Yakima RM 89.5- Floodplain Restoration

Basis of Design Report

SUBMITTED TO
Yakama Nation
Wildlife Resources Management Program

May, 2018

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Concept Designs Report

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PREPARED BY
Pollyanna Lind & Dan Miller
Inter-Fluve, Inc.
501 Portway Ave., Suite 101
Hood River, OR 97031
Principal Investigators:
    Pollyanna Lind, PhD Geomorphologist
    Dan Miller, PE

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2. Introduction

2.1 PROJECT AREA

The Yakima River RM 89.5 Floodplain Restoration Project area includes approximately 900 acres of historical floodplain along the river right (west) side of approximately 4 miles of the mainstem Yakima River (RM 87-91). The Yakima River is 214 miles long and is a major tributary in the Columbia River basin (Figure 1). The modern active floodplain within the project area is very low gradient (0.19%) and ranges from 0.8 miles to 0.1 miles wide relative to the modern location of the mainstem Yakima River. Irrigation ditching, roads, bridges, gravel mining, and agriculture have encroached on what was historically an active floodplain that was at least 2 miles wide, less than a hundred years ago (according to aerial photos and subtle topographic scarring). The ungraded portions of the modern floodplain have irregular surface topography with multiple historical channel pathways and meander scars (Figure 2). Pockets of active floodplain exist on the east side (river left) of the Yakima River between the channel and a partially confining natural terrace. A 3,400-foot long levee constructed in the late 1970’s on river-right along the mid-section of the mainstem river near RM 89.5 halted local lateral migration and disconnected the mainstem channel from its adjacent and downstream floodplain. Upstream from the project area, irrigation infrastructure that includes dams and irrigation diversions impose notable alterations to the site’s natural seasonal flow regimes. The two diversions immediately upstream from the project area (Wapato and Sunnyside) are estimated to reduce average summer flow by two thirds (USBR, 2017; Yakama Nation, 2017). An assessment of the existing conditions at the site is provided in the Yakima RM 89.5 – Floodplain Restoration Site Assessment (Inter-Fluve, 2018).

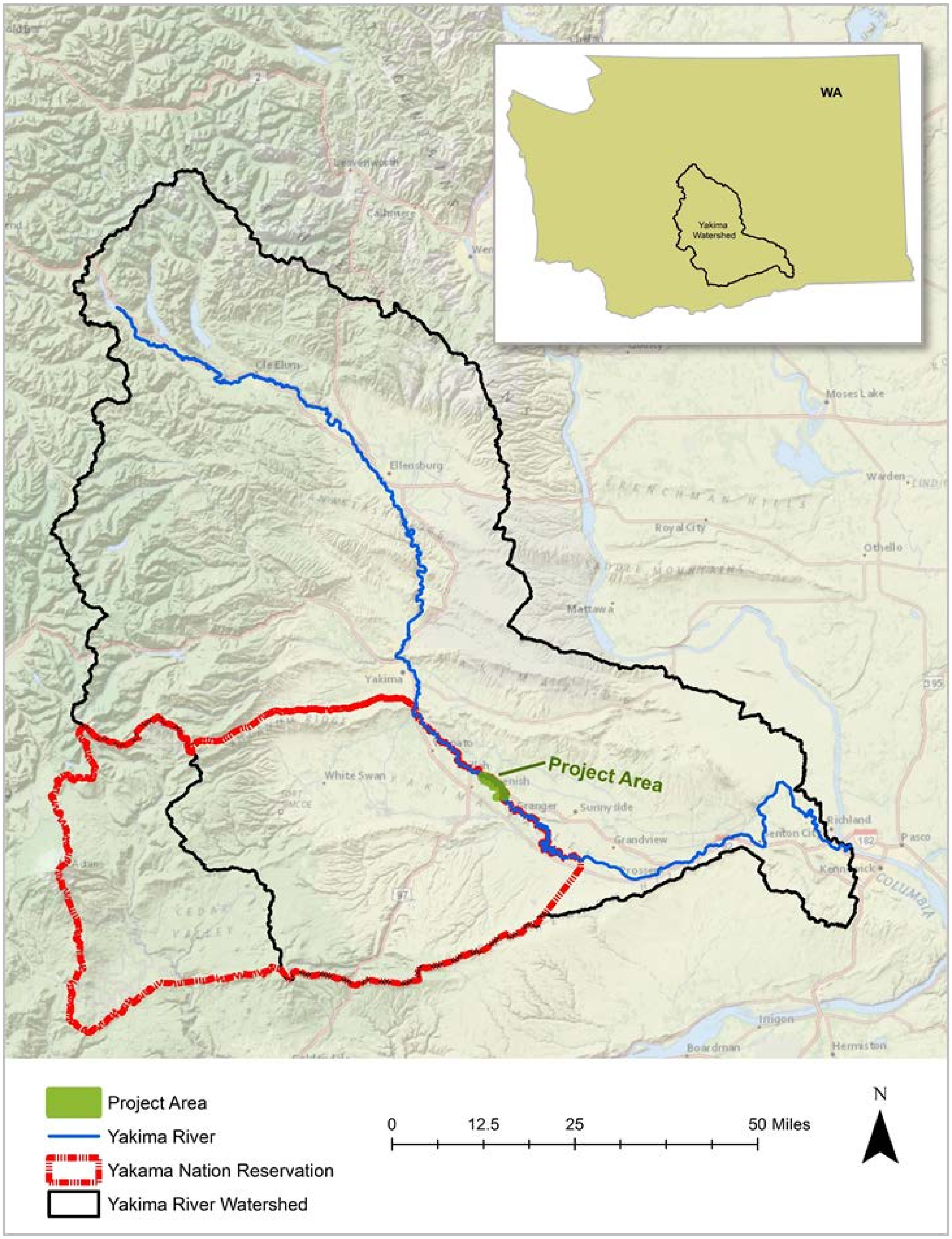


Figure 1. Yakima River basin with the project area (Yakima 89.5) highlighted in green.

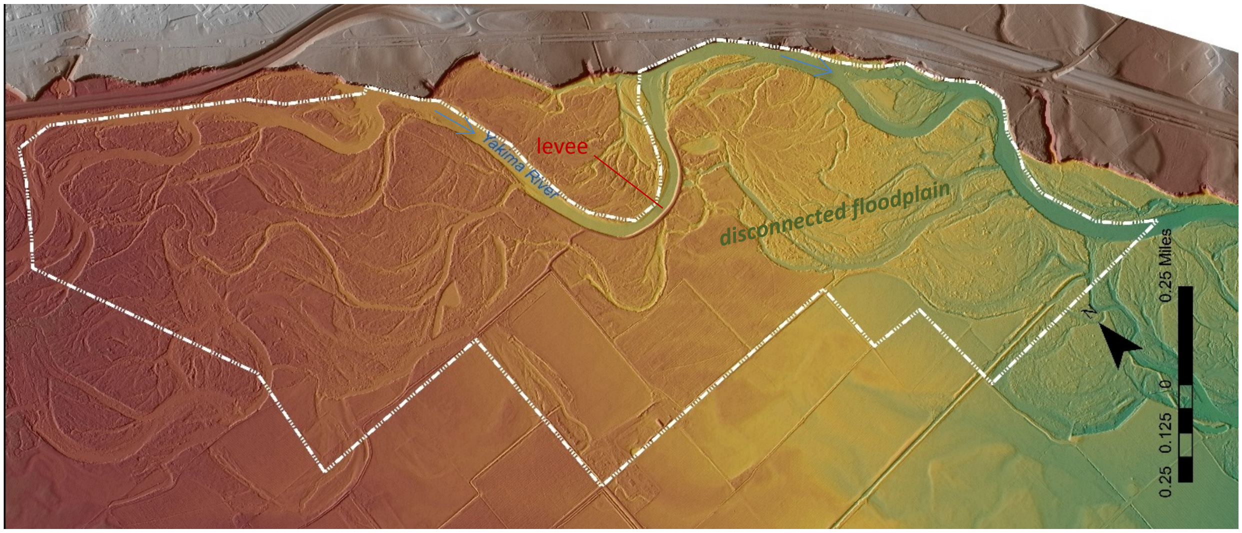


Figure 2. Project area with levee and disconnected floodplain identified. Basemap: LiDAR (WSI, 2015)

Floodplain wetland and riparian areas are important wildlife habitats, especially in the arid and semi-arid regions of the West. In otherwise dry landscapes, these ribbons of ecologic diversity provide critical resources to avian, terrestrial, and aquatic species. A few of the important resources offered by functioning floodplain wetlands and riparian areas include shelter, mobility corridors, food and nutrient production, and varied life-stage habitats. Well-functioning floodplain ecosystems are dependent on the frequency and duration of wetting by surface and groundwater resources.

The modern floodplain at the project area contains multiple meander scars. Some of the channel scars (oxbows) seasonally retain water supplied by groundwater or irrigation return flow. These areas provide annual or seasonal wet-environment habitats that support aquatic and riparian plants as well as birds, mammals, reptiles, amphibians, and insects that currently utilize the floodplain. Nonetheless, hydrologic flow regime alterations, built infrastructure (bridges, levees, irrigation, etc.), and a reduction in functioning floodplain due to human land-use encroachment has diminished the quantity and quality of habitat available on the floodplain and along the mainstem Yakima River, including within the project area. Therefore, reconnecting floodplain processes and side channel habitat at this site have significant potential to improve a complex and dynamic floodplain ecosystem that will yield important habitat benefits for aquatic, terrestrial and avian species.

Figure 3. Disconnected, groundwater-fed, well-vegetated oxbow downstream of levee. (Photo: Inter-Fluve, June 2017)

2.2 GOALS AND OBJECTIVES

The overarching goal of this project is to improve floodplain and side-channel connectivity to the mainstem river to restore high-quality habitat for native avian, terrestrial, and aquatic communities. The project objectives are:

1. to the extent possible, increase inundation of floodplain, wetland, and side-channels—emphasizing the area cut off by levee construction.
2. reduce or not increase flood hazard for properties adjacent to the project area.
3. enhance fish and wildlife habitat in the floodplain, side channels, and mainstem Yakima River.

3. Project Design

3.1 DESIGN CRITERIA

A list of design criteria developed for the project area incorporates site conditions, project area objectives, construction impacts, infrastructure constraints, property owner concerns, and feasibility. Design criteria serve three primary purposes: 1) to clearly document and communicate specific project objectives and constraints, 2) to help inform and guide the design process so that objectives are met, and 3) provide a basis for future performance monitoring. The following criteria have been developed:

Habitat

- Increase the quality and quantity of habitat within the riparian floodplain corridor for avian and terrestrial species.
- Improve aquatic habitat conditions in the mainstem channel along the levee, if possible.
- Increase the quality and quantity of off-channel habitat for ESA listed native salmonids.
- Consider off-channel habitat improvements for native lamprey.
- Make every effort to design treatments that do not require fish screens. If necessary, include appropriate fish screens or passage for designed water retention or diversion structures.
- Minimize fish stranding in side- or off-channel habitat features.
- Create/enhance improved habitats and stream function.

Geomorphology and Hydrology

- Support sustainable geomorphic conditions and processes.

- Support improved and sustainable hydrologic connectivity of the floodplain with an understanding that natural processes, over time, include sedimentation, debris accumulation, and system evolution.
- Consider existing active geomorphic processes of the mainstem channel (lateral migration, braiding, sediment and woody material transport, and floodplain development).
- Reconnect floodplain by increasing frequency and magnitude of inundation -- especially where it has been disconnected by the levee.
- Increase frequency of floodplain connectivity by activating/connecting side-channels.
- Activate multiple flow inputs for side-channel activation to build redundancy that supports long-term functionality and maximizes floodplain connectivity into the design.
- Avoid increased flood risk to existing infrastructure and properties.
- Maintain active geomorphic processes of the mainstem channel.
- Maintain connectivity of existing side/off channel features to the mainstem channel.
- Consider existing risks and future restoration potential of the gravel pit mines located on the river-left floodplain at the upstream end of the project area.

Groundwater Recharge and Irrigation Inputs

- Consider groundwater recharge and exchange with side channel and off-channel floodplain features.
- Based on limited available data of existing groundwater conditions, design side and off-channel features to receive groundwater inputs.
- Consider irrigation return locations and inputs (surface and potential groundwater).

Engineering and Risk

- Document flood flows and model with HEC-RAS changes in water surface elevations.
- Model flood inundation and changes in flood flow pathways. Design to minimize risk.
- Designs will minimize impacts to existing groundwater elevations.
- Design large wood (LW) jam structures and/or ballasting considering natural LW processes and risk of potential wood movement downstream.
- Design LW structures to use natural materials and avoid/minimize use of ballast boulders or cabling.
- Minimize risk of levee failure or main-stem channel pathway changes at the levee.

Construction Impacts

- Design to minimize disturbance during construction.

- Use locally sourced materials, to the degree possible.
- Excavated material to be exported to an appropriate site (to be determined by YN).
- Disturbed areas (areas of excavation, access routes, etc.) will be included in replanting plan (reseeding, etc.). Seed types and application to be developed in coordination with Yakama Nation staff will emphasize native species.

3.2 HYDROLOGY

Site Hydrology

Surface water discharge at the project area is characterized for this assessment using the stream gage at Parker, WA – which is located 17 miles upstream. The modern mean daily discharge hydrograph (1935-2017), is provided in Figure 4. The highest average discharge values usually occur in the spring when snow melt and rain-on-snow events occur in the headwater tributaries. Surface water in the mainstem Yakima River is diverted for irrigation upstream of the project at the Sunnyside Canal diversion located immediately upstream of the Parker discharge gage. This diversion notably reduces flow in the mainstem to supply water to the Yakima Valley from late spring through mid-October. The irrigation usage results in a muted hydrograph at the project site. The Bureau of Reclamation estimates that current summer base-level flows are one third of the historical, pre-dam discharge. According to USBR discharge data cited by the Yakama Nation, mean annual discharge at the Parker diversion has been reduced from an unregulated average of 4,765 cubic feet per second to 2,390 cubic feet per second (USBR, 2017; Yakama Nation, 2017).

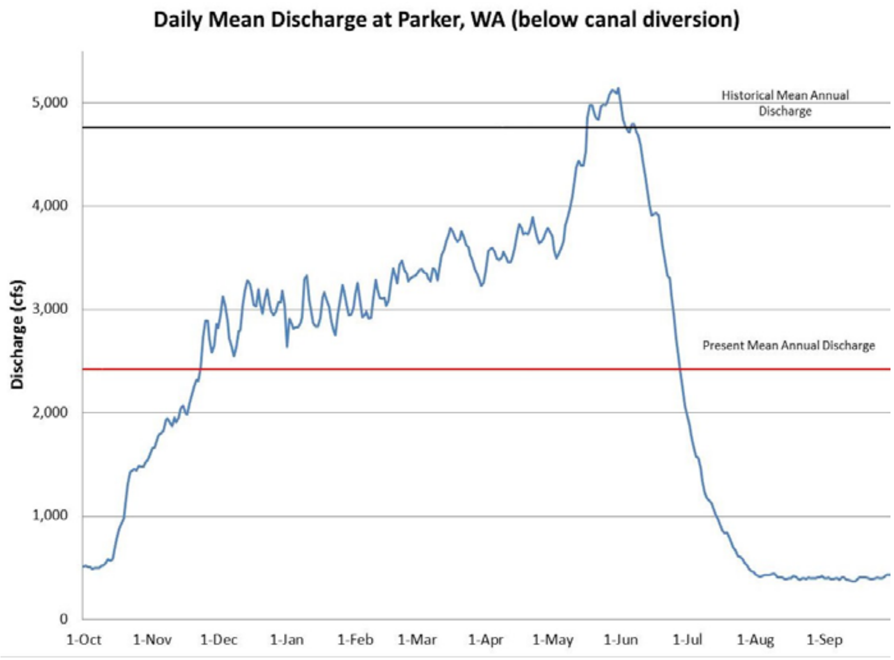


Figure 4. Mean daily discharge values at the Parker, WA gage with historical pre-dam (1900-1935) mean annual discharge and post-dam (1935-2017) mean annual discharge plotted (USBR, 2017a; USGS, n.d.).

Peak flow data available at the Parker, WA gage from 1935 to present were used to estimate the discharge and recurrence frequency for the 2, 10, 25, 50, and 100-year flood events using the Log-Pearson type III flood analysis technique. Those flood recurrence intervals are:

Recurrence Interval (years)	Discharge (cfs)
2	11,440
10	27,450
25	35,367
50	43,463
100	50,359

Hydrologic Design Analysis

In addition to reviewing the annual hydrograph and estimating peak flow events at the Parker gage on the mainstem Yakima River (Inter-Fluve, 2018), two basic hydrologic analyses were completed. These analyses were used to identify the frequency at which the mainstem channel conveys certain high-flows. This was done to aid in the process of identifying the preferred discharge at which restoration treatments will aim to activate the floodplain. Under existing conditions, the upstream portion of the project area begins to experience floodplain and oxbow connectivity with the mainstem channel at approximately 7000 cfs. Connectivity and activation of the oxbows at and downstream of the levee require flows =/>7000 cfs for a period of time (hours to days depending on discharge as well as groundwater and floodplain saturation status).

Inter-Fluve performed a basic flow duration analysis on the reported daily average discharge values for 35 years of complete records (1981-2016) at the Parker gage (USBR, 2017) and the estimated pre-dam/irrigation discharge at the same gage located approximately 15 river miles upstream of the project area. This identifies the number of days per year on average over this time period, that the mainstem discharge is expected to equal or exceed a particular discharge (includes all the months of the year) (Table 1).

Table 1. Average number of days per year that discharge at the Parker gage will experience a range of discharges -- modern hydrology and estimated pre-dam/irrigation hydrology. Based on 1981-2016 reported daily discharge values and USBR natural flow estimates.

Discharge (cfs):	>7000	≥6000	≥5000	≥4000	≥3000	≥1500	≥1000
Modern hydrology Probable days/year	21	28	39	58	86	181	225
Estimated pre-dam/irrigation hydrology Probable days/year	75	92	114	141	180	287	335

Yakama Nation staff counted the total number of days per month over the period of record between 1981 to 2017 that the daily average discharge of the mainstem was above 7000, 6000, 5000, and 4000 cfs (Table 2). Using these data combined, Yakama Nation Wildlands Management staff identified 1000 cfs as the preferred discharge for which the side channels and oxbows on the floodplain will be activated (instead of 7000 cfs). Side-channel and floodplain reactivation design for this project reflects this selected preferred discharge.

Table 2. Total number of days per month between 1981-2016 that discharge at the Parker gage recorded a range of discharges. Average number of days per year by month. Yakama Nation analysis

	>7000 cfs		**>6000 cfs**		**>5000 cfs**		**>4000 cfs**	
	total days	avg # of days per year	total days	avg # of days per year	total days	avg # of days per year	total days	avg # of days per year
January	81	2.3	111	3.1	152	4.2	228	6.3
February	102	2.8	149	4.1	188	5.2	277	7.7
March	132	3.7	176	4.9	252	7.0	372	10.3
April	142	3.9	173	4.8	230	6.4	332	9.2
May	176	4.9	228	6.3	312	8.7	420	11.7
June	113	3.1	157	4.4	221	6.1	314	8.7
July	**0**	0.0	**1**	0.0	**6**	0.2	**25**	0.7
August	0	0.0	0	0.0	0	0.0	0	0.0
September	0	0.0	0	0.0	0	0.0	0	0.0
October	1	0.0	2	0.1	2	0.1	3	0.1
November	30	0.8	43	1.2	64	1.8	100	2.8
December	64	1.8	78	2.2	100	2.8	144	4.0

3.3 HYDRAULIC MODELING

Yakima River and floodplain project site hydraulics were modeled using HEC-RAS (Hydraulic Engineering Center River Analysis System) version 5.0.3 (September 2016). An existing conditions model was developed and run using two-dimensional, unsteady state simulation mode to perform hydraulic computations for a representative discharge hydrograph. Model results depict hydraulic parameters such as depth, velocity, water surface elevations, and lateral inundation extents throughout the complex flow regions in the project area due to surface flow. Model results were compared to aerial photos taken by YN staff during flood events as well as photo sets available on GoogleEarth. Model roughness coefficients were adjusted to calibrate the model to observed conditions. The existing conditions model was then modified to represent design conditions to evaluate probable flow hydraulics under proposed conditions. Several iterations of the model were undertaken for multiple proposed conditions to evaluate and identify the designs that meet project goals and objectives (improved floodplain and habitat conditions as well as not increasing flood hazards for nearby private properties). Details about the model design and results are provided in Appendix B.

3.4 DESIGN COMPONENTS

The *Yakima River RM 89.5 – Floodplain Restoration 100% Design Plans* are provided in Appendix A. A summary description of the design component is provided below, including the benefits relative to the project design criteria, design considerations, and construction considerations. The Owner of the project refers to Yakama Nation Wildlands Management Program delegated staff and the Engineer refers to Inter-Fluve staff.

Floodplain and Side-Channel Activation

To increase floodplain connectivity, a set of side-channel alignments that re-connect the mainstem channel and perennial side-channel to existing oxbow ponds and flood-event flow pathways are designed. Alignment inlet locations and side-channel activation pathways are based on existing floodplain topography, hydraulic model analysis, and probability for geomorphic sustainability. The selected alignments are illustrated in (Figure 5). Activation flows for the alignment inlets are provided in Table 3. Alignments 1a and 1b activate the designed side-channel at the upstream end. Alignment 4 contributes discharge to the downstream portion of the same side-channel. Alignments 3a and 3b contribute additional flows along the middle portion. Having more than one activation inlet increases the complexity of floodplain reconnection and the ecologic benefits that supports. In addition, multiple activation inlets provide secondary and ancillary activation routes to the side-channel that increase the probability of long-term sustainable side-channel connectivity.

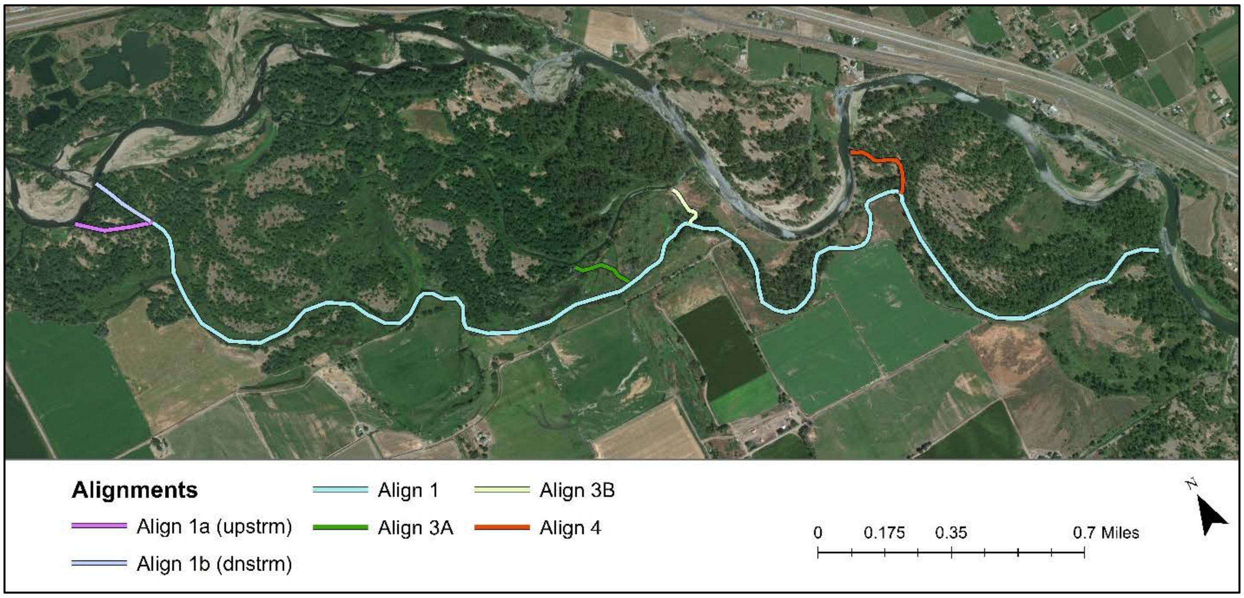


Figure 5. Basic orientation of selected activation alignments.

Table 3. Activation discharges for the inlets of the selected alignments.

Alignment	Align 1a (upstrm)	Align 1b (dnstrm)	Align 3A	Align 3B	Align 4
Activation Discharge	1000 cfs	1000 cfs	3000 cfs	1500 cfs	1000 cfs

Activation of the side-channel alignments requires excavation of inlet channels and connector flow paths through the floodplain at identified locations to create and maintain connectivity. Areas of excavation are designed to increase the frequency of through-flow by connecting existing oxbow ponds and abandoned side-channel scars. Routing side-channel alignments through existing floodplain features minimizes excavation requirements and takes advantage of existing established riparian vegetation along already wetted or seasonally wetted features within the floodplain. The orientations of the alignments are designed to activate wetland and floodplain feature more frequently than existing conditions.

Channel geometry (width and depth) and slope for each inlet and connector flow paths are designed to convey water through the alignments at the desired activation discharge while also increasing the frequency of floodplain inundation within the project area. Each inlet channel geometry is designed for its specific location and activation discharge. Hydraulic modeling of the inlets and connector flow paths was used to refine channel geometry through the design process. Channel geometry considers existing oxbow and side-channel dimensions as well as long-term maintenance of the activated side-channel alignments. The excavated channels will be seeded and planted with native species. Similar to natural channel dynamics, no additional armoring of the channel is proposed. See the Plans (Appendix A) for specification on the alignment orientations, channel geometry, and slope for each designed inlet and side-channel connector excavation area.

Fords

Two access routes through the site will be maintained by construction of three stream ford crossings. The surface of the ford is flush with the new channel finished grade profile to not disturb flow. Twelve inches of granular material are placed to allow a driving surface for four-wheel drive pickups and tractors. The crossings will be wetted more frequently with the proposed fords than under existing conditions.

Large Wood Structures

Large Wood (LW) jam structures will be constructed at the excavated side-channel inlet mouths of Align 1a (upstrm), Align 1b (dnstrm), and Align 4 on the mainstem Yakima River. The LW installations are designed as an apex jam located on the channel-left side of the inlet mouth and a bank jam located upstream from the excavated inlet. The intended purpose of the LW jams is to promote hydraulic maintenance of the side-channel inlet while also providing in-stream habitat features. The LW jams include approximately 21 18″dbh x 40′ long logs with rootwads that have their trunks buried into the bank and 21 12-15″ diameter by 30′ long log snag ballasts installed vertically and driven into the ground 15-20′ by vibratory pile driving equipment and bolted to the horizontal logs. The upstream end of the jam will have a matrix of six 15-18″dbh x 35-40′ long logs and slash (~75 CY) placed horizontally in the rootwads. A photo of an example of an inlet jam is provided in (Figure 6).

Figure 6. Example of inlet jam. Installed by Inter-Fluve 2013, photo taken in 2016 (Inter-Fluve).

In addition to back-fill burial, the horizontal LW trunks with rootwads will be further stabilized to resist buoyancy with placed boulders and backfill contained by biodegradable fabric encapsulated soil lifts that will support the maturation of vegetation on the bank. Boulders (~36” diameter) will be integrated into the backfill material and placed on the horizontal LW trunks. These elements are shown in the Plans on sheets 14-18.

Access Routes and Material Storage Areas

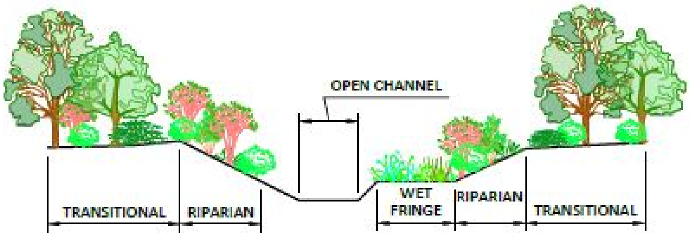
Access routes for the project were identified in collaboration with Yakama Nation staff. Where possible, existing routes are utilized. Elsewhere, temporary access routes have been identified to minimize impacts to vegetation and maximize equipment routing. Access into excavated areas is expected along the centerline of the area being excavated. This uses the construction footprint for access by applying an ‘inside-out’ construction sequencing (excavating from within the channel) to limit disturbance to existing vegetation along the banks. If and where necessary, the access routes will be improved by the contractor for construction purposes. Remediation guidelines of designated access routes are included in the Plans (Appendix A).

Two material storage areas will be used to store the excavated material outside of the active floodplain. Excavated materials will be stored in two general sorting piles: 1) fines – small gravels, and 2) gravel-boulders. The owner will be responsible for coordinating the removal of the excess excavated material. The location of these areas and guidelines on volumes and contouring of the material is provided in the Plans. In addition, two temporary staging areas are designated for staging equipment and LW jam materials during construction. These areas will be remediated immediately after construction is complete. Where identified, the Material Storage Areas will be replanted with appropriate native seed mixes. All vegetation remediation will follow the planting guidelines provided in the Plans.

Remediation and Revegetation

Areas disturbed during construction, including existing access routes, will be remediated after construction to similar or improved conditions. Temporary access routes, storage areas, newly constructed channel, and any additional disturbed areas will be replanted with appropriate native seed mixes to support site recover and reduce erosion risks. Plant lists, seed mixes, quantities, locations, and planting guidelines are included in the Plans (sheets 19-22). The contractor is responsible for procuring the seed and re-seeding all disturbed areas, except areas of the Material Storage Area holding stockpiled materials. The Owner will place seed in the Material Storage Areas after the material has been hauled off site. All woody plants (live cuttings, bare root, and container) will be procured and installed by the owner in autumn, after construction is complete and planting conditions are more optimal for survival.

Three different native seed mixes will be applied to three identified planting zones, delineated by surface elevation and expected days of wetting after construction. The three zones are Wet Fringe, Riparian, and Transitional. If surface elevations within the allowed areas of disturbance are different than existing conditions on access routes and along the border of the constructed channels after construction, then plating zones in those areas will need to be adjusted accordingly. All disturbed areas will be reseeded with QuickGuard Sterile Triticale at a rate of 15 lbs/acre to promote germination of the native seed mix and reduce weed-seed propagation.



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Yakima RM 89.5 – Floodplain Restoration

Basis of Design Report

Appendix A:

Yakima RM 89.5 Floodplain Restoration: 100% Design Plans (see attached Design Plans)

Yakima RM 89.5 – Floodplain Restoration

Basis of Design Report

Appendix B:

2-Dimensional Hydraulic Modeling and Results

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1. Hydraulic Modeling

Yakima RM 89.5 project site hydraulics were modeled using HEC-RAS (Hydraulic Engineering Center River Analysis System) version 5.0.3 (September 2016). An existing conditions model was developed and run using two-dimensional, unsteady state simulation mode to perform hydraulic computations for a designated discharge hydrograph. Model results depict hydraulic parameters of surface water such as depth, velocity, water surface elevations, and lateral inundation extents throughout the complex flow regions in the project area. The existing conditions model was calibrated by iteratively adjusting Mannings n roughness coefficients within acceptable range of values until the model results were representative of observed and recorded flow and inundation conditions documented by YN staff from oblique aerial photographs taken from an airplane and other field observations. The terrain of the existing conditions model was then modified to represent design conditions to evaluate probable flow hydraulics under proposed conditions. Several alternative proposed conditions were carefully modeled to evaluate and identify designs that meet all project goals and objectives. The project goals are to improve floodplain and habitat conditions while not increasing flood hazards for nearby private properties. The model results for the final Design Plans (Appendix A) meet the project goals and are presented here.

1.1 TERRAIN AND GEOMETRY

The modeled terrain is a compilation of multiple topographic and bathymetric datasets, consisting of field survey by Inter-Fluve and Lidar data (WSI, 2015). Topographic surveys of the site were completed by Inter-Fluve survey teams on October 3rd and 4th and again on November 9th and 10th, 2017. The site surveys included topography and bathymetry of selected areas, targeting dynamic regions, active flow channels, waterbodies, and potential project areas. Survey data was used to validate, supplement, or supersede the available LiDAR data (WSI, 2015). This composite terrain for existing conditions was sampled at a 1-foot resolution digital elevation model (DEM) raster from the composite surface developed in CAD. Although the typical computational mesh size (25 x25 feet) was greater than the 1x1-foot terrain resolution, the modeling capabilities of the HEC-RAS 5.0.3 series integrates the sub-grid terrain into the computations and projects the results accordingly. A series of irrigation ditch berms that run laterally across the floodplain interrupting flow patterns were included in the model as 2D Area Connection weirs to accurately model flow blocked by the berms and flow overtopping the berms. A graphic of the model mesh with boundary conditions and irrigation berms is shown in Figure 1.

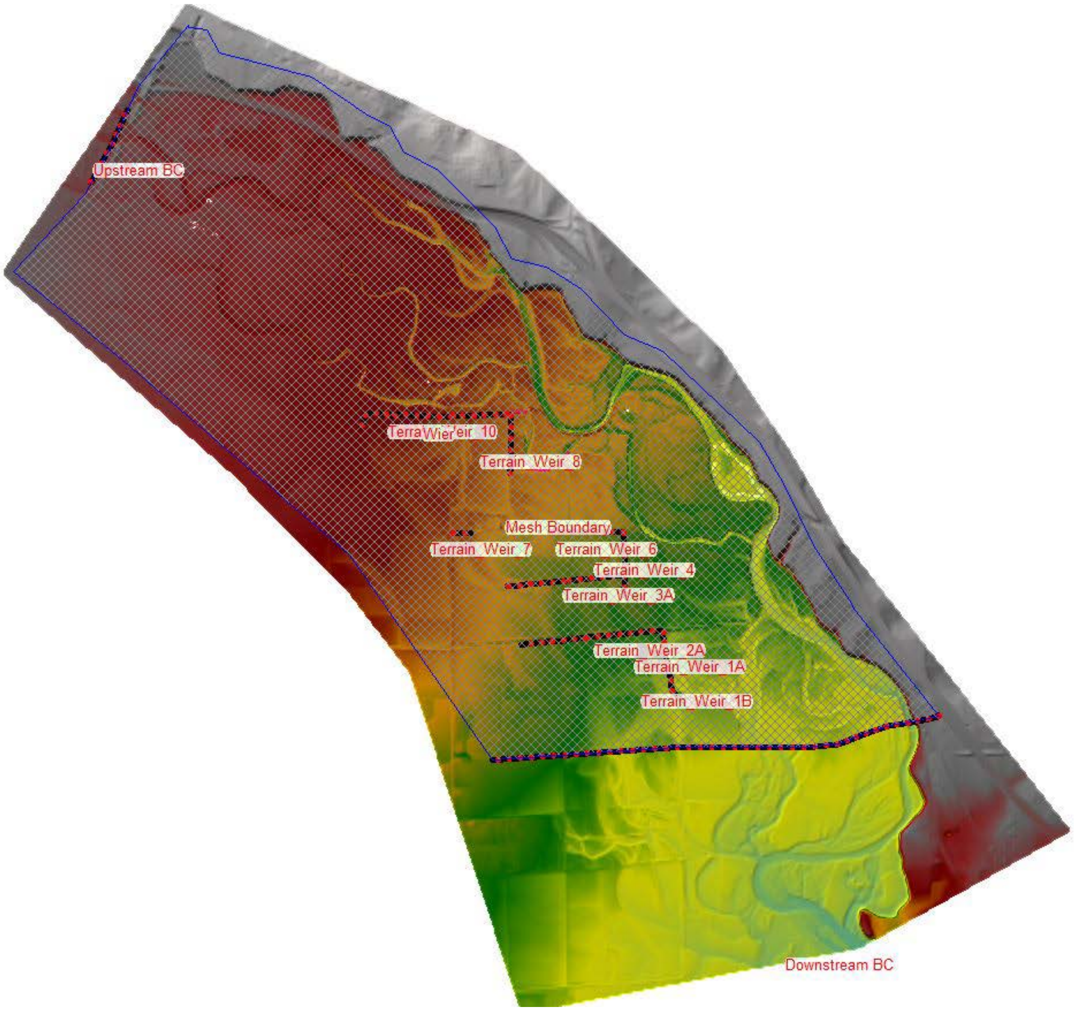


Figure 1. HEC-RAS modeled region (mesh, boundary conditions and irrigation berms)

1.2 UPDATED TERRAIN MODEL

The Yakima River at the upstream end of the project area is geomorphically dynamic and braided. In this area, the actively meandering portions of the main stem have shifted since the LiDAR flight in 2015. This was confirmed by the bathymetric field survey, as well as more current aerial imagery. Of note, particular regions have slightly more mature meanders within the active floodplain, while other areas have avulsed to reoccupy historically active flow paths. The bathymetry and topographic data collected in 2017 was used to update the terrain model. The 2015 LiDAR was otherwise used for the existing conditions model based on several points:

1. No flow events have occurred since the collection of the LiDAR in 2015 which changed the nature or general extent of the active river corridor and the floodplain.
2. The 2015 LiDAR, does not include bathymetric (below water surface) topographic data. Instead, wetted areas are represented as basically flat surface. By incorporating the 2017 bathymetry and topographic survey into the LiDAR, the result is a single mainstem channel with representative conveyance and hydraulic parameters, and improved accuracy of existing side channel and surveyed oxbow features that better represent current topography.

3. The LiDAR was in good agreement with ground shots taken from multiple static features (floodplain, roads, and levees) as verification for this data set.
4. This model is a representative snapshot in time, like all river models, and the compilation of available data will be sufficient for design purposes as it will inform activation flows of side channels, floodplain inundation patterns, as well as changes between existing and proposed hydraulic conditions.

1.3 ROUGHNESS

Roughness coefficients (Manning's n values) are used by the 2D model to calculate flow energy losses, or frictional resistance, caused by channel bed materials, and the type and density of floodplain vegetation. Manning's roughness values were delineated based on field observations, aerial photos, proposed grading locations, and published guidelines (Arcement & Schneider, 1989) for similar channel types and vegetation conditions. Four land cover types were observed and assigned roughness values in the project area: channel, floodplain tree and shrub mixture, floodplain grass, and wetland. Two sets of roughness values were established for the model, one for low-moderate (450 – 10,000 cfs) flow conditions when roughness features (vegetation, topography, etc.) impose more surface roughness and one for flood conditions (>11,400 cfs) when wide-spread inundation and flow depth occurs on the floodplain, including graded agricultural fields. These roughness values were calibrated by comparing model run results to inundation patterns observed and photographed by Yakama Nation staff. Table 1 summarizes the roughness values used in both the existing and in the proposed model.

Table 1. Manning's Roughness Coefficients used for the Yakima 89.5 Hydraulic Model.

Land Cover Type	Channel	floodplain tree and shrub mixture	floodplain grass	wetland	Large Wood jams (proposed)
Manning's Roughness low-moderate flows 450 – 10,000 cfs	0.040	0.100	0.060	0.050	0.15
Manning's Roughness flood flows >11,400 cfs	0.033	0.05	0.035	0.040	0.15

1.4 HYDROLOGY AND BOUNDARY CONDITIONS

Peak flow data available at the Parker, WA gage from 1935 to present were used to estimate the discharge and recurrence frequency for the 2, 10, 25, 50, and 100-year flood events using the Log-Pearson type III flood analysis technique.

Those flood recurrence intervals are:

Recurrence Interval (years)	Discharge (cfs)
2	11,440
10	27,450
25	35,367
50	43,463
100	50,359

The HEC-RAS model requires hydrologic flow inputs to complete a simulation. A synthetic hydrograph was created that included gaged baseflow (400-500cfs), various flows of interest, and estimated flood events. Table 2 shows the flow values used for modeling existing and designed conditions.

Table 2. Discharges (Q) used to model flow hydraulics in the 2-D Hec-Ras models used.

Description	Q (cfs)
Baseflow	450
Incremental Floodplain Activation Flow of Interest	1000
Incremental Floodplain Activation Flow of Interest	1,500
Incremental Floodplain Activation Flow of Interest	3,000
Incremental Floodplain Activation Flow of Interest	4,000
Incremental Floodplain Activation Flow of Interest	5,000
Incremental Floodplain Activation Flow of Interest	6,000
Incremental Floodplain Activation Flow of Interest	7,000
Incremental Floodplain Activation Flow of Interest	8,000
Incremental Floodplain Activation Flow of Interest	9,000
Incremental Floodplain Activation Flow of Interest	10,000
Q2	11,440
Incremental Floodplain Activation Flow of Interest	15,000
Q10	27,451
Incremental Floodplain Activation Flow of Interest	30000
Q25	36,567
Q50	43,463
Q100	55,000

This hydrograph was applied as an upstream boundary condition, where flow was initially distributed along the boundary using an assumed energy slope based on upstream terrain (0.005 ft/ft). The downstream boundary condition was set to a normal flow depth at a friction slope estimate derived from the average channel slope (.005). The hydrograph was defined by a series of increasing flow steps of sufficient duration (17-27 hours) for the modeled area to stabilize under each flow to provide a quasi-steady state flow condition before advancing to the next step. Flows were selected to capture the mainstem baseflow (450 cfs), bank-full (10,000 cfs), out-of-bank (11,440 and greater), and flood conditions (2-YR through 100-YR). Incremental flows of interest (3,000 through 10,000 cfs) were also modeled to capture Yakima River mainstem flows inundation of the adjacent floodplain. Other flows not listed were modeled for model calibration and validation purposes during early model iterations.

2. Results

Model results were compared against water surface elevations surveyed in the field, YN staff field observations as well aerial imagery available on Google Earth and aerial imagery of flow events provided by Yakama Nation staff. Roughness values were adjusted during the model calibration process until flows sufficiently matched observed conditions. An example of flood photo calibration with existing model results is provided in Figure 2.

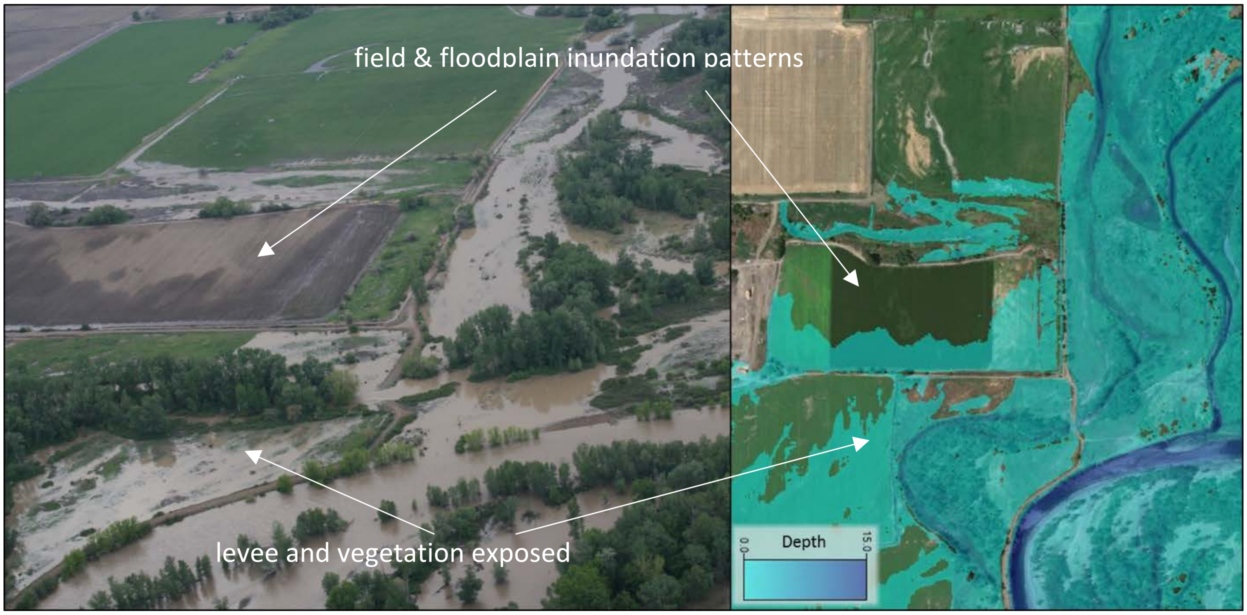


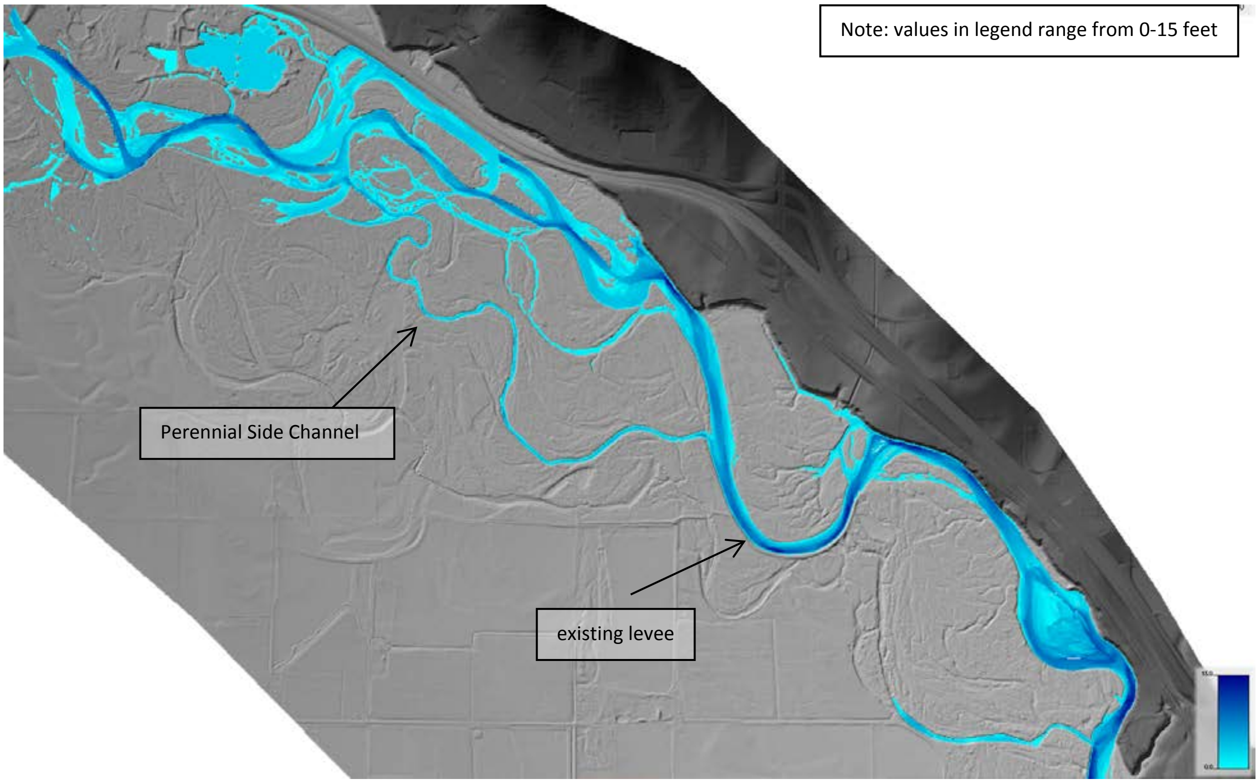
Figure 2. Left: oblique aerial photo showing inundation wetting pattern in a field from a ~30,000-35,000 cfs flow recorded the night before (photo: Yakama Nation May 17, 2011); Right: Hec-Ras existing conditions floodplain inundation (depth) results from ~35,000 cfs.

This hydraulic model is complex in that it covers a large surface area (over 1000 acres), the surface is topographically complex, and inundation patterns at flood-flows are complicated. The model results are expected to be conservative (over-predict inundation depths and patterns) because not all flow pathways with water in them at the time of LiDAR data collection were surveyed prior to creating the updated terrain surface. For example, some, but not all, wetted irrigation ditches on the floodplain within the model extent were surveyed. As a result, the model underpredicts the capacity of the un-surveyed features to convey surface water off the floodplain.

2.1 EXISTING CONDITIONS

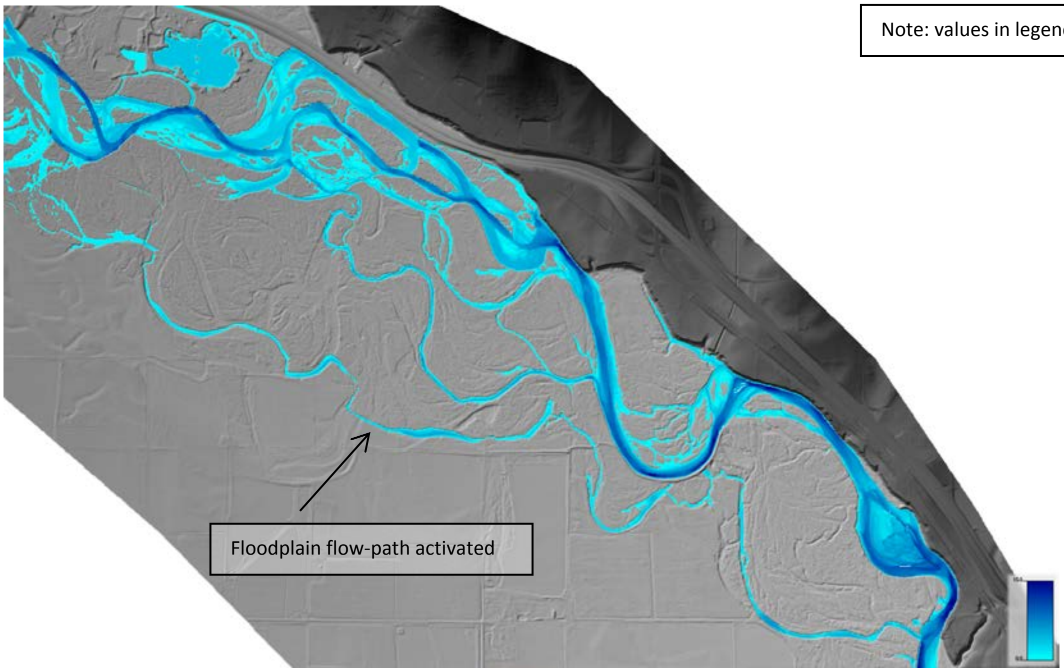
The model results represent existing conditions. Outputs show less connectivity on the floodplain at and downstream of the existing levee. Mainstem flow velocities are also generally higher in the levee-confined region, producing higher scour potential around the outside meander at the levee the levee. Further upstream, results indicate higher connectivity and activated complex flow paths at relatively frequently occurring flows (1,500-3,000 cfs). The existing perennial side channel is expected to convey flow most of the year, and model results are in agreement. Field observations confirm that the existing conditions in the area of Alignment 1 begin to receive overland surface from the mainstem Yakima River at approximately 6,000-7,000 cfs under existing conditions. The 2-year flood event at 11,440 cfs yields significant out-of-bank flows and activation of off-channel features. At higher flood flows, the floodplain continues to gradually engage laterally. By the estimated 100-year event (55,000 cfs) the entire floodplain and much of the adjacent farmland is inundated. Model results for existing conditions are shown in subsequent figures below.

Model Results Depicting Flow Depth at 5,000 cfs – existing conditions



Note: values in legend range from 0-15 feet

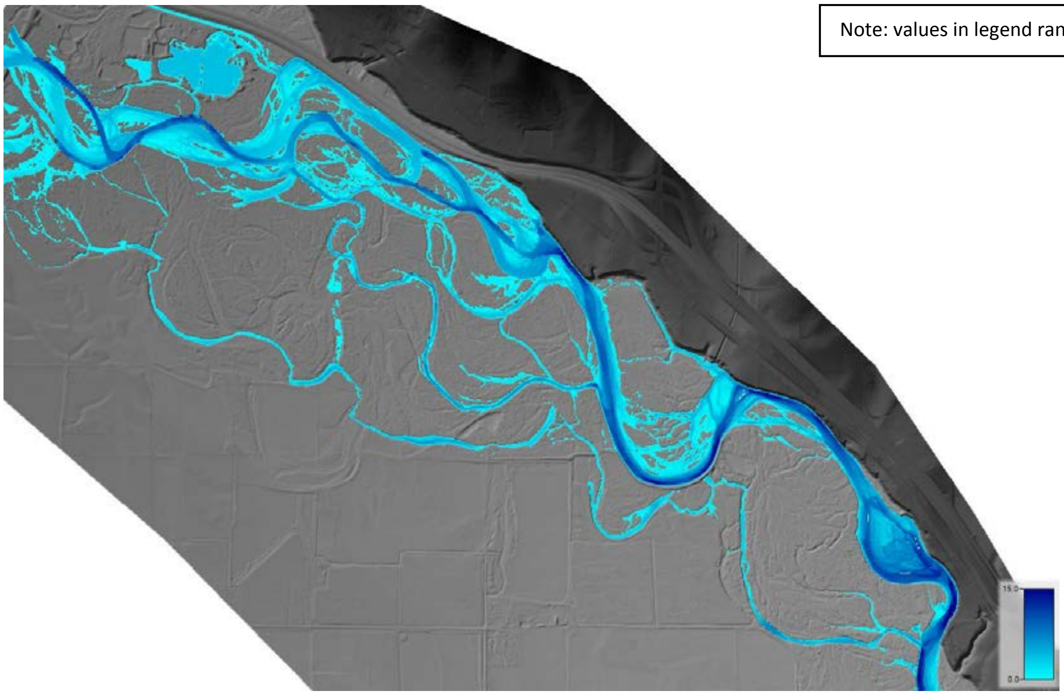
Model Results Depicting Flow Depth at 7,000 cfs – existing conditions



Note: values in legend range from 0-15 feet

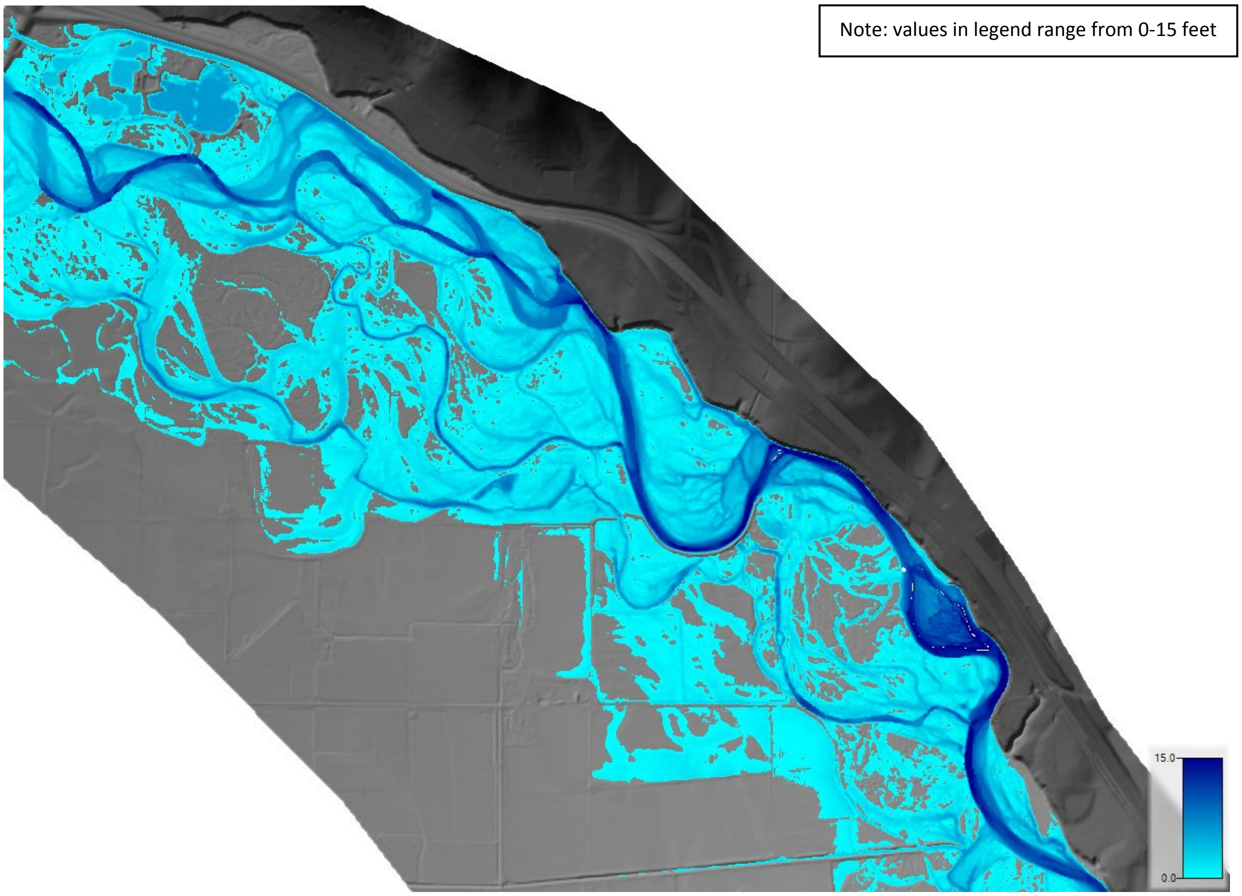
Floodplain flow-path activated

Model Results Depicting Flow Depth at the 2-Year Event (11,440 cfs) – existing conditions



Note: values in legend range from 0-15 feet

Model Results Depicting Flow Depth at the 10-Year Event (27450 cfs) – existing conditions



2.2 DESIGN CONDITIONS

Utilizing the same boundary conditions, hydrograph, and roughness values the design conditions terrain was also modeled to predict floodplain inundation and side-channel activation. As per design criteria, excavated inlets at Alignment 1a, 1b, and 4 are wetted at 1,000 cfs and inlets for Alignments 3a and 3b are activated at 3,000 cfs and 1,500 cfs, respectively. Results indicate that the floodplain flow-paths are activated earlier in the hydrograph and maintain an active side-channel for flows greater than 1,000 cfs. Flow velocities within the excavated side-channel pathways are all within desired range (0 – 15 ft/sec) to maintain throughflow and minimize risks of mainstem channel capture. Flow velocities in the mainstem and the existing side-channel at maximum flood conditions modeled (55,000 cfs) are equivalent between existing and proposed conditions (Figure 3).

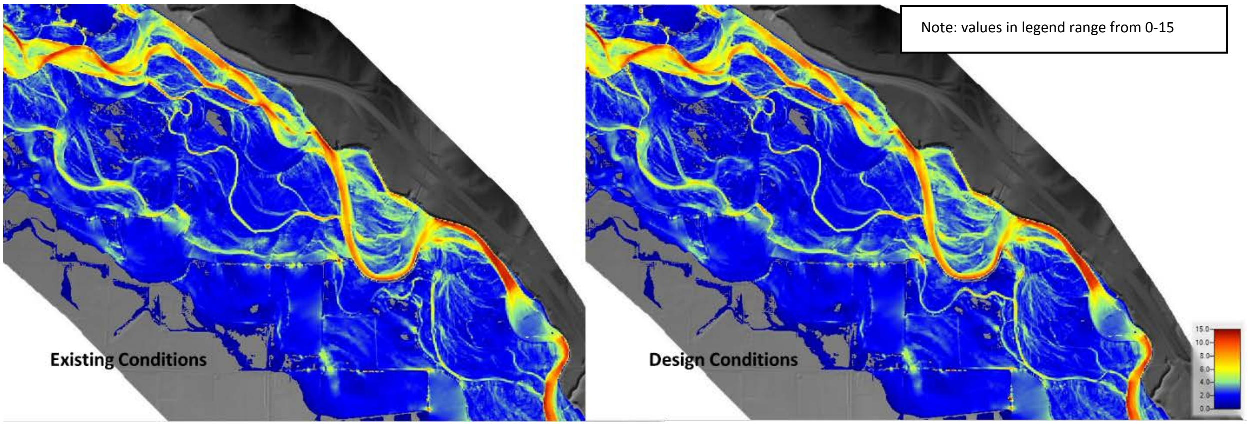
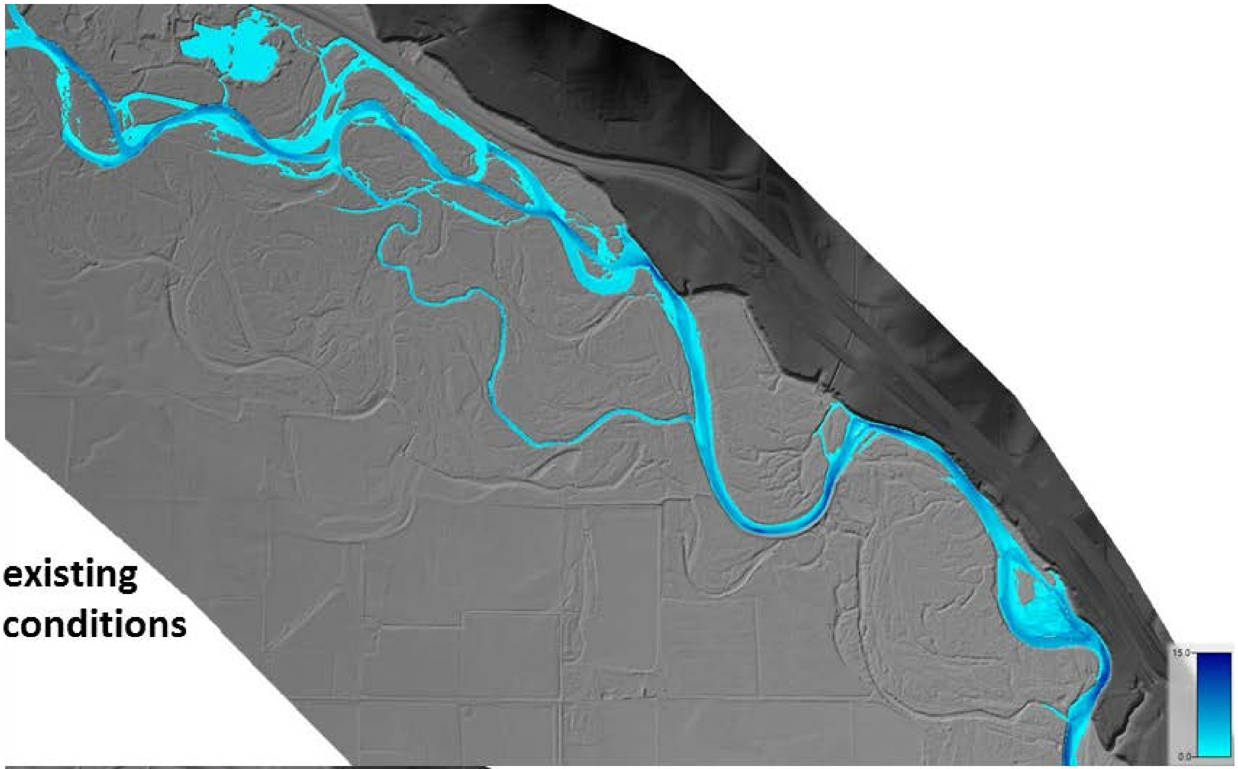
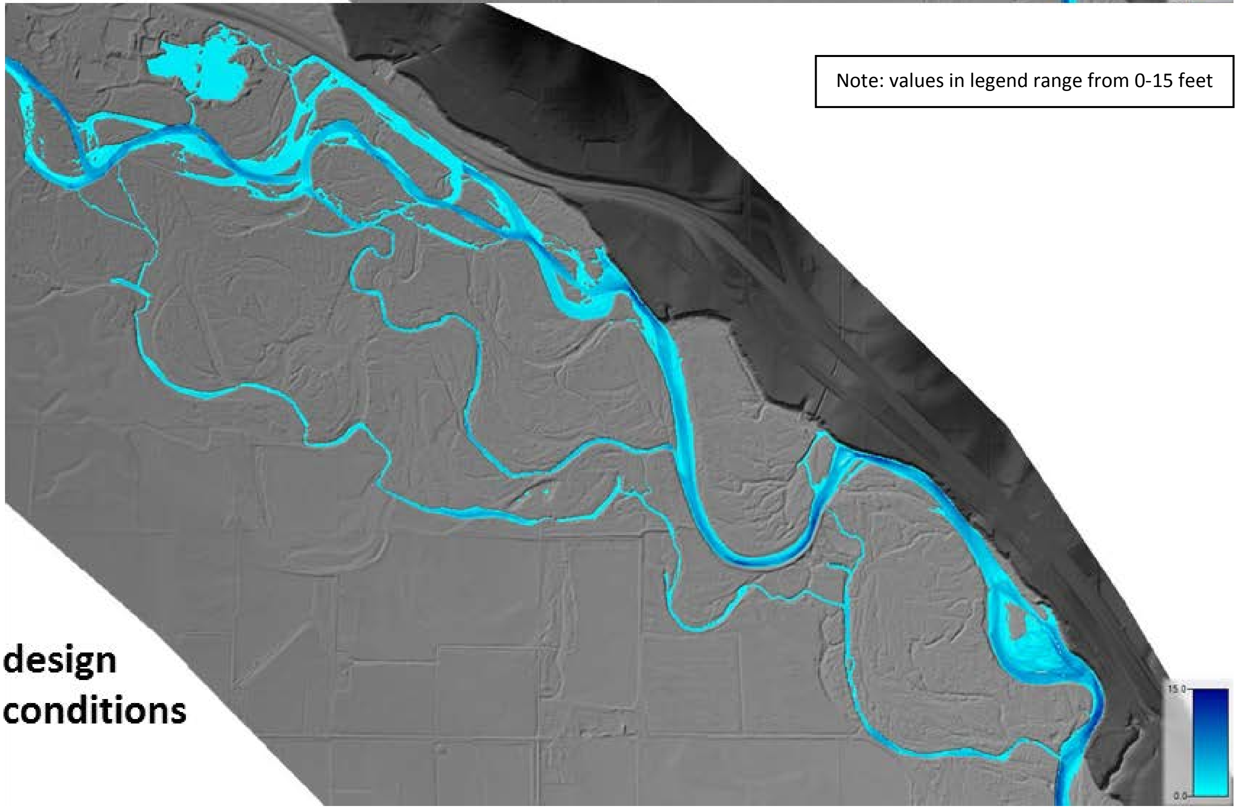


Figure 3. Modeled flow velocity at 55,000 cfs for existing and proposed design conditions.

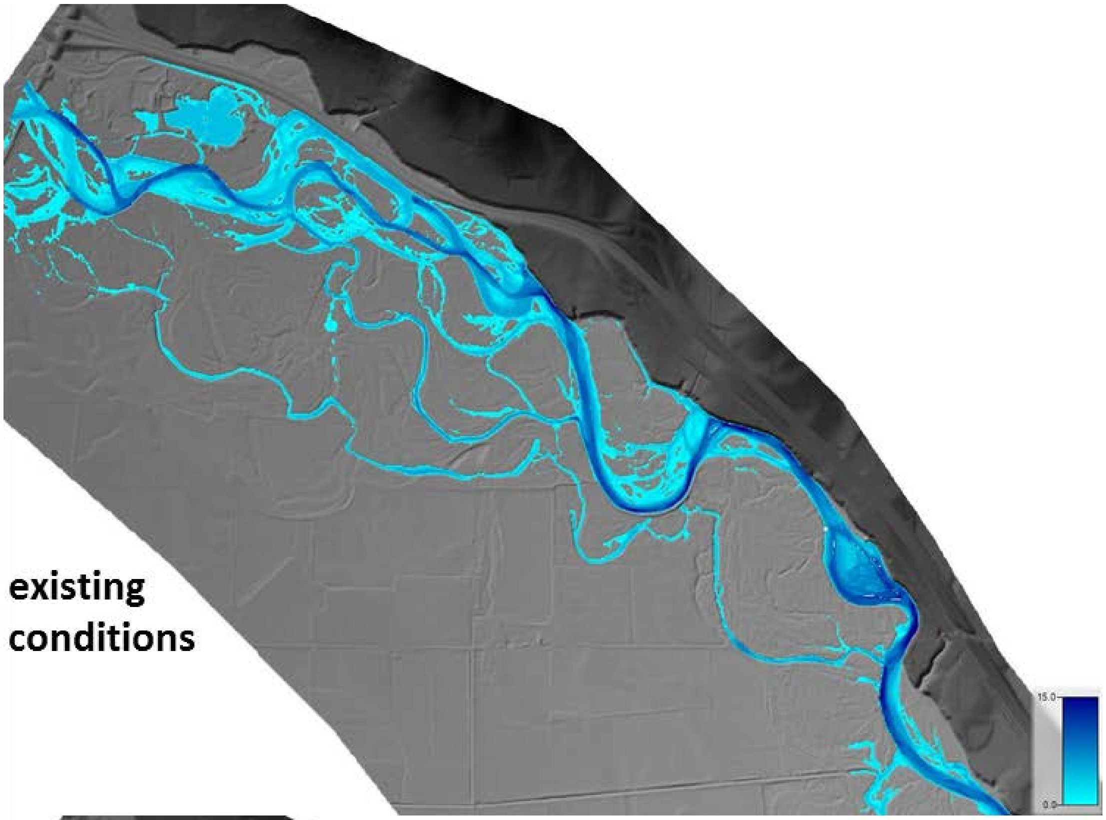
Model results indicate that inundation of the active floodplain increases for flows of approximately 15,000 cfs under proposed design conditions. However, large flood events (equal to or greater than 27,450 cfs) show similar inundation patterns and depths on the floodplain for proposed and existing conditions (comparable by only 0.1-0.2 feet depth changes). These differences in high flow water depths on the extended floodplain are within an expected range of variation for model results, especially for topographically-complex large-scale hydraulic models such as this. The following figures present Hec-Ras model results of water depth for a range of discharges (3,000 cfs – 36,576 cfs) for existing and proposed design conditions.

Model Results depicting 3,000 cfs – design conditions compared to existing conditions

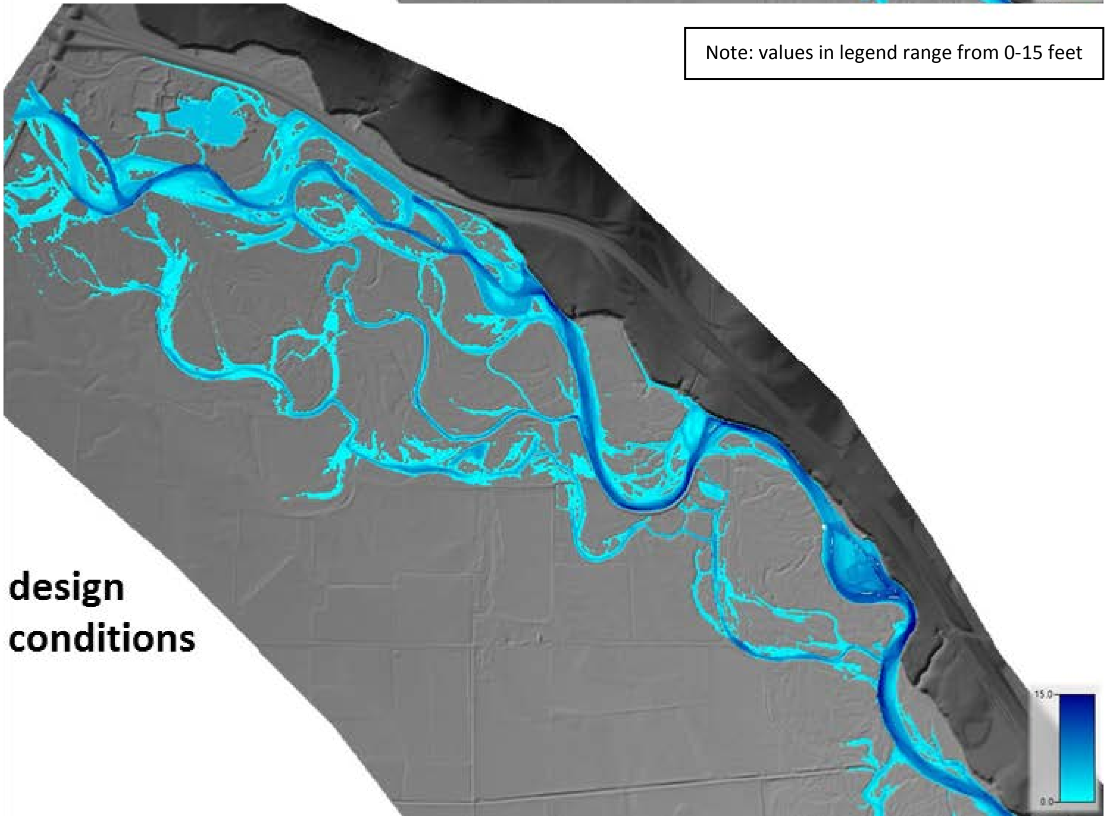



Note: values in legend range from 0-15 feet

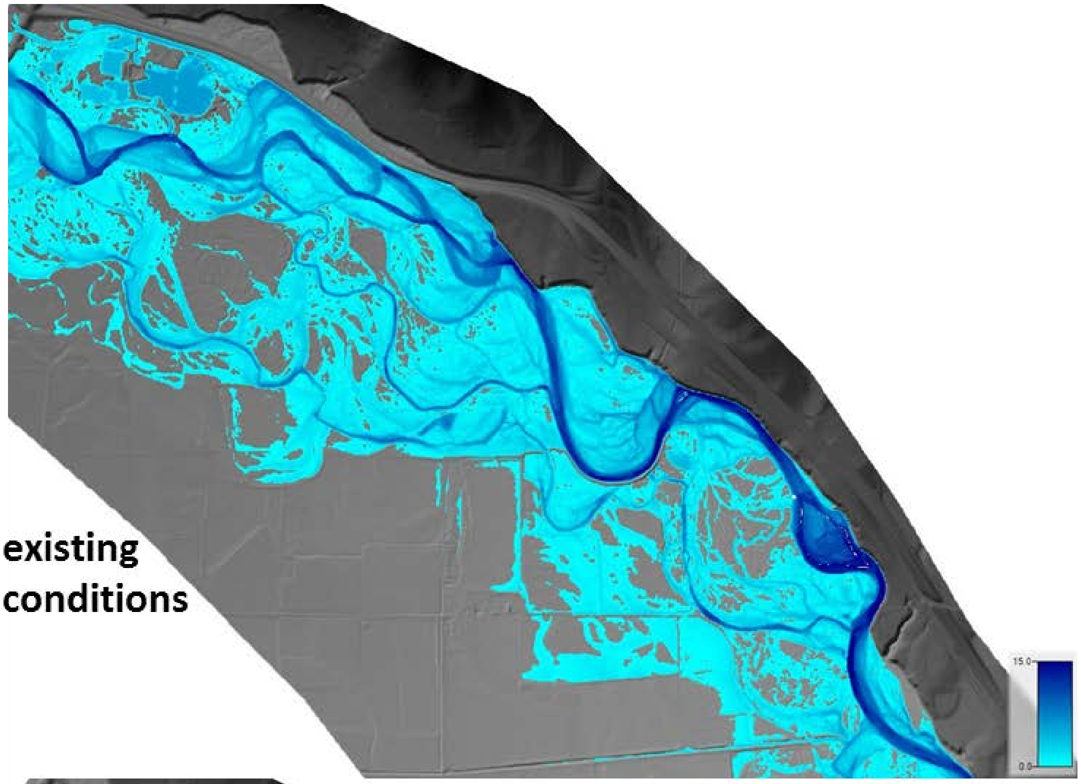
Model Results depicting 15,000 cfs – design conditions compared to existing conditions



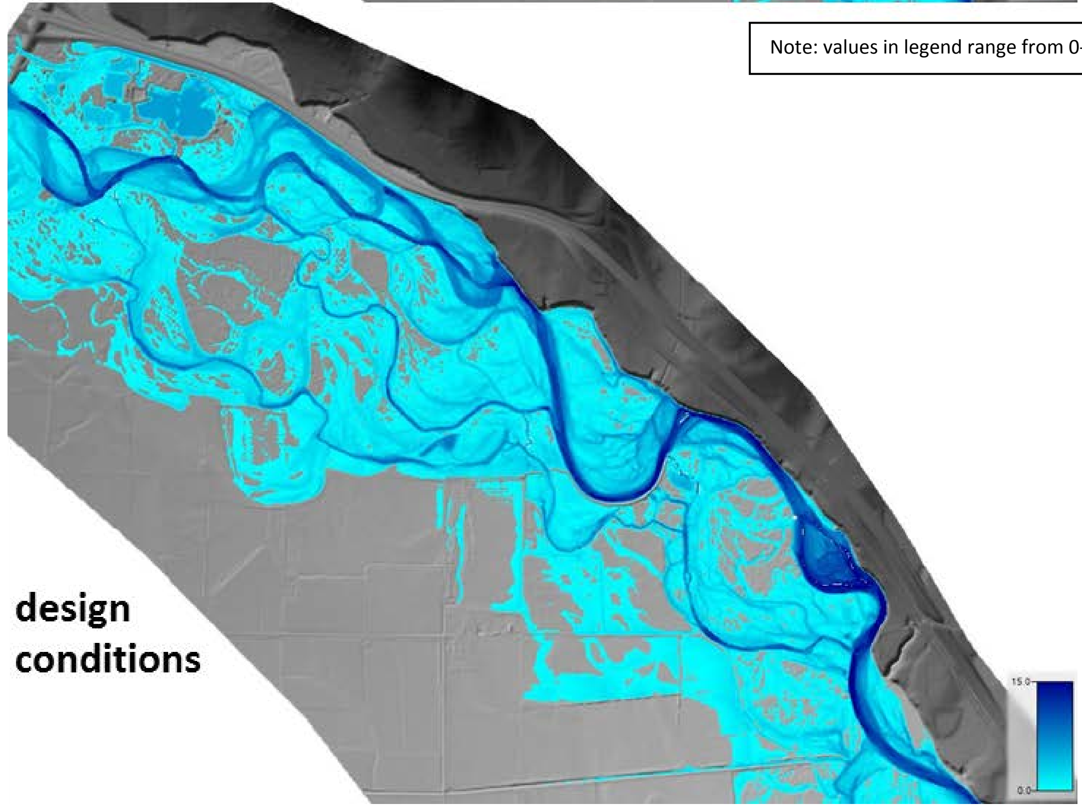
Note: values in legend range from 0-15 feet



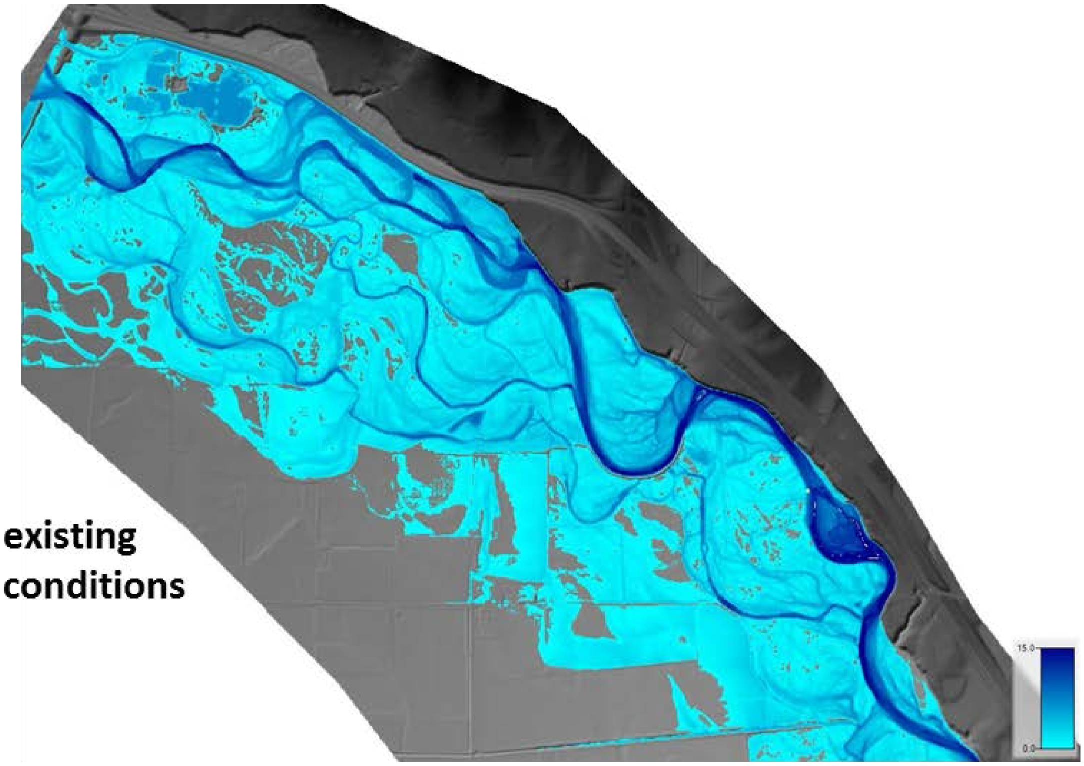
Model Results depicting 27,450 cfs – design conditions compared to existing conditions



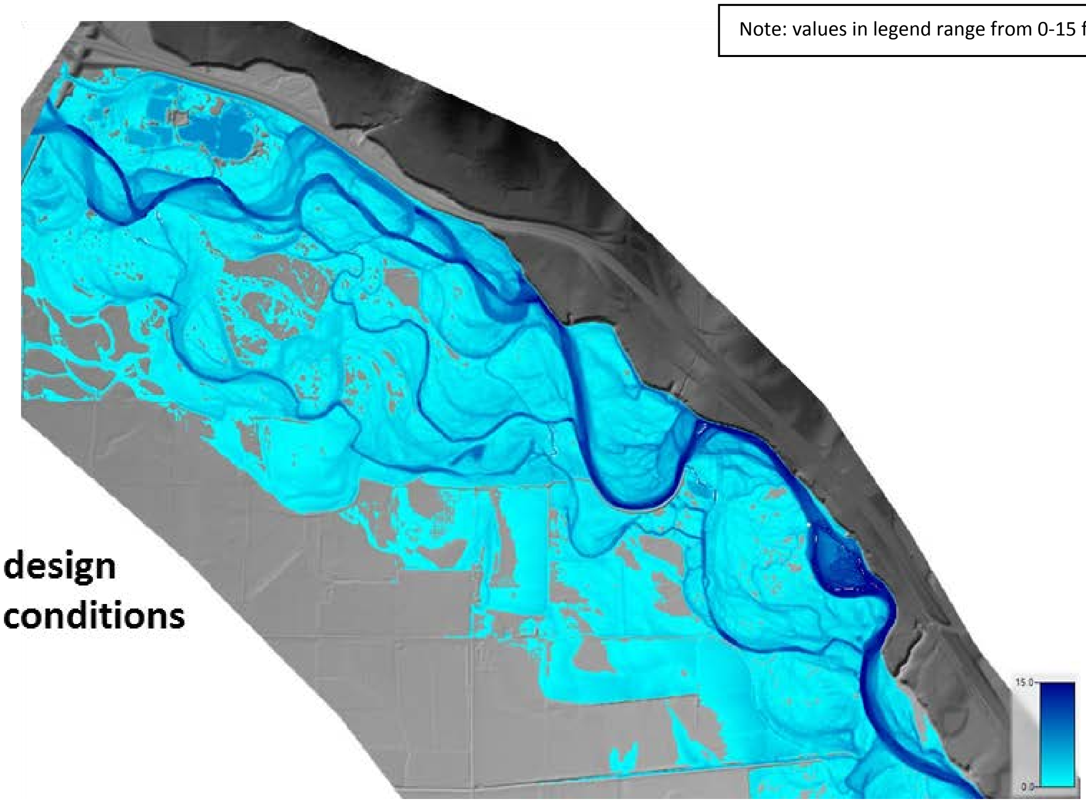
Note: values in legend range from 0-15 feet



Model Results depicting 36,567 cfs – design conditions compared to existing conditions



Note: values in legend range from 0-15 feet



2.3 NO-RISE ANALYSIS

A longitudinal profile was defined along the mainstem alignment of the Yakima River. Channel bed elevations and model results of water surface elevations for existing and proposed conditions along the same alignment were extracted from the model. The water surface elevation comparison shows that proposed conditions water surface elevations are less than or equivalent to existing conditions along the mainstem profile, as shown in Figure 4.

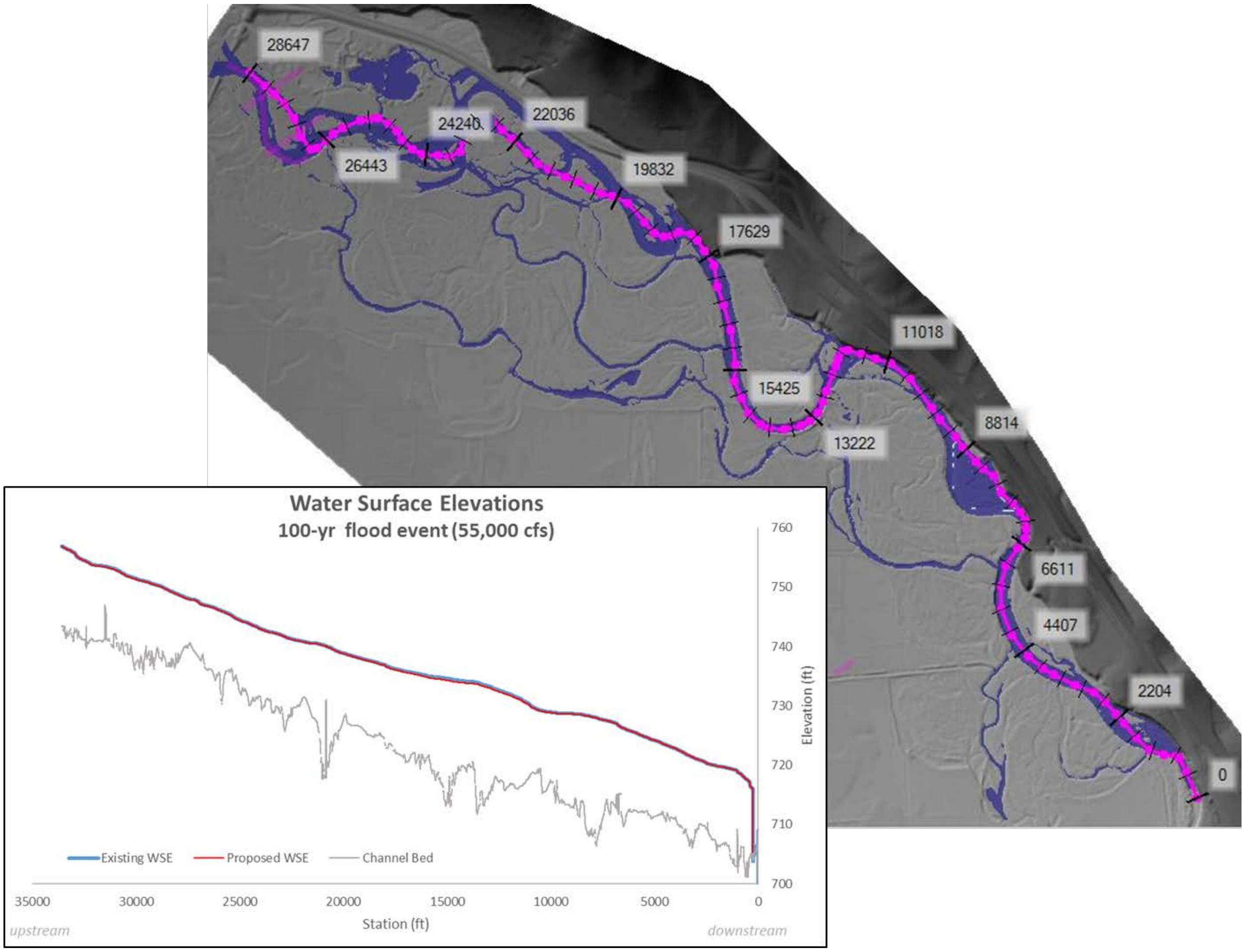


Figure 4. Profile of main stem Yakima River stream bed elevation and Existing and Proposed Conditions water surface elevations.

2.4 LARGE WOOD BALLASTING CALCULATIONS

Six large wood log jams are included in the project along the river right bank of the Yakima River at new channel inlets 1a, 1b and 4. A jam immediately upstream of the inlet is intended to intercept some debris to reduce frequency of inlet blocking. A second jam is located at the downstream edge of the new channels' inlets to encourage scour and channel complexity. Both jams are also intended to increase aquatic habitat complexity within the mainstem Yakima river. We understand that dynamic interaction with the river and some movement of wood is an acceptable condition. None-the-less, the jams will be ballasted by backfill using gravel and cobble material. The outer edge of the backfill will be retained using biodegradable fabric encapsulated soil lifts to provide stability for approximately three years as vegetation establishes to add natural bank roughness. Eighteen boulders approximately 36-inches in diameter and twenty-one vertical log piles driven to 18-ft below the structures provide additional ballasting.

The buoyancy calculations for stabilization design are provided below. The calculations consider backfill and boulders – piles will decay over a decade or two and are not included in the factor of safety calculation. Calculated factor of safety exceeds 2.0. As noted in the report, the river is dynamic and often changes its course and meanders laterally near the designed inlets of 1a and 1b. These log jams will not stop these processes and may become mobilized as the river changes its course over time.

Yakima River RM 89.5 - Log Jam ballasting

Ballasting calculation of Log Jams - ballasted by backfill, piles and boulders

Properties

specific gravity of log	0.61
gamma water	62.4 pcf

density	S.G.
30 pcf	0.48
35 pcf	0.56
38 pcf	0.61

Volume of log and rootwad

Log:	average diameter	1.50 ft	Volume Log =	(pi*r^2) * L
	average length, Lw	40 ft		70.7 cubic feet
Rootwad:	rootwad diameter	5 ft	Volume RW =	(pi*r^2) *(1-rho) Lrw
	Length rootwad, Lr	3 ft		47.1 cubic feet
	RW voids, rho	0.2		
			total volume =	**117.8 c.f. per each**

logs with rootwads	21	2474
logs without rootwads	6	424
total volume =		**2898.1 c.f.**

Bouyant forces on logs:

Total weight of logs: Wl = Vtotal*(s.g.*gamma) =	110,129	lbs, weight
Total bouyant Force on logs: Fb = Vtotal*gamma =	180,843	lbs, bouyancy
Total net Bouyant Force: Wl - Fb =	70,714	lbs, NET bouyancy

Trench backfilled with gravel/cobble material

Depth of backfill	3 ft	per plans
Width trench	30 ft	
Total length fill	30 ft	
Vfill	2700 cf	
Unit wt backfill	47.6 pcf	submerged unit weight of backfill material
wt fill	128,520 lbs	

Pile Ballast

Diameter, Db	1.25 ft
Embedded length	18 ft
pull out resistance	8,187 lbs, submerged weight per boulder
reduction factor	0.25

# piles	net restraint
21	42,982

Boulder Ballast

Diameter, Db		2.5 ft
Volume	pi*D^3 / 6	
		8.18 cubic feet
s.g		2.65
Unsubmerged wt	V*s.g.*gamma W	
		1353 lbs weight per boulder
Submerged wt	V*(s.g.-1)*gamma W	
		842 lbs, submerged weight per boulder

# boulders	net restraint
0	0
18	15,162

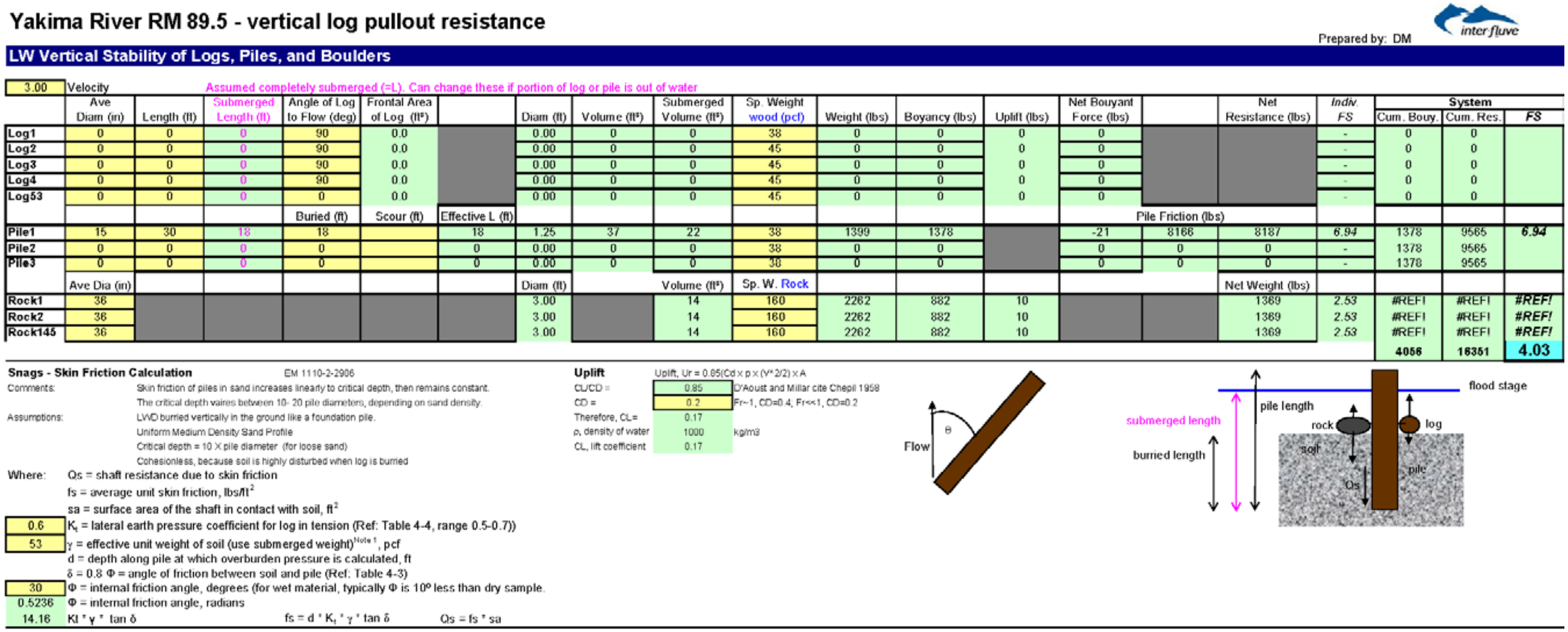
Factor of Safety - bouyancy:

$$F.S. = \frac{\text{restraint}}{\text{bouyant force}}$$

$$\text{Backfill only: } F.S. = \frac{128{,}520}{70{,}714} = 1.82$$

$$\text{Backfill \& boulders: } F.S. = \frac{143{,}682}{70{,}714} = 2.03$$

Note: piles will decay with time and are considered incidental for FS



Yakima River RM 89.5 - vertical log pullout resistance

Prepared by: DM

LW Vertical Stability of Logs, Piles, and Boulders

3.00 Velocity

Assumed completely submerged (=L). Can change these if portion of log or pile is out of water

	Ave Diam (in)	Length (ft)	Submerged Length (ft)	Angle of Log to Flow (deg)	Frontal Area of Log (ft²)		Diam (ft)	Volume (ft³)	Submerged Volume (ft³)	Sp. Weight wood (pcf)	Weight (lbs)	Boyancy (lbs)	Uplift (lbs)	Net Bouyant Force (lbs)		Net Resistance (lbs)	Indiv. FS	System Cum. Bouy.	Cum. Res.	FS
Log1	0	0	0	90	0.0		0.00	0	0	38	0	0	0	0			-	0	0	
Log2	0	0	0	90	0.0		0.00	0	0	45	0	0	0	0			-	0	0	
Log3	0	0	0	90	0.0		0.00	0	0	45	0	0	0	0			-	0	0	
Log4	0	0	0	90	0.0		0.00	0	0	45	0	0	0	0			-	0	0	
Log53	0	0	0	0	0.0		0.00	0	0	45	0	0	0	0			-	0	0	
				Buried (ft)	Scour (ft)	Effective L (ft)									Pile Friction (lbs)					
Pile1	15	30	18	18		18	1.25	37	22	38	1399	1378		-21	8166	8187	6.94	1378	9565	6.94
Pile2	0	0	0	0		0	0.00	0	0	38	0	0		0	0	0	-	1378	9565	
Pile3	0	0	0	0		0	0.00	0	0	38	0	0		0	0	0	-	1378	9565	
	Ave Dia (in)						Diam (ft)		Volume (ft³)	Sp. W. Rock						Net Weight (lbs)				
Rock1	36						3.00		14	160	2262	882	10			1369	2.53	#REF!	#REF!	#REF!
Rock2	36						3.00		14	160	2262	882	10			1369	2.53	#REF!	#REF!	#REF!
Rock145	36						3.00		14	160	2262	882	10			1369	2.53	#REF!	#REF!	#REF!
																		4056	16351	4.03

Snags - Skin Friction Calculation EM 1110-2-2906

Comments: Skin friction of piles in sand increases linearly to critical depth, then remains constant.
The critical depth vaires between 10- 20 pile diameters, depending on sand density.

Assumptions: LWD burried vertically in the ground like a foundation pile.
Uniform Medium Density Sand Profile
Critical depth = 10 X pile diameter (for loose sand)
Cohesionless, because soil is highly disturbed when log is burried

Where: Qs = shaft resistance due to skin friction
fs = average unit skin friction, lbs/ft^2
sa = surface area of the shaft in contact with soil, ft^2
0.6 K_t = lateral earth pressure coefficient for log in tension (Ref: Table 4-4, range 0.5-0.7))
53 γ = effective unit weight of soil (use submerged weight)$^{Note\ 1}$, pcf
d = depth along pile at which overburden pressure is calculated, ft
δ = 0.8 Φ = angle of friction between soil and pile (Ref: Table 4-3)
30 Φ = internal friction angle, degrees (for wet material, typically Φ is 10º less than dry sample.
0.5236 Φ = internal friction angle, radians
14.16 Kl * γ * tan δ   fs = d * K_t * γ * tan δ   Qs = fs * sa

Uplift Uplift, Ur = 0.85(Cd x ρ x (V^2/2) x A

CL/CD =	0.85	D'Aoust and Millar cite Chepil 1958
CD =	0.2	Fr~1, CD=0.4; Fr<<1, CD=0.2
Therefore, CL=	0.17	
ρ, density of water	1000	kg/m3
CL, lift coefficient	0.17	

Yakima RM 89.5 – Floodplain Restoration

Basis of Design Report

Appendix C:

Opinion of Probable Construction Costs Estimates

Opinion of Probable Construction Costs

In providing opinions of probable construction cost, the Owner (Yakama Nation Wildlands Management Program delegated staff) understands that the Engineer (Inter-Fluve staff) has no control over the cost or availability of labor, equipment or materials, or over market conditions or the Contractor's method of pricing. The Engineer's opinion of probable construction costs is made on the basis of professional judgement and experience. The Engineer makes no warranty, expressed or implied, that the bids or the negotiated cost of construction will not vary from the Engineer's opinion of probable construction cost. Cost provided in this opinion are based on May, 2018 dollars and do not include sales tax. Oversight of construction activities by the Engineer are not included in this opinion. Oversight construction services may include review of bid materials, project staking, construction quality assurance and documentation, field engineering design adjustments, and as-built survey and drawings.

The opinion of probable construction costs has been divided, for the Owner's convenience, into probable costs for work completed by Yakama Nation staff and probable costs for work completed by a Contractor. The division of costs is based on the expected work tasks that each entity is planned to complete, as per conversations between the Engineer and the Owner.

General Contractor OPCC

The general Contractor will be responsible for:

1. surface preparation and re-seeding of all areas disturbed during construction
2. construction of inlet mouths for Alignments 1A, 1B, and 4 – including connecting the inlets to the previously constructed channels for those alignments
3. ford crossings at Alignment 1A, 1B, and the existing levee breach
4. six large wood structures – two at the mouth of each inlet

Owner OPCC

The owner will be responsible for:

1. constructing the body of Alignments 1A-1F and 4, and the Alignments 3A and 3B
2. Woody Plant (bare root, live cuttings, and container) revegetation within the disturbed areas.
3. Offsite hauling to designated area of stockpiled excavated materials
4. Surface preparation and re-seeding of the materials stockpile sites after offsite hauling is complete

Abbreviations

CY	Cubic yards
EA	Each
FF	Face foot
LS	Lump sum
AC	Acre
SF	Square Feet
QTY	Quantity

Table 1. Work by General Contractor - OPCC

Location	Item	quantity	units	unit cost	item cost
Site	Mobilization (9-10%)	1	LS	$ 50,000	$ 50,000
	Erosion, Sediment and Dust control	1	LS	$ 20,000	$ 20,000
	Seed - Wet Fringe	4.90	Acre	$ 350	$ 1,715
	Seed - Riparian	8.80	Acre	$ 1,300	$ 11,440
	Seed - Transitional	8.10	Acre	$ 1,300	$ 10,530
1A	Stream diversion	1	LS	$ 10,000	$ 10,000
	Site dewatering	1	LS	$ 10,000	$ 10,000
	channel excavation (1)	1850	CY	$ 12	$ 22,200
	log structure excavation	1200	CY	$ 12	$ 14,400
	log structure (2)	2	EA	$ 20,000	$ 40,000
	log structure backfill	1000	CY	$ 12	$ 12,000
	FES lift	180	FF	$ 50	$ 9,000
	channel ford	70	CY	$ 40	$ 2,800
1B	Stream diversion	1	LS	$ 10,000	$ 10,000
	Site dewatering	1	LS	$ 10,000	$ 10,000
	channel excavation (1)	1480	CY	$ 12	$ 17,760
	log structure excavation	1200	CY	$ 12	$ 14,400
	log structure (2)	2	EA	$ 20,000	$ 40,000
	log structure backfill	1000	CY	$ 12	$ 12,000
	FES lift	180	FF	$ 50	$ 9,000
	channel ford	70	CY	$ 40	$ 2,800
4	Stream diversion	1	LS	$ 10,000	$ 10,000
	Site dewatering	1	LS	$ 10,000	$ 10,000
	channel excavation (1)	760	CY	$ 12	$ 9,120
	log structure excavation	1200	CY	$ 12	$ 14,400
	log structure (2)	2	EA	$ 20,000	$ 40,000
	log structure backfill	1000	CY	$ 12	$ 12,000
	FES lift	180	FF	$ 50	$ 9,000
Ford (at levee breach)	Stream diversion	1	LS	$ 2,000	$ 2,000
	Site dewatering	1	LS	$ 2,000	$ 2,000
	channel excavation (1)	550	CY	$ 12	$ 6,600
	Construction Total				$ 450,000

NOTES:

Excavation and fill quantities are in-place measure and do not include expansion of excavated material or compaction of placed material.

(1) Excavate and haul to on-site temporary stockpile location(s). Off-site haul by Owner.

(2) Logs provided by owner to deck on/near site. Contractor shall haul from designated location and install.

Table 2. Work by Owner - OPCC

Location	Item	quantity	units	unit cost	item cost
Site	Mobilization	1	LS	$ 35,000	$ 35,000
	Erosion, Sediment and Dust control	1	LS	$ 20,000	$ 20,000
	Planting - Wet Fringe	4.90	Acre	$ 3,000	$ 14,700
	Planting - Riparian	8.80	Acre	$ 5,000	$ 44,000
	Planting - Transitional	8.10	Acre	$ 4,000	$ 32,400
1A	Stream diversion	1	LS	$ 1,000	$ 1,000
	Site dewatering	1	LS	$ 2,500	$ 2,500
	Channel excavation upstream of conf (1)	1370	CY	$ 12	$ 16,440
	Channel excavation dnstream of conf (1)	1020	CY	$ 12	$ 12,240
1B	Stream diversion	1	LS	$ 1,000	$ 1,000
	Site dewatering	1	LS	$ 2,500	$ 2,500
	Channel excavation (1)	270	CY	$ 12	$ 3,240
1C	Stream diversion	1	LS	$ 2,000	$ 2,000
	Site dewatering	1	LS	$ 2,500	$ 2,500
	Channel excavation (1)	2610	CY	$ 12	$ 31,320
1D	Stream diversion	1	LS	$ 1,000	$ 1,000
	Site dewatering	1	LS	$ 2,500	$ 2,500
	Channel excavation (1)	200	CY	$ 12	$ 2,400
1E	Stream diversion	1	LS	$ 1,000	$ 1,000
	Site dewatering	1	LS	$ 2,500	$ 2,500
	Channel excavation (1)	1240	CY	$ 12	$ 14,880
1F	Stream diversion	1	LS	$ 1,000	$ 1,000
	Site dewatering	1	LS	$ 2,500	$ 2,500
	Channel excavation (1)	10130	CY	$ 13	$ 131,690
3A	Stream diversion	1	LS	$ 1,000	$ 1,000
	Site dewatering	1	LS	$ 2,500	$ 2,500
	Channel excavation (1)	1140	CY	$ 12	$ 13,680
3B	Stream diversion	1	LS	$ 1,000	$ 1,000
	Site dewatering	1	LS	$ 2,500	$ 2,500
	Channel excavation (1)	2310	CY	$ 12	$ 27,720
4	Stream diversion	1	LS	$ 1,000	$ 1,000
	Site dewatering	1	LS	$ 2,500	$ 2,500
	Channel excavation (1)	5360	CY	$ 13	$ 69,680
Beaver	Stream diversion	1	LS	$ 1,000	$ 1,000
	Site dewatering	1	LS	$ 2,500	$ 2,500
	Channel excavation (1)	40	CY	$ 14	$ 560
Offsite Haul	North Stockpile (2)	6390	CY	$ 14	$ 89,460
	South Stockpile (3)	29140	CY	$ 15	$ 437,100
	Construction Total :				$1,030,000

NOTES:

Excavation and fill quantities are in-place measure and do not include expansion of excavated material or compaction of placed material.

(1) Excavate and haul to on-site temporary stockpile location(s).

(2) North stockpile includes excavation from sites 1A and 1B

(3) South stockpile includes excavation from sites 1C, 1D, 1E, 1F, 4, and beaver enhancement

Table 3. Offsite haul cost estimation sheet (assumes 8-mile roundtrip to offsite haul location from stockpiles)

Item	Estimated Quantity	Unit	Unit Cost	Notes
Offsite Haul rate				
CY per round trip	*16*	*CY*		Truck and Pup 28-ton, 16 CY capacity (factoring in fine soil expansion)
Mileage / round trip	*8*	*Miles*		
Rate / hour	*170*	*Hr*		
Time per round trip	*45*	*Minutes*		Assume 45 minutes/trip to account for loading/unloading time
Haul cost per trip			$ 127.50	
Haul cost per cy			$ 7.97	
Load out rate				
Rate / hour	*170*	*Hr*		Exacavator
Time per loadout	*15*	*Minutes*		
Haul cost per trip			$ 42.50	
Haul cost per cy			$ 2.66	

Quantities Summaries

Table 4. Estimate of excavation and fill quantities by General Contractor work area.

Work area	Channel excavation	Log struc excavation	Disturbance		log structures	log struc backfill	FES lift	Ford fill
	(cy)	(cy)	(sf)	(ac)	(ea)	(cy)	(ff)	(cy)
1A	1850	1200	10730	0.25	2	1000	180	
1B	1480	1200	29660	0.68	2	1000	180	
4	5360	1200	46760	1.07	2	1000	180	0
Ex ford	550	0	31250	0.72	0	0	0	0

Table 5. Estimate of excavation quantities by owner work area.

Work area	Excavation	Disturbance	
	(cy)	(sf)	(ac)
1A - up	1370	35840	0.82
1A - dn	1020	128530	2.95
1B	270	8210	0.19
1C	2610	98500	2.26
1D	200	45230	1.04
1E	1240	44490	1.02
1F	10130	148470	3.41
3A	1140	96480	2.21
3B	2310	68470	1.57
4	5360	93000	2.13
Beaver	40	25760	0.59

Table 6. Estimate of total seed and revegetation areas.

Work area	Disturbance (sf)			Disturb
	Owner	Contractor	Total	(ac)
1A	164,370	10,730	175,100	4.02
1B	8,210	29,660	37,870	0.87
1C	98,500		98,500	2.26
1D	45,230		45,230	1.04
1E	44,490		44,490	1.02
1F	148,470		148,470	3.41
3A	96,480		96,480	2.21
3B	68,470		68,470	1.57
4	93,000	46,760	139,760	3.21
Beaver	25,760		25,760	0.59
Ford		31,250	31,250	0.72
		Total =	911,380	20.92

Table 7. Material quantities and cost estimate for Log Structures (assuming logs provided and delivered by Owner).

Log Structure (per individual structure)					
	item (Installed)	qty	units	Unit cost	item cost
	18"dbh, 40' long rootwad	21	ea	$ 300	$ 6,300
	15-18"dbh, 35-40' long no rootwad	6	ea	$ 250	$ 1,500
	12-15" dia, 30' Long vertical	21	ea	$ 400	$ 8,400
	Slash	75	cy	$ 8	$ 600
	36" dia boulders	18	ea	$ 200	$ 3,600
				Total =	$ 20,400