Rock Creek – Phase 3 Restoration Basis of Design Report

Prepared for the Confederated Tribes of the Umatilla Indian Reservation
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Project Background

Report Overview

Rio Applied Science and Engineering (Rio ASE) has prepared this basis of design report in collaboration with and for the Confederated Tribes of the Umatilla Indian Reservation (CTUIR). This report provides a summary of the Project Team's (Rio ASE and CTUIR) findings pertaining to the proposed restoration of the lower 1 mile of Rock Creek, 0.25 miles upstream from the confluence with the Grande Ronde River (Project Reach), and an explanation of the design process, analyses and outcomes for the proposed enhancement design.

Specifically, Rio ASE organized the following sections of this report to describe the General Project and Data Summary Requirements required by the Bonneville Power Administration (BPA) for coverage under the Habitat Improvement Program (HIP III). BPA developed the requirements to effectively communicate that appropriate planning, analysis, design, and resulting construction documentation are met. The historic and existing conditions of the project reach and watershed are described in terms of processes that shaped the stream and associated ecosystem within the context of various ecological disciplines. This includes discussions on hydrology, hydraulics, habitat, and geomorphology as well as pertinent land management practices as we understand them. The evaluation and consideration of the historic and existing conditions provide the basis for the project design.

- Appendix A – Hydrologic Analysis
- Appendix B – Hydraulic Analysis
- Appendix C – Rock Creek Phase 3 Restoration Design Drawings
- Appendix D – Construction Quantities and Cost Estimate
- Appendix E – Rio ASE Scope of Services

Project Responsible Parties

- The project sponsor is the Confederated Tribes of the Umatilla Indian Reservation and the project manager is Allen Childs. His email is AllenChilds@ctuir.org and his phone is 541-429-7940.
- The prime design consultant for channel grading is Rio Applied Science and Engineering and the lead professional engineer is Jeff Fealko. His email is Jeff@RioASE.com and his phone is 208-866-8753.

Site Location

The project site is approximately a 1 mile reach of Rock Creek, beginning approximately 0.25 miles upstream from the confluence with the Grande Ronde River, 6.8 miles west of La Grande, Oregon in Township 3 South, Range 37 East, all or portions of Sections 5 and 6 (Figure 1). The project is located on private land (one landowner, For the Girls Ranch, LLC). The Rock Creek watershed has an area of approximately 52.9 square miles (33,856 acres) and flows southeast to northwest. Elevations within the watershed range from 6,070 feet down to 2,930 feet with an average annual precipitation of over 25 inches. The project are is characterized as a typical mid-elevation Blue Mountain forested watershed interspersed with open dry meadows in the uplands and typically narrow floodplains (Figure 2).

FIGURE 1. VICINITY MAP OF ROCK CREEK PHASE 3 PROJECT AREA.

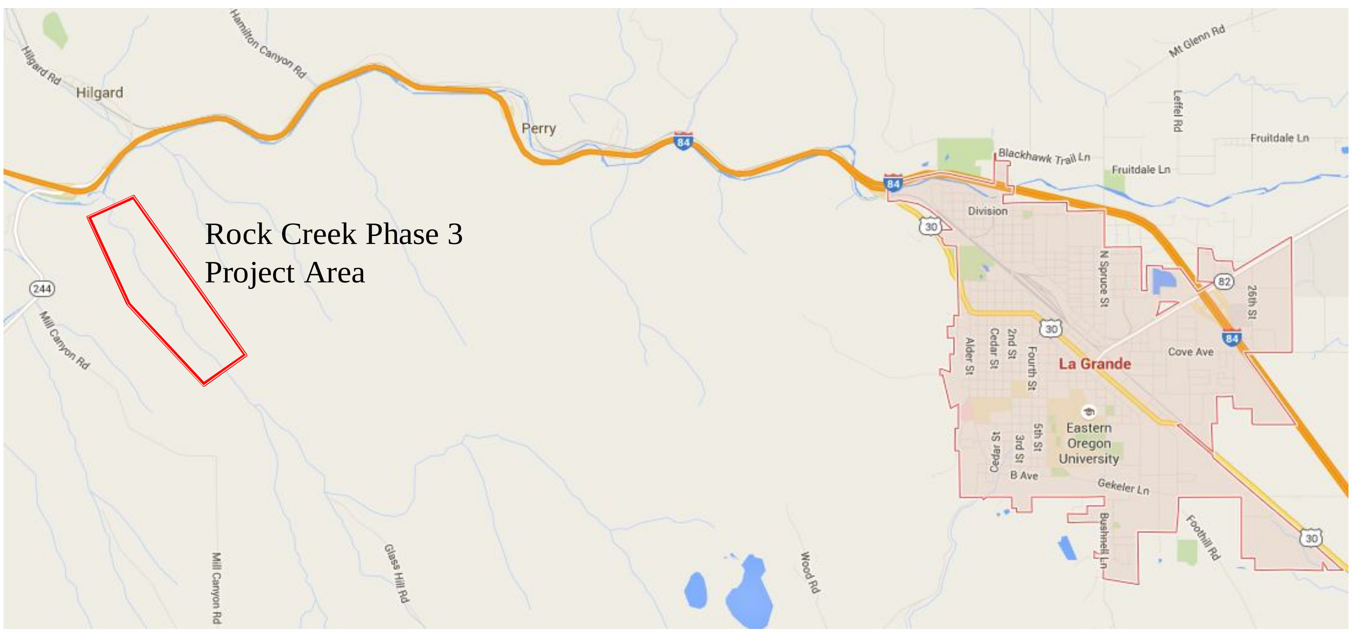


FIGURE 2. AERIAL VIEW OF ROCK CREEK LOOKING UPSTREAM.

Project Goals

The proposed project is intended to restore and enhance a one mile section of lower Rock Creek, a cold water tributary to the Grande Ronde River. The overall goal of the project as defined by the CTUIR is to restore natural channel and floodplain function and processes that improve habitat suitability for spawning and rearing summer steelhead *(O. mykiss)*, spring/summer Chinook Salmon *(O. Tshawytscha)*, and other native fish and wildlife resources.

Project objectives include:

- Increased channel complexity, with channel morphology closer to historical and natural form.
- Increased quantity and quality of habitat diversity, especially large wood (LW) and pools.
- Improved sediment sorting and routing.
- Increased stream velocity diversity at both low and high flows.
- Increased in-stream thermal diversity throughout the year.
- Increased floodplain connectivity and frequency of inundation.
- Increased riparian function with site-appropriate native vegetation.
- Increased area suitable for adult summer steelhead spawning.
- Increased area suitable for summer steelhead and spring/summer Chinook juvenile rearing.

Proposed Project Elements

The restoration team anticipates restoring in-stream and floodplain function and connectivity through the addition of structural features (large wood), channel re-alignment, reactivation or creation of historical primary, secondary and tertiary channels, removal of non-certified levees or berms, decommissioning of an access roadway within the floodplain, and upland/riparian plant community enhancement and restoration. The proposed project consists of multiple design elements as described above and listed below in Table 1. These elements are intended to work in conjunction with each other as well as previous restoration efforts upstream of the project area (phases 1 and 2). The proposed project elements can be seen in greater detail within the design drawings in Appendix C.

TABLE 1. PROPOSED ROCK CREEK PHASE 3 HIP III WORK ELEMENTS.

ID	Work Element	HIP III Category	HIP III Risk Level
29	Increase Instream Habitat Complexity and Stabilization	2d	Low
30	Realign, Connect, and/or Create Channel	2d, 2f	High
33	Decommission Road/Relocate Road	5b	Low
47	Plant Vegetation	9d, 9c	Low
180	Enhance Floodplain/ Remove Modify, Breach Dike	2a, 2b	Med.

Risk to Existing Infrastructure

Existing infrastructure through the project area consist of multiple utility lines located along the river left floodplain (southwest side), an access road and bridge crossing, and a house and associated outbuildings. The house and barn are located along river right (northeast side) of the Creek within the upper quarter of the project area. The house is accessed by a road and bridge over Rock Creek at the upstream extent of the project area. There are underground natural gas lines running parallel to the channel along the upper half of the project owned by Tesoro and Northwest Pipeline. There is one overhead power line that runs off of the western ridge and up the floodplain and across the channel which provides power to the house and outbuildings. Downstream of the project area, the channel flows into the Grande Ronde River, before turning east toward the town of La Grande, Oregon. This reach of the Grande Ronde runs parallel Interstate 84. Approximately 3.5 miles downstream of the project, Interstate 84 spans the Grande Ronde River on river right, upstream of the small community of Perry, Oregon.

The risk to existing infrastructure is low. The utilities through the floodplain limit the potential for lateral migration of Rock Creek through the upper third of the project area. Restoration efforts through this reach will develop stable banks along the outside of bends that reduce potential migration threats to the buried and overhead lines. The existing house and barn on river right will continue to be at risk of flooding due to high flow events and potential ice jams. The restoration efforts will reconnect the floodplain along river left, increasing floodplain capacity and the ability to accommodate ice flows, reducing or maintaining the same level of risk from flooding. At the confluence, Rock Creek is small in size relative to the Grande Ronde River, and the river has ample capacity to accommodate wood and other potential debris through existing infrastructure (I-84 bridges, etc.), creating minimal risk to downstream infrastructure.

Fisheries Background

Native fish assemblages in the Grande Ronde Basin evolved in a system of cold, clean water with complex and dynamic lotic habitats with dense riparian communities that were ecologically connected between the aquatic and terrestrial environment and floodplains. Past anthropogenic activities reduced the quality and quantity of fish habitat in Rock Creek, altering natural hydrologic and geomorphic processes that create and maintain high quality fish habitat. Focal Rock Creek fishery resources include summer steelhead spawning and juvenile rearing for both spring Chinook salmon and summer steelhead. Grande Ronde summer steelhead and spring Chinook salmon are listed as Threatened under the Endangered Species Act (ESA).

The Rock Creek Drainage within the project area has a number of limiting factors inhibiting salmonid spawning and juvenile survival. The area exhibits lethal limit water temperatures throughout the summer, has little riparian cover/shade, has a simplified channel with coarse substrate and actively eroding banks, and is isolated from the majority of its floodplain by draw bottom roads and dikes. In addition, Rock Creek goes dry in some reaches between Graves and Sheep Creeks during summer months. The densities of steelhead redds per mile are among the lowest of all the project streams surveyed by CTUIR Fish Habitat staff, yet densities of juvenile fish are among the highest of those projects sampled. Snorkel surveys indicate the age class of *O.mykiss* are dominated by 1 and 2 year old fish with little or no presence of age zero fish (young of the year). Young of the year *O. mykiss* may be rearing upstream of the project area where the majority of spawning is believed to occur and in areas with lower base flow water temperatures

Habitat protection through a conservation easement on 12 miles or Rock Creek and tributaries between the CTUIR and landowner, channel realignment, floodplain connectivity, and recovery of riparian and wetland vegetation has the potential to increase ecological processes and promote significant biological response in the project area.

Project Features

Proposed project features are designed to meet the overall goal of restoring natural channel and floodplain function and processes to Rock Creek. Design elements that address limiting factors and objectives of the project include:

- Removal of historic push up levees adjacent to the channel banks that currently restrict floodplain connection.
- Main channel construction including the development and creation of new meander bends that will increase channel sinuosity, decrease channel slope and assist in floodplain reconnection and the development of more diverse channel structure and hydraulic variability.
- Construction of riffles, pools, and glides throughout the main channel. Constructed riffles will aid in maintaining floodplain connection and preventing potential headcuts or channel degradation. Pools will be located in natural areas of scour to increase persistence of depth, while providing velocity refuge for adult and juvenile salmonids. Glides will occur in the transitions between pools and riffles and will typically be zones of depositional features where gravels are deposited to increase spawning potential through the reach.
- Construction of secondary channels, alcoves, and other periphery habitats. These features will be subtle and predominately located near the downstream connection end with the main channel. Construction of these features will be focused in areas where low swales or historic channels currently exist. These channel forms will principally be dependent on stream hydraulics for development.
- Large woody material will be placed throughout the constructed channel, side channels, swales, and associated floodplain to recreate complex and diverse habitat components within the project reach. Wood within the channel will provide fish habitat cover, structure for hydraulic scour and maintenance of pools, and zones of graded bedload deposition. Wood within the swales and floodplain will provide roughness, protection zones for vegetation, and restrict flows through certain areas.
- Boulders will be placed within the constructed channel to increase roughness, provide habitat diversity and velocity refuge, and assist in maintaining vertical grades.
- A road that currently runs parallel to Rock Creek on the southwest side (river left) of the channel will be decommissioned. This will result in the rehabilitation of floodplain vegetation, and hydraulic reconnection of cold water hillside springs with Rock Creek.
- A full revegetation plan for the impacted project area will set the stage for the reestablishment of a robust and diverse riparian corridor.

Performance and Sustainability Criteria

The performance and sustainability criteria vary based on each proposed action. In order to assess performance and sustainability criteria, key measurable attributes were evaluated for success and future project sustainability.

TABLE 2. PERFORMANCE AND SUSTAINABILITY CRITERIA FOR EACH HIP III ACTION.

HIP III ID	Work Element	Performance/ Sustainability Criteria
29	Large Wood Structures and Habitat Boulders	Annual fish surveys and mapping of aquatic habitat types will assess performance; repeat annual surveys and photo points will assess sustainability of structures.
30	Main Channel Construction, Realignment, Alcoves, Side Channels, etc.	Annual mapping of habitat types and inundation extents at near peak measured discharges will assess performance; repeat annual survey of cross sections and channel profile to measure sustainability.
33	Decommission Road/Relocate Road	Long-term monitoring of vegetation using photo points and vegetation transects will assess performance, monitoring of wetland development and floodplain connectivity will assess sustainability.
47	Plant Vegetation	Annual estimated percent survivability will assess performance; annual weed control and supplemental planting will provide short term sustainability; conservation easement will provide long-term sustainability.
180	Remove Non-Certified Levees/ Berms	Monitoring wetland development and floodplain connectivity using aerial photo points and wetland delineations will assess performance and sustainability.

Description of Disturbances

The proposed project includes those items described above. Levee/berm removal will include the disturbance of over 1,790 feet of historic berms. These areas will have material excavated, loaded, and hauled to specified fill zones. The noticed disturbance at these locations will be the loss of minor riparian shrubs and grasses. All mature trees will remain intact and the berms will be cut around these features. The road decommissioning will occur throughout the length of the project (road length is 5,345 feet long and approximately 15 feet wide). This disturbance will likely be one of the last actions within project area prior to revegetation and will begin at the downstream end and continue upstream to the upper boundary. This will be an in-place disturbance and will result in little if any excess material. The installation of habitat complexity features including large wood structures and habitat boulders will include temporary disturbances to excavate areas of backfill or bury depth as specified on the design plans. Habitat boulders will require a minimum embedment depth of 50% of the boulder diameter. Large wood structures will typically require the excavation of a scour hole in the existing channel and the excavation of trenches to accommodate key members that are buried in the channel bank. Little to no excess material is anticipated to come from these features and all disturbances will be localized. New channel, side channel, and alcove construction will require the largest disturbances associated with this project. The new main channel will intersect the existing channel in multiple locations. When not utilizing the existing channel, the proposed channel will require excavation from top of bank down to design thalweg elevations. The excavated material will be utilized for fill within the existing channel bed and strategically placed along the toe of the valley slopes in specified areas. All excavated material will remain on site. The design drawings in Appendix C graphically depict the proposed enhancements in greater detail.

Resource Inventory and Evaluation

Historic Impact

Fish habitat has been adversely affected by historic land uses, including livestock overgrazing, road construction, logging, and channelization. Large segments of Rock Creek, including the Phase III project area, have been channelized resulting in channel incision, increased channel slope, streambank erosion, coarsened sediment, high width:depth ratios, elevated water temperatures and decreased baseflow conditions. Additional alterations include: loss of floodplain and hyporheic connectivity, reduced riparian and wetland vegetation, and a loss of habitat diversity and complexity. Riparian conditions throughout the project are poor with lack of floodplain connectivity and altered hydrology which is limiting recovery of riparian and wetland vegetation and associated beaver colonization.

Project Constraints

There are multiple project constraints throughout the project area, but all are necessary to provide required protection to existing infrastructure. Constraints include:

- Underground gas utility lines running through the river left floodplain will be maintained and need to continue to provide protection from lateral migration as bury depth is often shallow.
- Overhead power line running through the river left floodplain and crossing Rock Creek at the existing house location must be maintained and protected from bank erosion.
- Existing house and associated outbuildings on river right need to be maintained and continue to maintain or enhance the level of flood protection.
- The upstream connection is at an existing bridge structure. This bridge and access road need to be maintained.

Geomorphic Conditions

The existing conditions of Rock Creek through the project area are defined predominately as a relatively straight single threaded channel with a moderate to low gradient (1 – 1.5%) with coarse alluvium and colluvium comprising the channel bed and banks. The channel is typically shallow and over-widened due to degraded riparian vegetation, promoting faster than normal lateral expansion. The existing channel bed form is dominated by a plane bed geometry with the exception of a small number of forced pools which developed from interaction with channel wood and channel bank structure (rock or root mass from riparian vegetation). These forced pools are short in length, and provide limited deep residual pool habitat. A summary of existing channel geomorphic conditions are shown in Table 3 below.

TABLE 3. EXISTING CHANNEL GEOMORPHIC CONDITIONS.

Characteristic	Existing Conditions
Main Channel Length (ft)	5,511
Sinuosity (ft/ft)	1.06
Channel Slope (ft/ft)	0.0125
Ave. Bankfull Width (ft) - 1.25 year	43
Ave. Bankfull Depth (ft) - 1.25 year	1.3
Ave. Width to Depth Ratio (ft/ft)	33
Entrenchment Ratio (ft/ft)	2.5
Number of Pools (Residual Depth >2 feet) (Each)	1
Number of Alcoves (Each)	1
Total Alcove Length (ft)	75
Inundation Area at 2-year discharge (Acres)	5.0
Large Wood Material - Key Members Only (Each)	2
Average Channel Bed Sediment Size (mm)	52
Average Bedload Sediment Size (mm)	19
Rosgen Channel Classification	C4

Riparian Conditions

The riparian corridor has been greatly altered from natural historic conditions. The corridor has been disrupted, segmented and manipulated. What was once likely a complex riparian corridor dominated by large cottonwood galleries and numerous beaver complexes is now a simplified grass, sedge and rush community isolated stands of single age class cottonwood trees and very few riparian shrubs. Anthropogenic effects including over grazing and channelization have led to the current state of degradation and over simplification of the riparian corridor. Root density and associated bank strengths have been greatly impacted, resulting in lateral channel expansion rather than vertical channel scour.

Floodplain Connectivity

Floodplain connectivity has been reduced largely due to anthropogenic effects. The greatest impacts to floodplain connectivity include the straightening of the historic channel, the bisection of the floodplain with an access road, and the development of long continuous berms/ levees parallel to the channel bank. Straightening of the channel has led to degradation and channel incision. Road construction has caused a reduction of hydrologic connection between floodplain features. Levee construction has led to direct limitations of floodplain connectivity and reduction or disconnection of hydrologic features between the river channel and floodplain areas outside of the channel. Table 4 below displays the floodplain inundation areas associated with flood frequency intervals for the overall reach (including both downstream and upstream of the project area). The overall entrenchment ratio of the channel through the project reach is approximately 2.5.

TABLE 4. FLOODPLAIN INUNDATIO FOR ROCK CREEK'S LOWER 2.4 MILES.

Annual Flood Return Interval (years)	Inundation Area (Acres)	Ave. Inundation Width (ft)
1.11	10.2	35
1.25	11.0	38
1.5	11.9	41
2	13.0	45
5	15.7	54
10	17.7	61
25	20.9	72
50	23.7	82
100	27.0	93
500	35.6	123

Technical Data

Specific Activity Conservation Measures

Specific activity conservation measures being adhered to from the Bonneville Power Administration HIP III guidance handbook include:

- Levee/ Berm Removal
  - Where it is not possible to remove or set-back all portions of dikes and berms, or in areas where existing berms, dikes, and levees support abundant riparian vegetation, openings will be created with breaches.
  - Breaches shall be equal to or greater than the active channel width (30 feet) to reduce the potential for channel avulsion during flood events.
  - Overburden or fill comprised of native materials, which originated from the project area, may be used within the floodplain to create set-back dikes and fill anthropogenic holes provided that does not impede floodplain function.
- Bank Protection (bioengineering methods)
  - Without changing the location of the bank toe, damaged streambanks will be restored to a natural slope, pattern, and profile suitable for establishment of permanent woody vegetation. This may include sloping of unconsolidated bank material to a stable angle of repose, or the use of benches in consolidated, cohesive soils. The purpose of bank shaping is to provide a more stable platform for the establishment of riparian vegetation, while also reducing the depth to the water table, thus promoting better plant survival.
  - Streambank restoration projects shall include the placement of a riparian buffer strip consisting of a diverse assemblage of species native to the action area or region, including trees, shrubs, and herbaceous species. Do not use invasive species.
  - Large wood (LW) will be used as an integral component of all streambank protection treatments unless restoration can be achieved with soil bioengineering techniques alone.
  - LW will be placed to maximize near bank hydraulic complexity and interstitial habitats through use of various LW sizes and configurations of the placements.
  - Structural placement of LW should focus on providing bankline roughness for energy dissipation vs. flow re-direction that may affect the stability of the opposite bankline.
  - Large wood will be intact, hard, and undecayed to partly decaying with untrimmed root wads to provide functional refugia habitat for fish. Use of decayed or fragmented wood found lying on the ground may be used for additional roughness and to add complexity to LW placements but will not constitute the primary structural components.
  - Wood that is already within the stream or suspended over the stream may be repositioned to allow for greater interaction with the stream.
  - LW anchoring will not utilize cable or chain.
  - Rock will not be used for streambank restoration, except as ballast to stabilize large wood

- The rock may not impair natural stream flows into or out of secondary channels or riparian wetlands.
- Fencing will be installed as necessary to prevent access and grazing damage to revegetated sites and project buffer strips.
- Riparian buffer strips associated with streambank protection shall extend from the project bankline towards the floodplain a minimum distance of 35 feet.

- Road Decommissioning
  - There are no specific conservation measures specified for road decommissioning.
- Bridge Removal
  - Remove all other artificial constrictions within the functional floodplain of the project area as follows: (a) remove existing roadway fill, embankment fill, approach fill, or other fills; (b) remove vacant bridge supports below total scour depth; and (c) reshape exposed floodplains and streambanks to match upstream and downstream conditions.
- Channel/ Floodplain Complexity (off channel, alcoves, large wood, habitat boulders, etc.)
  - Off- and side-channel improvements can include minor excavation (< 10%) of naturally accumulated sediment within historical channels. There is no limit as to the amount of excavation of anthropogenic fill within historic side channels as long as such channels can be clearly identified through field and/or aerial photographs.
  - Excavated material removed from off- or side-channels shall be hauled to an upland site or spread across the adjacent floodplain in a manner that does not restrict floodplain capacity. Hydric soils may be salvaged to provide appropriate substrate and/or seed source for hydrophytic plant community development. Hydric soils will only be obtained from wetland salvage sites.
  - Excavation depth will never exceed the maximum thalweg depth in the main channel.
  - All side channel and pool habitat work will occur in isolation from waters occupied by ESA-listed salmonid species until project completion, at which time a final opening may be made by excavation to waters occupied by ESA-listed salmonid or water will be allowed to return into the area.
  - Adequate precautions will be taken to prevent the creation of fish passage issues or stranding of juvenile or adult fish.
  - LW placements for other purposes than habitat restoration or enhancement are excluded from this consultation.
  - LW will be placed in channels that have an intact, well-vegetated riparian buffer area that is not mature enough to provide large wood, or in conjunction with riparian rehabilitation or management.
  - Stabilizing or key pieces of large wood that will be relied on to provide streambank stability or redirect flows must be intact, hard, and undecayed to partly decaying, and should have untrimmed root wads to provide functional refugia habitat for fish. Use of decayed or

fragmented wood found lying on the ground or partially sunken in the ground is not acceptable for key pieces but may be incorporated to add habitat complexity.
  - The partial burial of LW and boulders may constitute the dominant means of placement and key boulders (footings) or LW can be buried into the stream bank or channel.
  - LW anchoring will not utilize cable or chain.
  - Rock may be used for ballast but is limited to that needed to anchor the LW.
  - Boulders will be installed low in relation to channel dimensions so that they are completely overtopped during channel-forming flow events (approximately a 1.5-year flow event).
- Channel Reconstruction
  - Channel reconstruction consisted of an interdisciplinary team consisting of a biologist, engineer, and hydrologist.

- Riparian Vegetation Planting
  - Species to be planted must be of the same species that naturally occurs in the project area.
  - Tree and shrub species as well as sedge and rush mats to be used as transplant material shall come from outside the bankfull width, typically in abandoned flood plains, and where such plants are abundant.
  - Sedge and rush mats should be sized as to prevent their movement during high flow events.
  - Concentrate plantings above the bankfull elevation.
  - Species distribution shall mimic natural distribution in the riparian and floodplain areas.

Summary of Site Information and Measurements

Topographic information of the site is based on a combination of LiDAR (Light Detection and Ranging) and ground based topographic survey information. LiDAR was flown on April 9th and 10th, 2013. This data was procured by the US Bureau of Reclamation for planning purposes within the Upper Grande Ronde watershed. This data included delineated edge of water during the LiDAR flight and did not include any bathymetry. A land based bathymetric survey was completed by the CTUIR on March 28, 2013. This survey included break lines consisting of top of banks, toe of banks, edge of water, and channel thalweg throughout the project area. In addition to these break line features, 14 detailed cross sections were surveyed as well as general topographic points throughout the floodplain for validation of LiDAR data.

This information was analyzed, compared, and ultimately combined into one electronic topographic surface representing the existing topography through the project reach. All design features are based on this combined topography.

In addition to this topographic information, the CTUIR has collected sediment data (Wolman Pebble Counts) at the 14 detailed cross section locations. These samples include bed material through riffles, pools and depositional bar features. This information was used in the sediment analysis, channel design, and hydraulic model.

Hydrologic Analysis

To facilitate project design, Rio ASE completed a hydrologic evaluation of Rock Creek at its confluence with the Grande Ronde River, near the downstream end of the project area. This hydrologic analysis was conducted to estimate peak flows associated with annual flood recurrence intervals, channel design discharge, and to develop base flow data.

Peak Discharges

Streamflow gage information is unavailable for Rock Creek to estimate peak discharges for various annual flood frequencies, however, the CTUIR obtained peak discharge estimates based on regression equations utilized by the Oregon Water Resources Department (OWRD). Regression equations based on data over a large area (e.g. northeastern Oregon) often have the potential to be associated with large error bars on estimated values. Peak discharge estimates utilizing the ODWR regression equations have 95% confidence limits that average from 40% to 250% of the estimated discharge.

Rio ASE completed an alternative method to estimate peak discharge estimates for Rock Creek in an attempt to validate or refine the estimated peak discharge estimates from ODWR. Rock Creek is bound by historic gage sites on the Grande Ronde River, upstream and downstream of the confluence. The upstream historic US Geological Survey (USGS) gage on the Grande Ronde River is Gage #13318800 (Grande Ronde River at Hilgard). This gage has a basin area of approximately 544 square miles and a historic instantaneous peak and daily discharge records from 1967 – 1981. The downstream historic US Geological Survey (USGS) gage on the Grande Ronde River is Gage #13319000 (Grande Ronde River at La Grande). This gage has a basin area of approximately 688 square miles and a historic instantaneous peak and daily discharge records from 1904 – 1988. There is a 14 year period when both gages were active that can be compared against one another.

This 14 year overlap period can be analyzed to estimate the increase in discharge that was observed between these two gauges. At both gage locations instantaneous peak flows were compared to average daily discharges for the same day to develop an instantaneous peak to average daily discharge ratio. The daily average records were then subtracted from each other to show the discharge coming from the watersheds between the two gauge locations. This contributing watershed area is estimated to be approximately 144 square miles (688 – 544) The maximum daily average discharge from each water year was taken and multiplied by the average of the instantaneous peak ratios to estimate the instantaneous peak discharge input between the two gages for each water year (1967-1981). The results of this step are presented in Table 5.

TABLE 5. ESTIMATE OF INSTANTANEOUS PEAK DISCHARGE BETWEEN GAGE #13318800 AND GAGE #13319000 BETWEEN 1967 AND 1981.

Water Year	Max. Differential Discharge (cfs)	Estimated Instantaneous Peak Differential Discharge (cfs)
1967	430	529
1968	1,020	1,254
1969	670	824
1970	960	1,180
1971	540	664
1972	1,370	1,684
1973	141	173
1974	810	996
1975	930	1,143
1976	1,450	1,783
1977	380	467
1978	690	848
1979	740	910
1980	480	590
1981	930	1,143

These instantaneous values were then statistically analyzed using a Log Pearson Type III Distribution completed with the USGS PeakFQ program. The PeakFQ program utilizes the methodologies discussed within USGS Bulletin 17B (USGS, 1982). These resultant annual peak discharge recurrence values were than multiplied by the watershed area ratio between the project area of Rock Creek and the total contributing area between the two historic gauges (Area Ratio = 52.9 square miles / 144 square miles). This resulted in the estimation of annual peak discharge values for the project area as shown in Table 6.

TABLE 6. ANNUAL PEAK DISCHARGE VALUES FOR THE PROJECT AREA FOR VARIOUS RECURRENCE INTERVALS.

Annual Probability	Return Interval (yrs)	Gage Differential Discharge (cfs)	Rock Creek Project Area Discharge (cfs)
0.9	**1.11**	512	188
0.8	**1.25**	624	229
0.67	**1.50**	748	275
0.5	**2**	901	331
0.2	**5**	1282	471
0.1	**10**	1532	563
0.04	**25**	1846	678
0.02	**50**	2078	763
0.01	**100**	2307	848
0.002	**500**	2839	1043

These estimated peak discharges fall within the acceptable 95% confidence intervals of the OWRD regression equations. Since this data was based on data localized to the project area, was within the OWRD confidence intervals, and was close to bankfull discharge indicator estimates through the project reach, it was utilized for design purposes.

Daily Average Discharges

Rio ASE used the USGS online computer program StreamStats to estimate significant statistical daily average discharge values for the project area (USGS, 2016). Streamstats estimated annual low flow statistics based on basin characteristics for the project area. These annual exceedance flows represent the estimated daily average discharge that is exceeded during a certain percent of the year (e.g. 50% daily exceedance flow is met or exceeded 50% of the year or approximately 182 days per year). These values are shown in Table 7 and include typical fish passage design flows of the 5 and 95% daily average exceedance.

TABLE 7. DAILY AVERAGE EXCEEDANCE FLOW (CFS) ESTIMATES FOR THE PROJECT REACH.

Exceedance Value (%)	Discharge (cfs)	90% Confidence Interval	
		Min. Discharge (cfs)	Max. Discharge (cfs)
5%	127	71	208
10%	81	48	127
25%	33	19	51
50%	8	4	15
95%	2	0.5	4

Sediment Supply and Transport Analysis

The CTUIR completed 14 Wolman Pebble Counts throughout the project reach to assess the composition of existing bed features and to estimate the composition of associated bedload material. The samples were broken down into riffle locations, pool locations, and point bar locations. The breakdown of these materials is summarized in Table 8.

TABLE 8. SUMMARY OF SEDIMENT SIZE (mm) DATA THROUGHOUT THE PROJECT REACH.

Percent Passing	Riffles	Pools	Point Bars
100%	512	512	180
84%	120	125	64
50%	52	51	19
16%	7	6	7
10%	2	2	5

Note: Percent passing represents percentage of the sediment by weight that was smaller or passed through a given size class (e.g. 84% of the riffle material was smaller than 120 mm).

This data was used to assess the potential incipient motion of sediment within the channel upstream, downstream, and through the project reach to evaluate bed mobilization, bedload mobilization, and estimate the parameters for proposed conditions to develop a design that meets the goals and objectives of the project.

Project Design

The proposed enhancements associated with Rock Creek Phase 3 are described in more detail below. The design drawings can be found in Appendix C. Table 9 below summarizes proposed habitat features and compares them to the existing conditions through the project reach.

TABLE 9. PROJECT CHARACTERISTICS SUMMARY TABLE.

Rock Creek Phase 3 Floodplain & Fish Habitat Restoration Project Characteristics & Metrics	Existing Conditions	Proposed Conditions
Main Channel Length (ft)	5,511	6,871
Sinuosity (ft/ft)	1.06	1.35
Channel Slope (ft/ft)	0.0125	0.0100
Ave. Bankfull Width (ft) - 1.25 year	43	30
Ave. Bankfull Depth (ft) - 1.25 year	1.3	1.5
Ave. Width to Depth Ratio (ft/ft)	33	20
Number of Pools (Residual Depth >2 feet) (Each)	1	32
Number of Alcoves (Each)	1	10
Total Alcove Length (ft)	75	1,389
Side Channels	0	2
Side Channel Length (ft.)	0	462
Inundation Area at 2-year discharge (Acres)	5.0	11.0
Large Wood Material - Key Members Only (Each)	2	516
Levee/ Berm Removal (ft)	N/A	1,833
Road Decommissioning (ft)	N/A	5,248
Riparian & Floodplain Planting CREP Program)	N/A	20
Conservation Easement (1 mile Lower Rock Cr)	35	35

Note: Bankfull width and depth measurements for proposed conditions are based on riffle crest design geometry.

Channel Design

Proposed modifications to the main channel are centered on reducing bankfull width to depth ratios and increasing pool frequency and quality, while reestablishing connection to the adjacent floodplain to promote the redevelopment of a robust and wide riparian corridor. The existing channel planform is relatively straight with a measured sinuosity of 1.06. The proposed alignment creates a proposed sinuosity of 1.18. The proposed channel ties into the existing channel in multiple locations, and often crosses over the existing channel to develop access to both sides of the floodplain. At tie-in locations, the existing channel geometry will remain unchanged, but will be enhanced with placement of large wood structures and habitat boulders to promote thalweg development and narrowing of the channel width.

In addition to the proposed changes in main channel planform, the goal of increasing in-channel diversity led to the design goal of transitioning the main channel from a plane bed channel to a riffle – pool sequence channel. A variable vertical profile was created that transitions from riffle crests to pools, pools to glides, and glides back to riffles. This natural planform was based on observed channel profiles in analog reaches within similar systems within the Grande Ronde basin. These observations provided the templates for variations in profile, planform, and section and are discussed in more detail below.

The proposed channel design allows for geometries that provide floodplain activation at desired discharges. In eastern Oregon the channel forming flow is often related to the 1.2- to 2-year discharge (Castro and Jackson, 2001). With one of the design objectives to increase flood prone areas, the main channel design discharge used was based on the more frequent return interval of 1.25-years.

Riffles act as the vertical control of a channel regulating the amount of discharge through the main channel prior to overtopping the banks and activating the floodplain. The riffle cross section controls the conveyance capacity of the channel through a riffle pool sequence. Riffle design within the project reach was based off of a desired discharge through that reach depending on upstream floodplain activation, side channels, etc. Appropriate riffle cross sections were evaluated from hydraulic conditions upstream and downstream on Rock Creek as well as numerous empirical formulae. The cross section shape regardless of the design discharge was consistent, and was designed to convey the design discharge as well to reduce low flow top width (increase low flow depth). This resulted in a two stage channel. This two stage channel has the inset channel shaped as a trapezoid so that low flow tends to concentrate toward the center of the thalweg. This inset channel reduces top width at low flows reducing solar thermal inputs while maximizing depth for fish passage. The second stage channel was also trapezoidal in shape with a sloping bottom. The sloping bottom of the channel reduces the immediate bank height at the edges of the channel, creating a short bank height, reducing the potential for bank erosion. Proposed new riffle crest cross sections have a top width of 29 feet, a maximum depth of 2.4 feet, and an inset channel that is 16 feet wide and 1.2 feet deep.

Riffle construction will be require that existing streambed material be over-excavated to a depth of 20 inches and replaced with a specified gradation that is anticipated to be as stable as the existing material during a bankfull discharge event in areas that do not meet riffle gradation specifications.. In addition to the specified riffle gradation, each constructed riffle will have habitat boulders incorporated to increase hydraulic diversity through the riffles and assist in localized bed stability. Boulders will be embedded into the constructed riffle at a minimum of 50%, with a diverse range of depths to create a natural appearing and functioning riffle.

Pools throughout the main channel were developed based on reference pool data upstream of the project area at cross sections surveyed by the CTUIR. Reference pool data ranged from 0.8 up to 1.8 times the bankfull riffle width depending on pool formation and radius of curvature of channel bends. Proposed pools have an initial typical geometry moving from the outside bend toward the inside of the point bar of a 1.5:1 (horizontal-vertical) slope down to the thalweg elevation, a bottom width of 8 feet, up the point bar at a 2:1 slope to a break point along the point bar then a variable slope of 10:1 to 20:1 up to the bank on the inside of the point bar. The bottom width was increased to 8 feet to accommodate channel blockage associated with large wood structures typically located throughout a constructed channel bend. This allows for the development of more bank habitat along the outside of channel bends.

Glides were designed as a smooth transition point from the end of a pool to the downstream riffle crest. The glides were designed to have a negative slope of 1 to 2 percent transitioning out of the pool up to the riffle crest. This slope is based off reviewing pool and glide exit slopes upstream of the project site. Glides are typical zones of spawning activity where fish prefer clean gravel with limited fine substrate. Glides shall be evaluated on site to determine if they are composed of suitable material. They can be left intact if suitable material is present; otherwise glides shall be over-excavated up to 1.5 feet and replaced with acceptable material that meets the specified gradation. Where existing material is deemed acceptable, material shall be un-compacted and left relatively loose for a depth of 1 foot below the finished grade to provide easy mobilization of fines out of the glide matrix.

Channel and Floodplain Complexity

In-channel and floodplain complexity are being greatly increased through three major actions: vertical profile development within the channel and floodplain (e.g. pools), the addition of large wood structures, and the addition of habitat boulders. In the channel, pools, glides and riffles will be developed to increase the complexity and diversity of available habitat for salmonids. In the floodplain, grading activities will include the excavation of alcoves, filling of existing channel segments, and other periphery habitat improvements that diversify floodplain conditions at various discharge events. Large wood structures will be placed throughout the new and existing channel to provide cover, structure, reduce sediment inputs, and assist in the development and maintenance of scour pools. Wood will also be placed across the floodplain to create roughness, develop zones of deposition for the recruitment and development of an intact riparian corridor, and protect existing channel fill segments from potential future avulsions. Habitat boulders will be placed throughout the new and existing channel alignment within riffles and glides to provide aquatic cover, increase hydraulic diversity, and provide vertical stability to the channel.

Berm Removal

There are approximately seven locations scattered throughout the project reach where small, non-certified levees or push-up berms will be removed. The berm removal length totals approximately 1,790 feet. These berms are interspersed with existing vegetation including some larger trees. Where these larger trees are encountered the berm will remain in place and will only be removed on each side of the drip zone of affected trees. Berms will be removed to existing floodplain elevations.

Road Decommissioning

There is an existing access road that runs parallel to Rock Creek throughout the project length that will be decommissioned. This road length is approximately 5,345 feet long. Road decommissioning will consist of removal of any fill above adjacent floodplain elevations and will include ripping the road prism to a minimum depth of 1.5 feet to establish a more natural soil density layer that can provide for the establishment of an adequate root zone for riparian vegetation.

Revegetation

Revegetation efforts are focused on developing a robust and diverse riparian environment enveloping the entire restoration reach, focused in the areas of soil disturbance. This revegetation plan will be implemented over multiple years. The establishment of healthy, self-sustaining native vegetative communities throughout the project site is vital to the success of the project. Revegetation immediately after grading provides key initial site stabilization and energy dissipation as the plants begin to provide food web support. Such communities promote short-term and long-term bank stabilization; shade for cooler water; protective cover for fish; habitat for terrestrial and aquatic wildlife (birds, mammals, amphibians and macroinvertebrates); and woody debris recruitment in the future. A robust riparian plant community also provides greater protective cover, food sources, habitat complexity and diversity, and migration continuity for the larger ecosystem.

Riparian planting efforts are planned to be completed under the FSA CREP program following enrollment upon completion of project construction. Plant salvage and bio engineering will be completed during project construction as specified in design drawings. Seeding with native seed will also be completed following construction to facilitate vegetative recovery.

The species of plants planned of the project area vary in relation to the stream bankfull elevation, with more hydrophytic plants closer to the stream and more drought-tolerant species at higher elevations. The proposed vegetation consists of plant species native to the area that are typically found at similar sites within the region. Where possible and appropriate based on plant condition, clumps of existing shrubs and small whole trees may be salvaged and transplanted during construction. Willows that cannot be salvaged as whole plants can provide whips to be used as live stakes. Revegetation activities will occur immediately following earth moving activities. Once the final grade has been attained, all disturbed areas will be replanted as appropriate.

Hydraulic Model

Existing Conditions

The existing channel configuration and associated floodplain topography was modeled with a one-dimensional hydraulic model to evaluate hydraulic conditions and characteristics of the project reach including channel segments downstream and upstream of the project area. The existing conditions were evaluated for a range of hydrologic flows from the 95% annual daily exceedance flow up to the 500-year annual peak flood discharge.

Cross sections through the floodplain and existing channel were taken at 100 foot intervals from the confluence with the Grande Ronde upstream approximately 12,600 feet or 2.4 miles. The project reach is located approximately from river mile 0.25 up to river mile 1.25. Cross sections were then assigned initial roughness values associated with the floodplain and channel. Overbank floodplain areas were given a Manning's n-value of 0.06 and the channel was given an initial Manning's n-value of 0.048 based on professional judgment. Areas of ineffective flows and levees were identified in the hydraulic model to more accurately represent the true hydraulic conditions.

The existing hydraulic model was calibrated to the approximated average discharge in Rock Creek on the two days the 2013 LiDAR data was collected (April 9th and 10th). This water surface elevation data was obtained from water surface break lines available in the LiDAR data that represented the edge of water. These values were compared against the initial hydraulic output of water surface elevations. If estimated depths were low, roughness values were increased and where estimated depth values were high, roughness values were reduced. The calibration of the 127 cross sections representing the existing conditions resulted in an average variation from the measured water surface elevation of 0 feet. All measurements were within plus or minus .5 feet except for two cross sections where estimated water surface elevations were 0.8 and 1.0 feet higher than the measured water surface. One of these outlying points is downstream of the project area. The second point (1.0 feet high) is located within the project area, but in an area where only large wood placement will occur. These differences were deemed acceptable. Manning's n-values throughout the reach within the active channel are shown in Table 7 below.

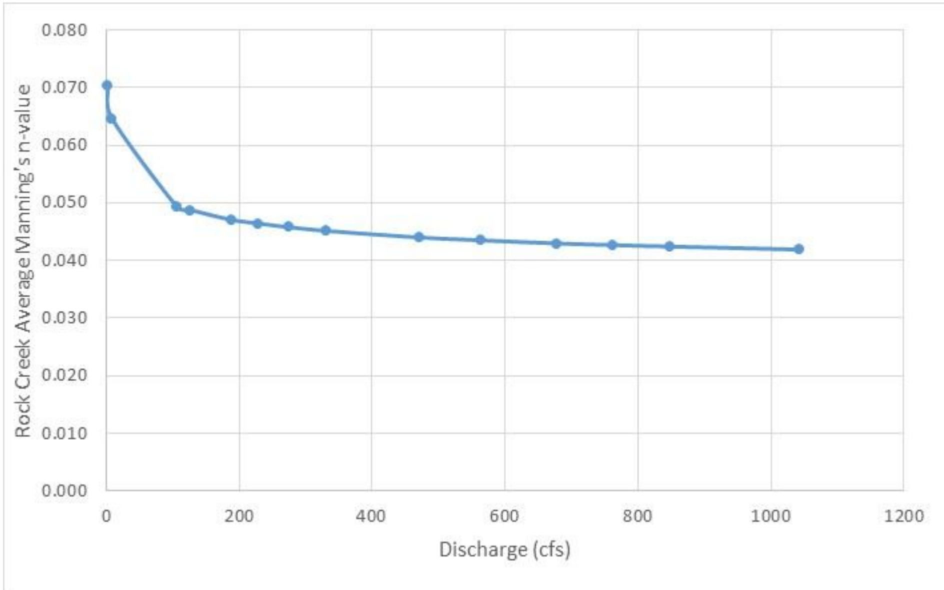
TABLE 10. RANGE IN MANNING'S N-VALUE FOR ROCK CREEK AT CALIBRATION FLOW OF 106 CFS.

	Manning's n-value
Maximum	0.120
Average	0.049
Minimum	0.020

As channel depth increases or decreases, the influence of the roughness of the bed increases or decreases. To account for this variation, Limerino's equation was used to evaluate the relative roughness of the channel at all modeled discharges. The estimated roughness values using this equation for the calibrated condition were used as a base line. All other flows were compared against the calibrated condition (n-value at "X" cfs / n-value at calibrated flow) to develop a factor that would be applied against the calibrated channel roughness to increase or decrease the roughness. These seasonal roughness factors are shown in Table 8.

TABLE 11 AND FIGURE 3. CHANNEL ROUGHNESS FACTORS AND AVERAGE MANNING'S N-VALUES FOR ROCK CREEK AT VARIOUS CHANNEL DISCHARGES.

Discharge (cfs)	n-value Factor
2	1.425
8	1.311
106	**1.000**
127	0.988
188	0.954
229	0.941
275	0.928
331	0.915
471	0.892
563	0.882
678	0.871
763	0.865
848	0.860
1043	0.849



Note: 106 cfs was the calibrated discharge value.

Terrain conditions were analyzed for the range of hydrologic flows previously mentioned. A summary of hydraulic characteristics within the project area are shown in Table 9 below. These characteristics include channel velocity, channel shear, channel depth, etc. and will be used for comparative purposes against the proposed conditions to evaluate and quantify projected change within the project reach.

TABLE 12. EXISTING CONDITIONS HYDRAULIC MODEL OUTPUT SUMMARY.

Reach	Statistic	1.25-Year Discharge				5-Year Discharge			
		Velocity (ft/s)	**Shear (lb/ft^2)**	**Depth (ft)**	**D_{50} Mobile (mm)**	**Velocity (ft/s)**	**Shear (lb/ft^2)**	**Depth (ft)**	**D_{50} Mobile (mm)**
Upstream	**Min.**	3.6	0.4	1.0	24	5.1	0.7	1.5	43
	Ave.	5.1	1.1	1.5	65	6.7	1.5	2.1	89
	Max.	6.6	1.9	2.4	111	8.1	2.3	2.9	134
Project	**Min.**	3.7	0.4	0.9	24	4.3	0.5	1.3	31
	Ave.	4.8	1.0	1.4	60	6.4	1.4	2.0	82
	Max.	6.8	1.9	2.5	115	10.2	2.5	3.4	149
Downstream	**Min.**	2.6	0.4	0.7	24	3.7	0.6	1.1	37
	Ave.	5.2	1.4	1.2	80	6.7	1.7	1.8	102
	Max.	7.0	2.5	1.9	147	8.6	2.7	2.7	157

Note: D_{50} is the average sediment size mobilized based on the statistical shear stresses within the channel.

Proposed Conditions

A hydraulic model was developed representing the proposed conditions. Channel banks were defined and appropriate channel roughness values were estimated based off of the proposed enhancements and the existing calibration data. An average channel roughness value of 0.048 was used during a discharge of 106 cfs (calibration flow). The same seasonal roughness factors used in the existing model were also used in the proposed conditions hydraulic model. This model was used to evaluate and refine design criteria, compare hydraulic characteristics between existing and proposed conditions and evaluate the results from those changes. The proposed conditions terrain was analyzed for the range of hydrologic flows previously mentioned. A summary of hydraulic characteristics within the project area are shown in Table 10 below. These characteristics include channel velocity, channel shear, channel depth, etc. and will be used for comparative purposes against the existing conditions to evaluate and quantify change within the project reach.

TABLE 13. PROJECT REACH PROPOSED CONDITIONS HYDRAULIC MODEL OUTPUT SUMMARY.

Reach	Statistic	1.25-Year Discharge				5-Year Discharge			
		Velocity (ft/s)	**Shear (lb/ft^2)**	**Depth (ft)**	**D_{50} Mobile (mm)**	**Velocity (ft/s)**	**Shear (lb/ft^2)**	**Depth (ft)**	**D_{50} Mobile (mm)**
Project	**Min.**	2.3	0.2	0.8	11	2.8	0.3	1.3	20
	Ave.	4.6	1.0	2.0	61	5.9	1.3	2.5	78
	Max.	10.1	4.1	4.7	245	10.4	3.2	5.4	188

Note: D_{50} is the average sediment size mobilized based on the statistical shear stresses within the channel.

Construction Contract Documentation

General and Construction Conservation Measures

The activities covered under the HIP III are intended to protect and restore fish and wildlife habitat with long-term benefits to ESA-listed species. Short term impacts shall be minimized to reduce adverse effects on ESA-listed species and associated critical habitat. The general and construction conservation measures described within the HIP III guidelines shall be applicable to the Rock Creek Phase 3 project.

Construction Drawings

The CTUIR prepared a construction plan set titled, "Rock Creek Phase 3 Design Drawings" (drawings) and included them in Appendix C. The drawings include plan and profile, sections, and details for appropriate bidding of the project.

Construction Quantities and Preliminary Construction Cost Estimate

Rio ASE and the CTUIR calculated construction quantities and the CTUIR applied unit costs based on recent past project experiences, and professional judgment. We included a summary of the anticipated construction costs in Appendix D.

References

Castro, J. M. and P. L. Jackson. 2001. "Bankfull Discharge Recurrence Intervals and Regional Hydraulic Geometry Relationships: Patterns in the Pacific Northwest, USA." in the Journal of the American Water Resources Association. 37 (5): 1248–1262.

US Geological Survey (USGS). 1982. "Guidelines for Determining Flood Flow Frequency Bulletin." #17B of the Hydrology Subcommittee.

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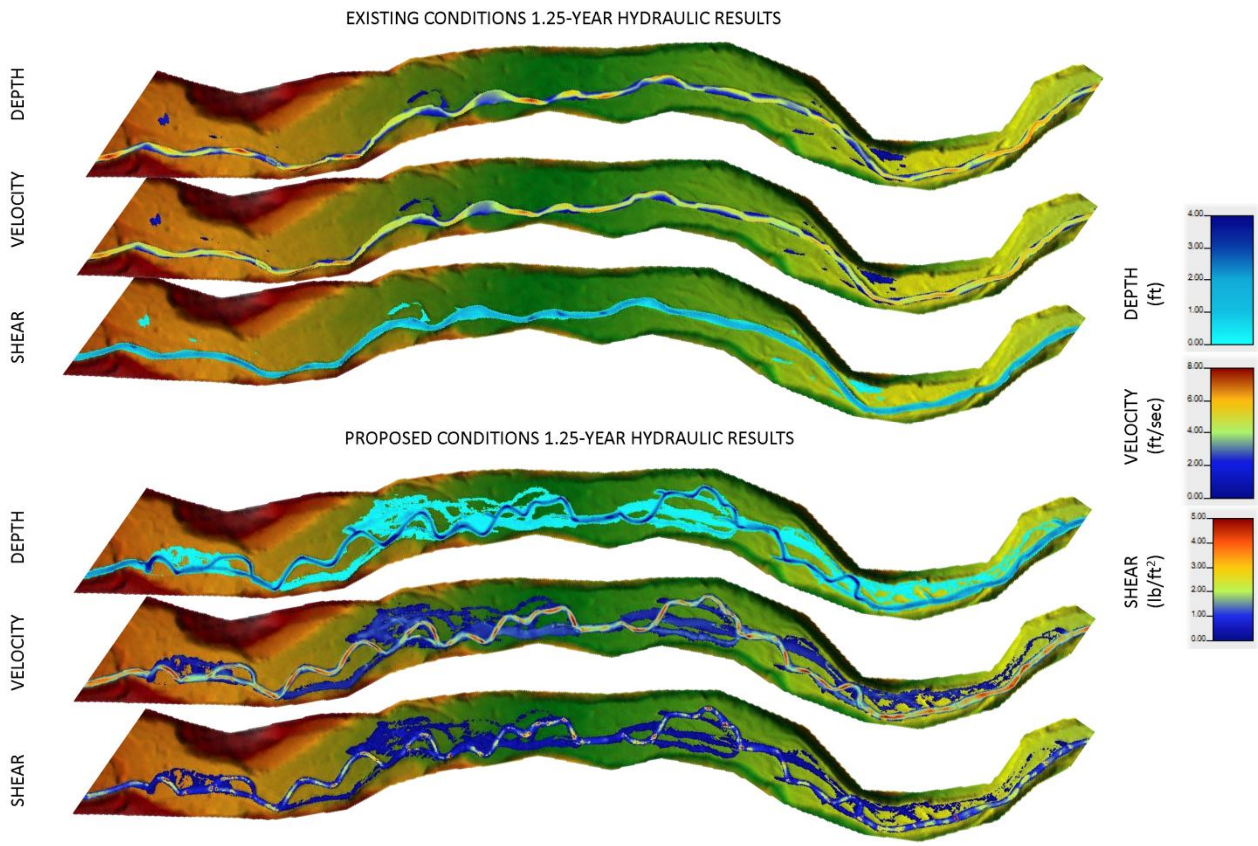
Appendix A – Hydrologic Analysis



Appendix B – Hydraulic Analysis

Riffle Gradation Design

Page: 1

Project: Rock Creek Phase 3
Client: CTUIR
Analyzed: Jeff Fealko
Date: 4/10/2017

This worksheet is intended to check existing channel material against incipient motion and compare those relative bed stability calculations against the proposed riffle conditions to ensure riffles are stable up to the design event.

Enter values in blue-shaded cells only.

Existing Conditions Check at 2-yr

Existing

	mm	cm	in	ft	
Fine Gravel	7.0	0.70	0.28	0.0230	$= D_{16}$
Coarse Gravel	52.0	5.20	2.05	0.1706	$= D_{50}$
Cobble	120.00	12.00	4.72	0.3937	$= D_{84}$
Boulder	512.0	51.20	20.16	1.6798	$= D_{100}$

Critical Velocity Analysis (Using D50)

Input From Cross-Section Spreadsheet

6.5 $= V_{bf}$ = Mean Bankfull Velocity (fps)
2.0 = y = Mean Bankfull Water Depth (ft)
1.6 = t = Shear Stress in Channel (lbs/sf)

Results (Modified from Laursen's Equation)

7.16 = Vc = Critical Velocity (fps)
1.10 = RBS = Relative Bed Stability (dimensionless)
D50 is close to threshold, material may move.

Critical Velocity Equations:

Where D50 > 0.03m $V_c = 6.35\, d^{0.167} (D_{50})^{0.333}$ m/s

Where 0.03m > D50 > 0.0003m $V_c = 4.16\, d^{y} (D_{50})^{0.25}$ m/s.

Where 0.0003m > D50 $V_c = 0.55\, d^{0.5}$ m/s

$y = 0.125/(D_{50})^{0.18}$

Critical Shear Stress Analysis (Using D_{84})

1.600 = t = Shear Stress in Channel (lbs/sf)

Results (Leopold, Wolman & Miller)

1.513 $= \tau_c$ = Critical Shear Stress: $\tau_c = (D_{84}/77.966)^{0.96}$
0.945 = RBS = Relative Bed Stability (dimensionless)
D84 is mobile.

Proposed Conditions Check at 2-yr

Proposed = Same gradation ratio as existing

	mm	cm	in	ft	
Fine Gravel	7.0	0.70	0.28	0.0230	$= D_{16}$
Cobble	89.0	8.90	3.50	0.2920	$= D_{50}$
Cobble	203.2	20.32	8.00	0.6667	$= D_{84}$
Boulder	512.0	51.20	20.16	1.6798	$= D_{100}$

Critical Velocity Analysis (Using D50)

Input From Cross-Section Spreadsheet

5.5 $= V_{crit}$ = Mean Flood Velocity (fps)
2.6 = y = Mean Flood Water Depth (ft)
1.5 = t = Shear Stress in Channel (lbs/sf)

Results (Modified from Laursen's Equation)

8.95 = Vc = Critical Velocity (fps)
1.63 = RBS = Relative Bed Stability (dimensionless)
D50 is stable

Critical Shear Equation:
Empercially derrived from Leopold, Wolman & Miller (1964) from lab and field data.
Where:
$D_{84}(mm) = 77.966\tau_c^{1.042}$
$R^2 = 0.9336$
Then:

Critical Shear Stress Analysis (Using D_{84})

1.50 = t = Shear Stress in Channel (lbs/sf)

Results (Leopold, Wolman & Miller)

2.508 $= \tau_c$ = Critical Shear Stress: $\tau_c = (D_{84}/77.966)^{0.96}$
1.672 = RBS = Relative Bed Stability (dimensionless)
D84 is stable

Critical Shear Equation:
Modification of Shields Komar (1987, 1996).
Where:

Existing		Proposed	
0.88	$= \tau_c$ = D50 Critical Shear Stress	1.56	$= \tau_c$ = D50 Critical Shear Stress
0.55	= RBS = Relative Bed Stability (dimensionless)	1.04	= RBS = Relative Bed Stability (dimensionless)
1.13	$= \tau_c$ = D84 Crtical Shear Stress	2.00	$= \tau_c$ = D84 Crtical Shear Stress
0.71	= RBS = Relative Bed Stability (dimensionless)	1.34	= RBS = Relative Bed Stability (dimensionless)
Bed is mobile.		Bed is stable.	

Although existing conditions show the existing channel bed mobilizing at the 2-year design event, pebble count estimates show on average 55% of sampled material was embedded into the channel bed. This level of embeddedness could lead to stable material at the 2-year design event for riffle stability. Proposed riffle gradations are proposed to not be embedded and are therefore an increase in D50 and D84 is required to reach design stability of proposed riffle material.

Appendix C – Rock Creek Phase 3 Restoration Design Drawings

Appendix D – Construction Quantities and Cost Estimate