	115029	793	1230	1586	1961
7	Ahtanum above Bachelor	114582	661	1098	1379	1657
8	Ahtanum above Bachelor	114213	671	1007	1177	1378
9	Ahtanum above Bachelor	114151	856	1225	1422	1688
10	Ahtanum above Bachelor	114024	813	1101	1286	1585
11	Ahtanum above Bachelor	113440	499	750	956	1269
12	Ahtanum above Bachelor	112877	412	488	628	855
13	Ahtanum above Bachelor	112317	428	512	680	937
14	Ahtanum above Bachelor	111865	431	519	690	951
15	Ahtanum above Bypass	110201	376	440	560	722
16	Ahtanum above Bypass	100407	394	476	615	796
17	Ahtanum above Bypass	79286	417	520	683	886
18	Ahtanum above Bypass	66541	373	402	548	658
19	Ahtanum above Bypass	66040	336	362	425	480
20	Ahtanum above Bypass	65681	311	331	374	409
21	Ahtanum above Bypass	65265	152	153	163	168
22	Ahtanum above Bypass	64455	142	142	152	157
23	Ahtanum above Bypass	64012	67	68	69	70
24	Ahtanum above Bypass	63547	78	92	103	115
25	Ahtanum LOB-Split	3954	1	1	1	1
26	Ahtanum LOB-Split	3718	44	118	135	228
27	Ahtanum LOB-Split	3193	81	158	258	406
28	Ahtanum LOB-Split	2809	106	189	309	477
29	Ahtanum LOB-Split	2398	265	367	520	718
30	Ahtanum LOB-Split	2096	265	367	520	718
31	Ahtanum LOB-Split	1769	275	378	531	729
32	Ahtanum LOB-Split	1509	350	452	614	816
33	Ahtanum below LOB Split	61217	428	542	717	931
34	Ahtanum below LOB Split	58259	433	551	731	949
35	Ahtanum below LOB Split	52765	433	568	795	1126
36	Ahtanum below LOB Split	51615	440	582	816	1155
37	Ahtanum below Hatton	48798	507	685	934	1286
38	Ahtanum below Hatton	44210	515	701	959	1319
39	Ahtanum below Hatton	39862	515	699	947	1286
40	Ahtanum below Hatton	39462	515	694	912	1190
41	Ahtanum below Hatton	28475	533	728	965	1261

	River Reach	RS	10 Yr	25 Yr	50 Yr	100 Yr
42	Ahtanum Emma Lane	14276	1	7	47	129
43	Ahtanum Emma Lane	9599	38	112	152	234
44	Ahtanum below Bachelor	18442	1093	1667	2180	2822
45	Ahtanum below Bachelor	10080	1100	1680	2200	2850
46	Bachelor above SCIT1	91149	1	1	1	1
47	Bachelor above SCIT1	90813	9	41	51	56
48	Bachelor above SCIT1	90468	25	28	32	99
49	Bachelor above SCIT1	89572	25	29	32	111
50	Bachelor above SCIT1	89248	157	160	164	290
51	Bachelor above SCIT1	88976	289	292	372	594
52	Bachelor above SCIT1	88707	279	383	574	872
53	Bachelor above SCIT1	88648	94	165	329	563
54	Bachelor above SCIT1	88465	137	289	465	666
55	Bachelor above SCIT1	88042	451	640	794	982
56	Bachelor above SCIT1	87789	538	902	1123	1396
57	Bachelor above SCIT1	87264	522	878	1070	1313
58	Bachelor above SCIT1	81424	511	844	1034	1258
59	Bachelor above SCIT1	80794	510	837	1018	1233
60	Bachelor above SCIT1	71288	521	857	1050	1275
61	Bachelor above SCIT1	66070	525	864	1061	1290
62	Bachelor Bach-Hatt OB FP	4243	1	1	1	1
63	Bachelor Bach-Hatt OB FP	3959	11	34	36	56
64	Bachelor Bach-Hatt OB FP	3628	12	41	52	80
65	Bachelor ROB Split	4636	1	1	1	1
66	Bachelor ROB Split	4217	118	210	222	390
67	Bachelor ROB Split	3710	118	241	256	443
68	Bachelor above SCIT1 b	60686	422	675	712	925
69	Bachelor above SCIT1 b	58320	304	465	490	535
70	Bachelor above SCIT1 b	57843	304	434	456	483
71	Bachelor above SCIT1 b	57185	304	398	406	426
72	Bachelor below ROB split	52857	422	639	662	868
73	Bachelor Below_SC1T1_b	43273	318	383	391	471
74	Bachelor Below_SC1T1_b	42943	318	392	404	502
75	Bachelor Below_SC1T1_b	42431	368	553	573	755
76	Bachelor Below SC1T1junct	23160	418	634	656	862
77	Bachelor Below SC1T1junct	21717	380	529	551	755
78	Bachelor Below SC1T1junct	12564	501	806	1041	1303
79	Bachelor below SC1	10943	522	827	1063	1325
80	Bachelor below Emma Ln	3312	560	939	1215	1561
81	BachEmma Main	3827	38	105	105	105
82	Hatton Main	50740	55	79	130	229
83	Hatton below Bach Split	42169	67	120	182	309
84	Hatton below Bach Split	38505	67	113	152	208
85	Hatton below Bach Split	36307	67	120	182	309

	River Reach	RS	10 Yr	25 Yr	50 Yr	100 Yr
86	Hatton MB Rd	15358	1	13	43	118
87	Hatton MB Rd	12302	1	16	53	148
88	Hatton MB Rd	11620	1	17	64	178
89	Hatton below MDB Split	18597	67	107	139	191
90	Hatton below MDB Split	15683	67	104	129	161
91	Hatton below MDB Split	15044	67	103	118	131
92	Hatton ROB Split	13583	1	1	1	1
93	Hatton ROB Split	13245	1	7	30	101
94	SC1 Main	7819	142	298	511	570
95	SC1 Main	1135	21	21	21	22
96	SC1T1 Main	40497	103	189	349	365
97	SC1T1 Main	36484	103	225	399	422
98	SC1T1 Main	35705	109	237	418	448
99	SC1T1 at ROB split	24712	66	74	82	83
100	SC1T1 ROB split	2107	43	163	336	365
101	SC1T1 DS ROB split	22077	109	237	418	448
102	SC1T1 DS ROB split	19633	121	260	454	496
103	SC1T1 below SC1T1_b	13057	125	265	460	502
104	SC1T1 below SC1T1_b	12120	95	197	345	375
105	SC1T1 below SC1T1_b	9609	76	136	211	224
106	SC1T1 SC1T2 Split2	7404	19	61	134	151
107	SC1T1 SC1T2 Split1	5257	30	68	115	127
108	SC1T1 SC1T2 Split2 DS	4988	49	129	375	278
109	SC1T1_b DS_Bach_Split	4868	5	5	6	6
110	SC1T1_b Main	18561	104	256	271	396
111	SC1T1_b Main	18329	104	247	258	365
112	SC1T1_b Main	17997	54	86	89	113
113	SC1T1_b Main	11656	49	81	83	107
114	SC1T1_b Main	8493	12	24	37	50
115	SC1T2 below SC1T1 Split	1175	61	153	286	328

Attachment B – Wide Hollow Hydrology Study

ENGINEERING METHODS

For the flooding sources studied by detailed methods in the community, standard hydrologic and hydraulic study methods were used to determine the flood hazard data required for this study. Flood events of a magnitude that are expected to be equaled or exceeded once on the average during any 10-, 50-, 100-, or 500-year period (recurrence interval) have been selected as having special significance for floodplain management and for flood insurance rates. These events, commonly termed the 10-, 50-, 100-, and 500-year floods, have a 10-, 2-, 1-, and 0.2-percent chance, respectively, of being equaled or exceeded during any year. Although the recurrence interval represents the long-term, average period between floods of a specific magnitude, rare floods could occur at short intervals or even within the same year. The risk of experiencing a rare flood increases when periods greater than 1 year are considered. For example, the risk of having a flood that equals or exceeds the 1-percent- annual-chance (100-year) flood in any 50-year period is approximately 40 percent (4 in 10); for any 90-year period, the risk increases to approximately 60 percent (6 in 10). The analyses reported herein reflect flooding potentials based on conditions existing in the community at the time of completion of this study. Maps and flood elevations will be amended periodically to reflect future changes.

1.1 Hydrologic Analyses

Hydrologic analyses were carried out to establish peak discharge-frequency relationships for each flooding source (Reference 1). A set of new regression equations was developed based on flood frequency data at selected gauging stations in the region with watershed characteristics similar to the Wide Hollow Creek basin. The station peak discharge-frequency relationships were taken from the U.S. Geology Survey Water-Resources Investigations Report 97-4277 (Reference 2). The regression equations account for the difference in the mean annual precipitation between the Wide Hollow Creek basin and the selected similar basins. The new regression equations were used to calculate the 10-, 2-, 1-, and 0.2-percent-annual-chance peak discharges.

Peak discharge-drainage area relationships for all the streams evaluated are shown in Table 1. The stream network is shown in Figure 1 .

Table 1. Summary of Discharges

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (Cubic Feet per Second)			
		10-Percent-Annual-Chance	2-Percent-Annual-Chance	1-Percent-Annual-Chance	0.2-Percent-Annual-Chance
Wide Hollow Creek					
At mouth	70.5	323	547	663	966
Above confluence with Wide Hollow Tributary 3	62.7	303	538	658	991
Above confluence with Shaw Creek	41.2	239	489	615	1,025
Above confluence with Cottonwood Creek	24.6	170	381	491	872
Above confluence with Wide Hollow Tributary 2	14.3	121	307	408	792
Above confluence with Wide Hollow Tributary 1	4.9	58	166	231	491
Wide Hollow Tributary 2					
At confluence with Wide Hollow Creek	7.9	80	219	299	611
Above confluence with Tributary to Wide Hollow Tributary 2	5.6	64	190	264	571
Tributary to Wide Hollow Tributary 2					
At confluence with Wide Hollow Tributary 2	2.2	34	114	164	388
Wide Hollow Tributary 1					
At confluence with Wide Hollow Creek	9.2	92	264	360	762
Shaw Creek					
At confluence with Wide Hollow Creek	11.0	93	213	281	505
Above confluence with Shaw Creek Tributary	2.9	39	116	164	355
Shaw Creek Tributary					
At confluence with Shaw Creek	6.4	66	169	229	448
Cottonwood Creek					
At confluence with Wide Hollow Creek	15.3	126	319	422	816
Above confluence with Cottonwood Creek Tributary 2	11.8	109	301	406	836
Above confluence with Cottonwood Creek Tributary 1	7.5	83	266	369	840

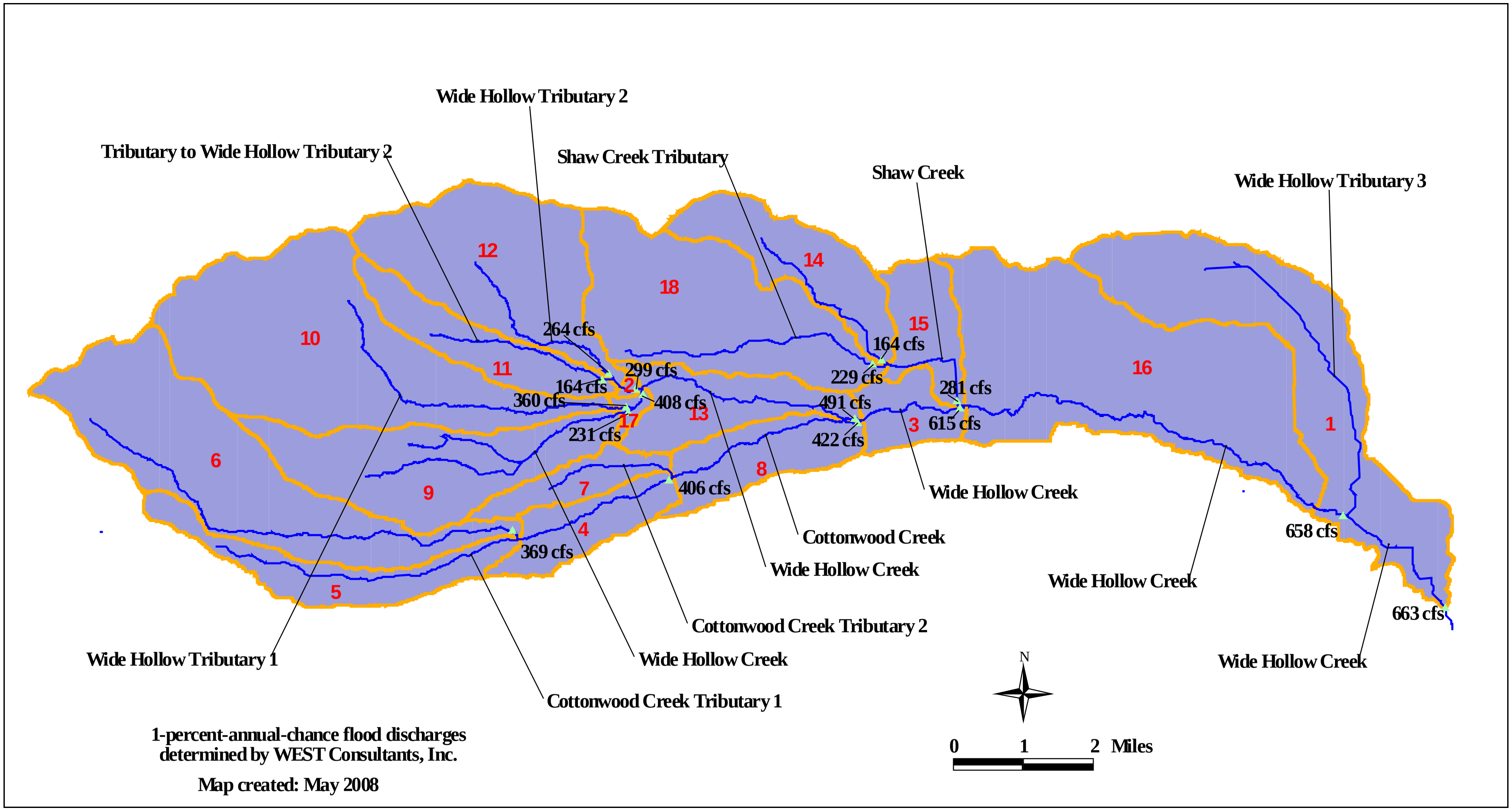


Figure 1. Study Streams within the Wide Hollow Creek Basin

2. REFERENCES

1. Sumioka S. S., Kresch, D. L., and Kasnick, K. D., Magnitude and Frequency of Floods in Washington, Water-Resources Investigation Report 97-4277, U.S. Geological Survey, Tacoma, Washington, 1998.
2. WEST Consultants, Inc., Hydrologic Analysis for Wide Hollow Creek and Tributaries, prepared for Yakima County Public Services, April 2008.