



# Nason Creek, Phase 2 RM 3.7-4.6 Floodplain Enhancement 60% Basis of Design Report

**SUBMITTED TO**  
Yakama Nation UCHRP

**January 14, 2026**

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## **SUBMITTED TO**

Confederated Tribes and  
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January 14, 2026

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## 1. Preface

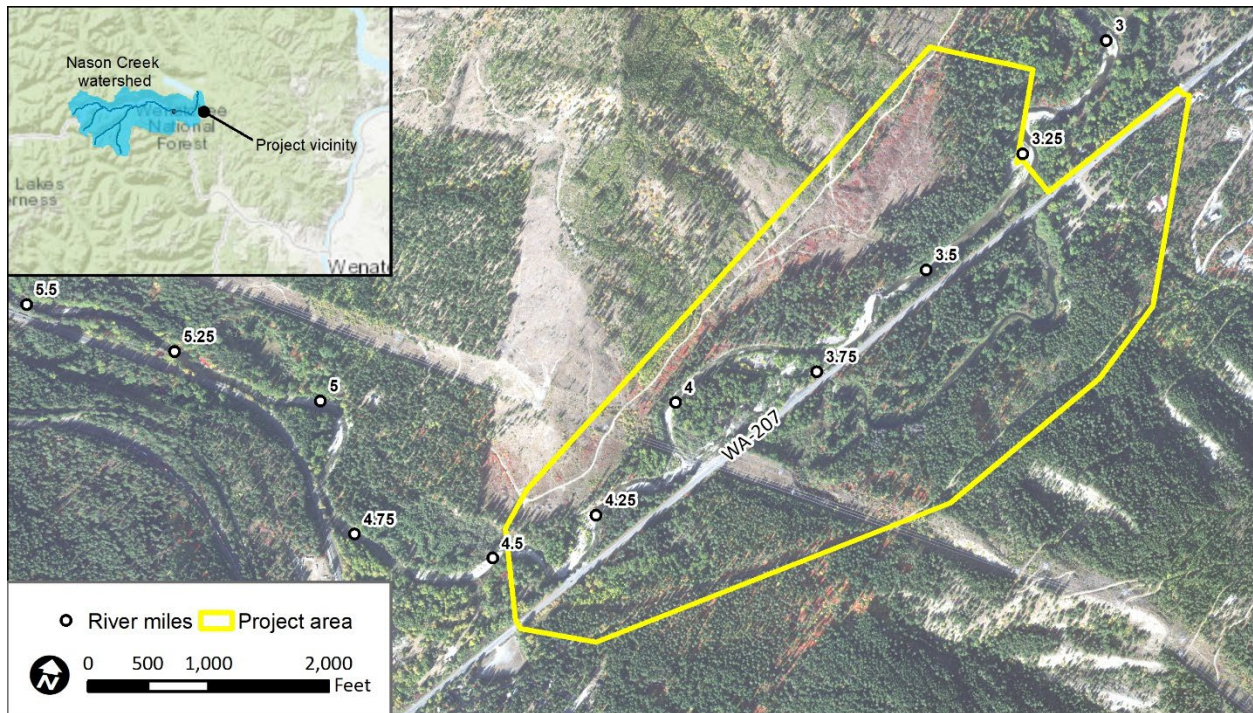
The Nason Creek Floodplain Project is located along Nason Creek between RM 3.2 and RM 4.6 in Chelan County, WA, along Highway 207 on land owned by a private landowner, the U.S. Forest Service, Chelan County and a Washington Department of Transportation (WSDOT) right of way (Figure 1). One privately owned parcel is located within the project area at the downstream end, east of Highway 207. Yakama Nation staff are in discussions with a second private landowner near RM 3.2 at the downstream end of the project area about adding large wood structures along approximately 1,000 ft of Nason Creek for habitat enhancements and address concerns with lateral migration.

The valley bottom within the project area is bisected by Highway 207, which was constructed circa 1942. Construction of Highway 207 significantly reduced the size of the river migration corridor, resulting in a reduction in stream length. This compressed migration corridor, and shortened channel appears to have disrupted geomorphic equilibrium at the site, putting Nason Creek in an unbalanced state. Nason Creek has repeatedly damaged the highway embankment in three locations during flood events. An existing side channel near RM 3.3 to 3.75, which was likely the historical main channel, is located east of Highway 207, and is connected to Nason Creek via two culverts approximately 12-feet in diameter under the highway at the inlet and outlet of the side channel.

The project is broken into three phases.

- Phase 1 includes relocating approximately one-half mile of Highway 207 out of the Nason Creek floodplain between RM 3.9 and 4.5. Designs to relocate the road and associated utilities are being prepared by Perteet.
- Phase 2 includes stream habitat enhancements between RM 3.7 and 4.6.
- Phase 3 includes stream habitat enhancements between RM 3.2 and 3.6.

This report summarizes Phase 2 site conditions and 60% designs and plans.



**Figure 1. Nason Floodplain project area location.**

The goal of the project is to create and enhance instream complexity and off channel aquatic habitats for salmon and steelhead, encourage floodplain connectivity, while also reducing river impacts to the Highway 207 embankment at three locations that have experienced repeated occurrences of erosion.

A number of alternatives for this project area were considered and documented by Inter-Fluve in a 2019 report. This current report documents 60% preliminary design for selected project features that are intended to enhance aquatic habitats while reducing conflicts between Nason Creek and Highway 207 for Phase 2 between RM 3.7 and 4.6 along the main stem, side channel and floodplain along the upstream half of the project area. Project elements for the downstream reach from RM 3.2 and 3.6 are documented in a Phase 3 report (Inter-Fluve, 2024) and will be updated in future design phases.

Currently, Nason Creek is contacting the Highway 207 road prism at three locations within the study area and has historically caused erosion of the road embankment. These locations have been designated as Chronic Environmental Deficiency (CED) sites by WSDOT. CED 1, 2 and 3 sites are located at RM 4.4, 4.1 and 3.7, respectively. CED 1 site is located at a mature meander bend near RM 4.4 (Figure 3b). CED 2 site is at an existing large and historically persistent log structure along the creek near RM 4.1 which directs a portion of Nason Creek flow into the highway embankment (Figure 2). CED 3 site is a riprapped bank along the road that appears stable. Both CED 1 and 2

locations have required emergency placement of rock by WSDOT to stabilize the road embankment. Phase 1 highway relocation will remove the road embankment at these two locations and allow restoration of a more natural geomorphic condition and dynamic stream processes.



*Figure 2. Looking downstream at existing log structure, BPA powerlines, and Highway 207 CED 2 site near RM 4.1. Note riprap placed at right to reduce damage to highway embankment.*

### **1.1 NAME AND TITLES OF SPONSOR, FIRMS AND INDIVIDUALS RESPONSIBLE FOR DESIGN**

The project is sponsored by the Yakama Nation with Chris Butler as project manager. Inter-Fluve is the engineering design firm with Dan Miller (PE) the licensed engineer of record for this project and the main point of contact for Inter-Fluve.

## 1.2 LIST OF PROJECT ELEMENTS THAT HAVE BEEN DESIGNED BY A LICENSED PROFESSIONAL ENGINEER

Dan Miller (PE) is the licensed engineer of record for this project. Project elements include the following, with BPA HIP activity and risk category included:

**Table 1. Activity categories and risk included in the Nason Floodplain project from RM 3.7 to 4.6.**

Description of Proposed Enhancement	Work Element	HIP Category	HIP Risk Level
Relocate existing Highway 207 and remove road embankment, grade to adjacent floodplain elevations including microtopography, and creation of low flow channel and wetland areas. Place floodplain roughness and habitat wood along cut surfaces to reduce avulsion risk. Designs are not intended to prevent channel migration across the valley bottom.	Road relocation outside of floodplain	5b	Low
	Road embankment (levee) removal.	2b	Medium
	Create wetlands	2a	Medium
Place whole trees and large wood (LW) structures of various types in the main stem and side channels to increase hydraulic roughness for floodplain connection, instream habitats and encourage formation of vegetated gravel bars.	Improve floodplain interactions.	2a	Medium
	Install habitat forming instream structures	2d	Medium
Construct low flow/groundwater fed channel and create wetlands along road removal footprint	Improve secondary channel and floodplain interactions.	2a	Medium
	Create wetlands	2a	Medium
Provide separation of Highway 207 riprap-lined embankment from Nason Creek by creation of floodplain terrace with large wood fringe.	Install habitat-forming natural material instream structures	2d	Medium
Revegetation of all disturbed surfaces (designed and installed by others).	Riparian vegetation planting	2e	Low

### **1.3 IDENTIFICATION AND DESCRIPTION OF RISK TO INFRASTRUCTURE OR EXISTING RESOURCES**

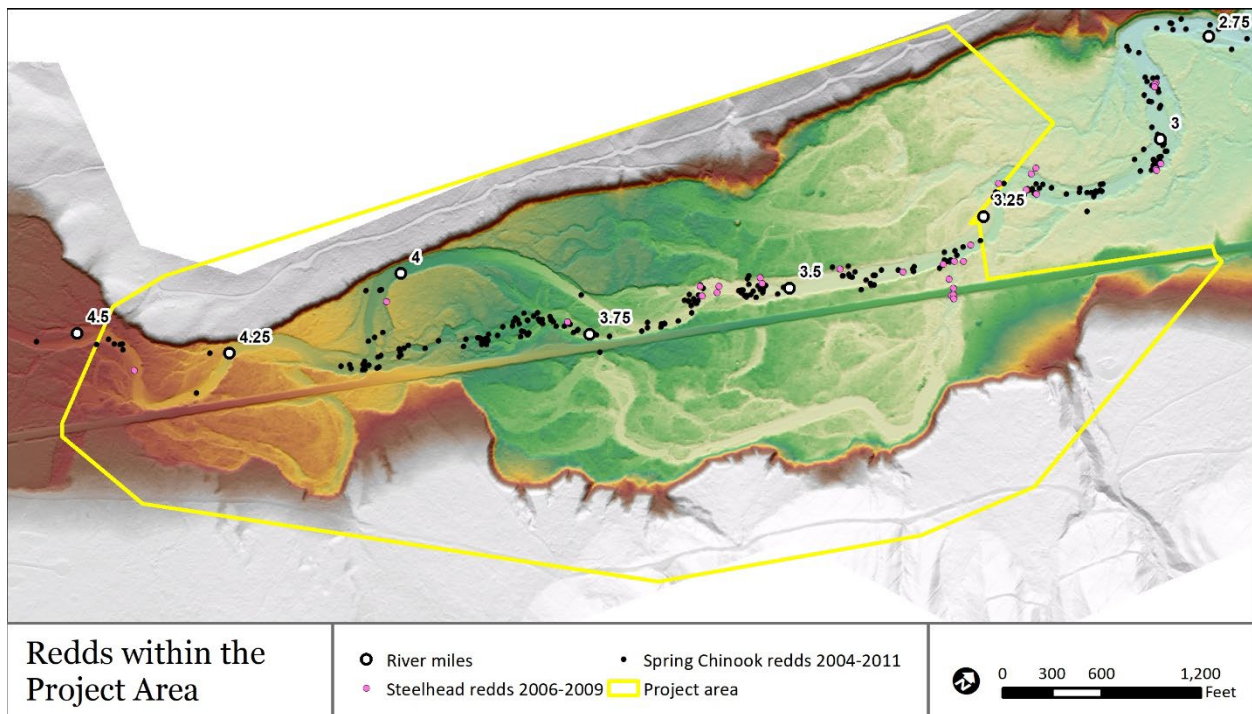
Existing infrastructure in the project vicinity includes Highway 207, two 12ft diameter corrugated metal pipe culverts under the road (RM 3.3 [Figure 3.A] and 3.75), miscellaneous existing concrete culverts ranging from 18" to 48" diameter located through the existing road embankment, a BPA powerline corridor which crosses Nason Creek at RM 4.1, miscellaneous overhead and buried utilities along Highway 207 and private residences downstream of the project area. Risk to Highway 207 is high and has historically been high under existing conditions, as evidenced by erosion damage at the three WSDOT CED sites (RM 3.7, 4.1 and 4.4) of the embankment incurred regularly during high-flow events. Relocating Highway 207 from RM 3.7 to 4.4 will move the highway out of harm's way from Nason Creek and eliminate CED 1 (RM 4.4) and CED 2 (RM 4.1) stream-road conflict areas. Risk to BPA powerlines is minimal because the towers are located outside of the present-day active channel and valley bottom. Risk to private residences is minimal because they are located on a higher terrace and well setback from the active channel.



**Figure 3. Infrastructure within the project area includes (A) CMP culvert with concrete headwalls (RM 3.75) which provide connectivity to the side channel on the east side of the highway, and (B) Highway 207 (RM 4.4) which has been reinforced with rock in several locations and can be removed with highway relocation and allow hydrologic connection to historic floodplain areas.**

#### 1.4 EXPLANATION AND BACKGROUND ON FISHERIES USE (BY LIFE STAGE – PERIOD) AND LIMITING FACTORS ADDRESSED BY THE PROJECT

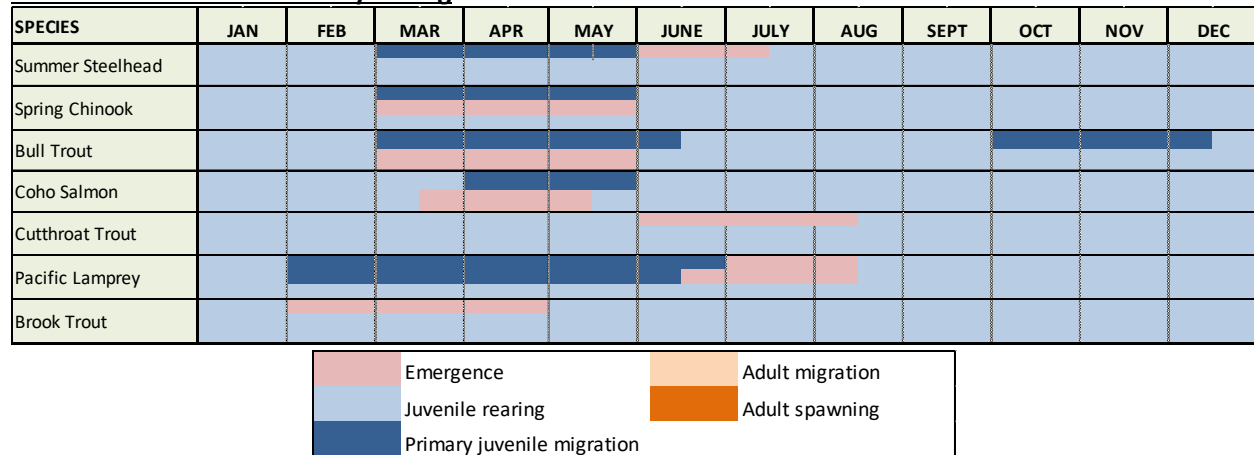
Current fish known to utilize the project area include ESA-listed spring Chinook (endangered), steelhead (threatened), Bull Trout (*Salvelinus confluentus*, threatened), species-of-concern Pacific Lamprey (*Lampetra tridentate*) and westslope cutthroat trout (*O. clarkii*), and non-listed summer Chinook, Coho Salmon (*O. kisutch*), mountain whitefish (*Prosopium williamsoni*), and non-native brook trout (*Salvelinus fontinalis*). Past redd counts show high Chinook Salmon and steelhead redd densities within the project area (Figure 4). The project reach is a low gradient reach with high quality spawning gravels located throughout.



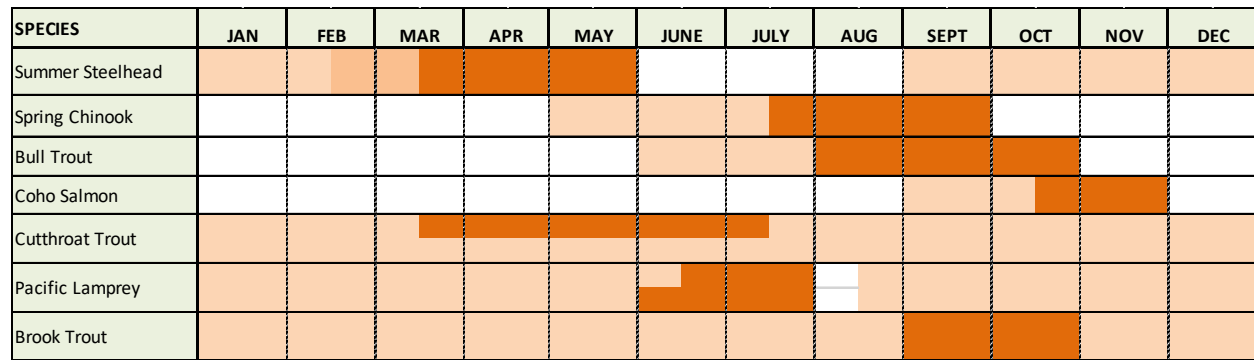
**Figure 4. Steelhead and spring Chinook redds recorded in the project area for the specified years, displayed over LiDAR elevation data. The channel network is clearly visible in the LiDAR data. Redd data from Upper Columbia Salmon Recovery Board (2018).**

According to the Subbasin Plan (NWPC 2004), habitat in the project area has high potential to improve populations of aquatic species, including ESA-listed salmonids within the lower Nason Creek. Summary of life-history timing for aquatic species are presented below (Figure 5). Detailed descriptions of habitat requirements by life stage for ESA-listed species are included in the following sections.

**Juvenile salmonid life-history timing**



**Adult salmonid life-history timing**



**Figure 5. Life history timing of target species within the project area.**

**1.4.1 Steelhead**

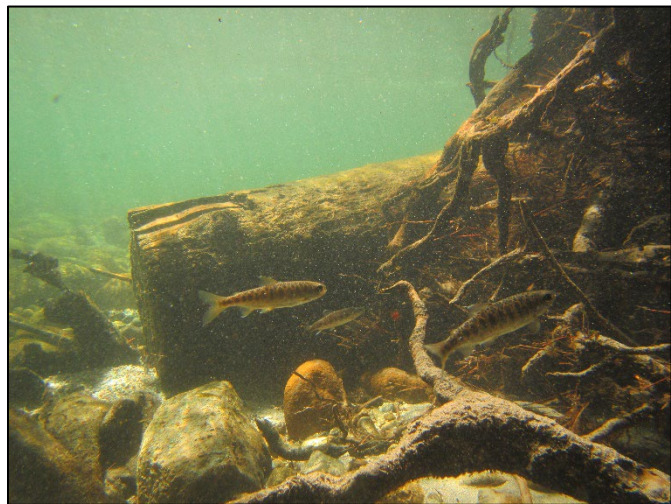
Adult steelhead enter the Wenatchee basin from August through April, holding in deep pools with overhead cover. Spawning begins in very late March, peaks in mid-April, and lasts through May. Egg survival is highly sensitive to intra-gravel flow and temperature (NWPCC 2004), and is particularly sensitive to siltation earlier in the incubation period (Healy 1991). Fry emerge from the redds 6-10 weeks after spawning (Peven 2003).

Age-0 juveniles spend their first year primarily in shallow riffle habitats, feeding on invertebrates and utilizing overhanging riparian vegetation and undercut banks for cover (Moyle et al. 2002, US Fish and Wildlife Service 1995). Age-0 steelhead use slower, shallower water than Chinook Salmon, preferring small boulder and large cobble substrate (Hillman et al. 1989). Older juveniles prefer faster moving water including deep pools and runs over cobble and boulder substrate (US Fish and Wildlife Service 1995). Juveniles outmigrate between ages one and three, though some hold over and display a resident life history form. Smolts begin migrating downstream from natal areas in March (NWPCC 2004).

### 1.4.2 Chinook Salmon

Adult spring Chinook enter the Wenatchee in May, holding in deeper pools with overhanging cover until water temperatures are suitable for spawning. Spawning typically begins in very late July, peaks in late August, and ends in late September (NWPCC 2004). Eggs are very sensitive to changes in oxygen levels and percolation, both of which are affected by sediment deposition and siltation in the redd (Healy 1991, Peven 2003). Fry emerge in June and July, which coincides with the rising hydrograph, forcing juveniles to seek out backwater or margin areas with lower velocities, dense cover, and abundant food (Quinn 2005). Fry are extremely vulnerable when they emerge, because their swimming ability is poor and flows are high. Near-shore areas with eddies, large woody debris, undercut tree roots, and other cover are very important for post-emergent fry (Hillman et al. 1989, Healy 1991). The proposed project features are expected to provide low velocity rearing habitat for post-emergent spring Chinook salmon fry because there are high redd densities immediately upstream, and the large woody material (LWM) features are on the outside of a meander bend and create scour pools where the majority of water and fry are expected to be during high flows (Figure 4).

As they increase in size, juveniles begin to select for deeper and faster moving water, particularly areas with overhanging cover (Moyle et al 2002b). These areas provide more holding and feeding habitat area for the larger juveniles to occupy. Upper-Columbia spring Chinook express a stream-type life history, meaning they rear in freshwater for at least one year before outmigrating as yearlings. Smolts begin migrating in March from natal areas (NWPCC 2004).



**Figure 6. Chinook Salmon parr resting behind a constructed log structure in the Entiat River between feeding forays.**

### 1.4.1 Bull trout

Nason Creek supports a population of resident and fluvial bull trout (NWPCC 2004). The project area is located in a reach of Nason Creek that is mapped as “possible bull trout spawning” in the Wenatchee Subbasin Plan (NWPCC 2004). Bull Trout spawn in the Wenatchee subbasin from August through October. Eggs incubate over the fall, winter, and spring, with fry emerging approximately 220 days after egg deposition. Juveniles select for margin habitat with overhanging cover, feeding primarily on aquatic insects until they grow larger and shift towards feeding on fish. Bull trout juveniles rear in headwater streams for at least two years before migrating downstream as adults or sub-adults to express fluvial life histories, or resident life histories in downstream reaches (McPhail and Baxter 1996). Downstream movement

of bull trout in the nearby Chiwawa River has been documented as bimodal, with one pulse in the spring and a second in the fall (NWPCC 2004).

#### 1.4.2 Limiting factors

Regional objectives for salmonid habitat protection and restoration in the Upper Columbia Region have been evaluated and summarized in the document *A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region* (2017) by the Upper Columbia Salmon Recovery Board (UCSRB) Regional Technical Team (RTT). This Biological Strategy is part of the Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan (UCSRB 2007) and recommends region-wide biological considerations and approaches for salmonid habitat restoration and protection actions. The RTT guides the development and evaluation of salmonid recovery projects within the Upper Columbia Region.

The Biological Strategy has identified several assessment units within the major watersheds of the Upper Wenatchee River. The Nason Floodplain project area falls within the Nason Creek Assessment Unit. Nason Creek is a Tier 1 watershed of highest priority for both protection and restoration.

All Chinook spawning that occurs in Nason Creek occurs in the lower 15 miles of the main stem, which also contains the poorest quality habitat (UCRTT 2017). The RTT has prioritized a list of restoration actions to address key ecological concerns in the Nason Creek Assessment Unit, and are listed below in priority order (UCRTT 2017):

1. **Peripheral and transitional habitat:** Reconnect side channels and off-channel habitat.
2. **Channel structure and form:** Increase large wood complexes, remove or modify levees and roads where feasible, restore channel structure and form to reduce sediment transport capacity to counteract recent incision and confinement.
3. **Riparian condition:** Improve riparian conditions to improve long term LWM recruitment.
4. **Channel structure and form:** Restore instream habitat diversity by enhancing large wood recruitment, retention, and complexity.
5. **Food**
6. **Sediment conditions:** Decommission roads that are affecting sediment delivery to the stream.
7. **Species interaction (competition)**

## 1.5 LIST OF PRIMARY PROJECT FEATURES INCLUDING CONSTRUCTED OR NATURAL ELEMENTS

Primary project features along the Phase 2 portion of the project from RM 3.7 to 4.6 consist of the following:

### **Remove existing Highway 207 and grade embankment to create floodplain and wetland areas:**

Relocation of Hwy 207 and utilities is included in the Phase 1 portion of the project currently in design by Perteet, Inc. Relocation will allow removal of a portion of the existing road embankment and associated utilities along the abandoned length of highway, reestablishing floodplain elevations and floodplain side channel continuity. Portions of the abandoned road will be excavated to, or below adjacent floodplain to create a low flow/groundwater fed channel and adjacent wetland creation areas for additional complexity. Risk of avulsion along the road removal corridor will be reduced through selective grading and a dense placement of floodplain roughness wood and slash stabilized with log piles and log burial. Structures include: 1) **low flow floodplain roughness large wood structures**, 2) **low flow floodplain roughness large wood logs**, and 3) **low flow habitat wood**. Cut surfaces will be vegetated with appropriate wetland, riparian and upland species. Revegetation designs will be completed by others at future phases of the project.

- **Large wood installation:** A number of large wood structure types are proposed to be constructed in the main stem and side channel of Nason Creek to provide complex salmonid holding and rearing habitat, floodplain inundation, allow channel migration and manage risk of avulsion along the removed road at a range of flow conditions.
  - **Apex jams:** are mid-channel structures intended to split flow, create scour and sediment deposition complexity to provide cover, rearing and spawning habitats. The structures are ballasted by burial in the stream bed with alluvial material, the face of the structures diverting flow energy away from the backfill materials. Log piles are included as supplemental ballast.
  - **Inlet and bank buried log structures:** These are back fill ballasted structures built in the banks. Locations of structures were selected based on flow patterns to encourage scour and sediment deposition complexity, recruit floating debris, and enhance gaps in the riparian fringe. The structures are comprised of logs with rootwads, slash, whole trees and tree tops, which will be restrained by burial in the banks and backfill with alluvial material. Log piles installed with a vibratory pile driver will supplement ballast of racking type wood. Structures are included in the plans as **inlet jams**, **bank buried jams** and **small bank buried jams**.
  - **Margin large wood structure:** These are partially buried and pile ballasted structures built against existing banks. Locations of structures were selected based on flow patterns to encourage flow energy complexity along the stream banks, scour and sediment deposition complexity, recruit floating debris, and enhance gaps in the riparian fringe. The structures are comprised of logs with rootwads, slash, whole trees and tree tops, which will be restrained by log piles installed with a vibratory pile driver and log ends buried into existing banks.

- **Bar roughness jams:** are smaller structures comprised of partially buried logs with exposed rootwads. Burial will provide ballasting. Piles are included to aid in ballasting and recruiting debris. Slash is pinned under the rootwads. **Deflector jams** are similar structures, minus the partially buried logs. The intent of both structure types is to deflect flow and create lower energy areas downstream of the jam that will encourage deposition of fine sediments and formation of vegetated gravel bars. Racking of floating debris is encouraged to augment the function of these structures.
- **CED 2 existing jam:** an existing naturally occurring log jam is located under the BPA lines at CED 2 site. If clearance from the power lines allow, log piles will be installed along the edges as equipment reach allows without disturbing the existing jam. LW structures installed downstream of this jam along the side channel will have similar 'log drift' features by placing **racking wood** added to upstream face of individual structures to mimic this existing jam. The structures will provide ballasting of the racking wood.
- **Whole trees:** Whole trees are incorporated into many structures as shown on the plans as incidental item. Whole trees are anticipated to be sourced in part from on site salvage.
- **Floodplain roughness logs:** installed large wood restrained by bracing to existing trees will provide floodplain roughness across a meander bend at the upstream end of the project.
- **Tipped trees:** along an outside bank of a meander bend will provide hydraulic and habitat complexity. Candidate trees will be identified and pulled over using cables to reduce disturbance of bank and adjacent floodplain
- **Bank habitat enhancements at existing riprap bank:** At the CED 3 (RM 3.7) site, bank habitat treatments are proposed to provide fish habitat, channel complexity and greater separation of flow from the highway where exposed riprap is currently armoring the road prism. The existing riprap would remain in-situ under the new bank treatment to serve as a failsafe protection for the highway embankment. Bank treatments include:
  - Creation of floodplain terraces with large wood as shown in the plan set. Bank habitat includes constructing a series of meander bend structures along the length of the riprapped bank. These structures would be constructed of logs with rootwads, logs without rootwads, whole trees, log piles, and slash, and backfilled with large alluvial material and rounded alluvial small boulder material. The results would be to create a floodplain terrace ranging about 25 to 30 feet wide along the existing bank, with about 10 to 15 feet of LWM exposed to active flow. The fill would be revegetated with native live willow, dogwood and cottonwood cuttings, riparian trees and shrubs. Revegetation is planned to be designed by Yakama Nations revegetation consultant.
  - To maintain channel flow conveyance, the opposing gravel bar on river left would be excavated to maintain a similar flow conveyance area and graded to blend to existing topography. The excavated bar material would be salvaged, sorted by size and used as log structure backfill. Nason Creek has dynamic sediment transport conditions with actively shifting gravel bars and is expected to transport material from the gravel bar naturally in response to encroachment into the main stem by the terrace. Excavation anticipates this future condition. Stream riffle and pool conditions are anticipated to be

similar to existing conditions, with habitat improvement by converting river right bank from a riprap condition to riparian margin with large wood condition.

- **Wetland, riparian and upland revegetation:** Native species will be planted in all disturbed areas to promote riparian function and increase food production and habitat complexity for target species. The planting plan will be developed separately in a future phase by Yakama Nation's planting consultant.

#### **1.6 DESCRIPTION OF DISTURBANCE INCLUDING TIMING AND AREAL EXTENT AND POTENTIAL IMPACTS ASSOCIATED WITH IMPLEMENTATION OF EACH ELEMENT**

Project disturbance at the site will be from excavation and temporary access routes used to remove portions of the existing road embankment and revetment, install large wood structures, and install plantings. Access to many sites will be along the abandoned road alignment. Trees and vegetation removed during excavation will be salvaged and used to supplement constructed large wood habitat structures. Disturbance during construction to large trees and riparian zones will be minimized, and all disturbed areas will be re-vegetated.

## 2. Resource inventory and evaluation

### 2.1 DESCRIPTION OF PAST AND PRESENT IMPACTS ON CHANNEL, RIPARIAN AND FLOODPLAIN CONDITIONS

Riparian and floodplain conditions in the project site and vicinity have been impacted most heavily by the construction of Highway 207 circa 1942 along the Nason Creek floodplain. The circa 1900 plat map indicates that the main stem of Nason Creek used to occupy the southeast side of the floodplain (Figure 7). The 1957 aerial shows Nason Creek in an alignment with planform similar to – though west of – what is seen today, and the BPA power corridor is also visible. Logging in the vicinity, and associated road building, has had impacts on large wood recruitment and sediment delivery to Nason Creek. Construction of the highway has reduced total off channel habitat connectivity, disconnected floodplain areas, and constricted channel migration zones, concentrated more flow into the main stem, and shortened overall channel length by cutting off a historical meander that is depicted in the circa 1900 plat map.

### 2.2 INSTREAM FLOW MANAGEMENT AND CONSTRAINTS IN THE PROJECT REACH

Not applicable to this project.

### 2.3 DESCRIPTION OF EXISTING GEOMORPHIC CONDITIONS AND CONSTRAINTS ON PHYSICAL PROCESSES

Figure 7, Figure 8, and Figure 9 show historical aerial imagery of the project area vicinity from 1957, 1963, 1974, 1991, 2006 and 2015. The 1942 Road Relocation plans include an indication of the Nason Creek alignment that appears similar to the 1957 photos. While in general the meandering plan form and bend locations are similar over the photographic history, the channel has migrated eastward closer to the highway. There appears to be a vegetated floodplain approximately 80- and 150-foot wide from the edge of Highway 207 to the right river bank at RM 4.4 and 4.1, respectively, in the 1942 plans (Chelan Co, 2012) and 1957 photos. It appears that Nason Creek encroached on to the road embankment during the time interval between the 1974 and 1991 photos. The side channel along the west side of highway between RM 3.7 to 4.1 is evident in all photos.

The Highway 207 embankment has prevented or limited flow to the east floodplain, leading to fewer off channel and side channel habitats. No pre-development survey is available to determine whether and to what degree incision may have occurred, however it is believed that this unnatural confinement has led to some level of incision (UCRTT 2017).

Nason Creek delivers a dynamic supply of substrate and wood to the project reach. Areas of wood accumulation exhibit defined scour pools and sediment deposit tail spills creating diverse habitats. The numbers and locations of redds mapped (Figure 4) indicate that diversity of LWM and bed forms provide spawning habitats.

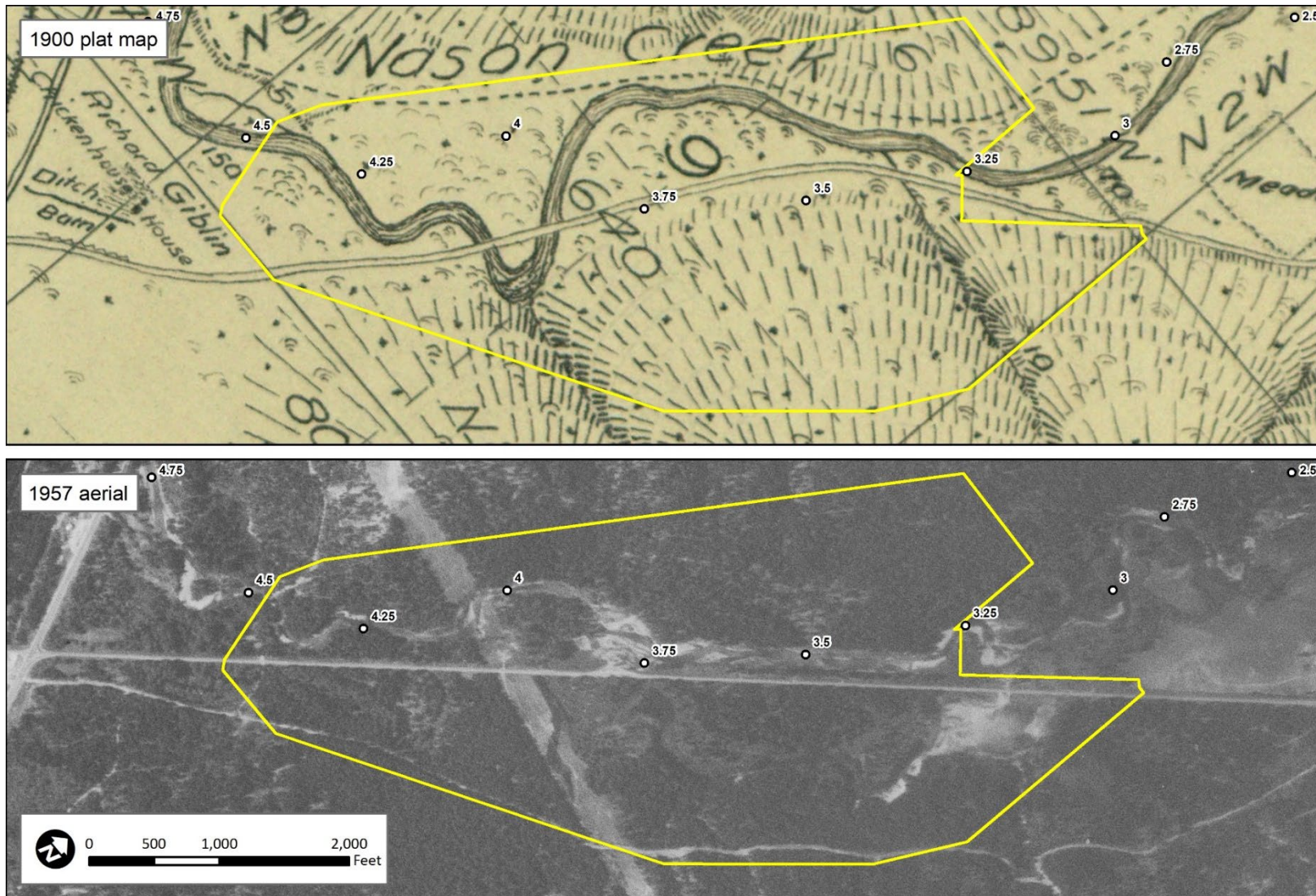


Figure 7. Historical plat map from 1900 and aerial image from 1957, project area boundary shown in yellow.

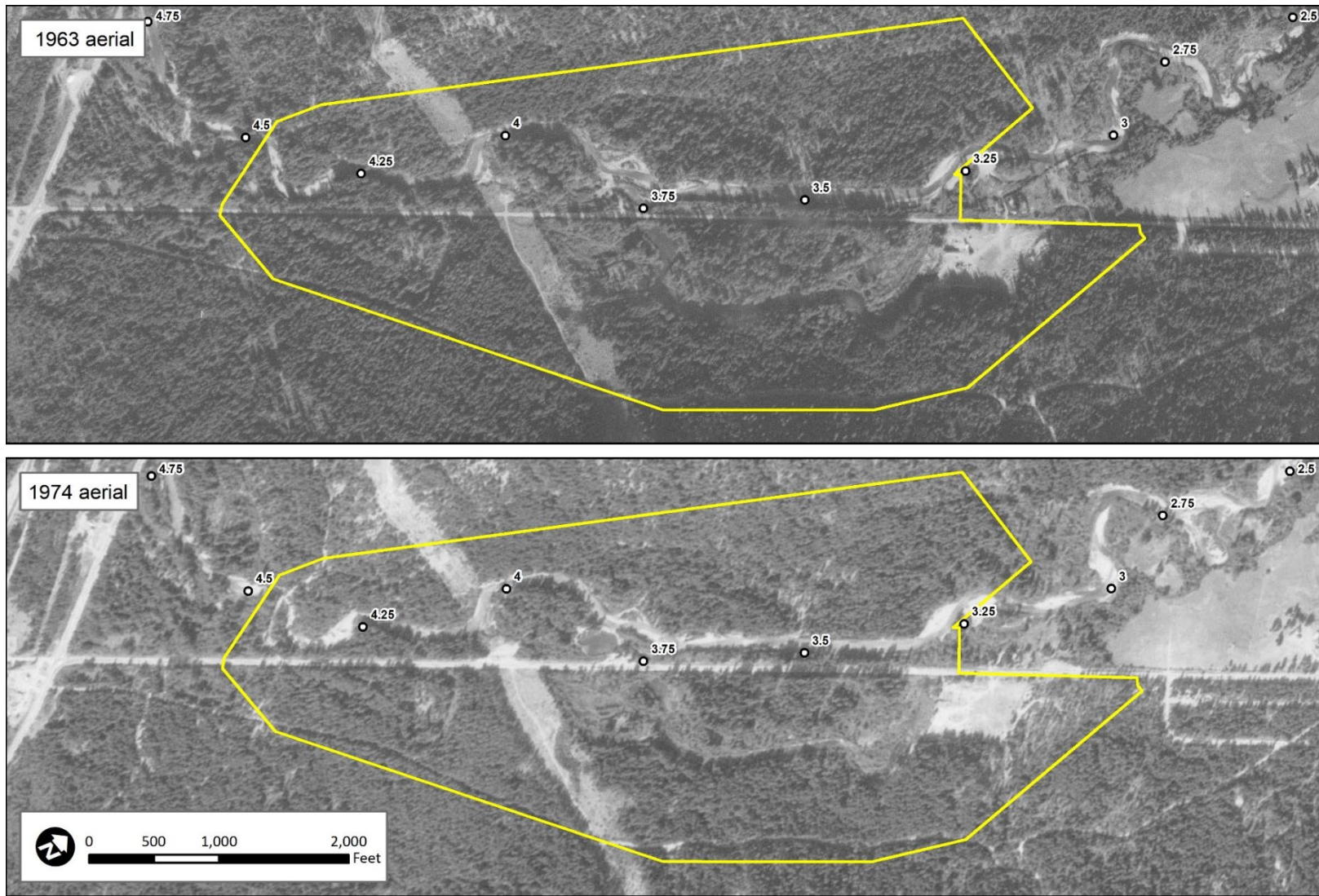


Figure 8. Aerial images from 1963 and 1974, project area boundary shown in yellow.

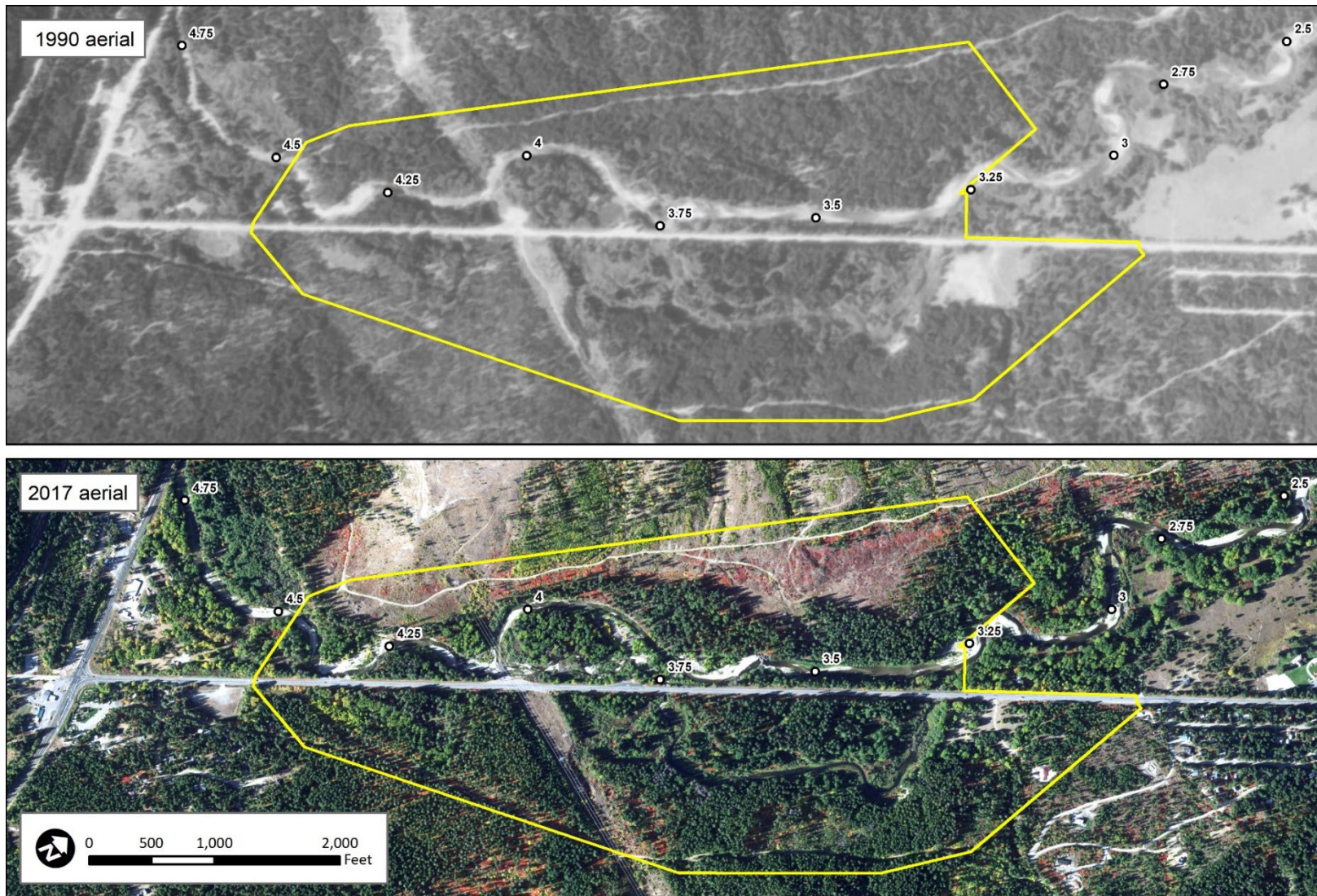


Figure 9. Aerial images from 1990 and 2017, project area boundary shown in yellow.

## **2.4 DESCRIPTION OF EXISTING RIPARIAN CONDITION AND HISTORICAL RIPARIAN IMPACTS**

Riparian conditions in the project area are generally good. The forest is a mixed-age stand of Ponderosa Pine, Douglas fir, willow, dogwood and cottonwood. Typically, conifers occupy higher elevation terraces that have not been disturbed by river activity for a number of decades. Deciduous trees and woody shrubs occupy the riparian zones and areas disturbed by river migration in the recent past. Coniferous trees have been removed along the BPA power line corridor and recently logged at the western edge of the river left floodplain from approximately RM 3.2-3.7. Wetlands were delineated by Hamer Environmental and documented in January 2021 and January 14, 2022 reports.

## **2.5 DESCRIPTION OF LATERAL CONNECTIVITY TO FLOODPLAIN AND HISTORICAL FLOODPLAIN IMPACTS**

Nason Creek historically had high floodplain connectivity with a myriad of off-channel wetlands, alcoves, and channels. This complexity was likely enhanced by large wood accumulations and beaver ponds. The current highway embankment and culvert system have reduced floodplain connectivity and eliminated lateral channel migration to the east of the highway by limiting water movement onto floodplain surfaces to areas east of the highway. Approximately 40.7-acres of active side channel, wetlands and floodplain are located east of the highway RM 3.3-3.9. Approximately 10.9-acres of inactive side channel, wetlands and floodplain are located east of the highway RM 4.15-4.4; which can be available to flow and channel migration with proposed highway relocation. The reduced floodplain width constricted by the highway embankment has reduced the available migration corridor.

## **2.6 TIDAL INFLUENCE IN PROJECT REACH AND INFLUENCE OF STRUCTURAL CONTROLS (DIKES OR GATES)**

Not applicable to this project.

## 3. Technical data

### 3.1 INCORPORATION OF HIP SPECIFIC ACTIVITY CONSERVATION MEASURES FOR ALL INCLUDED PROJECT ELEMENTS

HIP conservation measures are included in preliminary project plans. If necessary, requests for variances will be submitted for any conservation measures that cannot be met.

### 3.2 SUMMARY OF SITE INFORMATION AND MEASUREMENTS (SURVEY, BED MATERIAL, ETC) USED TO SUPPORT ASSESSMENT AND DESIGN

#### 3.2.1 Elevation data

A detailed topographic/bathymetric LiDAR data set collected in 2022 for the river corridor was supplemented with 2015 topographic LiDAR data set for floodplain areas was used to create an existing conditions surface and HEC-RAS model terrain. All data are referenced to the Washington State Plane North coordinate system, the NAVD88 vertical datum and US feet.

#### 3.2.2 Fish use

Fish use data were collected from primary literature, the Wenatchee Subbasin Plan (NWPC 2004), and the Upper Columbia biological strategy (UCRTT 2017).

#### 3.2.3 Geomorphic data

A pebble count survey was conducted in the project area to evaluate existing substrate conditions. See section 3.4.

#### 3.2.4 Hydrology data

Washington Department of Ecology (WDOE) records flows along Nason Creek at gage 45J070 located near the mouth. The WDOE gage has a period of record from 2002 to the present and is reported to have some inconsistencies – thus was not used solely for estimating flood peak flows. The WDOE gage does provide useful information on seasonal flow variation during the available period of record.

The USGS maintains a stream flow gage on nearby Icicle Creek (USGS Gage #12458000) which has a period of record from 1937 to present. The Icicle Creek watershed has many similarities to the Nason Creek watershed and is viable as a paired watershed to understand Nason Creek hydrology. The Icicle Creek data was used for paired watershed analyses for a number of studies including the U.S. Bureau of Reclamation Nason Creek Tributary Assessment (BOR, 2008).

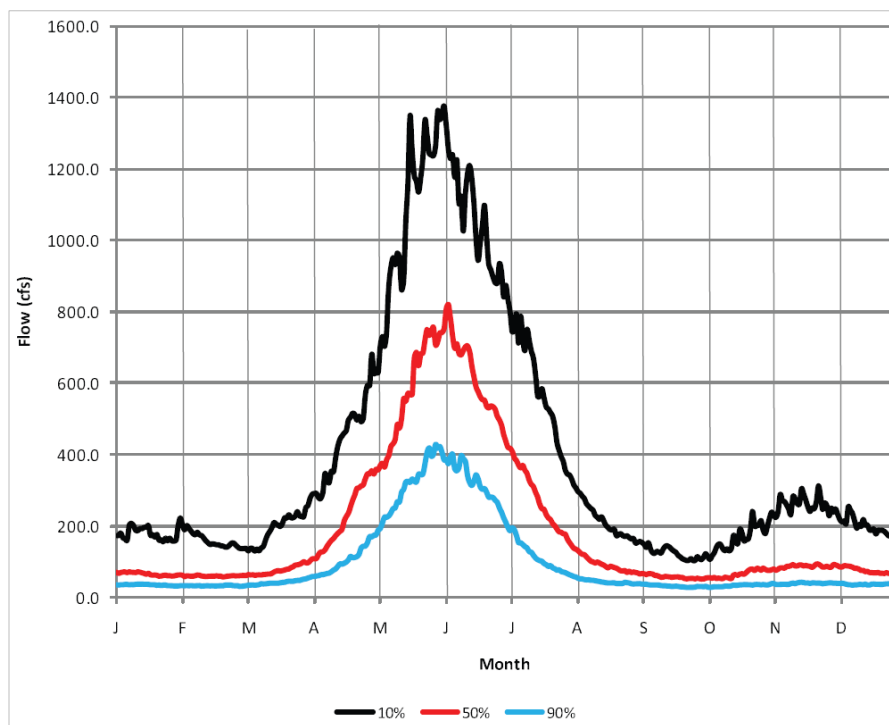
No field flow measurements were collected for this preliminary analysis.

### 3.3 SUMMARY OF HYDROLOGIC ANALYSES CONDUCTED, INCLUDING DATA SOURCES AND PERIOD OF RECORD INCLUDING A LIST OF DESIGN DISCHARGE (Q) AND RETURN INTERVAL (RI) FOR EACH DESIGN ELEMENT

#### 3.3.1 General Hydrology

Nason Creek drains high-elevation areas of the Chiwaukum Mountains and has a snowmelt-dominated hydrologic regime. Figure 10 shows typical seasonal median, high, and low exceedance flows for Nason Creek at RM 12.

Although peak flows typically occur due to snowmelt in the late spring or early summer, some of the largest floods have occurred from rain-on-snow events in late fall. Large past flood events occurred in May 1948, November 1990, November 1995, and November 2006. As noted in Chelan County’s Feasibility Study (2012), the November 1995 event washed out portions of Highway 207. As of 2011, three repairs to the highway embankment in 10 years at this location led to nomination for the WSDOT Chronic Environmental Deficient (CED) program.



**Figure 10. Modeled 10 percent, 50 percent, and 90 percent exceedance flows for RM 12 using data from 7 regional gages. Percentile flows represent the daily flow that is equaled or exceeded for the given percentage of time over the available period of record. Reprinted from Malmon (2010).**

### 3.3.2 Peak Flow Hydrology

As noted in Section 3.2.4, Washington Department of Ecology operates gage 45J070 near the mouth of Nason Creek since 2002, but no long-term stream gage record is available on Nason to reliably estimate peak flows for the project reach. The US Bureau of Reclamation Nason Creek Tributary Assessment (Reclamation, 2008) completed a flood event peak flow analysis using data recorded at the nearby Icicle Creek USGS gage and considers the WDOE peak flow values. The Reclamation estimated flood magnitudes are presented in Table 2. These flows were used in the project hydraulic model.

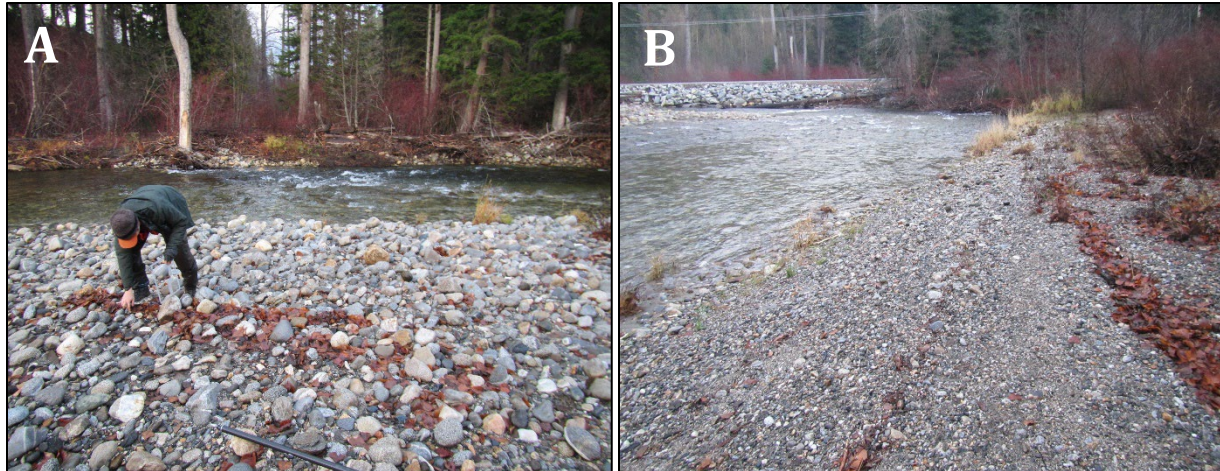
**Table 2. Peak flow estimates for Nason Creek at RM 4.0 (Reclamation, 2008. Appendix D, Table 5)**

Recurrence Interval (years)	Estimated flow at RM 4 (cfs)
2	2,600
5	3,900
10	4,900
25	6,500
50	7,900
100	9,400

### 3.4 SUMMARY OF SEDIMENT SUPPLY AND TRANSPORT ANALYSES CONDUCTED, INCLUDING DATA SOURCES INCLUDING SEDIMENT SIZE GRADATION USED IN STREAMBED DESIGN

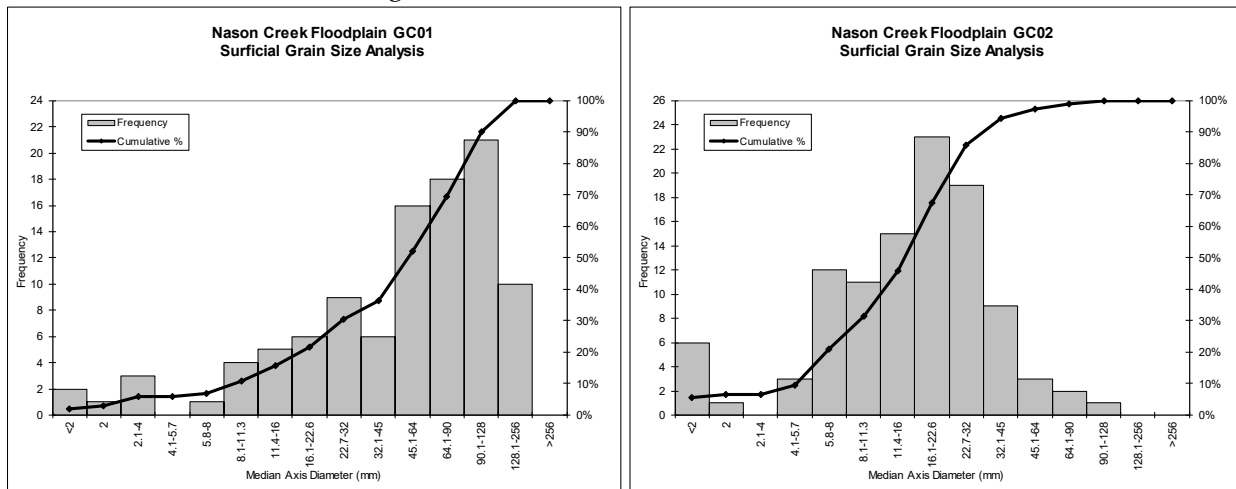
There are some bed rock expressions in the stream bed, banks and valley wall along the west edge of the Nason Creek flood plain. Occasional boulders that are not mobile during normal flood flows have been delivered to the valley bottom during much larger glacial outwash flows and delivered to the contemporary channel by being eroded out of the adjacent outwash terraces or exhumed as Nason Creek eroded down through the post glacial outwash. Upstream of the project reach, a number of actively eroding streambanks are seen which supply a significant volume of mobile sized sediments to the project reach. Placed riprap occurs at three locations along the Highway 207 embankment, some of which has moved downstream along the streambed a short distance.

With this understanding, substrate measured by the pebble count is a good approximation of mobile bedload sized sediments transported through the project reach and found in alluvial formed bed, bar and bank deposits. Wolman pebble counts were completed in Nason Creek near RM 4.45 to help estimate sediment particle sizes moving into and through the project reach. Pebble counts were performed at two locations along the river right bar surfaces at the crest (Figure 11.A) of a riffle and along the edge of the same riffle (Figure 11.B) to capture the range of substrates observed.



**Figure 11. Location of pebble counts performed on Nason Creek. A) GC01 was performed on a gravel bar adjacent to a riffle, on river right of Nason Creek. B) GC02 was performed on a bar adjacent to a riffle on river left.**

Results of the pebble count provide a grain size distribution. GC01 contained coarser material compared to GC02, with a d50 best described as very coarse gravel (Figure 12). Some sand and finer gravels were found within the interstices of larger material. GC02 contained finer material with a d50 best described as medium gravel.



**Figure 12. Grain size distribution at GC01 and GC02 based on Wolman pebble counts.**

### 3.5 SUMMARY OF HYDRAULIC MODELING OR ANALYSES CONDUCTED AND OUTCOMES – IMPLICATIONS RELATIVE TO PROPOSED DESIGN

#### 3.5.1 Hydraulic Modeling

The U.S. Army Corps of Engineers HEC-RAS 6.6 (USACE, September 2024) two-dimensional (2D) hydraulic model was used to develop model runs for existing and proposed conditions for the overall Nason Floodplain project reach. Existing conditions model geometry was copied and runs representing design features from RM 3.7-4.6 prepared. HEC-RAS computes hydraulic properties related to the physical processes governing water flow through natural rivers and other channels. Model runs for both existing and proposed conditions were used to assess the current and proposed channel dynamics, as well as assess the overall impacts of a wide range of flows on the existing landscape with and without the proposed design improvements.

The following sections describe the capabilities and limitations of HEC-RAS 6.6 and document the development and output processing of the project existing and proposed conditions models.

#### 3.5.2 Model Capabilities and Limitations

HEC-RAS 6.6 was used in its two-dimensional (2D) unsteady flow simulation mode with the capacity to model the complex flow patterns, on-site water storage, spatial variation of hydraulic roughness and temporally variable boundary conditions. The 2D hydraulic model calculates depth averaged water velocities (including magnitude and direction), water surface elevation, and mesh cell face conveyance throughout the simulation. Other hydraulic parameters such as depth, shear stress, and stream power can be calculated by the model following completion of the simulation.

#### 3.5.3 Model Extent

The downstream extent of the model is near RM 2.9 about 1,750 feet downstream of the lower project boundary. The upstream extent is near RM 4.9 about 3,000 feet upstream of the upper project boundary. Width of the model is valley wide, encompassing channel and floodplain including east of the existing Highway 207. The overall mesh coverage is shown in Appendices C and D.

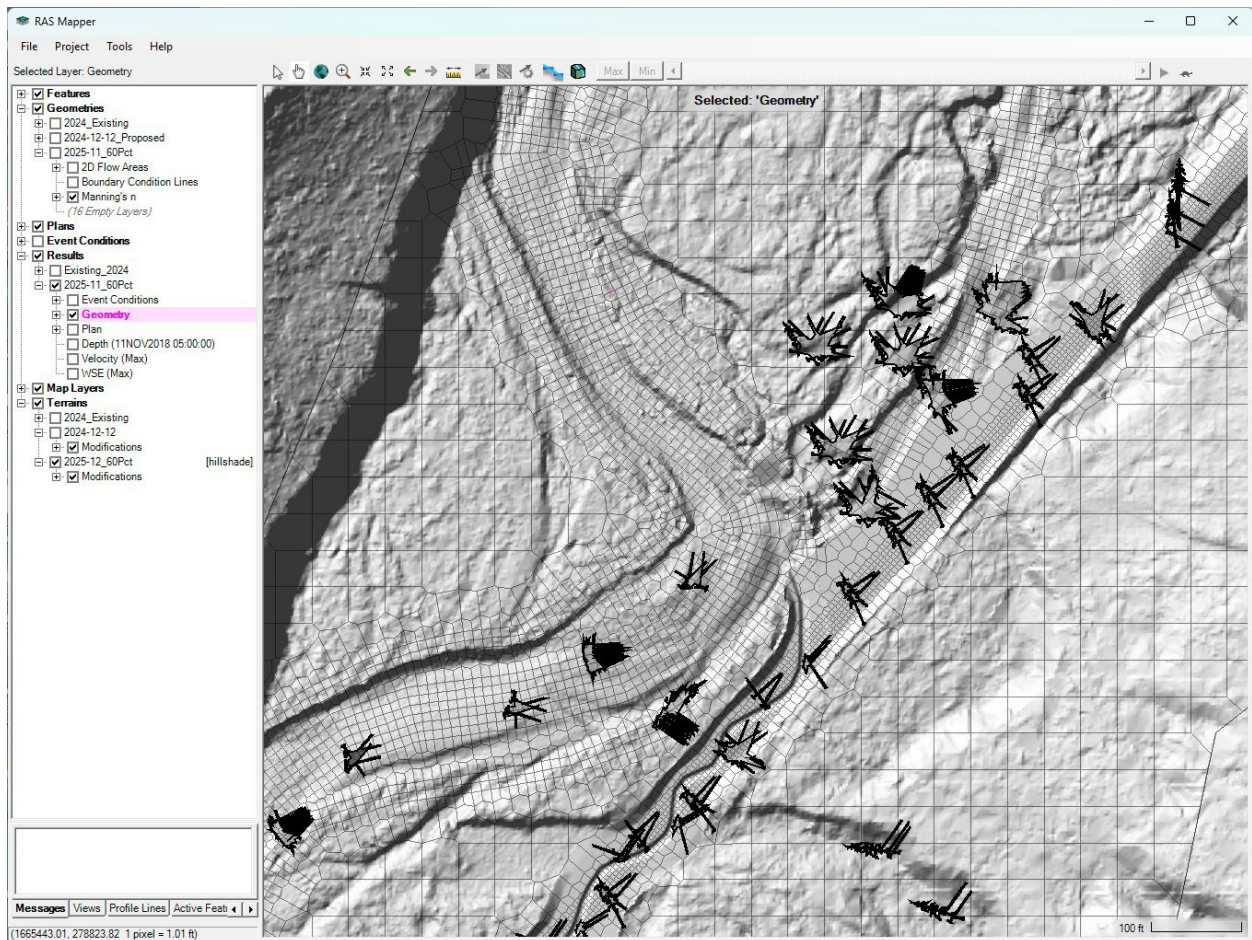
#### 3.5.4 Model Terrain

The existing conditions model terrain was developed using 2022 bathymetric/topographic LiDAR (USBR 2022) combined with 2015 LiDAR (Quantum Spatial 2016). The LiDAR provided a 1 meter (3.28 feet) horizontal resolution bare earth digital elevation model (DEM) raster for the entire site, including floodplain areas and valley hillslopes. The 2022 LiDAR dataset includes topographic and bathymetric surfaces for the river corridor. The 2015 LiDAR dataset was used to represent the floodplain and hillslopes beyond the limits of the 2022 LiDAR coverage. No transitional buffer between the two LiDAR datasets was used, occasionally resulting in minor surface discontinuities. The proposed condition model terrains were copied from the existing conditions terrain and

modified to incorporate the design grading surfaces. Large wood structures were represented in the model as regions of extremely rough Manning’s n coefficient values. The model terrains are projected on the Washington State Plane North Zone, North American Datum 1983 (NAD83), coordinate system with US feet distance units. The terrain elevations are in US feet relative to the North American Vertical Datum of 1988 (NAVD88).

### 3.5.5 Model Geometry

The 2D model geometry used a 40-ft square computational mesh for the entire area of interest with smaller mesh size for greater resolution along the main stem, side channels and road embankment. . A zoomed in view of the mesh shows an example of mesh detail as shown in Figure 13. The overall and example of mesh detail for existing conditions as seen in Appendix C. The modeling capabilities of HEC-RAS 6.6 integrates the sub-grid terrain into the computations and projects the results accordingly. The proposed conditions model domain mesh is seen in Appendix D.



**Figure 13. Detailed view of proposed conditions model mesh.**

### 3.5.6 Model 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, type and density of floodplain vegetation and large wood. Existing conditions roughness coefficients were applied across the model extent to represent the various types and densities of vegetation or surface conditions. Roughness coefficients were modified in the proposed conditions models to represent immediate post construction conditions. In general, roughness regions were delineated based on field observations, aerial photos, and proposed designs. Roughness values for each region were selected using professional judgment and guided by published guidelines (Arcement & Schneider 1989) for channel types and vegetation conditions. Manning's n values were assigned for:

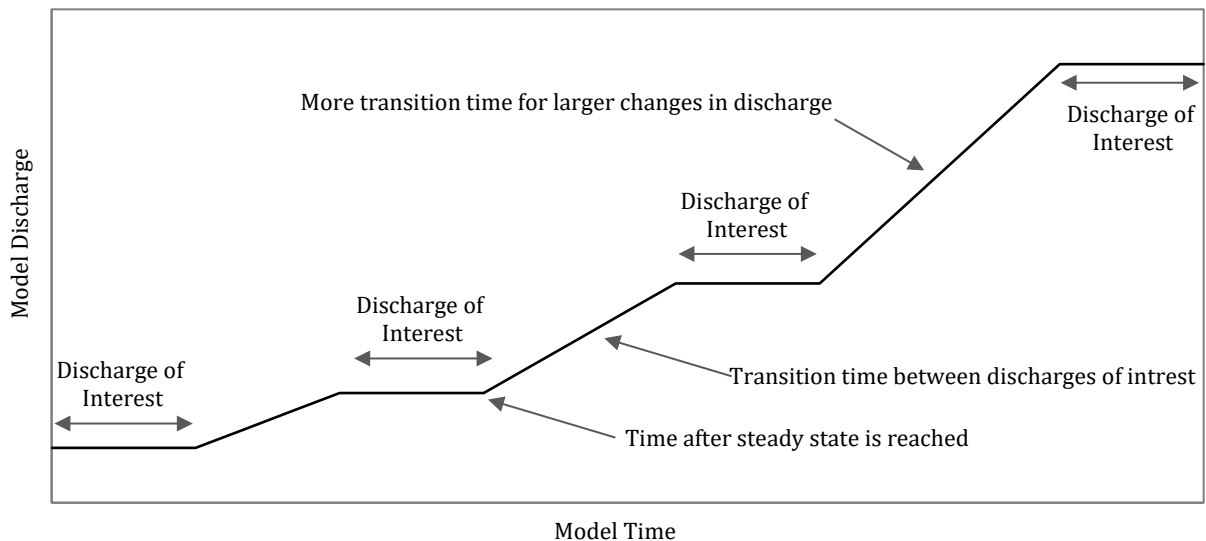
- Main stem and side channel as 0.038-0.043 depending on complexity and amount of LWM.
- Forested bars as 0.055
- Forest and floodplain as 0.080
- LWM structures as 0.15 to 0.2.
- Floodplain roughness as 0.12

### 3.5.7 Model Boundary Conditions

HEC-RAS 6.6 2D models require boundary conditions at the upstream and downstream ends of the model to control the flow into and out of the model extent. The synthetic hydrograph described in the next section was applied as the upstream boundary condition. The flow was initially distributed along the boundary assuming normal flow depth at a friction slope estimated from topography to be approximately 0.005 feet per foot. The downstream boundary condition assumed normal flow depth at a friction slope estimated from topography to be 0.005 feet per foot. Boundary conditions were set far enough distant from the area of interest that potential uncertainties would be negligible within the project reach.

### 3.5.8 Model Discharges

The modeled discharges of interest included 2-, 5-, 10-, 25-, 50-, and 100-year recurrence interval peak flows listed in Table 2. Additional low flows of interest included summary low flow through extrapolated annual peak discharges and included: 20-, 50-, 100-, 200-, 300-, 600-, 1000-, and 2000--cfs. These discharges were incorporated into a synthetic hydrograph with periods of steady flow (at the discharges of interest) to create a stair-step like pattern similar to Figure 14. The periods of steady flow allow the model to come to a quasi-steady state condition, improving the interpretation of hydraulics at discharges of interest. It's worth noting that allowing the model to reach a steady state during large flood events may overestimate extents of flooding results, as floodplain storage throughout the model domain must reach capacity to reach steady-state conditions, which in reality may not occur during actual floods, especially short duration events. The receding limb of a typical flood hydrograph is also not represented when using this methodology.



**Figure 14. Stepped hydrograph Example**

### 3.5.9 Model Output

To examine the inundation patterns, velocities, and other hydraulic parameters within the model extent for proposed conditions, the RAS Mapper utility of HEC-RAS 6.6 was used to view results in the form of raster data sets at the discharges of interest. Model output graphics for computational mesh, Manning's n coverage, water depths and velocities for the entire project area are included in Appendix C for existing conditions. Appendix D includes similar graphics for proposed conditions.

It should be noted that the 100-year water surface for proposed conditions is higher than existing conditions water surface elevations in several locations. A FEMA CLOMR/LOMR will be completed in a future design phase.

### 3.5.10 Model Findings

Model findings are preliminary, and the model will continue to be refined as the project progresses. Model results are used for design of LWM structures and evaluation of inundation limits and flow splits.

### **3.6 STABILITY ANALYSES AND COMPUTATIONS FOR PROJECT ELEMENTS, AND COMPREHENSIVE PROJECT PLAN**

LWM structure stability analyses were prepared using guidelines for large wood design (Knutson et. al. 2014 and Reclamation/ERDC 2016). Calculations are included in Appendix E.

### **3.7 DESCRIPTION OF HOW PRECEDING TECHNICAL ANALYSIS HAS BEEN INCORPORATED INTO AND INTEGRATED WITH THE CONSTRUCTION – CONTRACT DOCUMENTATION**

The preceding analysis is the basis for the project features shown in the design drawings. The drawings will be refined as the project progresses to final stamped construction drawing set with sufficient detail to allow contractors to bid and build the project.

### **3.8 FOR PROJECTS THAT ADDRESS PROFILE DISCONTINUITIES (GRADE STABILIZATION, SMALL DAM AND STRUCTURE REMOVALS): A LONGITUDINAL PROFILE OF THE STREAM CHANNEL THALWEG FOR 20 CHANNEL WIDTH UPSTREAM AND DOWNSTREAM OF THE STRUCTURE SHALL BE USED TO DETERMINE THE POTENTIAL FOR CHANNEL DEGRADATION**

Not applicable to this project.

### **3.9 FOR PROJECTS THAT ADDRESS PROFILE DISCONTINUITIES (GRADE STABILIZATION, SMALL DAM AND STRUCTURE REMOVALS): A MINIMUM OF THREE CROSS-SECTIONS – ONE DOWNSTREAM OF THE STRUCTURE, ONE THROUGH THE RESERVOIR AREA UPSTREAM OF THE STRUCTURE, AND ONE UPSTREAM OF THE RESERVOIR AREA OUTSIDE OF THE INFLUENCE OF THE STRUCTURE) TO CHARACTERIZE THE CHANNEL MORPHOLOGY AND QUANTIFY THE STORED SEDIMENT**

Not applicable to this project.

## 4. Construction – contract documentation

### 4.1 INCORPORATION OF HIP GENERAL AND CONSTRUCTION CONSERVATION MEASURES

General and construction conservation measures are included in the 60% level plans.

### 4.2 DESIGN – CONSTRUCTION PLAN SET INCLUDING BUT NOT LIMITED TO PLAN, PROFILE, SECTION AND DETAIL SHEETS THAT IDENTIFY ALL PROJECT ELEMENTS AND CONSTRUCTION ACTIVITIES OF SUFFICIENT DETAIL TO GOVERN COMPETENT EXECUTION OF PROJECT BIDDING AND IMPLEMENTATION

60% level plans are included in Appendix A.

### 4.3 LIST OF ALL PROPOSED PROJECT MATERIALS AND QUANTITIES

Proposed materials types and quantities are included in the plans and attached opinion of probable construction quantities. Materials include logs, logs with rootwads, slash, whole trees, tree tops, log piles, excavation and backfill of alluvial materials. Additional materials may include boulders and small boulder alluvial backfill if in sufficient sized material for backfill is encountered. The project area will be planted with native riparian plant species to be designed by Yakama Nation’s vegetation consultant in a future phase.

### 4.4 DESCRIPTION OF BEST MANAGEMENT PRACTICES THAT WILL BE IMPLEMENTED AND IMPLEMENTATION RESOURCE PLANS INCLUDING:

HIP conservation measures are included in the preliminary plans including an erosion and sediment control plan using standard BMPs.

### 4.5 CALENDAR SCHEDULE FOR CONSTRUCTION/IMPLEMENTATION PROCEDURES

A construction timeframe has not been determined at this time.

### 4.6 SITE OR PROJECT SPECIFIC MONITORING TO SUPPORT POLLUTION PREVENTION AND/OR ABATEMENT

Standard erosion and pollution control measures by the contractor are specified in the construction drawing set.

## 5. Monitoring and adaptive management plan

The monitoring and adaptive management plan will be determined at the discretion of Yakama Nation Fisheries in subsequent design phases.

## 6. References

- Chelan County Natural Resources Department. May 8, 2012. Nason Creek River Mile 3.3-4.6 Feasibility Study.
- Healey, M. C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). Pages 313-393 IN: C. Groot and L. Margolis, Editors. Pacific salmon life histories. University of British Columbia Press, Vancouver, Canada.
- Hillman, T. W. and M. D. Miller. 1989. Seasonal habitat use and behavioral interaction of juvenile chinook salmon and steelhead. I: Daytime habitat selection. Pages 42-82 IN: Don Chapman Consultants, Inc. Summer and winter ecology of juvenile chinook salmon and steelhead trout in the Wenatchee River, Washington. Final report to Chelan County PUD. Wenatchee, Washington.
- Inter-Fluve 2019. Nason Flood plain RM 3.4-4.6 10% Basis of Design Report.
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- Malmon, D. 2010. Nason Creek Hydrology: Characterization of flow rates in the Lower White Pine Reach based on USGS and DOE stream gages. Technical Memo prepared by CH2M Hill for ICF International.
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- Northwest Power and Conservation Council (NWPCC). 2004. Wenatchee Subbasin Plan. May 28, 2004. Pages 1-394.
- Peven, C.M. 2003. Population structure, status and life histories of upper Columbia steelhead, spring and late-run chinook, sockeye, coho salmon, bull trout, westslope cutthroat trout, non-migratory rainbow trout, pacific lamprey, and sturgeon. Wenatchee, Washington.
- Quinn T. 2005. The Behavior and Ecology of Pacific Salmon and Trout. American Fisheries Society in Association with University of Washington Press. Seattle, WA.
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- U.S. Army Corps of Engineers. 2024. Hydrologic Engineering Center River Analysis System HEC-RAS, version 6.6.
- U.S. Geologic Survey. 2016. Stream Stats online.

U.S. Bureau of Reclamation. July 2008. Nason Creek Tributary Assessment, Chelan County, Washington.

## Appendix A – Phase 2 RM 3.7-4.6 60% project drawings

Plans submitted separately.

## Appendix B – Opinion of probable construction quantities

**Nason Floodplain RM 3.7-4.6 Phase 2 60%: Opinion of Probable Construction Cost**

version: 1/14/2026

Item	Description	Quantity	Units	Unit Cost	Subtotal	Notes
1	TESC, SPCC Plan and Implementation	1	LS	\$ 94,000	\$ 94,000	~5% of Items 7-30
2	Mobilization	1	LS	\$ 169,000	\$ 169,000	~9% of Items 7-30
3	Traffic Control	1	LS	\$ 38,000	\$ 38,000	~2% of Items 7-30
4	Clearing and Grubbing	1	LS	\$ 38,000	\$ 38,000	~2% of Items 7-30
5	Cofferdam and Diversion	1	LS	\$ 94,000	\$ 94,000	~5% of Items 7-30
6	Pumping	1	LS	\$ 38,000	\$ 38,000	~2% of Items 7-30
7	Temporary bridge	1	LS	\$ 100,000	\$ 100,000	one bridge, three locations
<b>River Left project components</b>						
8	Apex jams	2	EA	\$ 29,000	\$ 58,000	Install Owner provided logs and salvaged slash and trees
9	Bar roughness wood structures	5	EA	\$ 6,750	\$ 33,750	Install Owner provided logs and salvaged slash and trees
10	FP roughness logs	4	EA	\$ 500	\$ 2,000	Install Owner provided logs and salvaged slash and trees
11	Tipped trees	4	EA	\$ 1,000	\$ 4,000	
<b>River Right project components</b>						
12	CED-1 & 2 Riprap removal and salvage	700	CY	\$ 25	\$ 17,500	Approximately 225+250LF x 3ft thick x 12ft high plus barbs
13	CED-1 & 2 Road embankment removal, low flow channel and wetland creation excavation and off site disposal	30700	CY	\$ 15	\$ 460,500	CADD volume
14	CED-1 Mainstem Meander excavation	2950	CY	\$ 15	\$ 44,250	CADD volume minus volume of riprap removal
15	CED-1 Mainstem Meander gravel bar alluvial material fill	2330	CY	\$ 12	\$ 27,960	CADD volume
16	CED-3 Mainstem Meander gravel bar alluvial material excavation	1850	CY	\$ 15	\$ 27,750	CADD volume
17	CED-2 bank revetment for Phase 1 road	1050	CY	\$ 75	\$ 78,750	42" thick Class B stone
18	Apex jams	4	EA	\$ 29,000	\$ 116,000	Install Owner provided logs and salvaged slash and trees
19	Bank buried jam	3	EA	\$ 25,000	\$ 75,000	Install Owner provided logs and salvaged slash and trees
20	Bank buried jam w/trees	2	EA	\$ 31,000	\$ 62,000	Install Owner provided logs and salvaged slash and trees
21	Small bank buried jam	9	EA	\$ 8,400	\$ 75,600	Install Owner provided logs and salvaged slash and trees
22	Bank margin wood	7	EA	\$ 20,250	\$ 141,750	Install Owner provided logs and salvaged slash and trees
23	Bar roughness wood structures	12	EA	\$ 8,470	\$ 101,640	Install Owner provided logs and salvaged slash and trees
24	BR and SM-BB racking wood	4	EA	\$ 9,970	\$ 39,880	Install Owner provided logs and salvaged slash and trees
25	CED3 Bank barb structure	4	EA	\$ 39,250	\$ 157,000	Install Owner provided logs and salvaged slash and trees
26	Deflector jam	3	EA	\$ 9,500	\$ 28,500	Install Owner provided logs and salvaged slash and trees
27	Inlet structure	2	EA	\$ 32,150	\$ 64,300	Install Owner provided logs and salvaged slash and trees
28	low flow channel floodplain roughness LW	11	EA	\$ 11,950	\$ 131,450	Install Owner provided logs and salvaged slash and trees
29	low flow channel habitat cover logs	11	EA	\$ 4,980	\$ 54,780	Install Owner provided logs and salvaged slash and trees
30	low flow channel floodplain roughness log	18	EA	\$ 3,480	\$ 62,640	Install Owner provided logs and salvaged slash and trees
<b>Subtotal Items 8-28</b>					<b>\$ 1,870,000</b>	
<b>Subtotal items 1-7</b>					<b>\$ 571,000</b>	
<b>Total</b>					<b>\$ 2,441,000</b>	

Abbreviations:

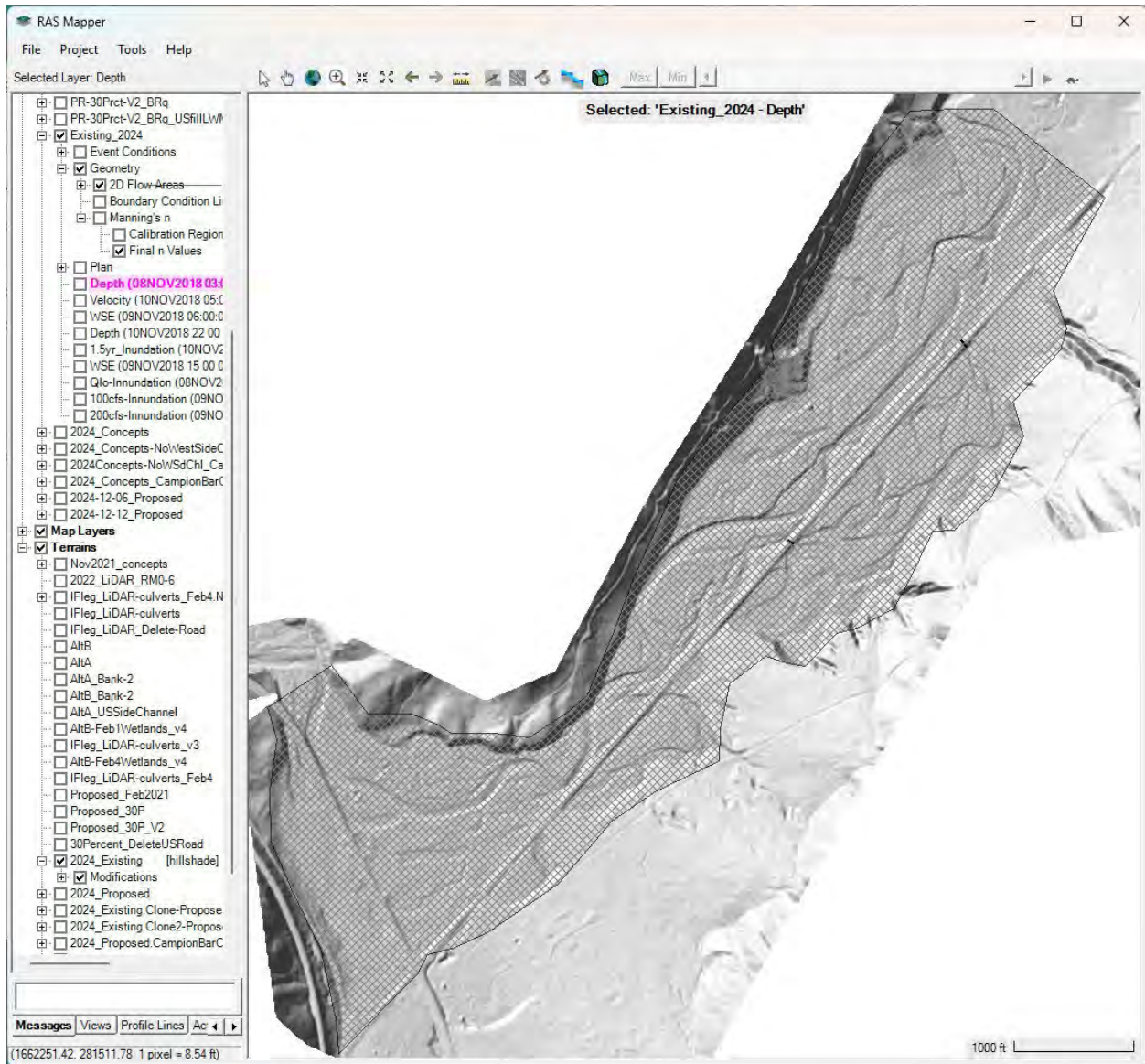
CY = Cubic Yards  
 EA = Each  
 LS = Lump Sum

Assumptions:

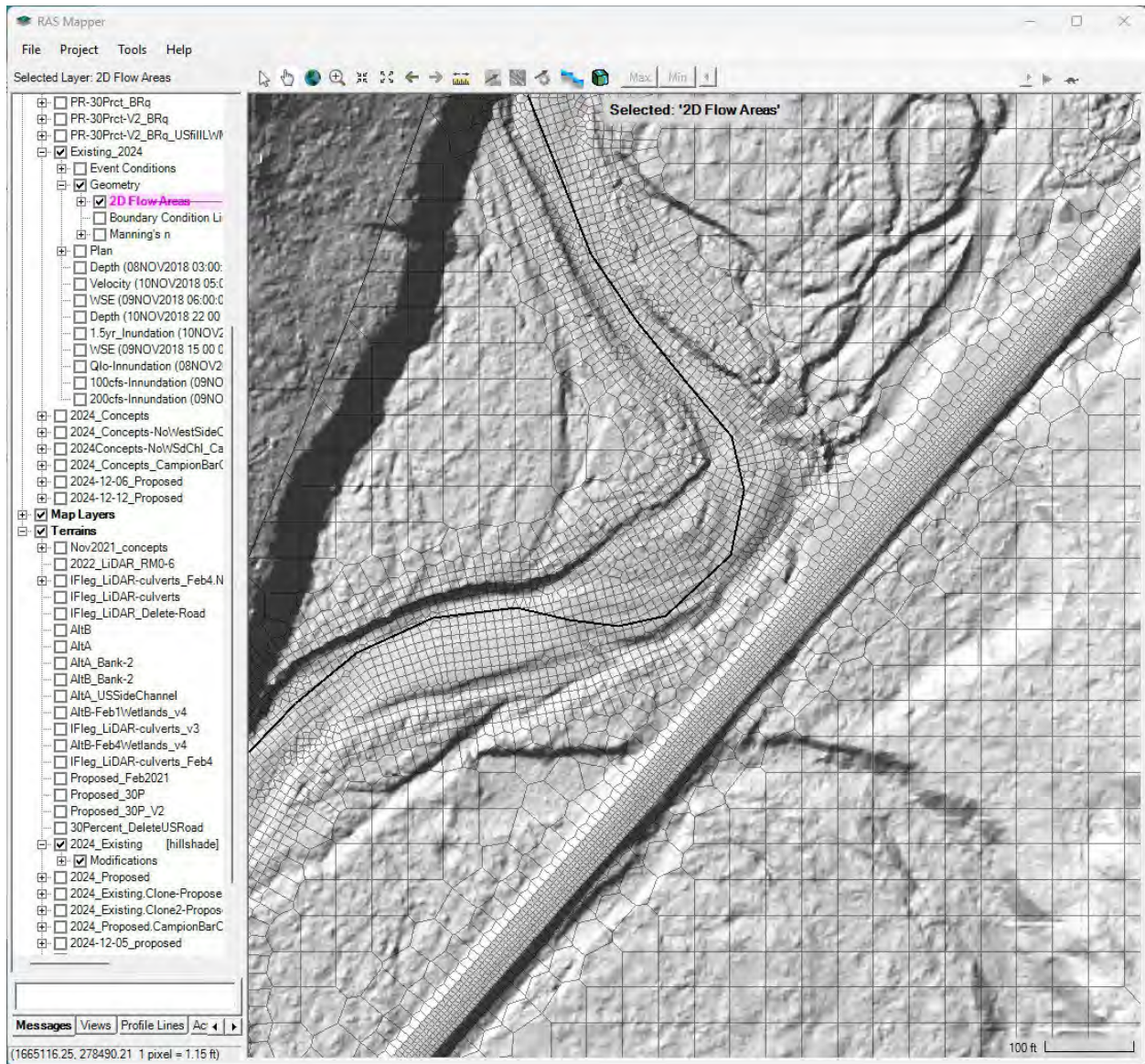
Large wood is provided by Owner and stockpiled in close proximity to site  
 Planting plan and revegetation to be designed by others in future phase  
 Utility removal by others.

## Appendix C – Existing conditions HEC-RAS model

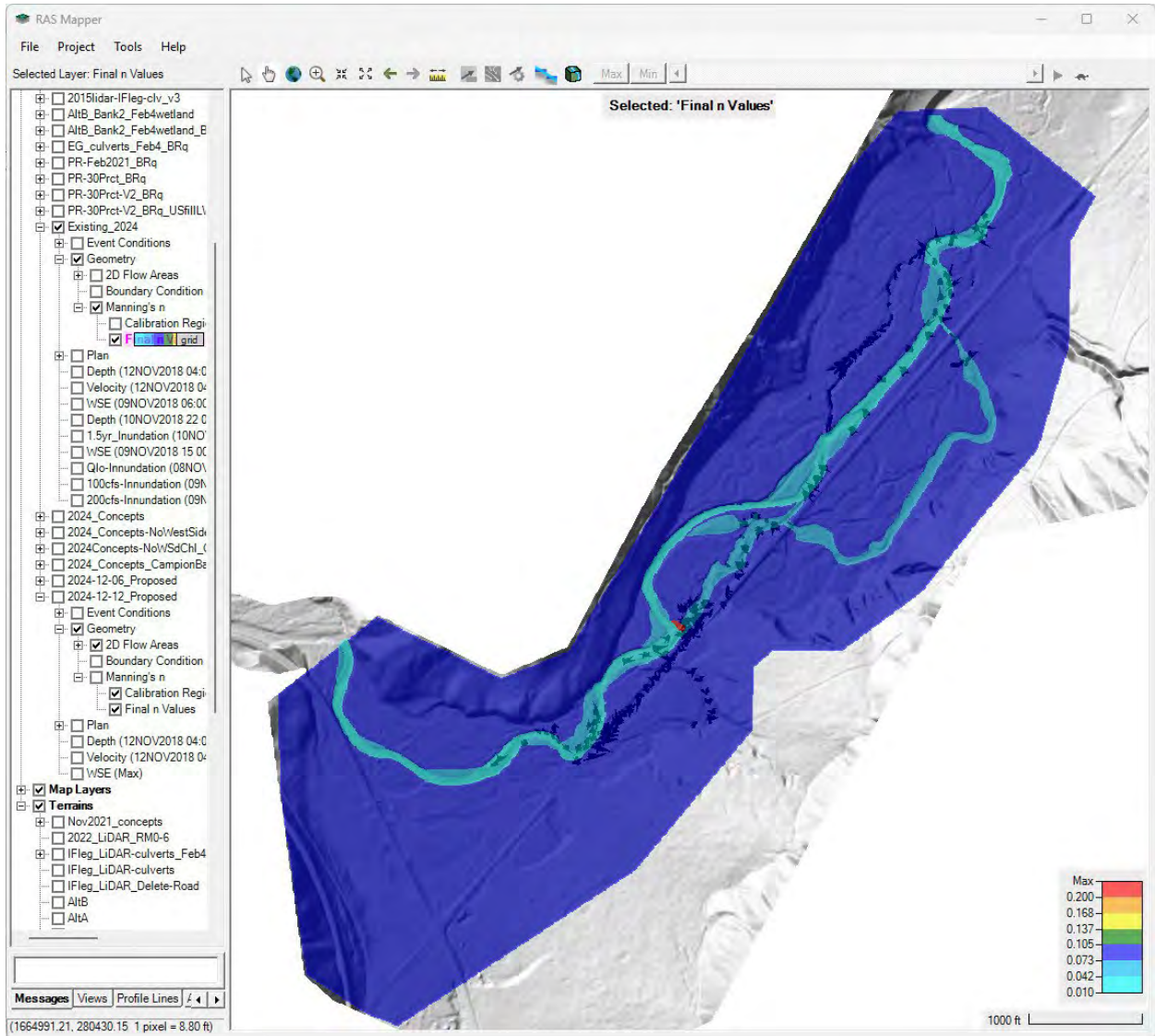
# Existing condition model mesh



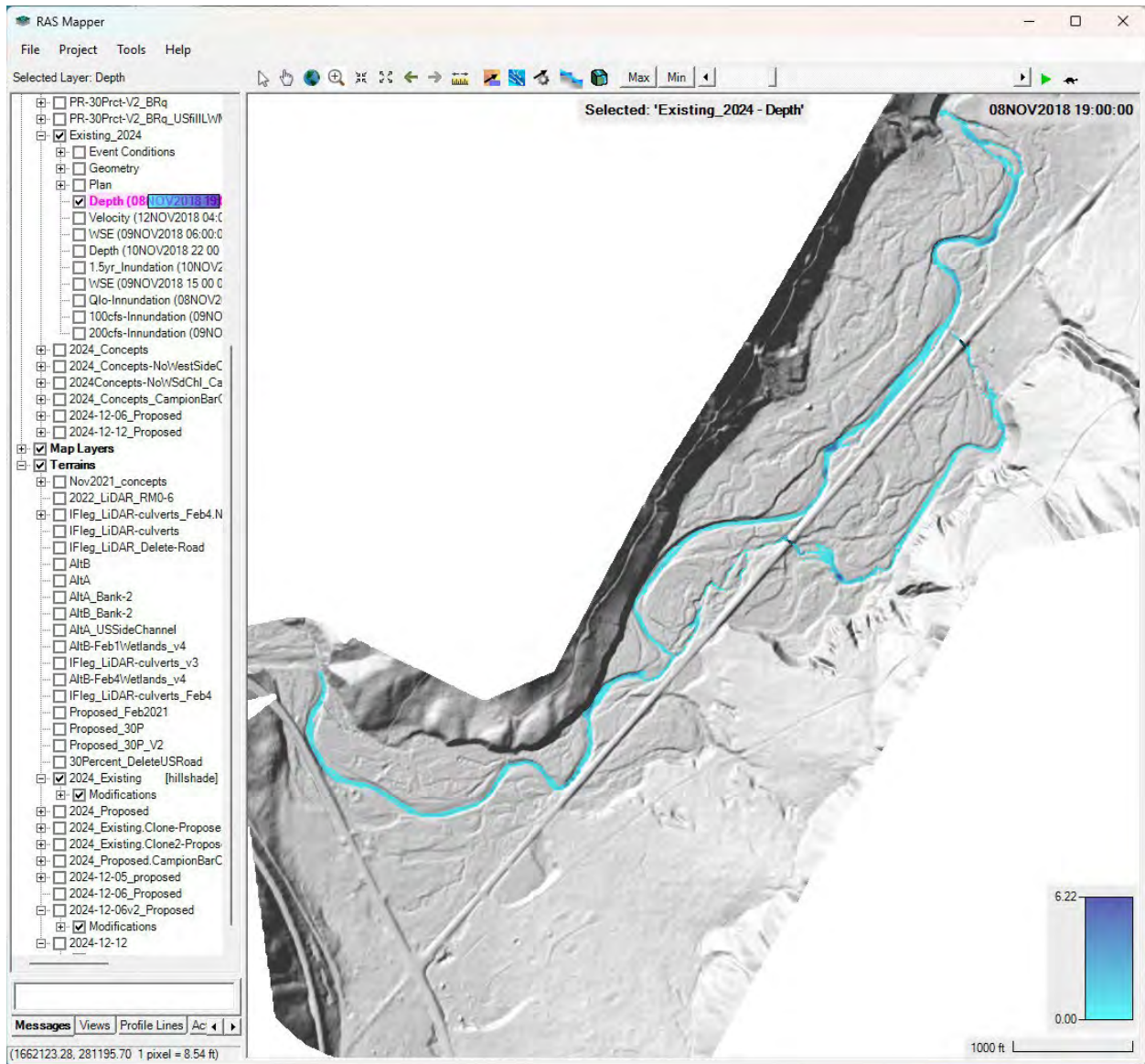
# Existing condition model mesh example of detail



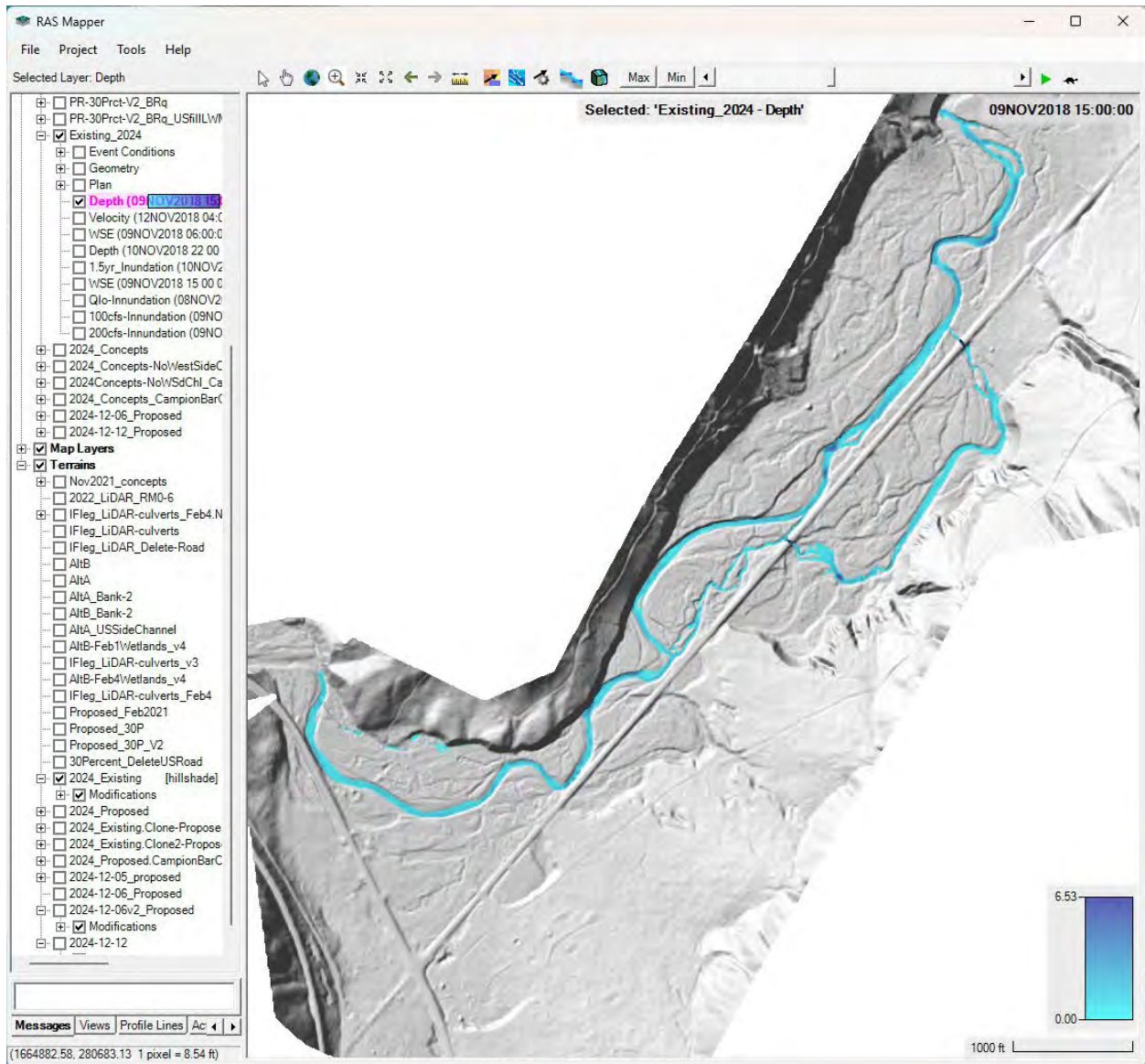
# Existing condition Manning's n



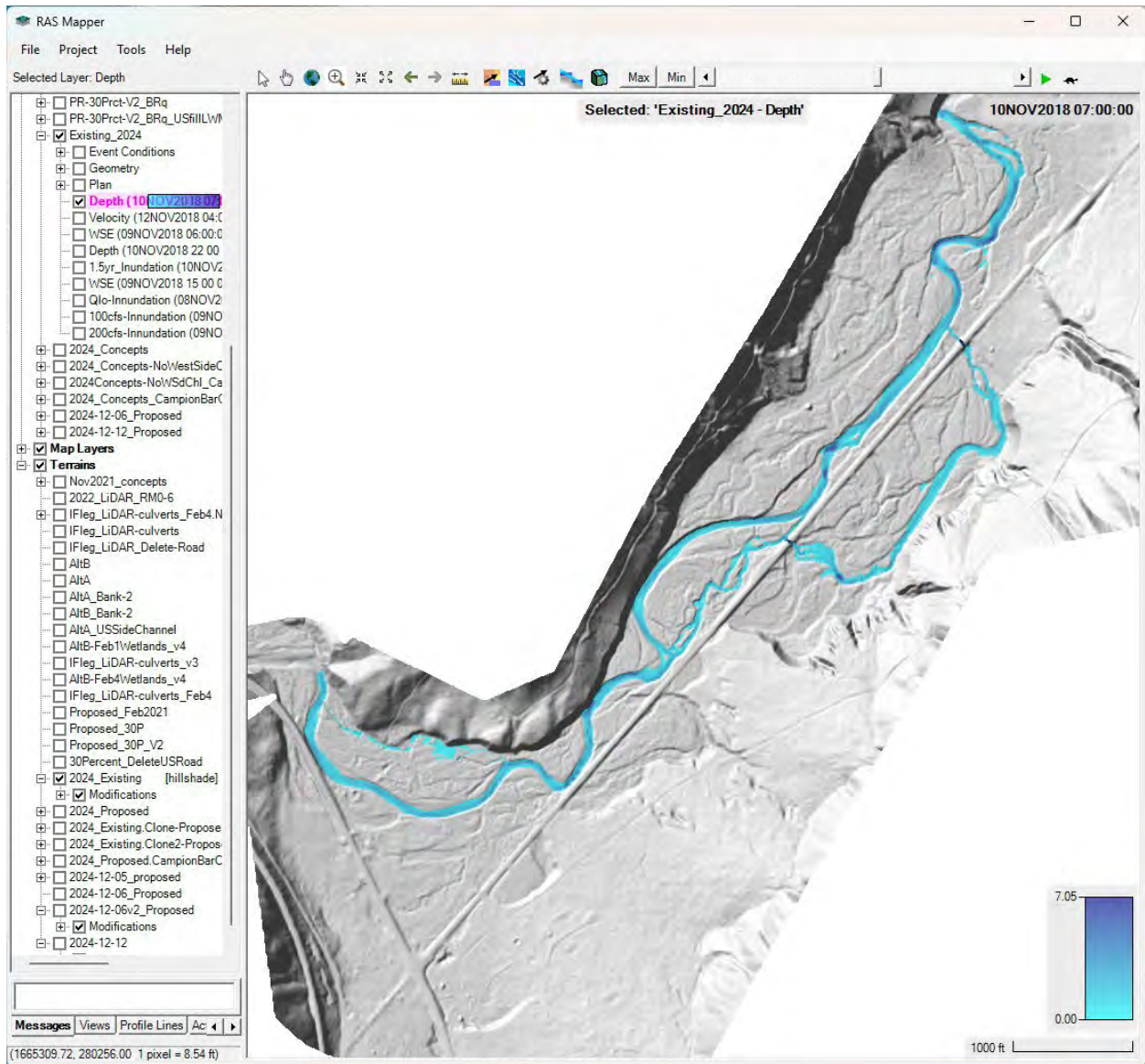
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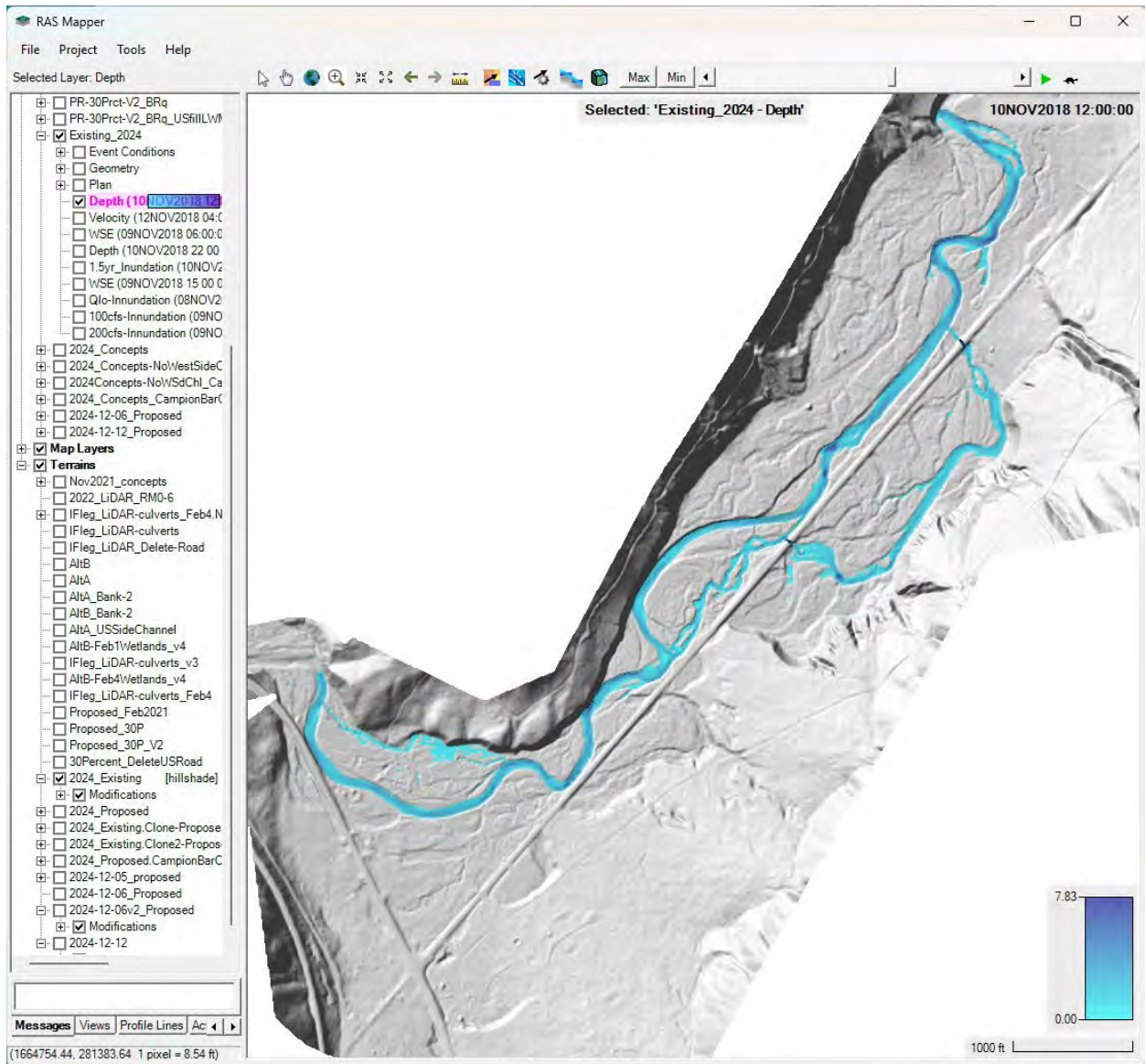
# Existing condition: 200-cfs flow depth through project area



# Existing condition: 600-cfs flow depth through project area



# Existing condition: 1,000-cfs flow depth through project area

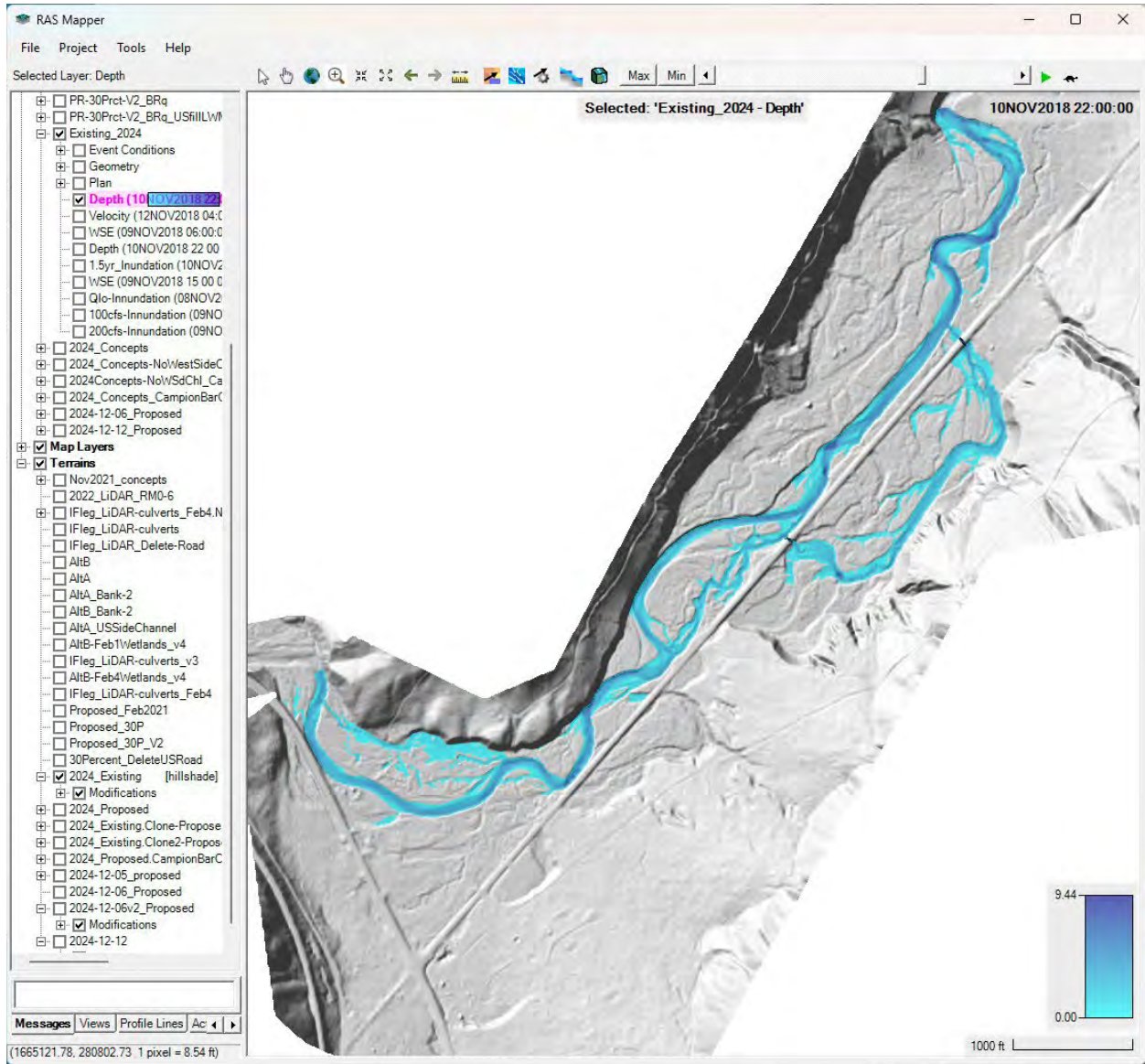


Messages Views Profile Lines Ac

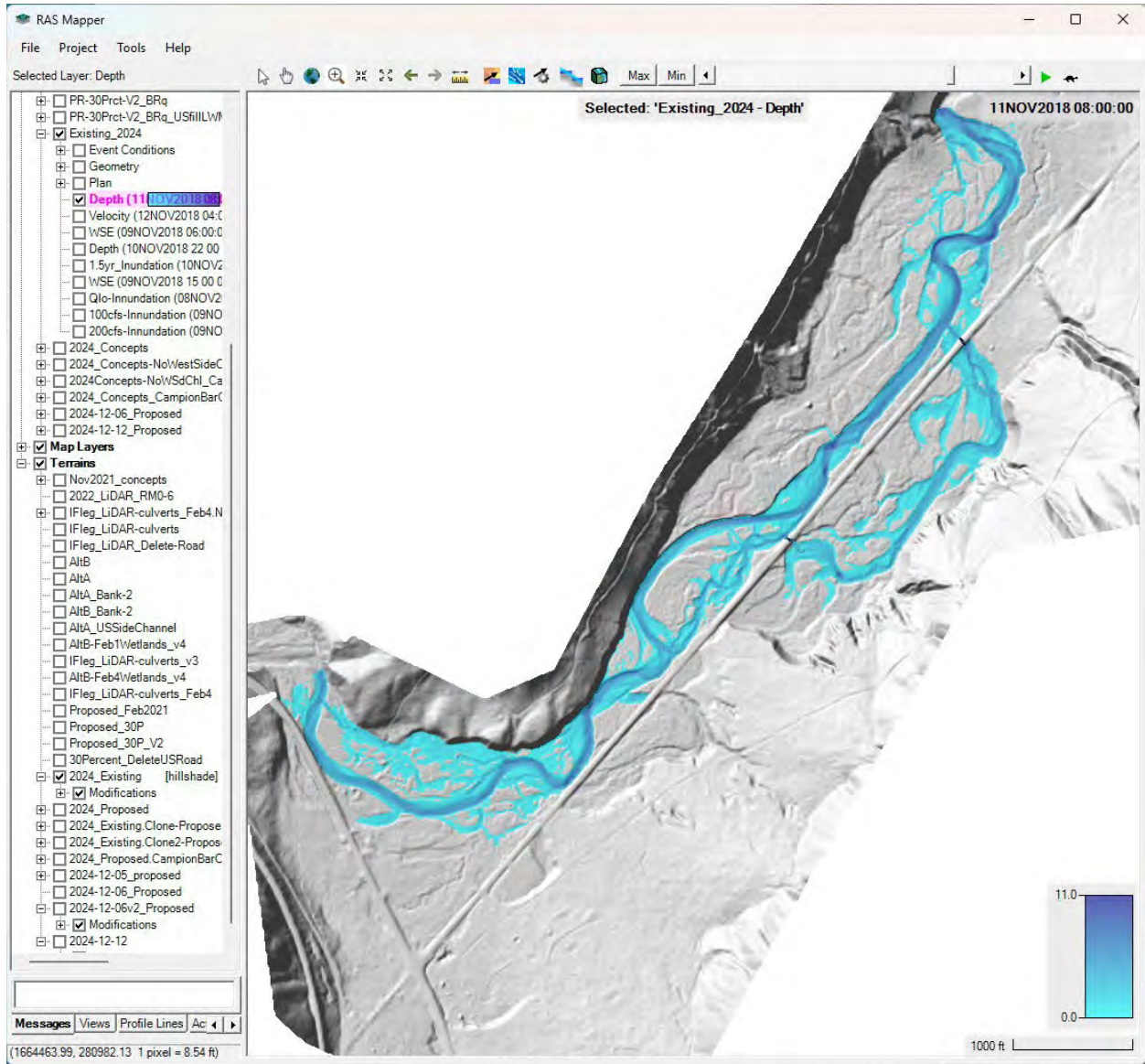
(1664754.44, 281383.64 1 pixel = 8.54 ft)

1000 ft

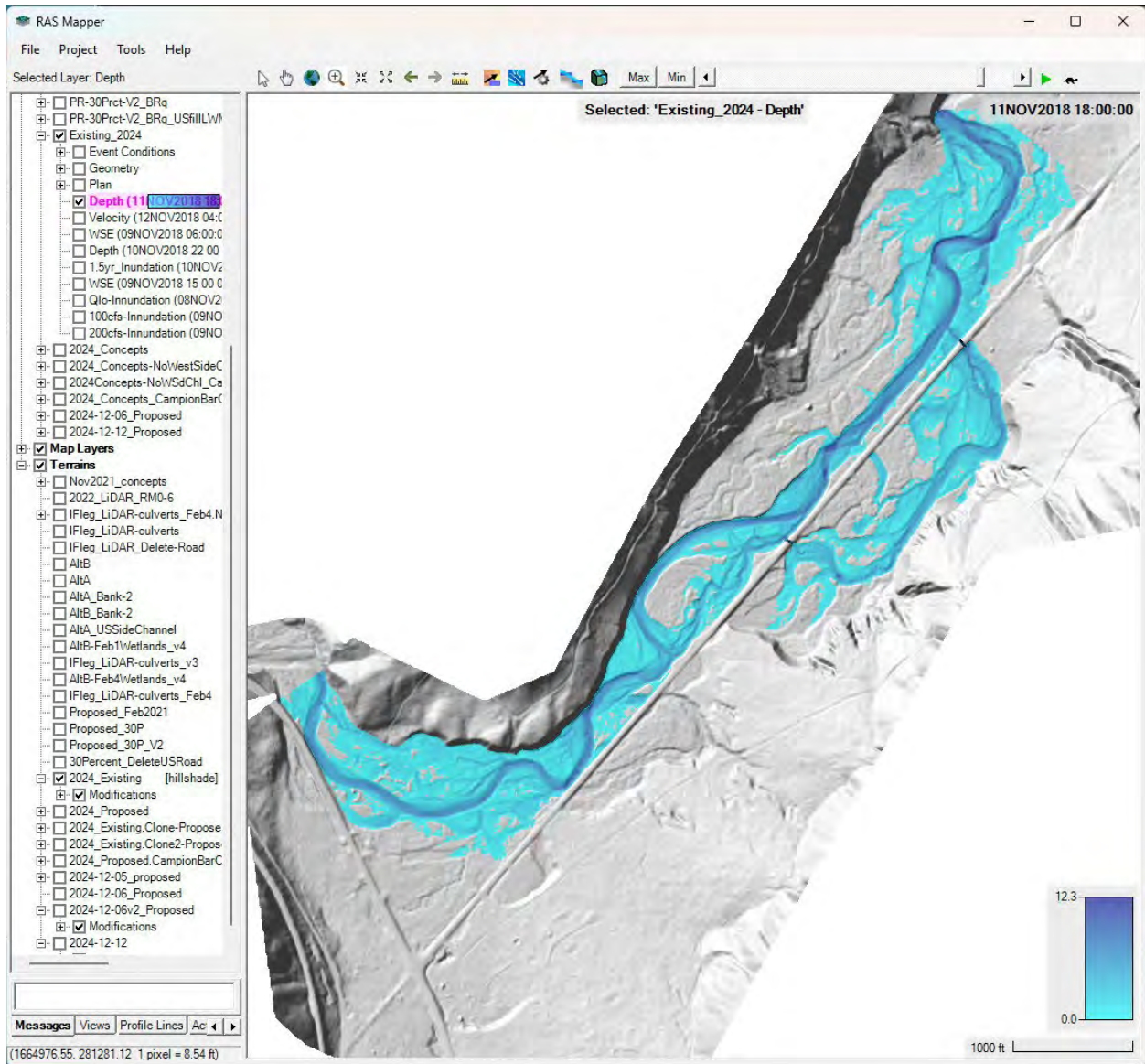
Existing condition: 1.5-year (2,200-cfs) flow depth, entire model domain



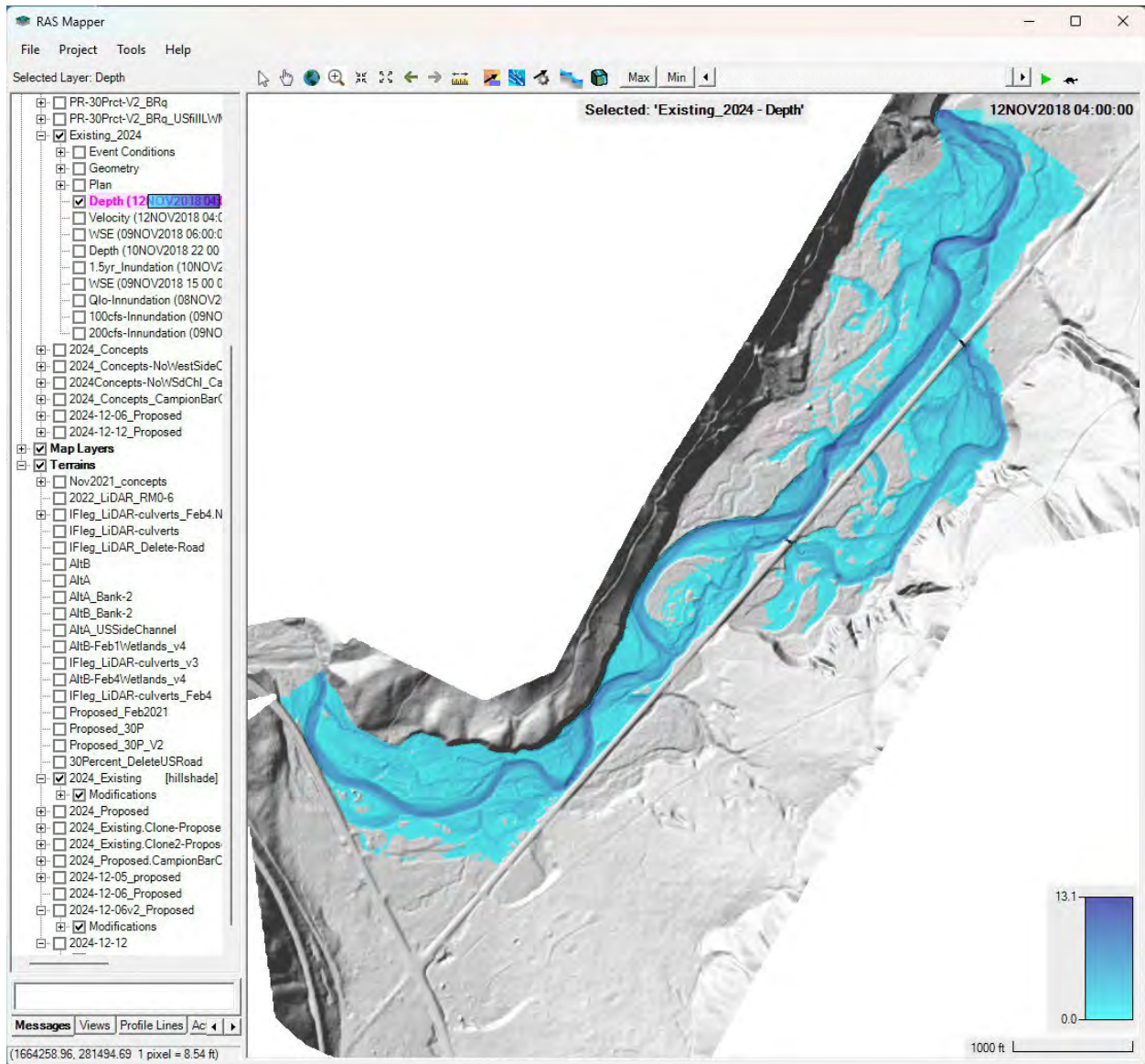
Existing condition: 5-year (3,900-cfs) flow depth, entire model domain



Existing condition: 25-year (6,500-cfs) flow depth, entire model domain



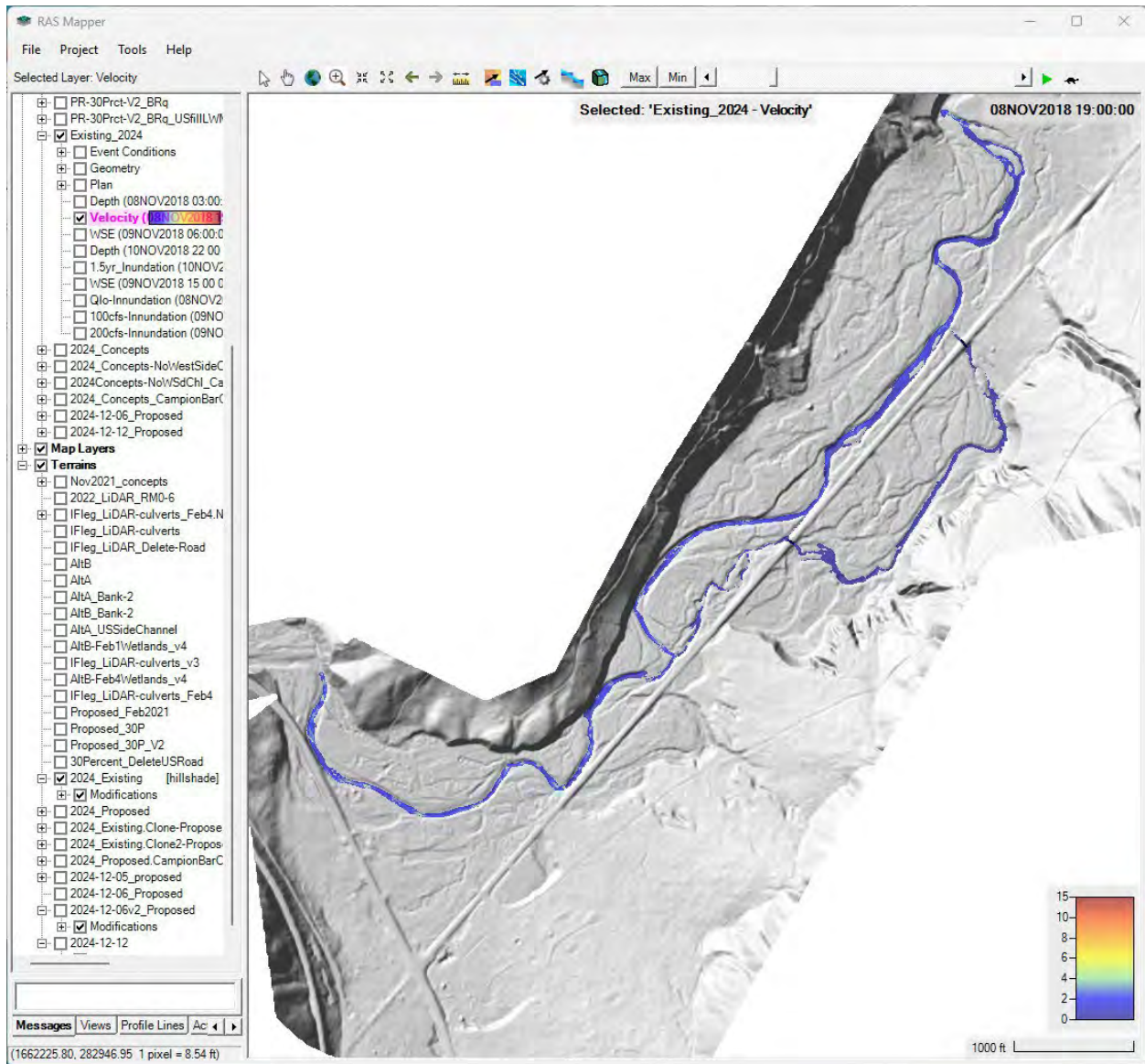
Existing condition: 100-year (9,400-cfs) flow depth, entire model domain



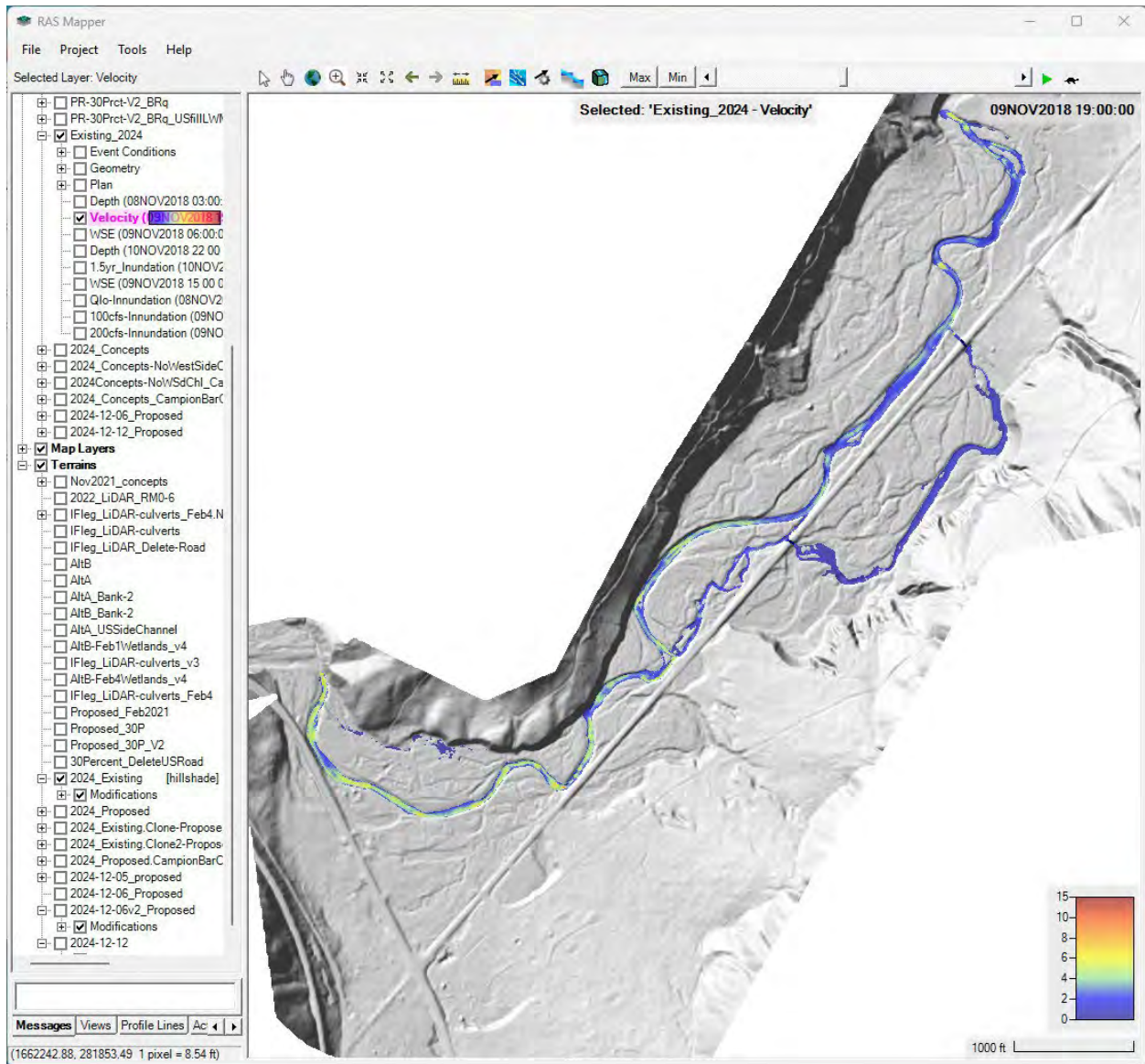
(1664258.96, 281494.69 1 pixel = 8.54 ft)

1000 ft

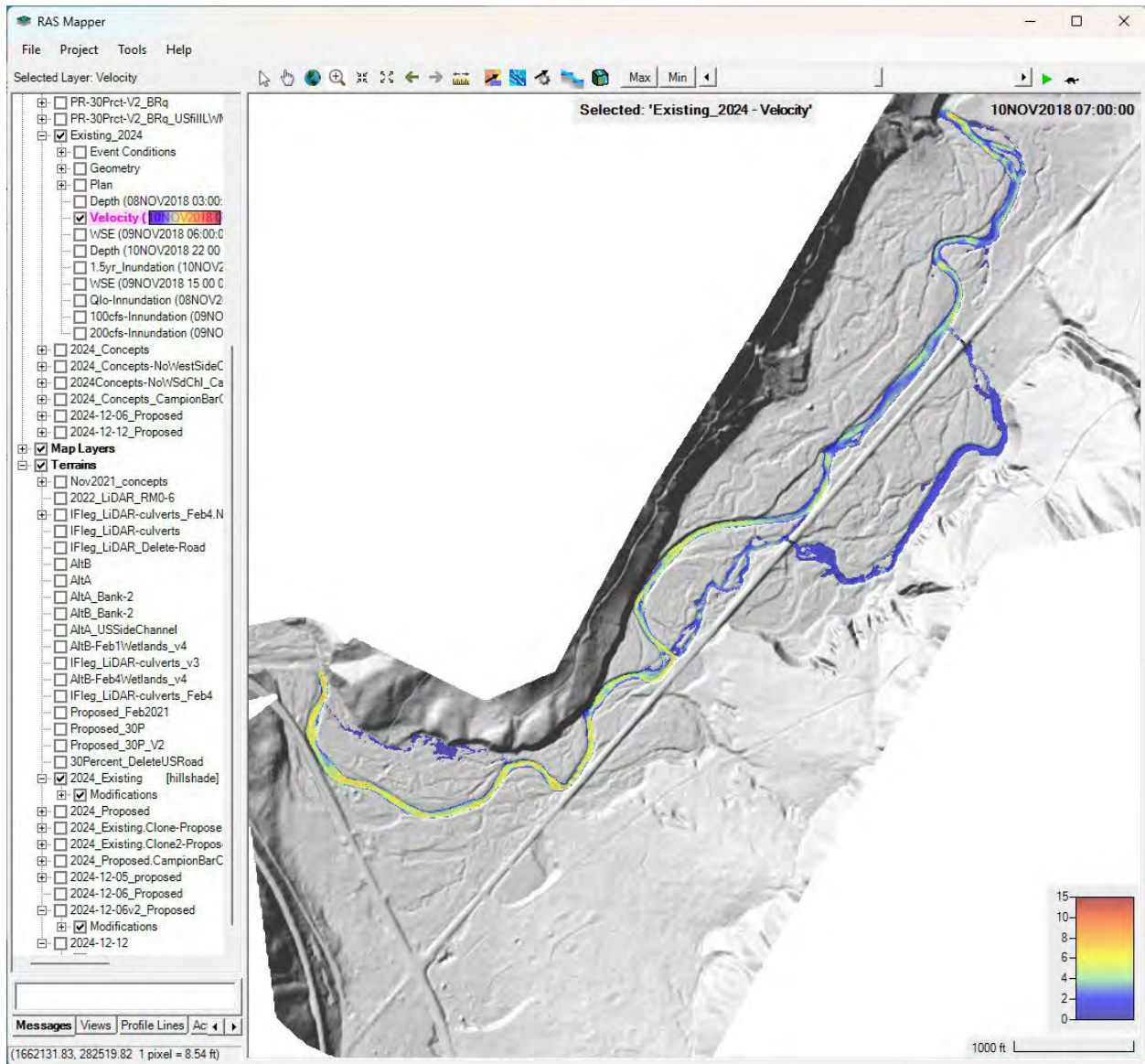
# Existing condition: 50-cfs flow velocity through project area



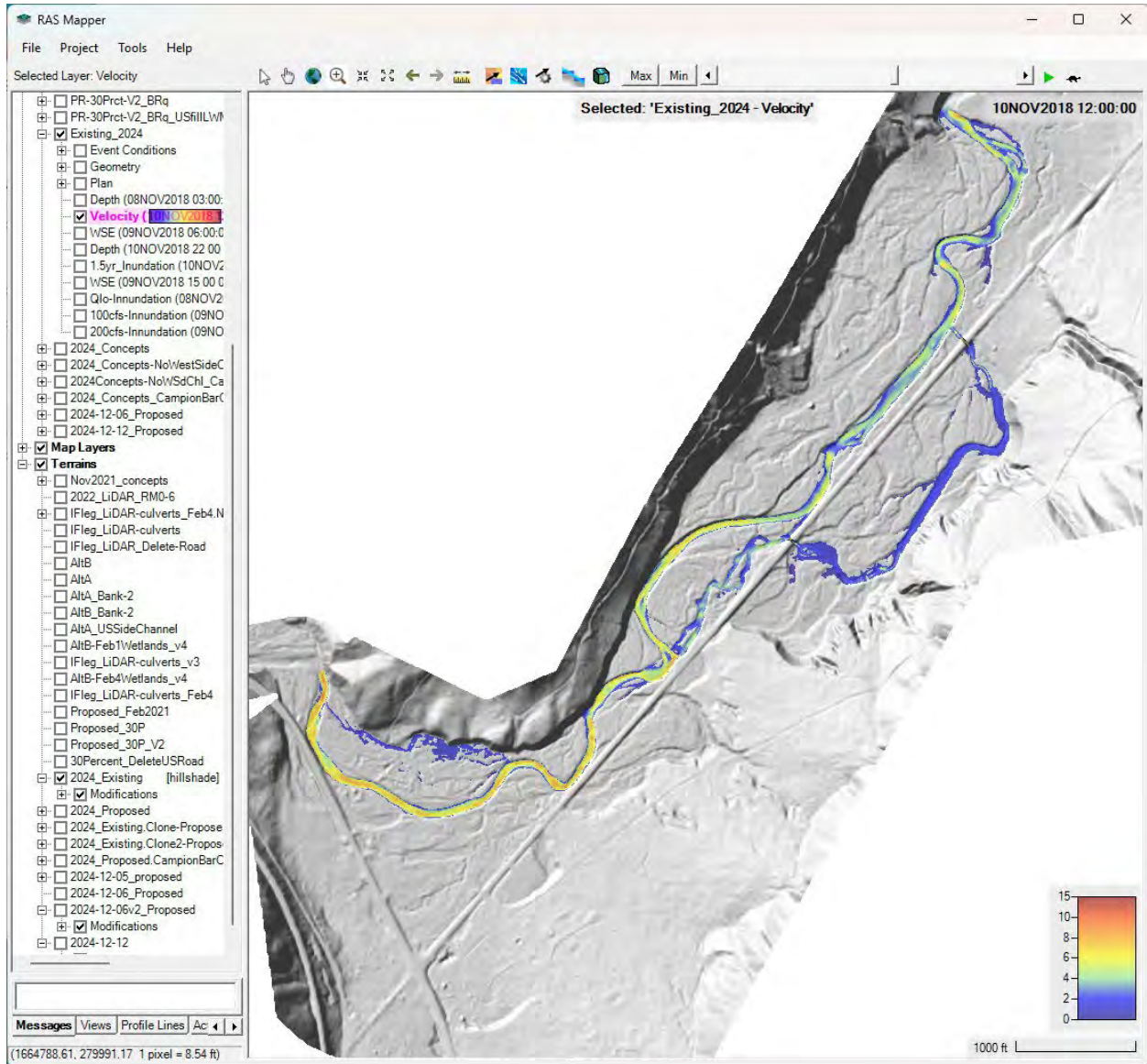
# Existing condition: 200-cfs flow velocity through project area



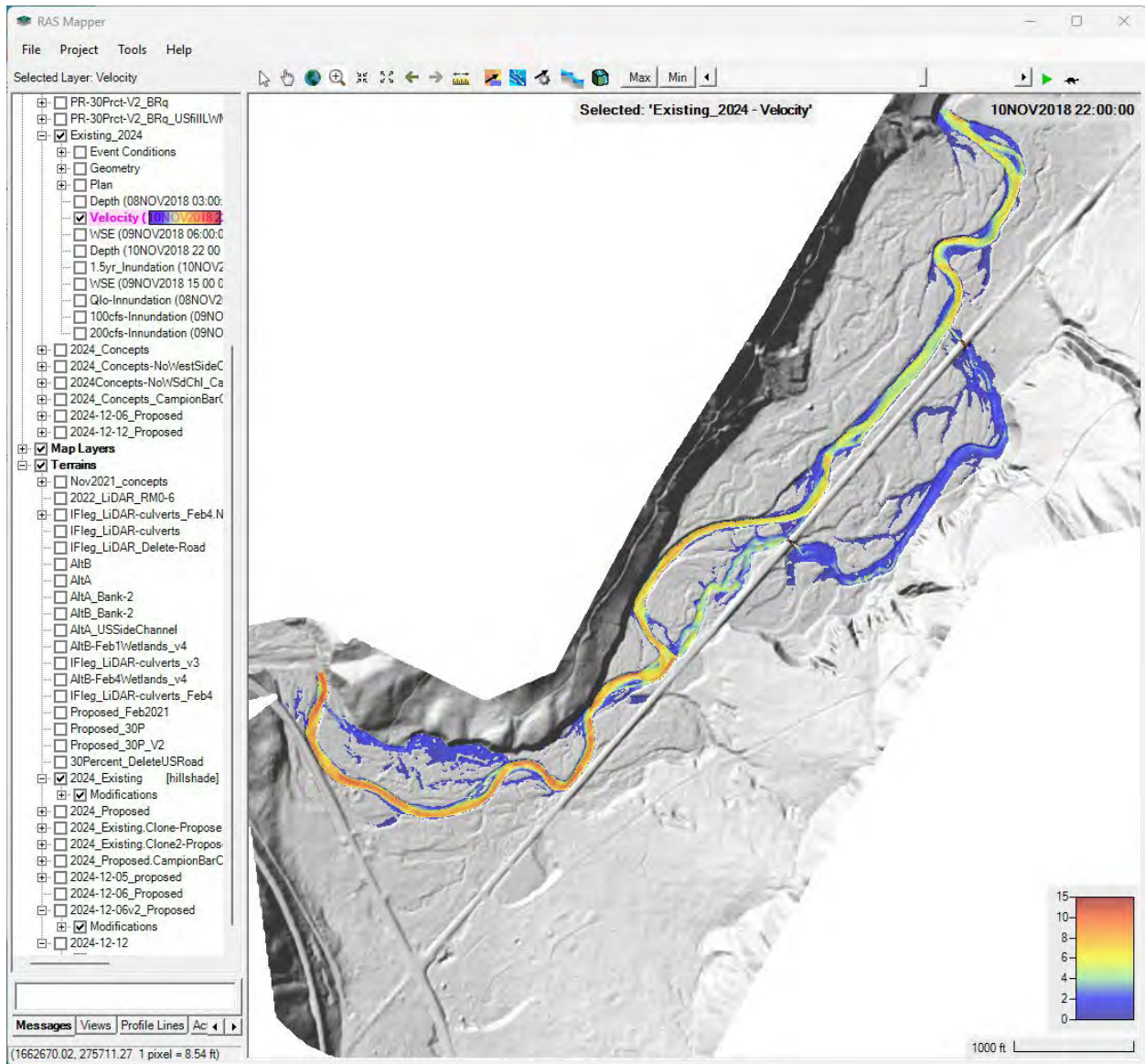
# Existing condition: 600-cfs flow velocity through project area



# Existing condition: 1,000-cfs flow velocity through project area



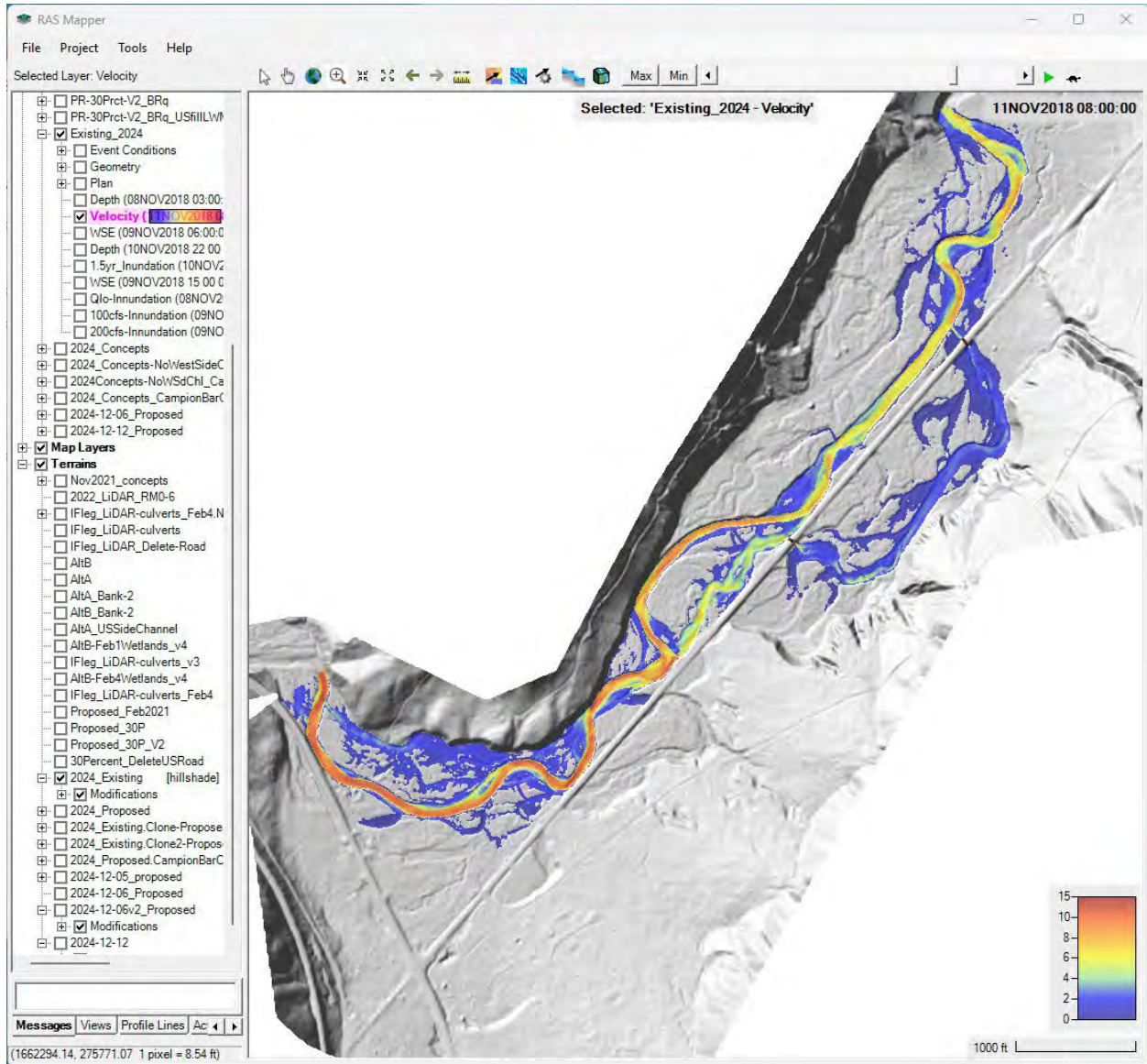
Existing condition: 1.5-year (2,200-cfs) flow velocity through project area



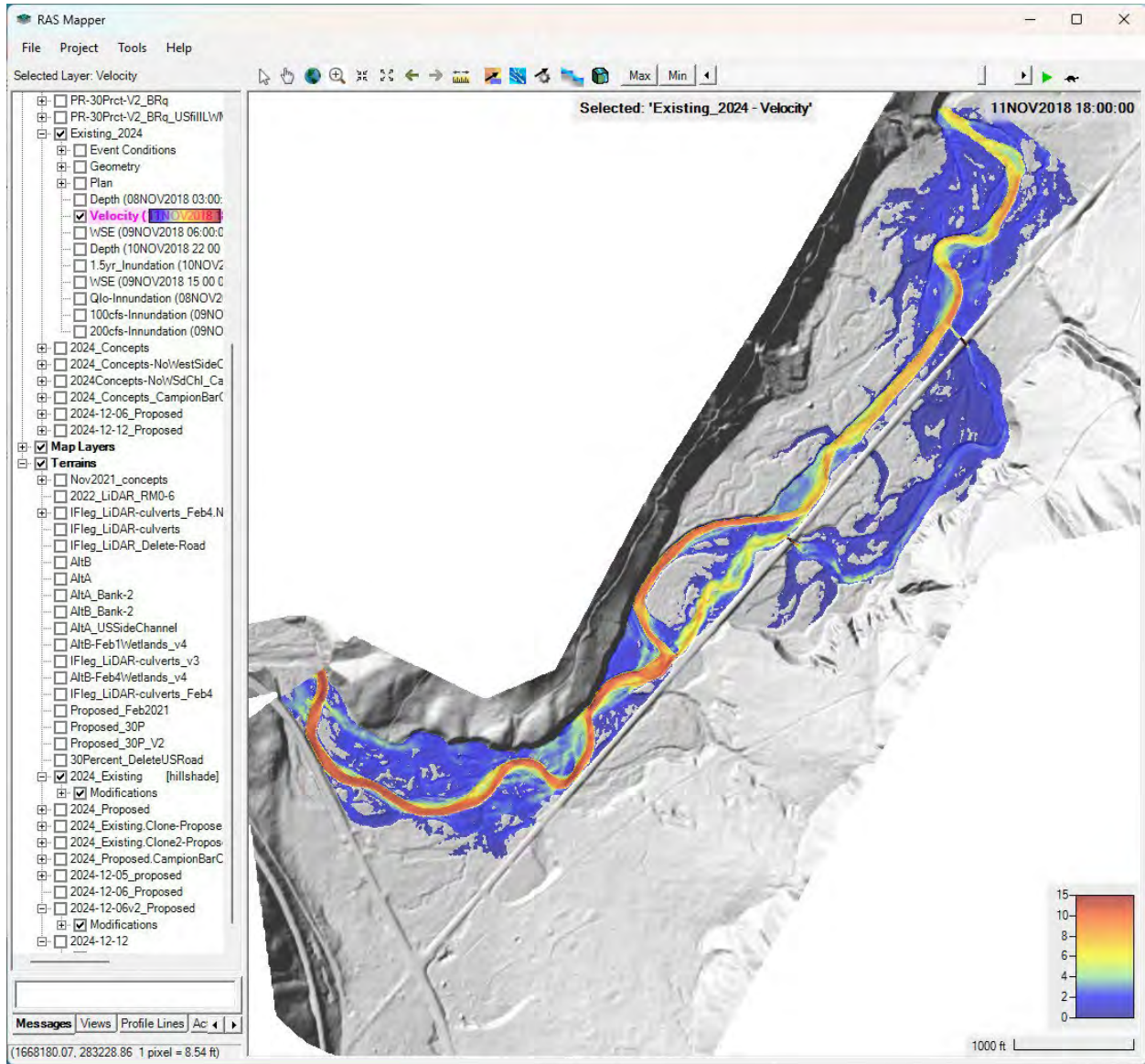
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1000 ft

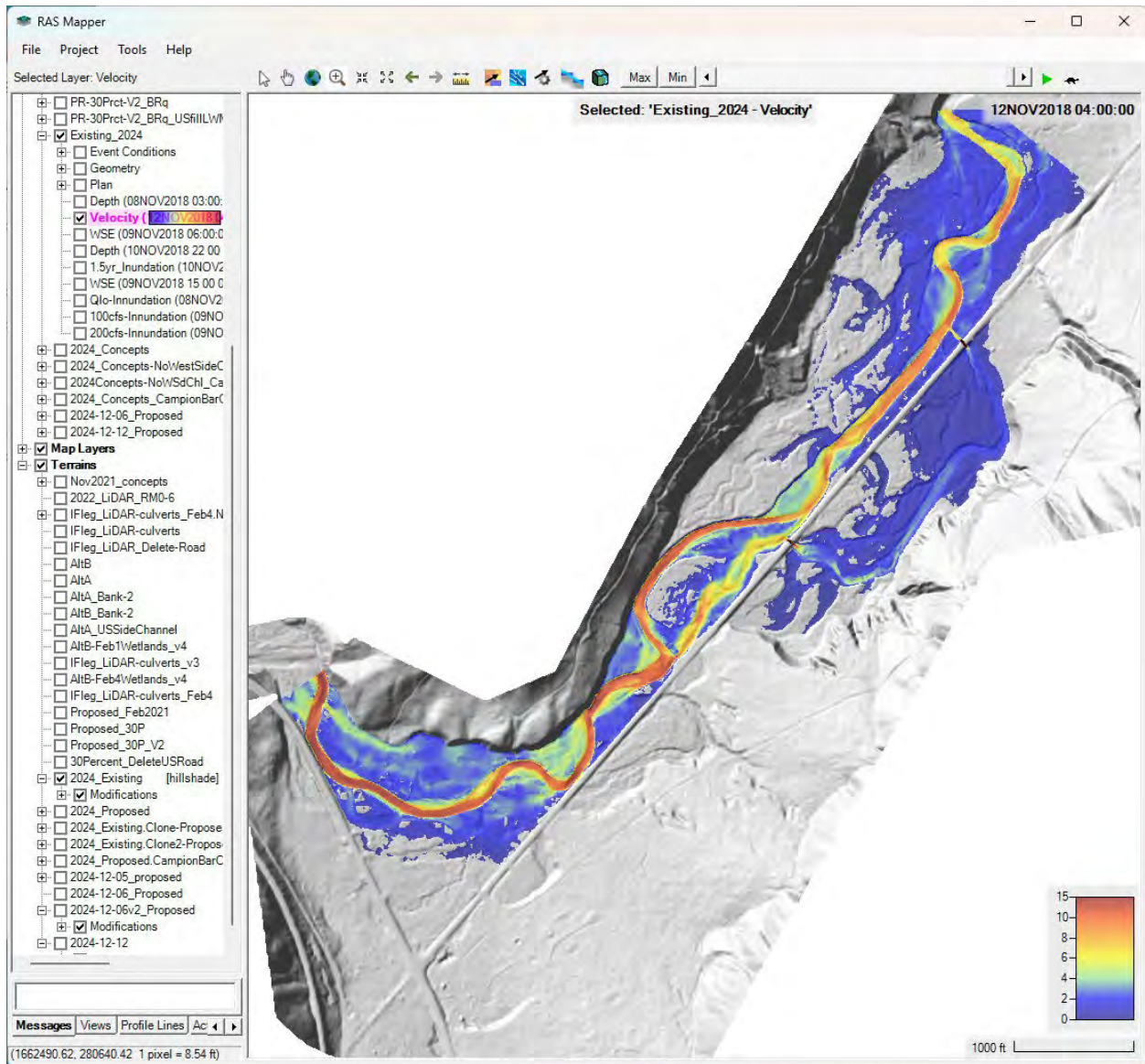
Existing condition: 5-year (3,900-cfs) flow velocity through project area



Existing condition: 25-year (6,500-cfs) flow velocity through project area

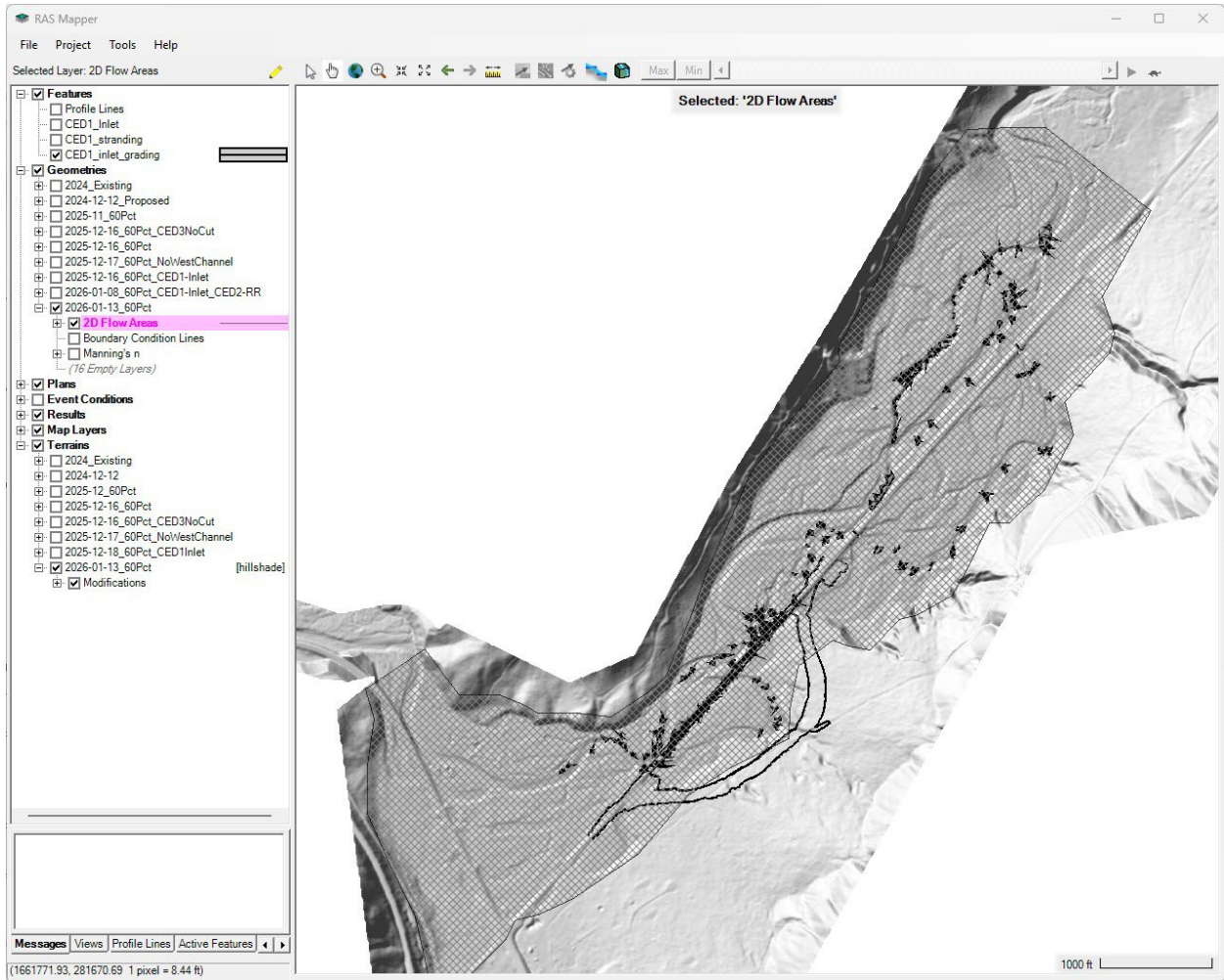


Existing condition: 100-year (9,400-cfs) flow velocity through project area

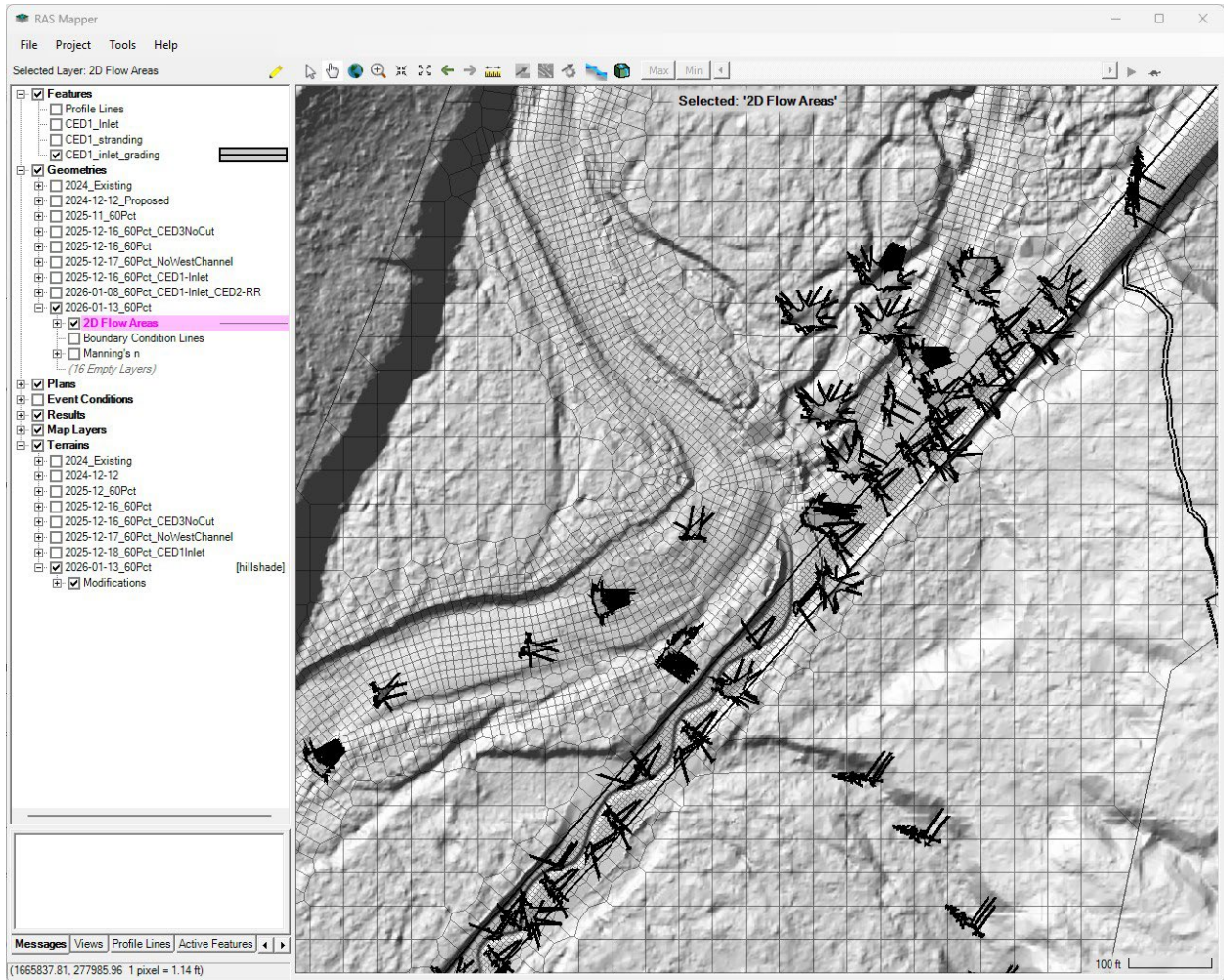


## Appendix D – Proposed conditions HEC-RAS model

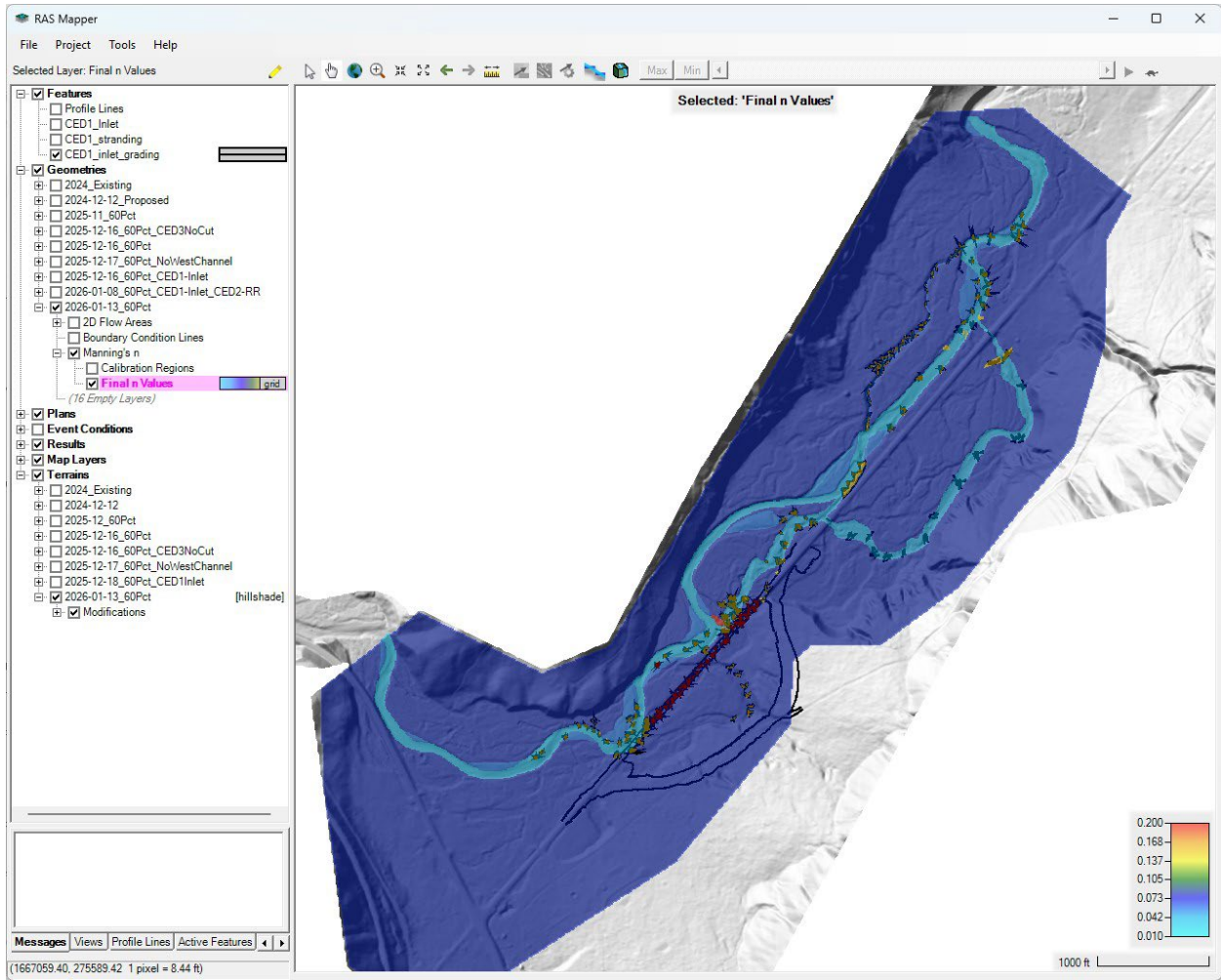
# Proposed condition model mesh



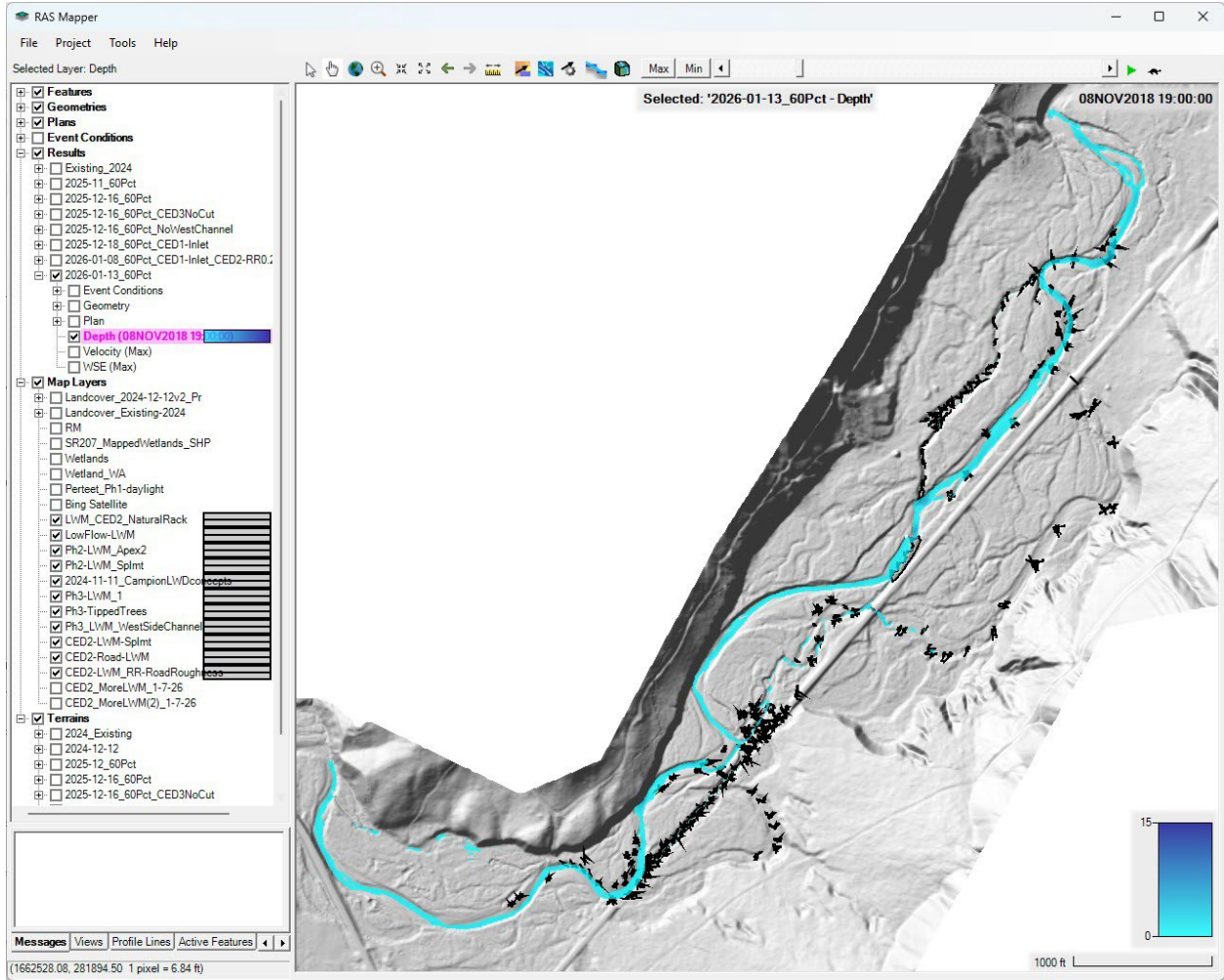
# Proposed condition model mesh – example of mesh detail



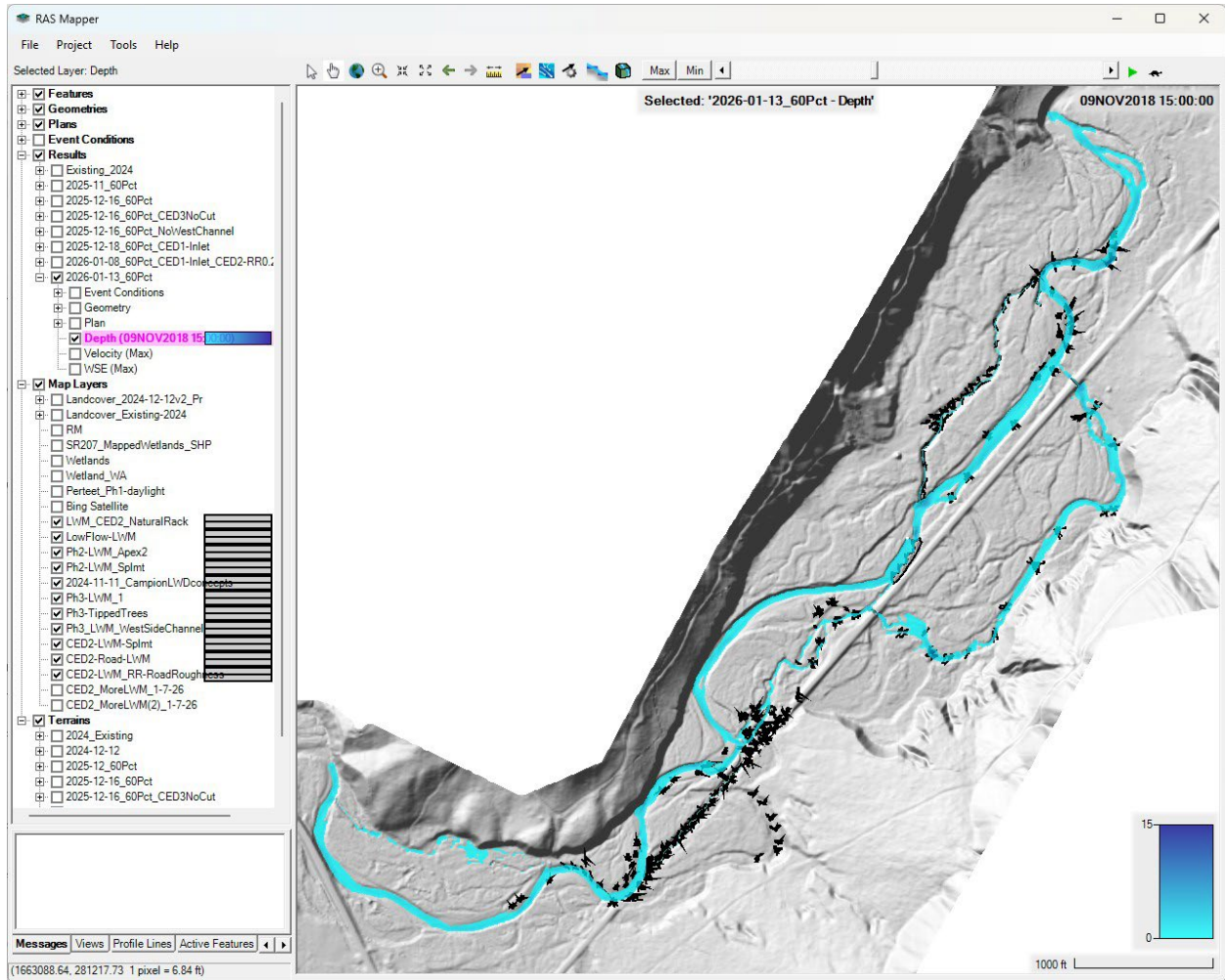
# Proposed condition Manning's n



# Proposed condition: 50-cfs flow depth through project area



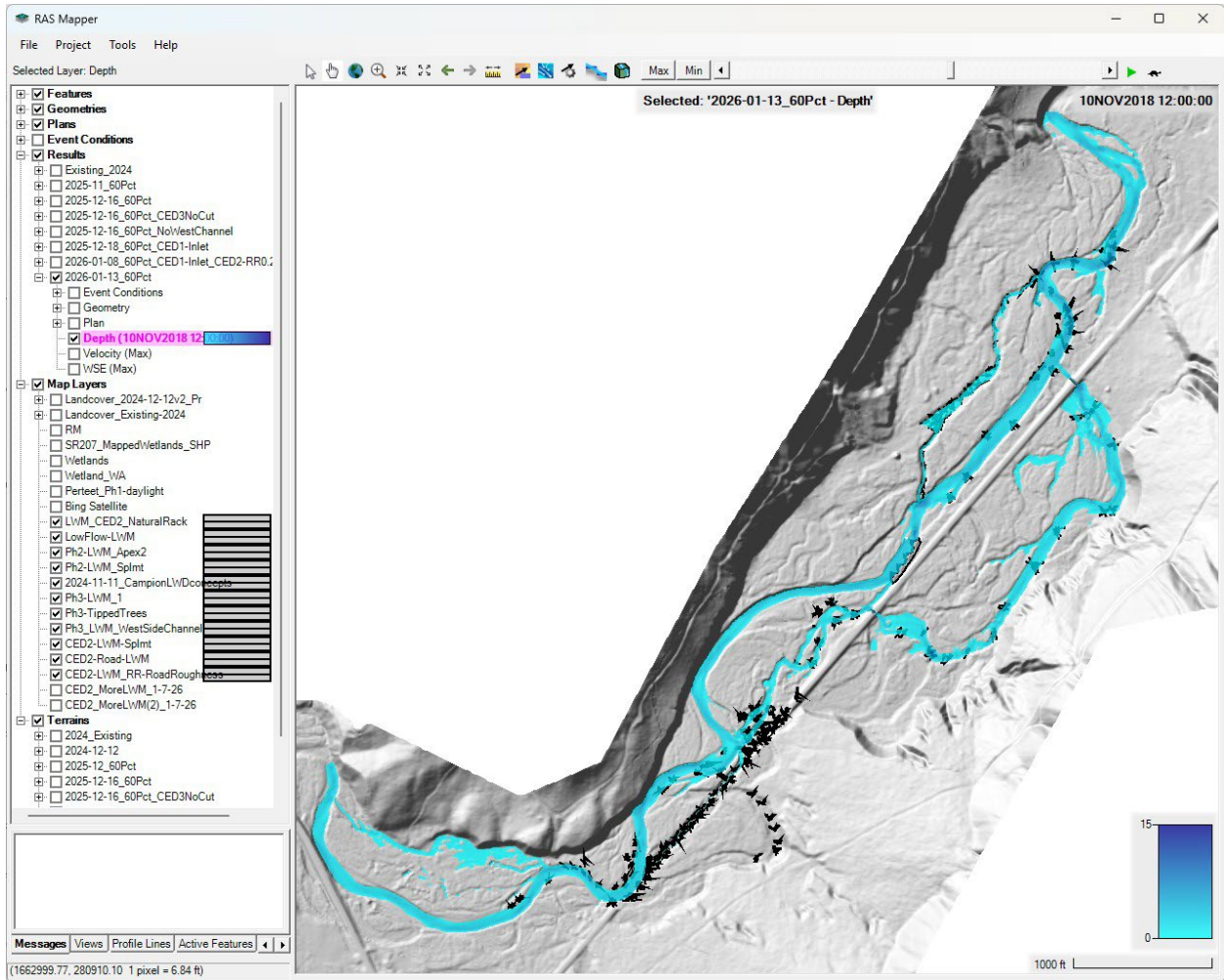
# Proposed condition: 200-cfs flow depth through project area



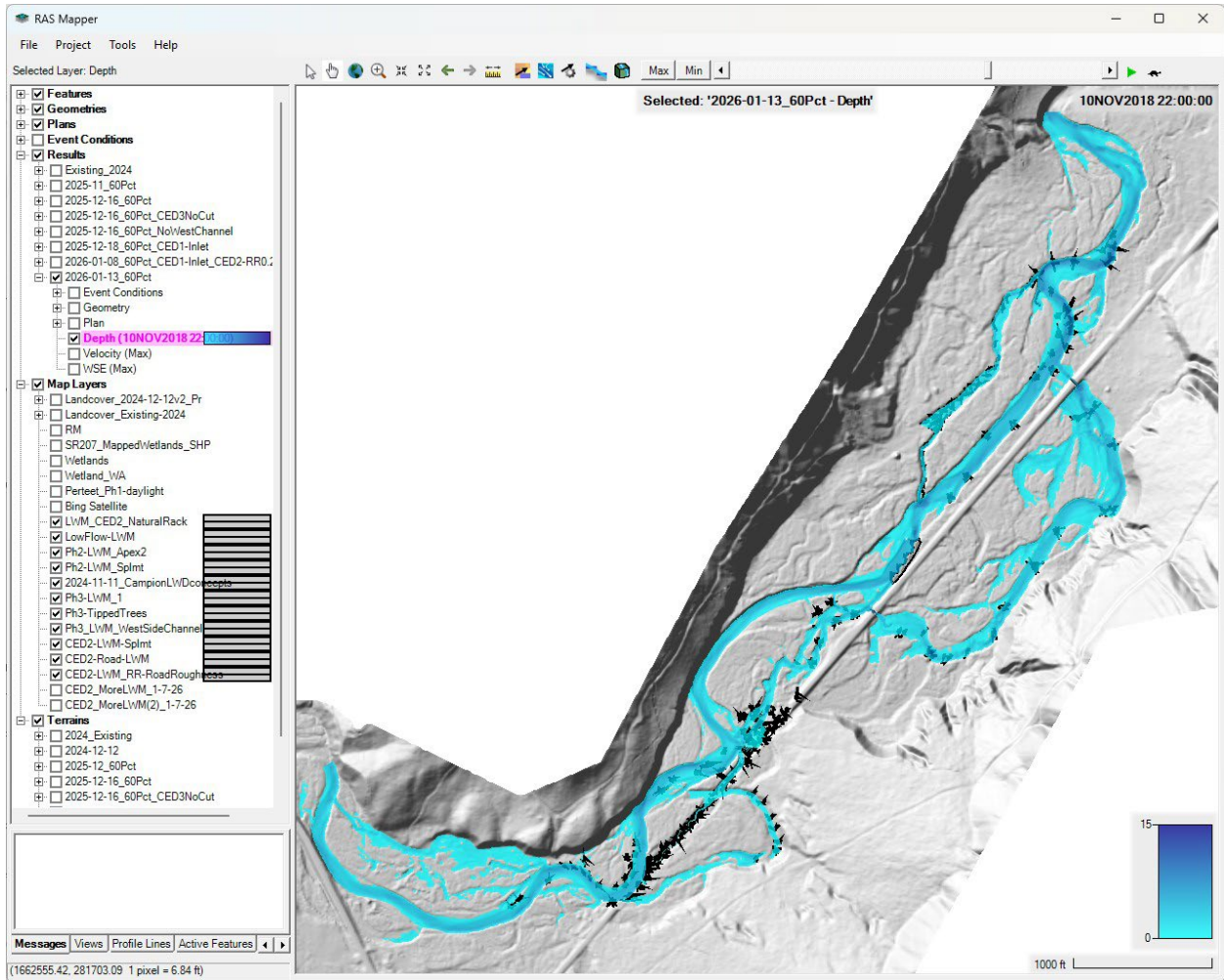
# Proposed condition: 600-cfs flow depth through project area



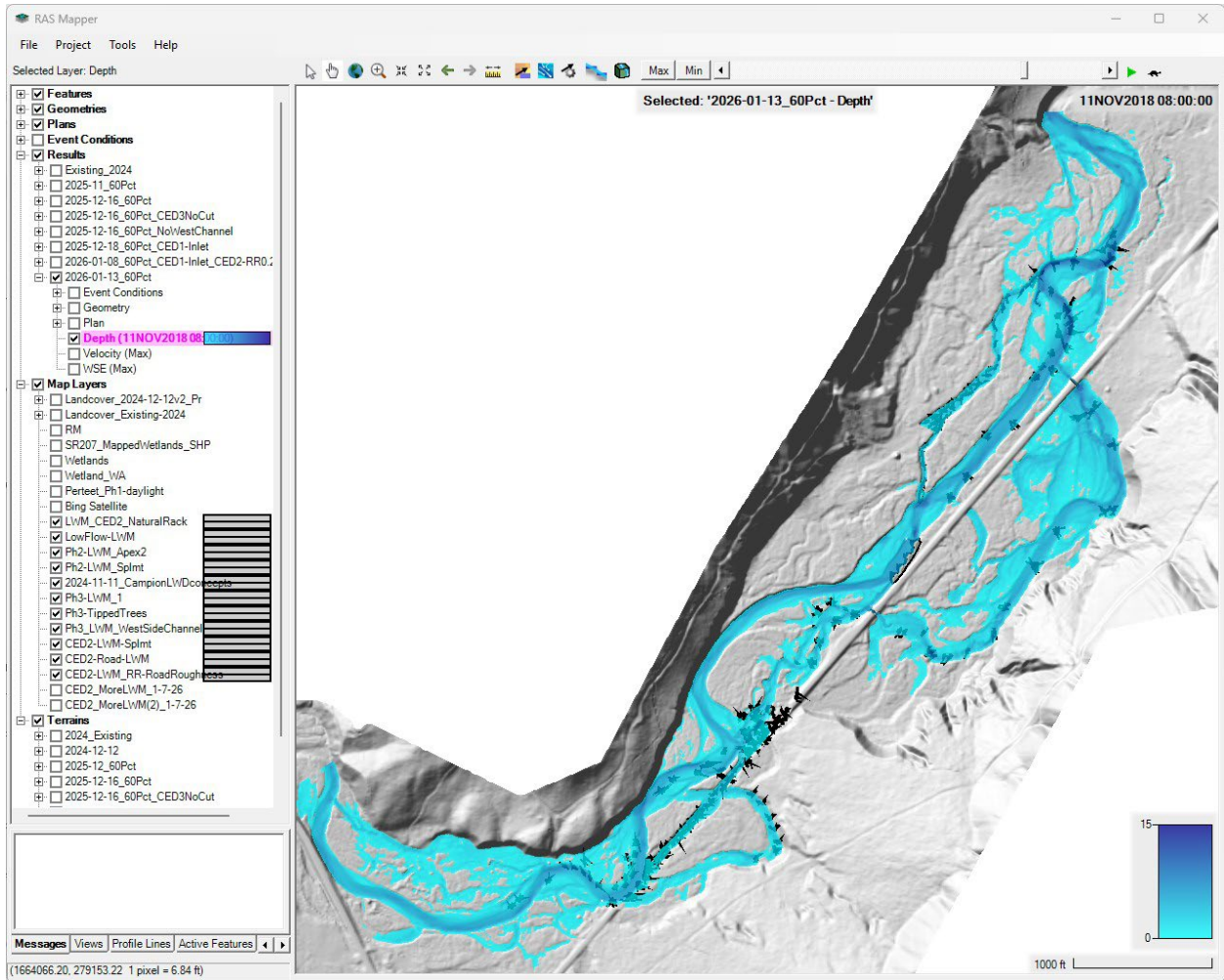
Proposed condition: 1,000-cfs flow depth through project area



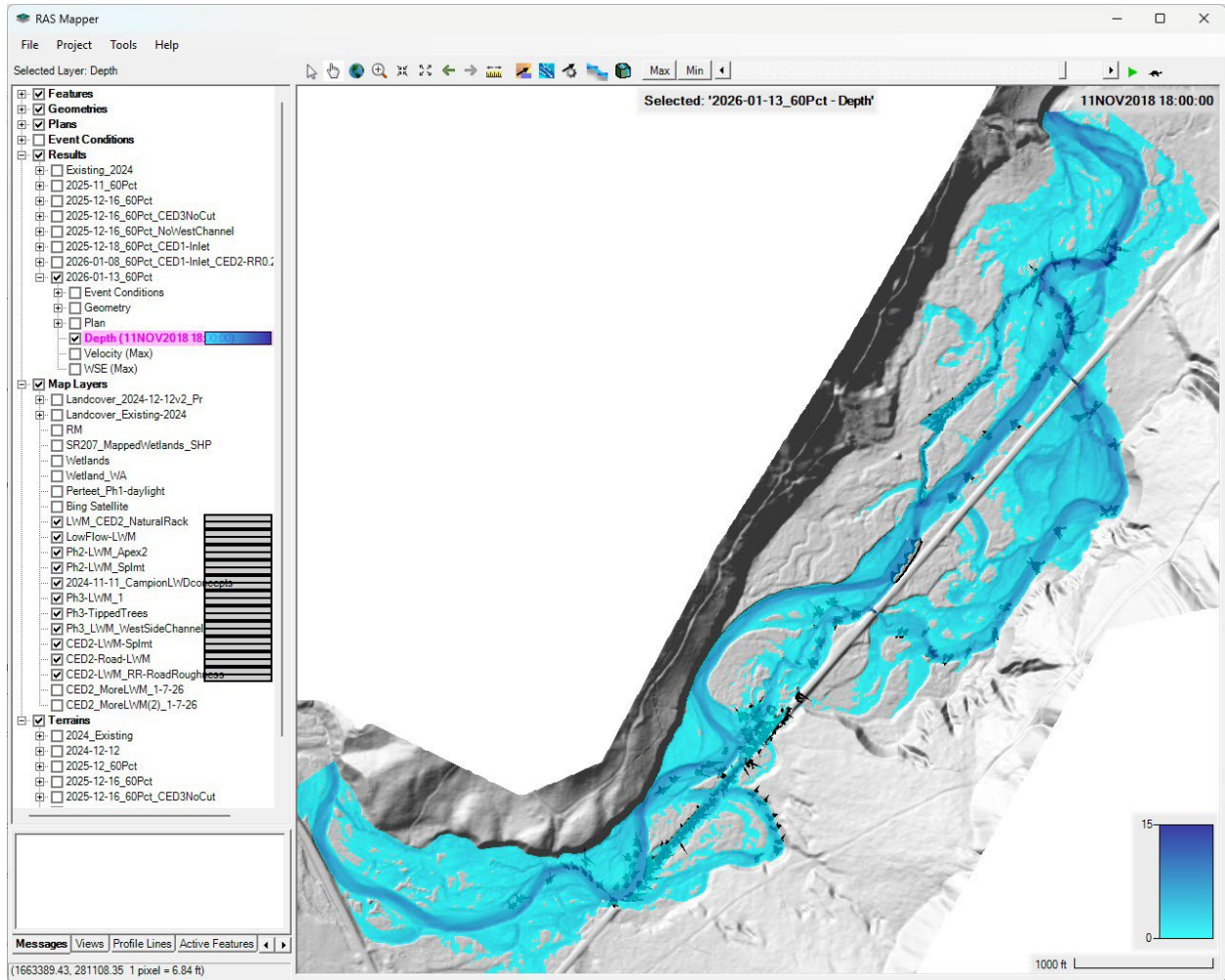
Proposed condition: 1.5-year (2,200-cfs) flow depth, entire model domain



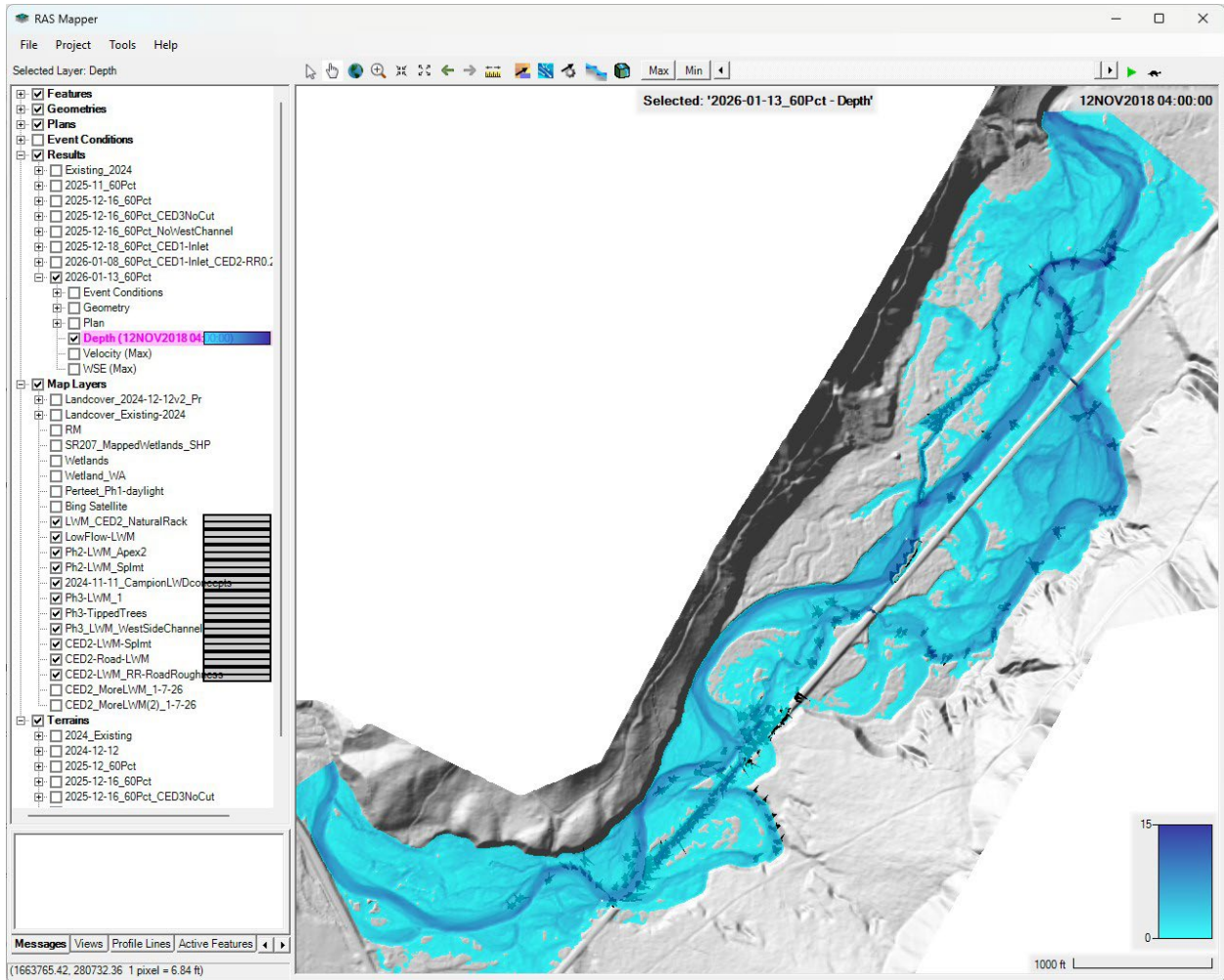
Proposed condition: 5-year (3,900-cfs) flow depth, entire model domain



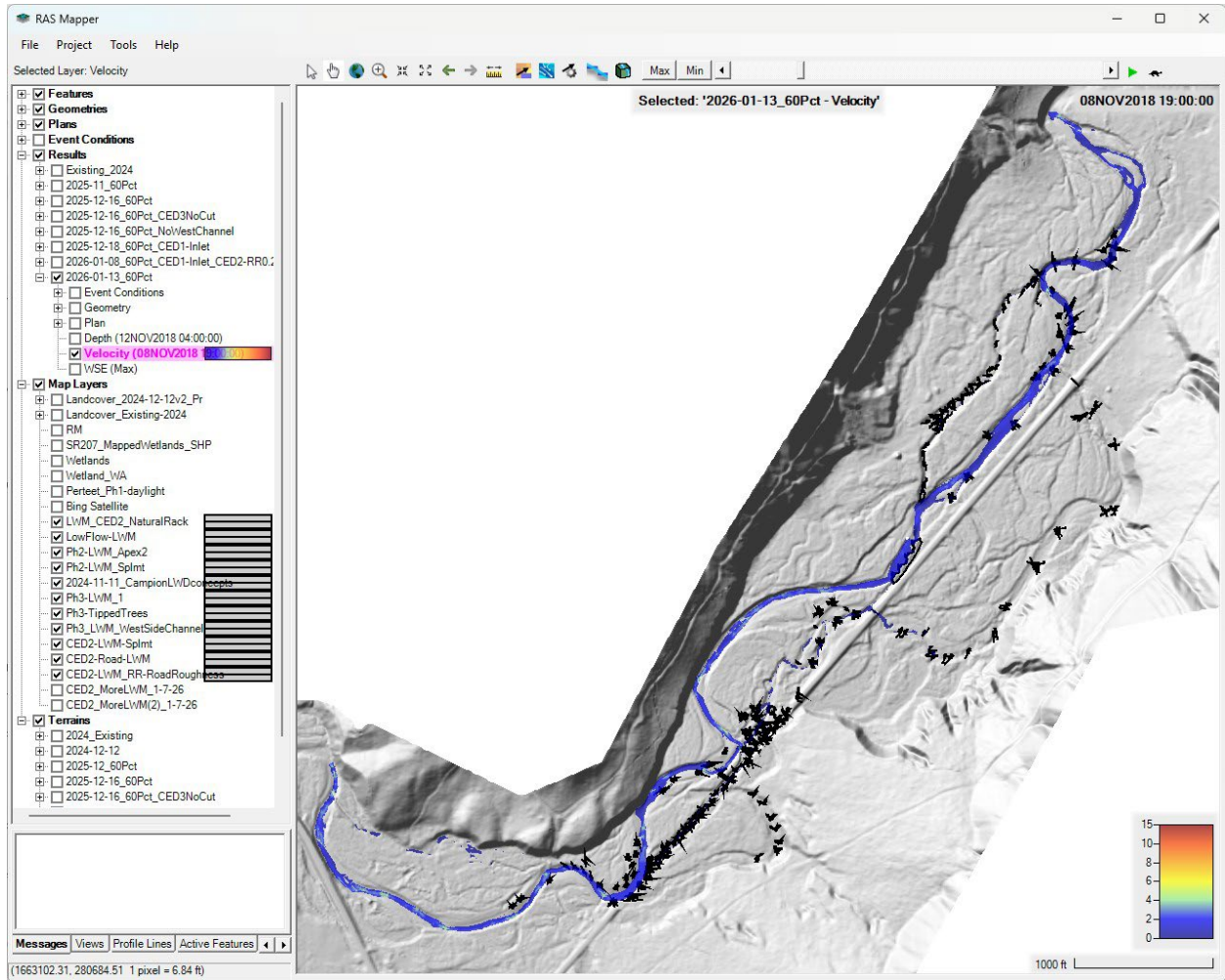
Proposed condition: 25-year (6,500-cfs) flow depth, entire model domain



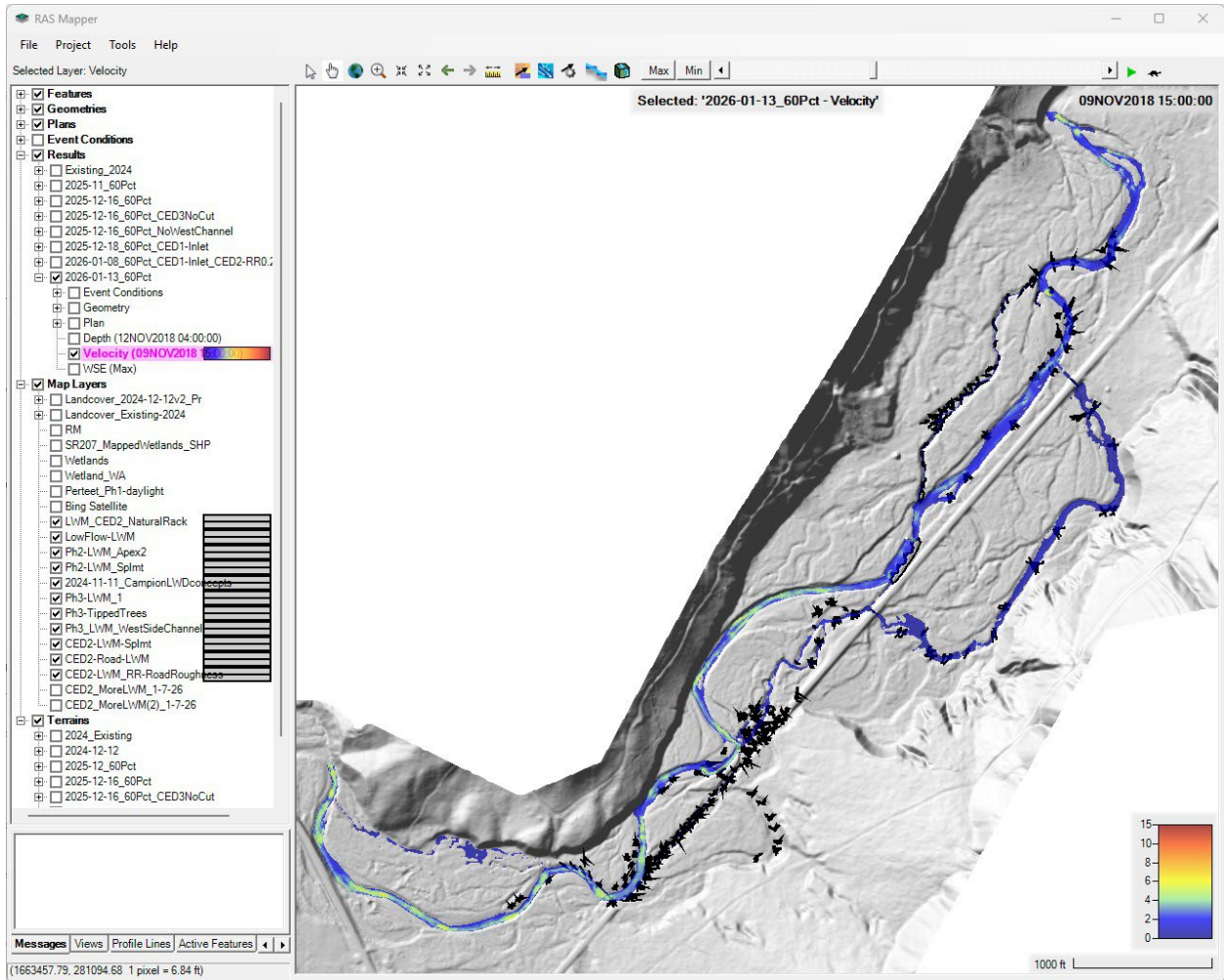
Proposed condition: 100-year (9,400-cfs) flow depth, entire model domain



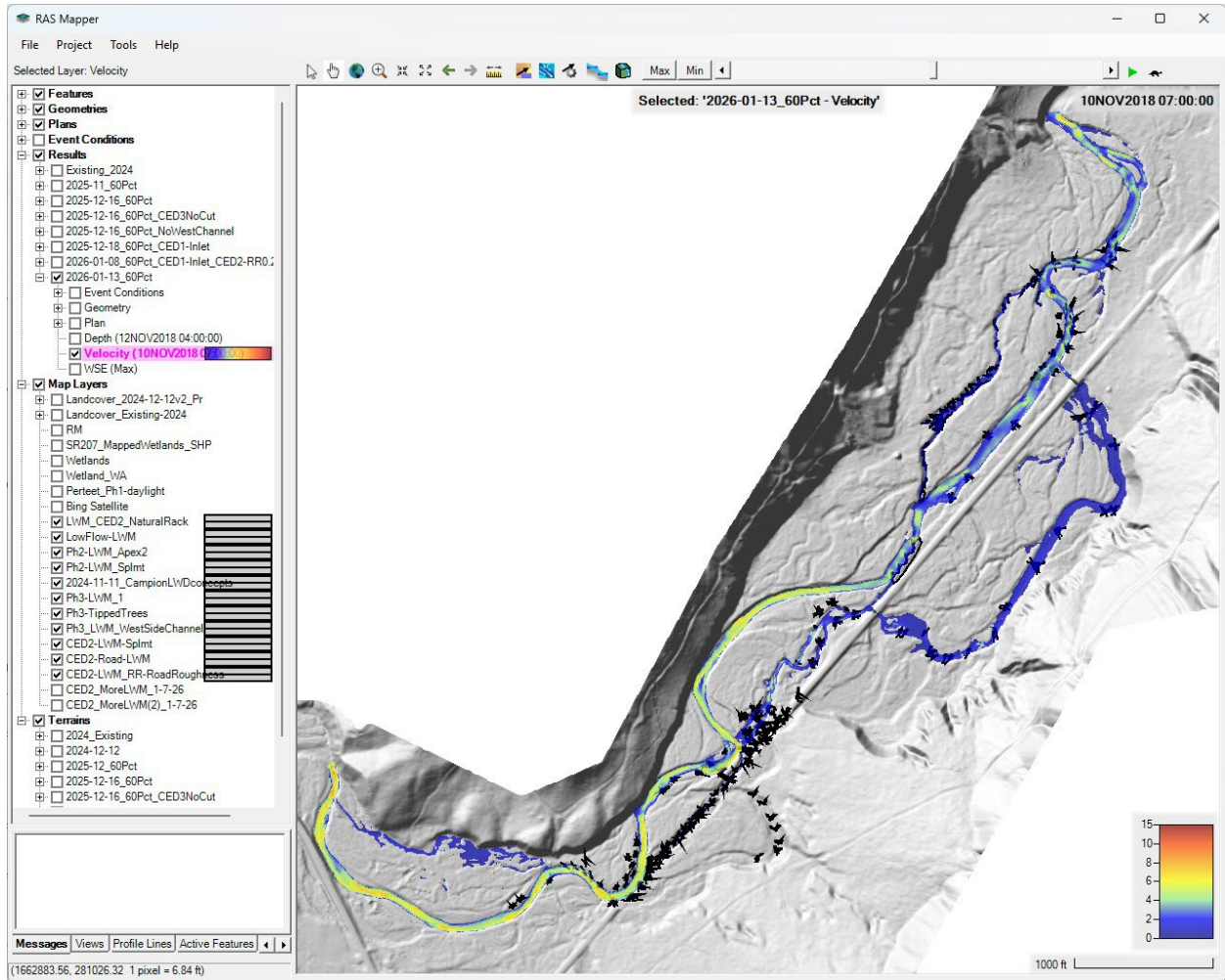
# Proposed condition: 50-cfs flow velocity through project area



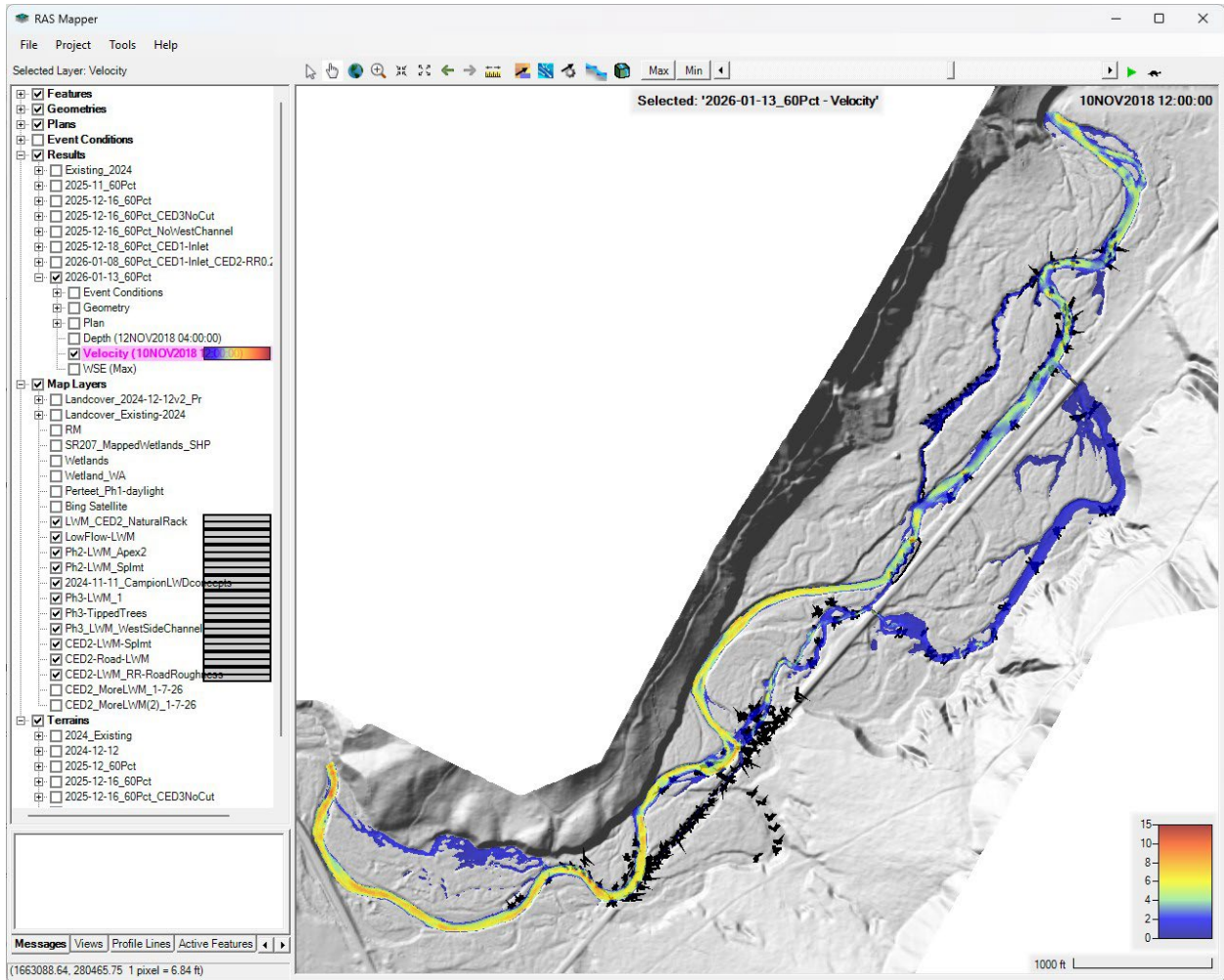
# Proposed condition: 200-cfs flow velocity through project area



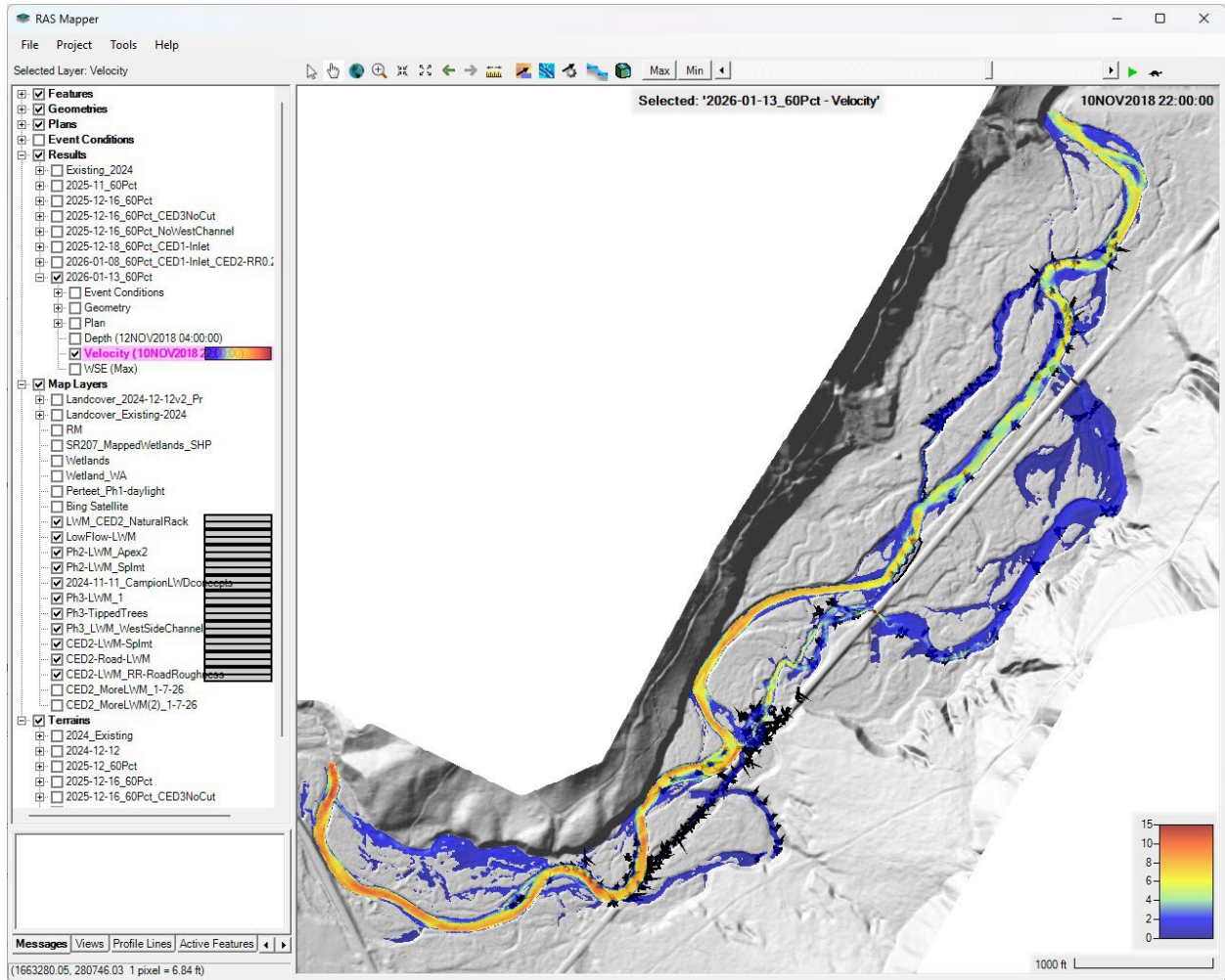
# Proposed condition: 600-cfs flow velocity through project area



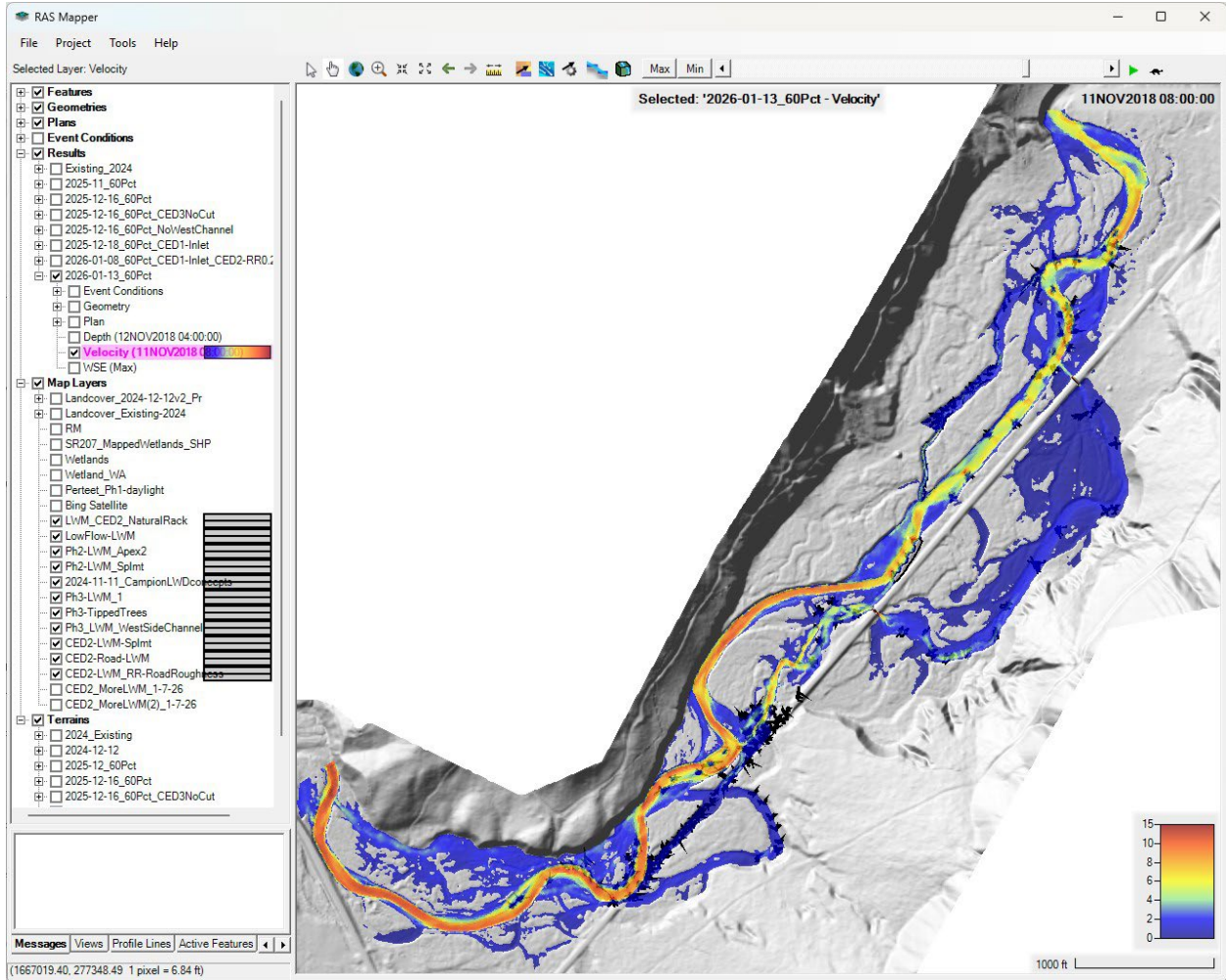
Proposed condition: 1,000-cfs flow velocity through project area



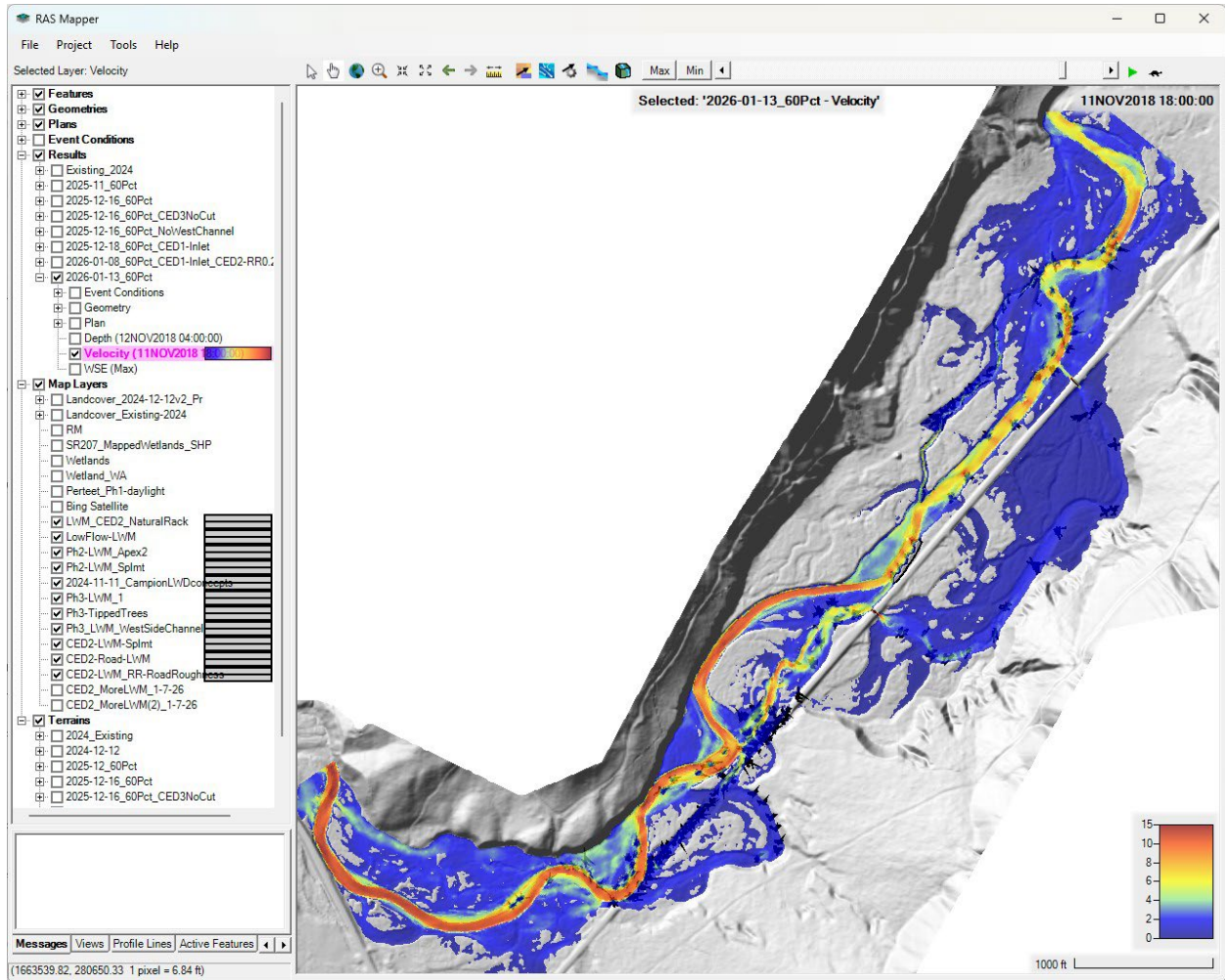
Proposed condition: 1.5-year (2,200-cfs) flow velocity through project area



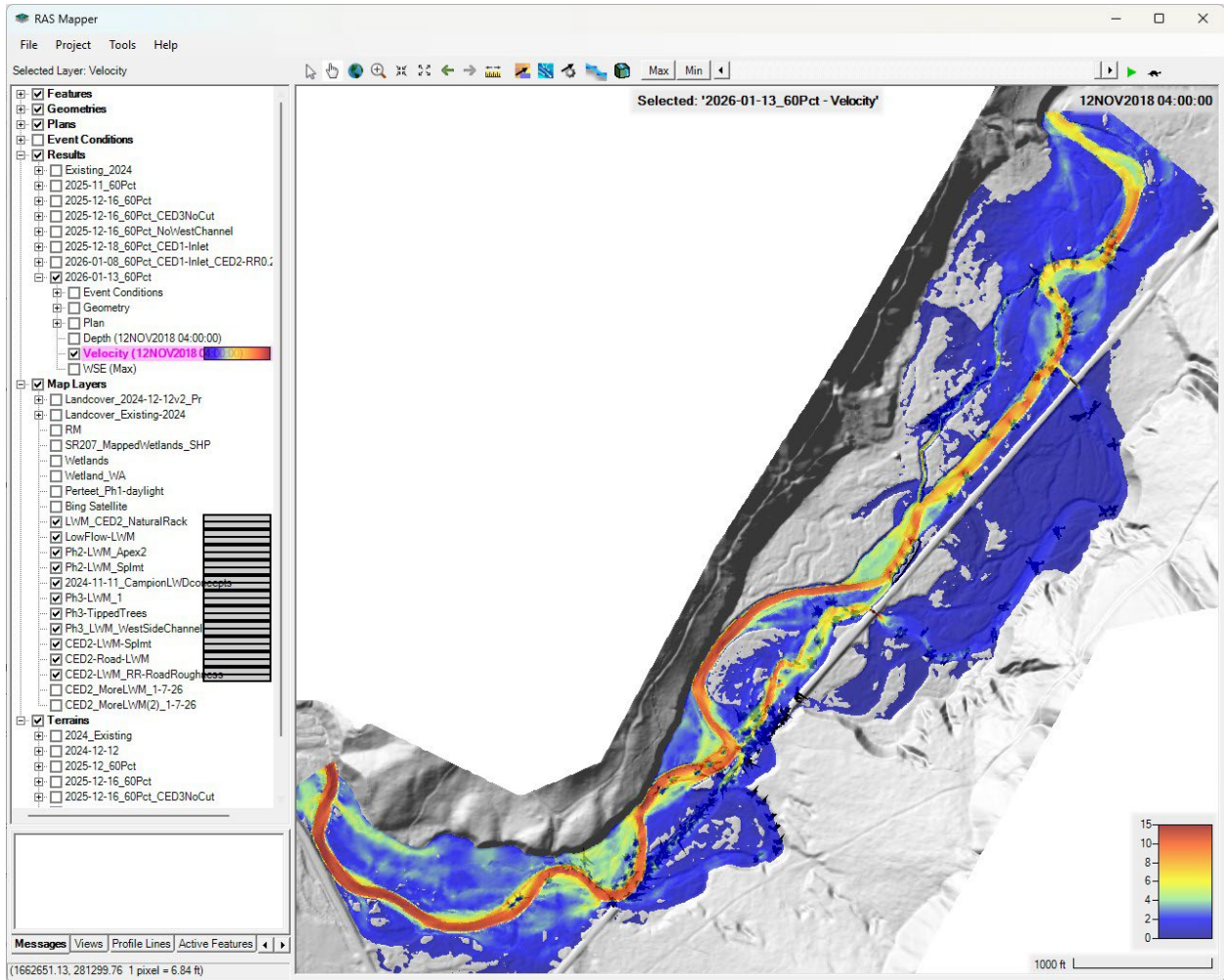
Proposed condition: 5-year (3,900-cfs) flow velocity through project area



# Proposed condition: 25-year (6,500-cfs) flow velocity through project area



Proposed condition: 100-year (9,400-cfs) flow velocity through project area



## Appendix E – Large Wood Stability Calculations

**Nason Floodplain - Large Woody Structure Stability Evaluation**

**Structural Stability | 6.4**

Structural stability of large woody material placements is evaluated herein using the procedures, formulas, and recommendations provided in the Reclamation's *Large Woody Material - Risk Based Design Guidelines* (Knutson et. al. 2014) along with insight gained from professional experience and general engineering judgment.

**Factors of Safety | 6.4.1**

Safety factors for structural stability were selected from *Table 4. Minimum recommended factors of safety* given the site specific public safety and property damage risk levels.

<b>Public Safety Risk</b> Moderate	Criteria: <b>FOS<sub>sliding</sub></b> 1.5
<b>Property Damage Risk</b> Moderate	<b>FOS<sub>buoyancy</sub></b> 1.75
<b>Stability Design Flow Criteria</b> 50-year	<b>FOS<sub>rotation</sub></b> 1.5

**Resistance to Flotation | 6.4.2**

Flotation is typically caused by the buoyant force and the lift force acting on the wood material from water passing over its surface.

**Large Wood Material Force**

Accounts for the vertical buoyant force of submerged large wood and the vertical weight force of unsubmerged large wood.

$$F_{LWMS} = V_{LWMS} \times (\gamma_{wood} - \gamma_w)$$

$V_{LWMS}$  = total volume of submerged large wood material

$$V_{LWMS} = \sum N_{LWMi} \times V_{LWMi}$$

Variable	Design Value Units
$\gamma_{wood}$ = unit weight of wood	38 lb/ft <sup>3</sup>
$\gamma_w$ = unit weight of water	62.4 lb/ft <sup>3</sup>
$V_{LWMS}$	1129 ft <sup>3</sup>

<b><math>F_{LWMS}</math> (lb) 27,542</b>	<i>Positive values are upward forces.</i>
------------------------------------------	-------------------------------------------

**Lift Force**

Accounts for the lift force of large wood in flowing water. Not applicable to LWS where the bed will deform around the leading edges.

$$F_L = \frac{C_L \times A_{LWM} \times \gamma_w \times U_o^2}{2 \times g}$$

	Design Value	Units / Notes
$C_L =$ lift coefficient	0.2	typ. LWM value
$A_{LWM} =$ area of large woody material perpendicular to flow		$A_{LWM} =$ See Design Plan
$U_u =$ upstream channel velocity at design event	7	ft/s
$g =$ acceleration due to gravity	32.2	ft/s <sup>2</sup>
<b><math>F_L</math> (lb)</b>		<b>N/A</b>

**Boulder Ballast Force**

Accounts for the ballasting force of large boulders directly attached to or placed over LWM.

$$F_{bouldersub} = N_{bouldersub} \times \pi/6 \times d_{bouldersub}^3 \times (\gamma_{boulder} - \gamma_w)$$

	Design Value	Units / Notes
$N_{bouldersub} =$ number of submerged boulders	0	number
$d_{bouldersub} =$ effective diameter of submerged boulders	0	ft
$\gamma_{boulder} =$ unit weight of boulders		165 lb/ft <sup>3</sup>
<b><math>F_{bouldersub}</math> (lb)</b>		<b>N/A</b>

**Backfill Ballast Force**

Accounts for the ballasting force of backfill placed directly over LWM members. Volume is based on the fill area over the log(s) and a the effective cover depth shown on the Drawings.

$$F_{backfillsub} = V_{backfillsub} \times (\gamma_s - \gamma_w)$$

	Design Value	Units / Notes
$V_{backfillsub} =$ volume of backfill over LWM members	3,150	ft <sup>3</sup>
$\gamma_s =$ unit weight of backfill material		See design plans 110 lb/ft <sup>3</sup>
<b><math>F_{backfillsub}</math> (lb)</b>		<b>-149,940</b>

**Pile Skin Friction**

Accounts for the vertical resistance provided by piles within the LWM structure. USBR document equation modified by Inter-Fluve to match industry pile design standard formulations.

$$F_{piles-v} = N_{piles} \times \pi \times d_{piles} \times L_{piles} \times (k_s \times \tan \frac{2}{3}\theta \times \sigma')$$

	<b>Design Values</b>	<b>Units</b>
$N_{piles}$ = number of piles	5.25	number
$L_{piles}$ = length of pile embedded below potential scour depth	15	ft
$d_{piles}$ = nominal diameter of the piles	1.30	ft
$\sigma' = (L_{piles} \times (\gamma_{sat} - \gamma_w)) / 2$	357	lb/ft <sup>2</sup>
$K_s$ = coefficient of lateral earth pressure (0.5 to 1.0)	1.0	unit less
$\theta$ = internal friction angle of soils	36	deg.
<b><math>F_{piles-v}</math> (lb)</b>		
<b>-51,121</b>		<i>Negative values resist upward displacement.</i>

**Piles Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bPiles} = \frac{F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 1.9**

*Note this value does not include the backfill assuming it's all lost but the piles are holding.*

**Backfill Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bBackfill} = \frac{F_{backfillsub}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 5.4**

*Note this value does not include the piles.*

**Net Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bNet} = \frac{F_{backfillsub} + F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 7.3**

*Note this value includes the piles and backfill.*

**Resistance to Sliding | 6.4.3**

LWM structures are also susceptible to failure through sliding.

**Drag Force**

LWM structures are pushed downstream by the fluid drag forces acting upon the wood by the flowing water.

	Design Value	Units / Notes
$F_d = \frac{C_D \times A_{LWM} \times \gamma_w \times U_c^2}{2 \times g}$		
$C_D = \text{drag coefficient}$		1 Per Equations 23 and 24
$A_{LWM} = \text{area of wetted wood normal to the flow direction}$		$A_{LWM} = \text{See Design Plan}$
		<b><math>A_{LWM} \text{ (ft}^2\text{)}</math> 152</b>
$U_c = \text{velocity adjacent to the LWM structure}$		7 ft/s
		Velocity value is conservative for all LWS locations. Value from 100-yr event 2D model results for main channel.
$g = \text{acceleration due to gravity}$		32.2 ft/s <sup>2</sup>
<b><math>F_d \text{ (lb)}</math> 7,217</b>		

**Hydrostatic Force**

Hydrostatic forces act on the upstream and downstream faces of a LWM structure. They account for differences in the upstream and downstream water depths against the structure.

$F_{hu} = \frac{1}{2} \times \gamma_w \times Y_u \times A_u$	$F_{hd} = \frac{1}{2} \times \gamma_w \times Y_d \times A_d$	<b>Variable Design Value</b>
		$Y_u \text{ (ft)}$ 5.5
$F_{hu}, F_{hd} = \text{hydrostatic force on upstream and downstream side of the wood structure}$		$A_u \text{ (ft}^2\text{)}$ 152
		Post racking area
$Y_u, Y_d = \text{water depth upstream and downstream of the structure}$		$Y_d \text{ (ft)}$ 5.5
		$A_d \text{ (ft}^2\text{)}$ 152
$A_u, A_d = \text{area projected to flow direction on the upstream and downstream of the structure}$		Plan downstream area
<b><math>F_{hu} + F_{hd} = F_h \text{ (lb)}</math></b>		<b>N/A</b>

**Impact Force**

The impact force associated with debris impacting a large wood structure can be estimated by the impact force equation.

$$F_i = \frac{w_{debris}}{g} \times \frac{V_{channel}^2}{2 \times \Delta x} \times C_i \times C_o \times C_d \times C_b \times R_{max}$$

$w_{debris}$  = weight of debris

$V_{channel}$  = channel approach velocity

$\Delta x$  = deceleration distance

Coefficients (see Table 6 and Figures 11, 12 for values)

$C_i$  = importance,  $C_o$  = orientation = 0.8,  $C_d$  = depth,  $C_b$  = blockage,  $R_{max}$  = impulse response ratio

Variable Design Value	
$W_{debris}$ (lb)	3,774
$V_{channel}$ (ft/s)	7
$\Delta x$ (ft)	5
$C_i$	0.5
$C_o$	0.8
$C_d$	1.0
$C_b$	1.0
$R_{max}$	0.8

<b><math>F_i</math> (lb) 184</b>
----------------------------------

**Friction Force**

Accounts for the friction force between the LWM and the channel bed. Restraint force from piles is not included as it does not exert a pressure on the LWS / bed interface.

$$F_f = -\mu_{bed} \times (F_{LWMS} + F_L + F_{bouldersub} + F_{backfillsub})$$

	Design Value Units / Source
$\mu_{bed}$ = coefficient of bed friction = $\tan(\theta)$	0.78 unit less
$\theta$ = internal friction angle (degrees)	38 Table 5, (Knutson et. al. 2014)

<b><math>F_f</math> (lb) -95,628</b>
--------------------------------------

Negative values resist downstream displacement.

**Lateral Resistance From Piles**

Accounts for the lateral resistance provided by piles within the LWM structure. Assumes soil resistance is limiting, i.e. the pile pushes over before it breaks.

$$F_{piles-h} = N_{piles} \times \frac{L_{pile}^3 \times \frac{1}{2} \times (\gamma_s - \gamma_w) \times d_{pile} \times K_p}{h_{load} \times L_{pile}}$$

	Design Values Units
$N_{pile}$ = number of piles	5.25 number
$L_{pile}$ = length of pile embedded below potential scour depth	15 ft
$d_{pile}$ = diameter of the pile	1.30 ft
$h_{load}$ = applied load height above the potential scour depth	2.5 ft
$K_p = \frac{1 + \sin \theta}{1 - \sin \theta}$	4.2 unit less

<b><math>F_{piles-h}</math> (lb) -61,455</b>
----------------------------------------------

Negative values resist downstream displacement.

**Sliding Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{sliding} = \frac{F_f + F_{piles-h}}{F_d + F_{nu} + F_{hd} + F_i}$$

**FOS<sub>sliding</sub> 21.2**

**Pile Strength Factor of Safety**

The factor of safety for the timber bending stress capacity of the pile. This evaluates the potential for the pile(s) to break under load prior to the pile pushing over in the ground.

		<b>Design Values Units</b>
$F_b = \text{Timber Bending Stress Capacity}$ per Timber Pile Manual Table 3-1 or AWC NDS Supplement Table 4D		1,200 psi 172,800 psf
$d_{pile} = \text{diameter of the pile}$		1.30 ft
$I = \text{circular cross - sectional moment of inertia}$	$I = \frac{\pi B^4}{4}$	2.24 ft <sup>4</sup>
$S = \text{circular section modulus}$	$S = \frac{\pi B^3}{32}$	0.216 ft <sup>3</sup>
$C_F = \text{strength reduction size factor}$ for diameters greater than 12"	$C_F = \frac{1}{B}^{(1/9)}$	0.971 --
$M_p = \text{applied moment per pile}$	$M_p = \frac{(F_d + F_i + F_h) \times h_{load}}{N_{piles}}$	3,524 ft-lb
$f_b = \text{applied pile bending stress}$	$f_b = \frac{M_p}{S}$	16,338 psf
$F_{bx} = \text{Pile bending stress capacity}$	$F_{bx} = F_b \times C_F$	1,166 psi 167,835 psf
$FOS_{pile\ strength} = \frac{F_{bx}}{f_b}$		
	<b>FOS<sub>pile strength</sub> 10.3</b>	

**References**

Large Woody Material - Risk Based Design Guidelines  
M. Knutson, J. Fealko. 2014. *Large Woody Material - Risk Based Design Guidelines*. U.S. Department of the Interior Bureau of Reclamation Pacific Northwest Region & Technical Services. Boise, Idaho. September 2014. Online at: <http://www.usbr.gov/pn/fcrps/documents/lwm.pdf>

ASTM D25. Allowable Stress Values for Treated Round Timber Piles.

Timber Pile Design and Construction Manual, Timber Piling Council, 2015.

American Wood Council (2018) National Design Specifications for Wood Construction, Design Supplement.

**Nason Floodplain - Large Woody Structure Stability Evaluation**

**Structural Stability | 6.4**

Structural stability of large woody material placements is evaluated herein using the procedures, formulas, and recommendations provided in the Reclamation's *Large Woody Material - Risk Based Design Guidelines* (Knutson et. al. 2014) along with insight gained from professional experience and general engineering judgment.

**Factors of Safety | 6.4.1**

Safety factors for structural stability were selected from *Table 4. Minimum recommended factors of safety* given the site specific public safety and property damage risk levels.

<b>Public Safety Risk</b> Moderate	Criteria: <b>FOS<sub>sliding</sub></b> 1.5
<b>Property Damage Risk</b> Moderate	<b>FOS<sub>buoyancy</sub></b> 1.75
<b>Stability Design Flow Criteria</b> 50-year	<b>FOS<sub>rotation</sub></b> 1.5

**Resistance to Flotation | 6.4.2**

Flotation is typically caused by the buoyant force and the lift force acting on the wood material from water passing over its surface.

**Large Wood Material Force**

Accounts for the vertical buoyant force of submerged large wood and the vertical weight force of unsubmerged large wood.

$$F_{LWMS} = V_{LWMS} \times (\gamma_{wood} - \gamma_w)$$

$V_{LWMS}$  = total volume of submerged large wood material

$$V_{LWMS} = \sum N_{LWMi} \times V_{LWMi}$$

Variable	Design Value Units
$\gamma_{wood}$ = unit weight of wood	38 lb/ft <sup>3</sup>
$\gamma_w$ = unit weight of water	62.4 lb/ft <sup>3</sup>
$V_{LWMS}$	800 ft <sup>3</sup>

<b><math>F_{LWMS}</math> (lb) 19,513</b>	<i>Positive values are upward forces.</i>
------------------------------------------	-------------------------------------------

**Lift Force**

Accounts for the lift force of large wood in flowing water. Not applicable to LWS where the bed will deform around the leading edges.

$F_L = \frac{C_L \times A_{LWM} \times \gamma_w \times U_o^2}{2 \times g}$	<b>Design Value</b>	<b>Units / Notes</b>
$C_L = \text{lift coefficient}$		0.2 typ. LWM value
$A_{LWM} = \text{area of large woody material perpendicular to flow}$		$A_{LWM} = \text{See Design Plan}$
$U_u = \text{upstream channel velocity at design event}$		<b><math>A_{LWM} \text{ (ft}^2\text{) 40}</math></b> For pre-racking condition
$g = \text{acceleration due to gravity}$		10 ft/s
		32.2 ft/s <sup>2</sup>
<b><math>F_L \text{ (lb)}</math></b>		<b>N/A</b>

**Boulder Ballast Force**

Accounts for the ballasting force of large boulders directly attached to or placed over LWM.

$F_{bouldersub} = N_{bouldersub} \times \pi/6 \times d_{bouldersub}^3 \times (\gamma_{boulder} - \gamma_w)$	<b>Design Value</b>	<b>Units / Notes</b>
$N_{bouldersub} = \text{number of submerged boulders}$		0 number
$d_{bouldersub} = \text{effective diameter of submerged boulders}$		0 ft
$\gamma_{boulder} = \text{unit weight of boulders}$		165 lb/ft <sup>3</sup>
<b><math>F_{bouldersub} \text{ (lb)}</math></b>		<b>N/A</b>

**Backfill Ballast Force**

Accounts for the ballasting force of backfill placed directly over LWM members. Volume is based on the fill area over the log(s) and a the effective cover depth shown on the Drawings.

$F_{backfillsub} = V_{backfillsub} \times (\gamma_s - \gamma_w)$	<b>Design Value</b>	<b>Units / Notes</b>
$V_{backfillsub} = \text{volume of backfill over LWM members}$		3,150 ft <sup>3</sup>
$\gamma_s = \text{unit weight of backfill material}$		See design plans 110 lb/ft <sup>3</sup>
<b><math>F_{backfillsub} \text{ (lb)}</math></b>		<b>-149,940</b>

**Pile Skin Friction**

Accounts for the vertical resistance provided by piles within the LWM structure. USBR document equation modified by Inter-Fluve to match industry pile design standard formulations.

$$F_{piles-v} = N_{piles} \times \pi \times d_{piles} \times L_{piles} \times (k_s \times \tan \frac{2}{3}\theta \times \sigma')$$

	<b>Design Values</b>	<b>Units</b>
$N_{piles}$ = number of piles	0	number
$L_{piles}$ = length of pile embedded below potential scour depth	12	ft
$d_{piles}$ = nominal diameter of the piles	1.30	ft
$\sigma' = (L_{piles} \times (\gamma_{sat} - \gamma_w)) / 2$	285.6	lb/ft <sup>2</sup>
$K_s$ = coefficient of lateral earth pressure (0.5 to 1.0)	1.0	unit less
$\theta$ = internal friction angle of soils	36	deg.

<b><math>F_{piles-v}</math> (lb)</b>	<b>0</b> Negative values resist upward displacement.
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**Piles Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bPiles} = \frac{F_{piles-v}}{F_{LWMS} + F_L}$$

<b><math>FOS_b</math> 0.0</b>
-------------------------------

Note this value does not include the backfill assuming it's all lost but the piles are holding.

**Backfill Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bBackfill} = \frac{F_{backfillsub}}{F_{LWMS} + F_L}$$

<b><math>FOS_b</math> 7.7</b>
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Note this value does not include the piles.

**Net Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bNet} = \frac{F_{backfillsub} + F_{piles-v}}{F_{LWMS} + F_L}$$

<b><math>FOS_b</math> 7.7</b>
-------------------------------

Note this value includes the piles and backfill.

**Resistance to Sliding | 6.4.3**

LWM structures are also susceptible to failure through sliding.

**Drag Force**

LWM structures are pushed downstream by the fluid drag forces acting upon the wood by the flowing water.

	<b>Design Value</b>	<b>Units / Notes</b>
$F_d = \frac{C_D \times A_{LWM} \times \gamma_w \times U_c^2}{2 \times g}$		
$C_D = \text{drag coefficient}$		1 Per Equations 23 and 24
$A_{LWM} = \text{area of wetted wood normal to the flow direction}$		$A_{LWM} = \text{See Design Plan}$
		<b><math>A_{LWM} \text{ (ft}^2\text{)}</math></b> 40
$U_c = \text{velocity adjacent to the LWM structure}$	10	ft/s <i>Velocity value is conservative for all LWS locations. Value from 100-yr event 2D model results for main channel.</i>
$g = \text{acceleration due to gravity}$	32.2	ft/s <sup>2</sup>
<b><math>F_d \text{ (lb)}</math> 3,876</b>		

**Hydrostatic Force**

Hydrostatic forces act on the upstream and downstream faces of a LWM structure. They account for differences in the upstream and downstream water depths against the structure.

$F_{hu} = \frac{1}{2} \times \gamma_w \times Y_u \times A_u$	$F_{hd} = \frac{1}{2} \times \gamma_w \times Y_d \times A_d$	<b>Variable Design Value</b>
		$Y_u \text{ (ft)}$ 7
$F_{hu}, F_{hd} = \text{hydrostatic force on upstream and downstream side of the wood structure}$		$A_u \text{ (ft}^2\text{)}$ 40 Post racking area
$Y_u, Y_d = \text{water depth upstream and downstream of the structure}$		$Y_d \text{ (ft)}$ 7
$A_u, A_d = \text{area projected to flow direction on the upstream and downstream of the structure}$		$A_d \text{ (ft}^2\text{)}$ 40 Plan downstream area
<b><math>F_{hu} + F_{hd} = F_h \text{ (lb)}</math></b>		<b>N/A</b>

**Impact Force**

The impact force associated with debris impacting a large wood structure can be estimated by the impact force equation.

$$F_i = \frac{w_{debris}}{g} \times \frac{V_{channel}^2}{2 \times \Delta x} \times C_i \times C_o \times C_d \times C_b \times R_{max}$$

$w_{debris}$  = weight of debris

$V_{channel}$  = channel approach velocity

$\Delta x$  = deceleration distance

Coefficients (see Table 6 and Figures 11, 12 for values)

$C_i$  = importance,  $C_o$  = orientation = 0.8,  $C_d$  = depth,  $C_b$  = blockage,  $R_{max}$  = impulse response ratio

Variable Design Value	
$W_{debris}$ (lb)	3,774
$V_{channel}$ (ft/s)	10
$\Delta x$ (ft)	5
$C_i$	0.5
$C_o$	0.8
$C_d$	1.0
$C_b$	1.0
$R_{max}$	0.8

<b><math>F_i</math> (lb) 375</b>
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**Friction Force**

Accounts for the friction force between the LWM and the channel bed. Restraint force from piles is not included as it does not exert a pressure on the LWS / bed interface.

$$F_f = -\mu_{bed} \times (F_{LWMS} + F_L + F_{bouldersub} + F_{backfillsub})$$

	Design Value Units / Source
$\mu_{bed}$ = coefficient of bed friction = $\tan(\theta)$	0.78 unit less
$\theta$ = internal friction angle (degrees)	38 Table 5, (Knutson et. al. 2014)

<b><math>F_f</math> (lb) -101,901</b>
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Negative values resist downstream displacement.

**Lateral Resistance From Piles**

Accounts for the lateral resistance provided by piles within the LWM structure. Assumes soil resistance is limiting, i.e. the pile pushes over before it breaks.

$$F_{piles-h} = N_{piles} \times \frac{L_{pile}^3 \times \frac{1}{2} \times (\gamma_s - \gamma_w) \times d_{pile} \times K_p}{h_{load} \times L_{pile}}$$

	Design Values Units
$N_{pile}$ = number of piles	0 number
$L_{pile}$ = length of pile embedded below potential scour depth	12 ft
$d_{pile}$ = diameter of the pile	1.30 ft
$h_{load}$ = applied load height above the potential scour depth	2.5 ft
$K_p = \frac{1 + \sin \theta}{1 - \sin \theta}$	4.2 unit less

<b><math>F_{piles-h}</math> (lb) 0</b>
----------------------------------------

Negative values resist downstream displacement.

**Sliding Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{sliding} = \frac{F_f + F_{piles-h}}{F_d + F_{nu} + F_{hd} + F_i}$$

**FOS<sub>sliding</sub> 24.0**

**Pile Strength Factor of Safety**

The factor of safety for the timber bending stress capacity of the pile. This evaluates the potential for the pile(s) to break under load prior to the pile pushing over in the ground.

			<b>Design Values</b>	<b>Units</b>
$F_b = \text{Timber Bending Stress Capacity}$ per Timber Pile Manual Table 3-1 or AWC NDS Supplement Table 4D			1,200	psi
			172,800	psf
$d_{pile} = \text{diameter of the pile}$			1.30	ft
$I = \text{circular cross - sectional moment of inertia}$	$I = \frac{\pi B^4}{4}$		2.24	ft <sup>4</sup>
$S = \text{circular section modulus}$	$S = \frac{\pi B^3}{32}$		0.216	ft <sup>3</sup>
$C_F = \text{strength reduction size factor}$ for diameters greater than 12"	$C_F = \frac{1}{B}^{(1/9)}$		0.971	--
$M_p = \text{applied moment per pile}$	$M_p = \frac{(F_d + F_i + F_h) \times h_{load}}{N_{piles}}$	#DIV/0!		ft-lb
$f_b = \text{applied pile bending stress}$	$f_b = \frac{M_p}{S}$	#DIV/0!		psf
$F_{bx} = \text{Pile bending stress capacity}$	$F_{bx} = F_b \times C_F$		1,166	psi
			167,835	psf

$$FOS_{pile\ strength} = \frac{F_{bx}}{f_b}$$

**FOS<sub>pile strength</sub> #DIV/0!**

**References**

Large Woody Material - Risk Based Design Guidelines  
 M. Knutson, J. Fealko. 2014. *Large Woody Material - Risk Based Design Guidelines*. U.S. Department of the Interior Bureau of Reclamation Pacific Northwest Region & Technical Services. Boise, Idaho. September 2014. Online at: <http://www.usbr.gov/pn/fcrps/documents/lwm.pdf>

ASTM D25. Allowable Stress Values for Treated Round Timber Piles.

Timber Pile Design and Construction Manual, Timber Piling Council, 2015.

American Wood Council (2018) National Design Specifications for Wood Construction, Design Supplement.

**Nason Floodplain - Large Woody Structure Stability Evaluation**

**Structural Stability | 6.4**

Structural stability of large woody material placements is evaluated herein using the procedures, formulas, and recommendations provided in the Reclamation's *Large Woody Material - Risk Based Design Guidelines* (Knutson et. al. 2014) along with insight gained from professional experience and general engineering judgment.

**Factors of Safety | 6.4.1**

Safety factors for structural stability were selected from *Table 4. Minimum recommended factors of safety* given the site specific public safety and property damage risk levels.

<b>Public Safety Risk</b> Moderate	Criteria: <b>FOS<sub>sliding</sub></b> 1.5
<b>Property Damage Risk</b> Moderate	<b>FOS<sub>buoyancy</sub></b> 1.75
<b>Stability Design Flow Criteria</b> 50-year	<b>FOS<sub>rotation</sub></b> 1.5

**Resistance to Flotation | 6.4.2**

Flotation is typically caused by the buoyant force and the lift force acting on the wood material from water passing over its surface.

**Large Wood Material Force**

Accounts for the vertical buoyant force of submerged large wood and the vertical weight force of unsubmerged large wood.

$$F_{LWMS} = V_{LWMS} \times (\gamma_{wood} - \gamma_w)$$

$V_{LWMS}$  = total volume of submerged large wood material

$$V_{LWMS} = \sum N_{LWMi} \times V_{LWMi}$$

Variable	Design Value Units
$\gamma_{wood}$ = unit weight of wood	38 lb/ft <sup>3</sup>
$\gamma_w$ = unit weight of water	62.4 lb/ft <sup>3</sup>
$V_{LWMS}$	275 ft <sup>3</sup>

<b><math>F_{LWMS}</math> (lb) 6,700</b>	<i>Positive values are upward forces.</i>
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**Lift Force**

Accounts for the lift force of large wood in flowing water. Not applicable to LWS where the bed will deform around the leading edges.

$F_L = \frac{C_L \times A_{LWM} \times \gamma_w \times U_o^2}{2 \times g}$	<b>Design Value</b>	<b>Units / Notes</b>
$C_L = \text{lift coefficient}$		0.2 typ. LWM value
$A_{LWM} = \text{area of large woody material perpendicular to flow}$		$A_{LWM} = \text{See Design Plan}$
$U_u = \text{upstream channel velocity at design event}$		<b><math>A_{LWM} \text{ (ft}^2\text{) 30}</math></b> For pre-racking condition
$g = \text{acceleration due to gravity}$		4 ft/s
		32.2 ft/s <sup>2</sup>
	<b><math>F_L \text{ (lb)}</math></b>	<b>N/A</b>

**Boulder Ballast Force**

Accounts for the ballasting force of large boulders directly attached to or placed over LWM.

$F_{bouldersub} = N_{bouldersub} \times \pi/6 \times d_{bouldersub}^3 \times (\gamma_{boulder} - \gamma_w)$	<b>Design Value</b>	<b>Units / Notes</b>
$N_{bouldersub} = \text{number of submerged boulders}$		0 number
$d_{bouldersub} = \text{effective diameter of submerged boulders}$		0 ft
$\gamma_{boulder} = \text{unit weight of boulders}$		165 lb/ft <sup>3</sup>
	<b><math>F_{bouldersub} \text{ (lb)}</math></b>	<b>N/A</b>

**Backfill Ballast Force**

Accounts for the ballasting force of backfill placed directly over LWM members. Volume is based on the fill area over the log(s) and a the effective cover depth shown on the Drawings.

$F_{backfillsub} = V_{backfillsub} \times (\gamma_s - \gamma_w)$	<b>Design Value</b>	<b>Units / Notes</b>
$V_{backfillsub} = \text{volume of backfill over LWM members}$		630 ft <sup>3</sup>
$\gamma_s = \text{unit weight of backfill material}$		See design plans 110 lb/ft <sup>3</sup>
	<b><math>F_{backfillsub} \text{ (lb)}</math></b>	<b>-29,988</b>

**Pile Skin Friction**

Accounts for the vertical resistance provided by piles within the LWM structure. USBR document equation modified by Inter-Fluve to match industry pile design standard formulations.

$$F_{piles-v} = N_{piles} \times \pi \times d_{piles} \times L_{piles} \times (k_s \times \tan \frac{2}{3}\theta \times \sigma')$$

	<b>Design Values</b>	<b>Units</b>
$N_{piles}$ = number of piles	1.5	number
$L_{piles}$ = length of pile embedded below potential scour depth	12	ft
$d_{piles}$ = nominal diameter of the piles	1.30	ft
$\sigma' = (L_{piles} \times (\gamma_{sat} - \gamma_w)) / 2$	285.6	lb/ft <sup>2</sup>
$K_s$ = coefficient of lateral earth pressure (0.5 to 1.0)	1.0	unit less
$\theta$ = internal friction angle of soils	36	deg.
<b><math>F_{piles-v}</math> (lb)</b>		<b>-9,348</b> Negative values resist upward displacement.

**Piles Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bPiles} = \frac{F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 1.4**

Note this value does not include the backfill assuming it's all lost but the piles are holding.

**Backfill Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bBackfill} = \frac{F_{backfillsub}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 4.5**

Note this value does not include the piles.

**Net Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bNet} = \frac{F_{backfillsub} + F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 5.9**

Note this value includes the piles and backfill.

**Resistance to Sliding | 6.4.3**

LWM structures are also susceptible to failure through sliding.

**Drag Force**

LWM structures are pushed downstream by the fluid drag forces acting upon the wood by the flowing water.

	Design Value	Units / Notes
$F_d = \frac{C_D \times A_{LWM} \times \gamma_w \times U_c^2}{2 \times g}$		
$C_D = \text{drag coefficient}$		1 Per Equations 23 and 24
$A_{LWM} = \text{area of wetted wood normal to the flow direction}$		$A_{LWM} = \text{See Design Plan}$
		<b><math>A_{LWM} \text{ (ft}^2\text{)}</math> 30</b>
$U_c = \text{velocity adjacent to the LWM structure}$		Velocity value is conservative for all LWS locations. Value from 100-yr event 2D model results for main channel.
		4 ft/s
$g = \text{acceleration due to gravity}$		32.2 ft/s <sup>2</sup>
<b><math>F_d \text{ (lb)}</math> 465</b>		

**Hydrostatic Force**

Hydrostatic forces act on the upstream and downstream faces of a LWM structure. They account for differences in the upstream and downstream water depths against the structure.

$F_{hu} = \frac{1}{2} \times \gamma_w \times Y_u \times A_u$	$F_{hd} = \frac{1}{2} \times \gamma_w \times Y_d \times A_d$	<b>Variable Design Value</b>
		Y <sub>u</sub> (ft) 5
$F_{hu}, F_{hd} = \text{hydrostatic force on upstream and downstream side of the wood structure}$		A <sub>u</sub> (ft <sup>2</sup> ) 30
		Post racking area
$Y_u, Y_d = \text{water depth upstream and downstream of the structure}$		Y <sub>d</sub> (ft) 5
		A <sub>d</sub> (ft <sup>2</sup> ) 30
$A_u, A_d = \text{area projected to flow direction on the upstream and downstream of the structure}$		Plan downstream area
<b><math>F_{hu} + F_{hd} = F_h \text{ (lb)}</math></b>		<b>N/A</b>

**Impact Force**

The impact force associated with debris impacting a large wood structure can be estimated by the impact force equation.

$$F_i = \frac{w_{debris}}{g} \times \frac{V_{channel}^2}{2 \times \Delta x} \times C_i \times C_o \times C_d \times C_b \times R_{max}$$

$w_{debris}$  = weight of debris

$V_{channel}$  = channel approach velocity

$\Delta x$  = deceleration distance

Coefficients (see Table 6 and Figures 11, 12 for values)

$C_i$  = importance,  $C_o$  = orientation = 0.8,  $C_d$  = depth,  $C_b$  = blockage,  $R_{max}$  = impulse response ratio

Variable Design Value	
$w_{debris}$ (lb)	3,774
$V_{channel}$ (ft/s)	4
$\Delta x$ (ft)	5
$C_i$	0.5
$C_o$	0.8
$C_d$	1.0
$C_b$	1.0
$R_{max}$	0.8

<b><math>F_i</math> (lb) 60</b>
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**Friction Force**

Accounts for the friction force between the LWM and the channel bed. Restraint force from piles is not included as it does not exert a pressure on the LWS / bed interface.

$$F_f = -\mu_{bed} \times (F_{LWMS} + F_L + F_{bouldersub} + F_{backfillsub})$$

	Design Value Units / Source
$\mu_{bed}$ = coefficient of bed friction = $\tan(\theta)$	0.78 unit less
$\theta$ = internal friction angle (degrees)	38 Table 5, (Knutson et. al. 2014)

<b><math>F_f</math> (lb) -18,194</b>
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Negative values resist downstream displacement.

**Lateral Resistance From Piles**

Accounts for the lateral resistance provided by piles within the LWM structure. Assumes soil resistance is limiting, i.e. the pile pushes over before it breaks.

$$F_{piles-h} = N_{piles} \times \frac{L_{pile}^3 \times \frac{1}{2} \times (\gamma_s - \gamma_w) \times d_{pile} \times K_p}{h_{load} \times L_{pile}}$$

	Design Values Units
$N_{pile}$ = number of piles	1.5 number
$L_{pile}$ = length of pile embedded below potential scour depth	12 ft
$d_{pile}$ = diameter of the pile	1.30 ft
$h_{load}$ = applied load height above the potential scour depth	2.5 ft
$K_p = \frac{1 + \sin \theta}{1 - \sin \theta}$	4.2 unit less

<b><math>F_{piles-h}</math> (lb) -11,238</b>
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Negative values resist downstream displacement.

**Sliding Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{sliding} = \frac{F_f + F_{piles-h}}{F_d + F_{nu} + F_{hd} + F_i}$$

**FOS<sub>sliding</sub> 56.1**

**Pile Strength Factor of Safety**

The factor of safety for the timber bending stress capacity of the pile. This evaluates the potential for the pile(s) to break under load prior to the pile pushing over in the ground.

	<b>Design Values</b>	<b>Units</b>
$F_b =$ Timber Bending Stress Capacity per Timber Pile Manual Table 3-1 or AWC NDS Supplement Table 4D	1,200	psi
	172,800	psf
$d_{pile} =$ diameter of the pile	1.30	ft
$I =$ circular cross – sectional moment of inertia	$I = \frac{\pi B^4}{4}$	2.24 ft <sup>4</sup>
$S =$ circular section modulus	$S = \frac{\pi B^3}{32}$	0.216 ft <sup>3</sup>
$C_F =$ strength reduction size factor for diameters greater than 12"	$C_F = \frac{1}{B}^{(1/9)}$	0.971 --
$M_p =$ applied moment per pile	$M_p = \frac{(F_d + F_i + F_h) \times h_{load}}{N_{piles}}$	875 ft-lb
$f_b =$ applied pile bending stress	$f_b = \frac{M_p}{S}$	4,058 psf
$F_{bx} =$ Pile bending stress capacity	$F_{bx} = F_b \times C_F$	1,166 psi 167,835 psf
$FOS_{pile\ strength} = \frac{F_{bx}}{f_b}$	<b>FOS<sub>pile strength</sub> 41.4</b>	

**References**

Large Woody Material - Risk Based Design Guidelines  
 M. Knutson, J. Fealko. 2014. *Large Woody Material - Risk Based Design Guidelines*. U.S. Department of the Interior Bureau of Reclamation Pacific Northwest Region & Technical Services. Boise, Idaho. September 2014. Online at: <http://www.usbr.gov/pn/fcrps/documents/lwm.pdf>

ASTM D25. Allowable Stress Values for Treated Round Timber Piles.

Timber Pile Design and Construction Manual, Timber Piling Council, 2015.

American Wood Council (2018) National Design Specifications for Wood Construction, Design Supplement.

**Nason Floodplain - Large Woody Structure Stability Evaluation**

**Structural Stability | 6.4**

Structural stability of large woody material placements is evaluated herein using the procedures, formulas, and recommendations provided in the Reclamation's *Large Woody Material - Risk Based Design Guidelines* (Knutson et. al. 2014) along with insight gained from professional experience and general engineering judgment.

**Factors of Safety | 6.4.1**

Safety factors for structural stability were selected from *Table 4. Minimum recommended factors of safety* given the site specific public safety and property damage risk levels.

<b>Public Safety Risk</b> Moderate	Criteria: <b>FOS<sub>sliding</sub></b> 1.5
<b>Property Damage Risk</b> Moderate	<b>FOS<sub>buoyancy</sub></b> 1.75
<b>Stability Design Flow Criteria</b> 50-year	<b>FOS<sub>rotation</sub></b> 1.5

**Resistance to Flotation | 6.4.2**

Flotation is typically caused by the buoyant force and the lift force acting on the wood material from water passing over its surface.

**Large Wood Material Force**

Accounts for the vertical buoyant force of submerged large wood and the vertical weight force of unsubmerged large wood.

$$F_{LWMS} = V_{LWMS} \times (\gamma_{wood} - \gamma_w)$$

$V_{LWMS}$  = total volume of submerged large wood material

$$V_{LWMS} = \sum N_{LWMi} \times V_{LWMi}$$

Variable	Design Value Units
$\gamma_{wood}$ = unit weight of wood	38 lb/ft <sup>3</sup>
$\gamma_w$ = unit weight of water	62.4 lb/ft <sup>3</sup>
$V_{LWMS}$	1005 ft <sup>3</sup>

<b><math>F_{LWMS}</math> (lb) 24,527</b>	<i>Positive values are upward forces.</i>
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**Lift Force**

Accounts for the lift force of large wood in flowing water. Not applicable to LWS where the bed will deform around the leading edges.

$F_L = \frac{C_L \times A_{LWM} \times \gamma_w \times U_o^2}{2 \times g}$	<b>Design Value</b>	<b>Units / Notes</b>
$C_L = \text{lift coefficient}$		0.2 typ. LWM value
$A_{LWM} = \text{area of large woody material perpendicular to flow}$		$A_{LWM} = \text{See Design Plan}$
$U_u = \text{upstream channel velocity at design event}$		<b><math>A_{LWM} \text{ (ft}^2\text{) 80}</math></b> For pre-racking condition
$g = \text{acceleration due to gravity}$		5 ft/s
		32.2 ft/s <sup>2</sup>
<b><math>F_L \text{ (lb)}</math></b>		<b>N/A</b>

**Boulder Ballast Force**

Accounts for the ballasting force of large boulders directly attached to or placed over LWM.

$F_{bouldersub} = N_{bouldersub} \times \pi/6 \times d_{bouldersub}^3 \times (\gamma_{boulder} - \gamma_w)$	<b>Design Value</b>	<b>Units / Notes</b>
$N_{bouldersub} = \text{number of submerged boulders}$		0 number
$d_{bouldersub} = \text{effective diameter of submerged boulders}$		0 ft
$\gamma_{boulder} = \text{unit weight of boulders}$		165 lb/ft <sup>3</sup>
<b><math>F_{bouldersub} \text{ (lb)}</math></b>		<b>N/A</b>

**Backfill Ballast Force**

Accounts for the ballasting force of backfill placed directly over LWM members. Volume is based on the fill area over the log(s) and a the effective cover depth shown on the Drawings.

$F_{backfillsub} = V_{backfillsub} \times (\gamma_s - \gamma_w)$	<b>Design Value</b>	<b>Units / Notes</b>
$V_{backfillsub} = \text{volume of backfill over LWM members}$		3,150 ft <sup>3</sup>
$\gamma_s = \text{unit weight of backfill material}$		See design plans 110 lb/ft <sup>3</sup>
<b><math>F_{backfillsub} \text{ (lb)}</math></b>		<b>-149,940</b>

**Pile Skin Friction**

Accounts for the vertical resistance provided by piles within the LWM structure. USBR document equation modified by Inter-Fluve to match industry pile design standard formulations.

$$F_{piles-v} = N_{piles} \times \pi \times d_{piles} \times L_{piles} \times (k_s \times \tan \frac{2}{3}\theta \times \sigma')$$

	<b>Design Values</b>	<b>Units</b>
$N_{piles}$ = number of piles	9	number
$L_{piles}$ = length of pile embedded below potential scour depth	12	ft
$d_{piles}$ = nominal diameter of the piles	1.30	ft
$\sigma' = (L_{piles} \times (\gamma_{sat} - \gamma_w)) / 2$	285.6	lb/ft <sup>2</sup>
$K_s$ = coefficient of lateral earth pressure (0.5 to 1.0)	1.0	unit less
$\theta$ = internal friction angle of soils	36	deg.
<b><math>F_{piles-v}</math> (lb)</b>		<b>-56,086</b>

Negative values resist upward displacement.

**Piles Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bPiles} = \frac{F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 2.3**

Note this value does not include the backfill assuming it's all lost but the piles are holding.

**Backfill Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bBackfill} = \frac{F_{backfillsub}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 6.1**

Note this value does not include the piles.

**Net Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bNet} = \frac{F_{backfillsub} + F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 8.4**

Note this value includes the piles and backfill.

**Resistance to Sliding | 6.4.3**

LWM structures are also susceptible to failure through sliding.

**Drag Force**

LWM structures are pushed downstream by the fluid drag forces acting upon the wood by the flowing water.

	Design Value	Units / Notes
$F_d = \frac{C_D \times A_{LWM} \times \gamma_w \times U_c^2}{2 \times g}$		
$C_D = \text{drag coefficient}$		1 Per Equations 23 and 24
$A_{LWM} = \text{area of wetted wood normal to the flow direction}$		$A_{LWM} = \text{See Design Plan}$
		<b><math>A_{LWM} \text{ (ft}^2\text{)}</math> 80</b>
$U_c = \text{velocity adjacent to the LWM structure}$		5 ft/s
		Velocity value is conservative for all LWS locations. Value from 100-yr event 2D model results for main channel.
$g = \text{acceleration due to gravity}$		32.2 ft/s <sup>2</sup>
<b><math>F_d \text{ (lb)}</math> 1,938</b>		

**Hydrostatic Force**

Hydrostatic forces act on the upstream and downstream faces of a LWM structure. They account for differences in the upstream and downstream water depths against the structure.

$F_{hu} = \frac{1}{2} \times \gamma_w \times Y_u \times A_u$	$F_{hd} = \frac{1}{2} \times \gamma_w \times Y_d \times A_d$	<b>Variable Design Value</b>
		$Y_u \text{ (ft)}$ 6.5
$F_{hu}, F_{hd} = \text{hydrostatic force on upstream and downstream side of the wood structure}$		$A_u \text{ (ft}^2\text{)}$ 80
		Post racking area
$Y_u, Y_d = \text{water depth upstream and downstream of the structure}$		$Y_d \text{ (ft)}$ 6.5
		$A_d \text{ (ft}^2\text{)}$ 80
		Plan downstream area
<b><math>F_{hu} + F_{hd} = F_h \text{ (lb)}</math></b>		<b>N/A</b>

**Impact Force**

The impact force associated with debris impacting a large wood structure can be estimated by the impact force equation.

$$F_i = \frac{w_{debris}}{g} \times \frac{V_{channel}^2}{2 \times \Delta x} \times C_i \times C_o \times C_d \times C_b \times R_{max}$$

$w_{debris}$  = weight of debris

$V_{channel}$  = channel approach velocity

$\Delta x$  = deceleration distance

Coefficients (see Table 6 and Figures 11, 12 for values)

$C_i$  = importance,  $C_o$  = orientation = 0.8,  $C_d$  = depth,  $C_b$  = blockage,  $R_{max}$  = impulse response ratio

Variable Design Value	
$W_{debris}$ (lb)	3,774
$V_{channel}$ (ft/s)	5
$\Delta x$ (ft)	5
$C_i$	0.5
$C_o$	0.8
$C_d$	1.0
$C_b$	1.0
$R_{max}$	0.8

<b><math>F_i</math> (lb) 94</b>
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**Friction Force**

Accounts for the friction force between the LWM and the channel bed. Restraint force from piles is not included as it does not exert a pressure on the LWS / bed interface.

$$F_f = -\mu_{bed} \times (F_{LWMS} + F_L + F_{bouldersub} + F_{backfillsub})$$

	Design Value Units / Source
$\mu_{bed}$ = coefficient of bed friction = $\tan(\theta)$	0.78 unit less
$\theta$ = internal friction angle (degrees)	38 Table 5, (Knutson et. al. 2014)

<b><math>F_f</math> (lb) -97,983</b>
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Negative values resist downstream displacement.

**Lateral Resistance From Piles**

Accounts for the lateral resistance provided by piles within the LWM structure. Assumes soil resistance is limiting, i.e. the pile pushes over before it breaks.

$$F_{piles-h} = N_{piles} \times \frac{L_{pile}^3 \times \frac{1}{2} \times (\gamma_s - \gamma_w) \times d_{pile} \times K_p}{h_{load} \times L_{pile}}$$

	Design Values Units
$N_{pile}$ = number of piles	9 number
$L_{pile}$ = length of pile embedded below potential scour depth	12 ft
$d_{pile}$ = diameter of the pile	1.30 ft
$h_{load}$ = applied load height above the potential scour depth	2.5 ft
$K_p = \frac{1 + \sin \theta}{1 - \sin \theta}$	4.2 unit less

<b><math>F_{piles-h}</math> (lb) -67,425</b>
----------------------------------------------

Negative values resist downstream displacement.

**Sliding Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{sliding} = \frac{F_f + F_{piles-h}}{F_d + F_{nu} + F_{hd} + F_i}$$

**FOS<sub>sliding</sub> 81.4**

**Pile Strength Factor of Safety**

The factor of safety for the timber bending stress capacity of the pile. This evaluates the potential for the pile(s) to break under load prior to the pile pushing over in the ground.

		<b>Design Values Units</b>
$F_b = \text{Timber Bending Stress Capacity}$ per Timber Pile Manual Table 3-1 or AWC NDS Supplement Table 4D		1,200 psi 172,800 psf
$d_{pile} = \text{diameter of the pile}$		1.30 ft
$I = \text{circular cross – sectional moment of inertia}$	$I = \frac{\pi B^4}{4}$	2.24 ft <sup>4</sup>
$S = \text{circular section modulus}$	$S = \frac{\pi B^3}{32}$	0.216 ft <sup>3</sup>
$C_F = \text{strength reduction size factor}$ for diameters greater than 12"	$C_F = \frac{1}{B}^{(1/9)}$	0.971 --
$M_p = \text{applied moment per pile}$	$M_p = \frac{(F_d + F_i + F_h) \times h_{load}}{N_{piles}}$	564 ft-lb
$f_b = \text{applied pile bending stress}$	$f_b = \frac{M_p}{S}$	2,616 psf
$F_{bx} = \text{Pile bending stress capacity}$	$F_{bx} = F_b \times C_F$	1,166 psi 167,835 psf
$FOS_{pile\ strength} = \frac{F_{bx}}{f_b}$		
		<b>FOS<sub>pile strength</sub> 64.1</b>

**References**

Large Woody Material - Risk Based Design Guidelines  
M. Knutson, J. Fealko. 2014. *Large Woody Material - Risk Based Design Guidelines*. U.S. Department of the Interior Bureau of Reclamation Pacific Northwest Region & Technical Services. Boise, Idaho. September 2014. Online at: <http://www.usbr.gov/pn/fcrps/documents/lwm.pdf>

ASTM D25. Allowable Stress Values for Treated Round Timber Piles.

Timber Pile Design and Construction Manual, Timber Piling Council, 2015.

American Wood Council (2018) National Design Specifications for Wood Construction, Design Supplement.

**Nason Floodplain - Large Woody Structure Stability Evaluation**

**Structural Stability | 6.4**

Structural stability of large woody material placements is evaluated herein using the procedures, formulas, and recommendations provided in the Reclamation's *Large Woody Material - Risk Based Design Guidelines* (Knutson et. al. 2014) along with insight gained from professional experience and general engineering judgment.

**Factors of Safety | 6.4.1**

Safety factors for structural stability were selected from *Table 4. Minimum recommended factors of safety* given the site specific public safety and property damage risk levels.

<b>Public Safety Risk</b> Moderate	Criteria: <b>FOS<sub>sliding</sub></b> 1.5
<b>Property Damage Risk</b> Moderate	<b>FOS<sub>buoyancy</sub></b> 1.75
<b>Stability Design Flow Criteria</b> 50-year	<b>FOS<sub>rotation</sub></b> 1.5

**Resistance to Flotation | 6.4.2**

Flotation is typically caused by the buoyant force and the lift force acting on the wood material from water passing over its surface.

**Large Wood Material Force**

Accounts for the vertical buoyant force of submerged large wood and the vertical weight force of unsubmerged large wood.

$$F_{LWMS} = V_{LWMS} \times (\gamma_{wood} - \gamma_w)$$

$V_{LWMS}$  = total volume of submerged large wood material

$$V_{LWMS} = \sum N_{LWMi} \times V_{LWMi}$$

Variable	Design Value Units
$\gamma_{wood}$ = unit weight of wood	38 lb/ft <sup>3</sup>
$\gamma_w$ = unit weight of water	62.4 lb/ft <sup>3</sup>
$V_{LWMS}$	458 ft <sup>3</sup>

<b><math>F_{LWMS}</math> (lb) 11,165</b>	<i>Positive values are upward forces.</i>
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**Lift Force**

Accounts for the lift force of large wood in flowing water. Not applicable to LWS where the bed will deform around the leading edges.

$F_L = \frac{C_L \times A_{LWM} \times \gamma_w \times U_o^2}{2 \times g}$	<b>Design Value</b>	<b>Units / Notes</b>
$C_L = \text{lift coefficient}$		0.2 typ. LWM value
$A_{LWM} = \text{area of large woody material perpendicular to flow}$		$A_{LWM} = \text{See Design Plan}$
$U_u = \text{upstream channel velocity at design event}$		<b><math>A_{LWM} \text{ (ft}^2\text{) 70}</math></b> For pre-racking condition
$g = \text{acceleration due to gravity}$		5 ft/s
		32.2 ft/s <sup>2</sup>
<b><math>F_L \text{ (lb)}</math></b>		<b>N/A</b>

**Boulder Ballast Force**

Accounts for the ballasting force of large boulders directly attached to or placed over LWM.

$F_{bouldersub} = N_{bouldersub} \times \pi/6 \times d_{bouldersub}^3 \times (\gamma_{boulder} - \gamma_w)$	<b>Design Value</b>	<b>Units / Notes</b>
$N_{bouldersub} = \text{number of submerged boulders}$		0 number
$d_{bouldersub} = \text{effective diameter of submerged boulders}$		0 ft
$\gamma_{boulder} = \text{unit weight of boulders}$		165 lb/ft <sup>3</sup>
<b><math>F_{bouldersub} \text{ (lb)}</math></b>		<b>N/A</b>

**Backfill Ballast Force**

Accounts for the ballasting force of backfill placed directly over LWM members. Volume is based on the fill area over the log(s) and a the effective cover depth shown on the Drawings.

$F_{backfillsub} = V_{backfillsub} \times (\gamma_s - \gamma_w)$	<b>Design Value</b>	<b>Units / Notes</b>
$V_{backfillsub} = \text{volume of backfill over LWM members}$		1,125 ft <sup>3</sup>
$\gamma_s = \text{unit weight of backfill material}$		See design plans 110 lb/ft <sup>3</sup>
<b><math>F_{backfillsub} \text{ (lb)}</math></b>		<b>-53,550</b>

**Pile Skin Friction**

Accounts for the vertical resistance provided by piles within the LWM structure. USBR document equation modified by Inter-Fluve to match industry pile design standard formulations.

$$F_{piles-v} = N_{piles} \times \pi \times d_{piles} \times L_{piles} \times (k_s \times \tan \frac{2}{3}\theta \times \sigma')$$

	<b>Design Values</b>	<b>Units</b>
$N_{piles}$ = number of piles	3.75	number
$L_{piles}$ = length of pile embedded below potential scour depth	12	ft
$d_{piles}$ = nominal diameter of the piles	1.30	ft
$\sigma' = (L_{piles} \times (\gamma_{sat} - \gamma_w)) / 2$	285.6	lb/ft <sup>2</sup>
$K_s$ = coefficient of lateral earth pressure (0.5 to 1.0)	1.0	unit less
$\theta$ = internal friction angle of soils	36	deg.
<b><math>F_{piles-v}</math> (lb)</b>		<b>-23,369</b>

Negative values resist upward displacement.

**Piles Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bPiles} = \frac{F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 2.1**

Note this value does not include the backfill assuming it's all lost but the piles are holding.

**Backfill Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bBackfill} = \frac{F_{backfillsub}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 4.8**

Note this value does not include the piles.

**Net Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bNet} = \frac{F_{backfillsub} + F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 6.9**

Note this value includes the piles and backfill.

**Resistance to Sliding | 6.4.3**

LWM structures are also susceptible to failure through sliding.

**Drag Force**

LWM structures are pushed downstream by the fluid drag forces acting upon the wood by the flowing water.

	Design Value	Units / Notes
$F_d = \frac{C_D \times A_{LWM} \times \gamma_w \times U_c^2}{2 \times g}$		
$C_D = \text{drag coefficient}$		1 Per Equations 23 and 24
$A_{LWM} = \text{area of wetted wood normal to the flow direction}$		$A_{LWM} = \text{See Design Plan}$
		<b><math>A_{LWM} \text{ (ft}^2\text{)}</math></b> 70
$U_c = \text{velocity adjacent to the LWM structure}$		Velocity value is conservative for all LWS locations. Value from 100-yr event 2D model results for main channel.
		5 ft/s
$g = \text{acceleration due to gravity}$		32.2 ft/s <sup>2</sup>
<b><math>F_d \text{ (lb)}</math> 1,696</b>		

**Hydrostatic Force**

Hydrostatic forces act on the upstream and downstream faces of a LWM structure. They account for differences in the upstream and downstream water depths against the structure.

$F_{hu} = \frac{1}{2} \times \gamma_w \times Y_u \times A_u$	$F_{hd} = \frac{1}{2} \times \gamma_w \times Y_d \times A_d$	<b>Variable Design Value</b>
		Y <sub>u</sub> (ft) 4
$F_{hu}, F_{hd} = \text{hydrostatic force on upstream and downstream side of the wood structure}$		A <sub>u</sub> (ft <sup>2</sup> ) 70
		Post racking area
$Y_u, Y_d = \text{water depth upstream and downstream of the structure}$		Y <sub>d</sub> (ft) 4
		A <sub>d</sub> (ft <sup>2</sup> ) 70
$A_u, A_d = \text{area projected to flow direction on the upstream and downstream of the structure}$		Plan downstream area
<b><math>F_{hu} + F_{hd} = F_h \text{ (lb)}</math></b>		N/A

**Impact Force**

The impact force associated with debris impacting a large wood structure can be estimated by the impact force equation.

$$F_i = \frac{w_{debris}}{g} \times \frac{V_{channel}^2}{2 \times \Delta x} \times C_i \times C_o \times C_d \times C_b \times R_{max}$$

$w_{debris}$  = weight of debris

$V_{channel}$  = channel approach velocity

$\Delta x$  = deceleration distance

Coefficients (see Table 6 and Figures 11, 12 for values)

$C_i$  = importance,  $C_o$  = orientation = 0.8,  $C_d$  = depth,  $C_b$  = blockage,  $R_{max}$  = impulse response ratio

Variable Design Value	
$W_{debris}$ (lb)	3,774
$V_{channel}$ (ft/s)	5
$\Delta x$ (ft)	5
$C_i$	0.5
$C_o$	0.8
$C_d$	1.0
$C_b$	1.0
$R_{max}$	0.8

<b><math>F_i</math> (lb) 94</b>
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**Friction Force**

Accounts for the friction force between the LWM and the channel bed. Restraint force from piles is not included as it does not exert a pressure on the LWS / bed interface.

$$F_f = -\mu_{bed} \times (F_{LWMS} + F_L + F_{bouldersub} + F_{backfillsub})$$

	Design Value Units / Source
$\mu_{bed}$ = coefficient of bed friction = $\tan(\theta)$	0.78 unit less
$\theta$ = internal friction angle (degrees)	38 Table 5, (Knutson et. al. 2014)

<b><math>F_f</math> (lb) -33,115</b>
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Negative values resist downstream displacement.

**Lateral Resistance From Piles**

Accounts for the lateral resistance provided by piles within the LWM structure. Assumes soil resistance is limiting, i.e. the pile pushes over before it breaks.

$$F_{piles-h} = N_{piles} \times \frac{L_{pile}^3 \times \frac{1}{2} \times (\gamma_s - \gamma_w) \times d_{pile} \times K_p}{h_{load} \times L_{pile}}$$

	Design Values Units
$N_{pile}$ = number of piles	3.75 number
$L_{pile}$ = length of pile embedded below potential scour depth	12 ft
$d_{pile}$ = diameter of the pile	1.30 ft
$h_{load}$ = applied load height above the potential scour depth	2.5 ft
$K_p = \frac{1 + \sin \theta}{1 - \sin \theta}$	4.2 unit less

<b><math>F_{piles-h}</math> (lb) -28,094</b>
----------------------------------------------

Negative values resist downstream displacement.

**Sliding Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{sliding} = \frac{F_f + F_{piles-h}}{F_d + F_{nu} + F_{hd} + F_i}$$

**FOS<sub>sliding</sub> 34.2**

**Pile Strength Factor of Safety**

The factor of safety for the timber bending stress capacity of the pile. This evaluates the potential for the pile(s) to break under load prior to the pile pushing over in the ground.

		<b>Design Values Units</b>
$F_b = \text{Timber Bending Stress Capacity}$ per Timber Pile Manual Table 3-1 or AWC NDS Supplement Table 4D		1,200 psi 172,800 psf
$d_{pile} = \text{diameter of the pile}$		1.30 ft
$I = \text{circular cross – sectional moment of inertia}$	$I = \frac{\pi B^4}{4}$	2.24 ft <sup>4</sup>
$S = \text{circular section modulus}$	$S = \frac{\pi B^3}{32}$	0.216 ft <sup>3</sup>
$C_F = \text{strength reduction size factor}$ for diameters greater than 12"	$C_F = \frac{1}{B}^{(1/9)}$	0.971 --
$M_p = \text{applied moment per pile}$	$M_p = \frac{(F_d + F_i + F_h) \times h_{load}}{N_{piles}}$	1,193 ft-lb
$f_b = \text{applied pile bending stress}$	$f_b = \frac{M_p}{S}$	5,531 psf
$F_{bx} = \text{Pile bending stress capacity}$	$F_{bx} = F_b \times C_F$	1,166 psi 167,835 psf
$FOS_{pile\ strength} = \frac{F_{bx}}{f_b}$		<b>FOS<sub>pile strength</sub> 30.3</b>

**References**

Large Woody Material - Risk Based Design Guidelines  
 M. Knutson, J. Fealko. 2014. *Large Woody Material - Risk Based Design Guidelines*. U.S. Department of the Interior Bureau of Reclamation Pacific Northwest Region & Technical Services. Boise, Idaho. September 2014. Online at: <http://www.usbr.gov/pn/fcrps/documents/lwm.pdf>

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American Wood Council (2018) National Design Specifications for Wood Construction, Design Supplement.

**Nason Floodplain - Large Woody Structure Stability Evaluation**

**Structural Stability | 6.4**

Structural stability of large woody material placements is evaluated herein using the procedures, formulas, and recommendations provided in the Reclamation's *Large Woody Material - Risk Based Design Guidelines* (Knutson et. al. 2014) along with insight gained from professional experience and general engineering judgment.

**Factors of Safety | 6.4.1**

Safety factors for structural stability were selected from *Table 4. Minimum recommended factors of safety* given the site specific public safety and property damage risk levels.

<b>Public Safety Risk</b> Moderate	Criteria: <b>FOS<sub>sliding</sub></b> 1.5
<b>Property Damage Risk</b> Moderate	<b>FOS<sub>buoyancy</sub></b> 1.75
<b>Stability Design Flow Criteria</b> 50-year	<b>FOS<sub>rotation</sub></b> 1.5

**Resistance to Flotation | 6.4.2**

Flotation is typically caused by the buoyant force and the lift force acting on the wood material from water passing over its surface.

**Large Wood Material Force**

Accounts for the vertical buoyant force of submerged large wood and the vertical weight force of unsubmerged large wood.

$$F_{LWMS} = V_{LWMS} \times (\gamma_{wood} - \gamma_w)$$

$V_{LWMS}$  = total volume of submerged large wood material

$$V_{LWMS} = \sum N_{LWMi} \times V_{LWMi}$$

Variable	Design Value Units
$\gamma_{wood}$ = unit weight of wood	38 lb/ft <sup>3</sup>
$\gamma_w$ = unit weight of water	62.4 lb/ft <sup>3</sup>
$V_{LWMS}$	1525 ft <sup>3</sup>

<b><math>F_{LWMS}</math> (lb) 37,215</b>	<i>Positive values are upward forces.</i>
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**Lift Force**

Accounts for the lift force of large wood in flowing water. Not applicable to LWS where the bed will deform around the leading edges.

$$F_L = \frac{C_L \times A_{LWM} \times \gamma_w \times U_o^2}{2 \times g}$$

	<b>Design Value</b>	<b>Units / Notes</b>
$C_L =$ lift coefficient	0.2	typ. LWM value
$A_{LWM} =$ area of large woody material perpendicular to flow		$A_{LWM} =$ See Design Plan
$U_u =$ upstream channel velocity at design event	6	ft/s
$g =$ acceleration due to gravity	32.2	ft/s <sup>2</sup>
<b><math>F_L</math> (lb)</b>		<b>N/A</b>

**Boulder Ballast Force**

Accounts for the ballasting force of large boulders directly attached to or placed over LWM.

$$F_{bouldersub} = N_{bouldersub} \times \pi/6 \times d_{bouldersub}^3 \times (\gamma_{boulder} - \gamma_w)$$

	<b>Design Value</b>	<b>Units / Notes</b>
$N_{bouldersub} =$ number of submerged boulders	0	number
$d_{bouldersub} =$ effective diameter of submerged boulders	0	ft
$\gamma_{boulder} =$ unit weight of boulders		165 lb/ft <sup>3</sup>
<b><math>F_{bouldersub}</math> (lb)</b>		<b>N/A</b>

**Backfill Ballast Force**

Accounts for the ballasting force of backfill placed directly over LWM members. Volume is based on the fill area over the log(s) and a the effective cover depth shown on the Drawings.

$$F_{backfillsub} = V_{backfillsub} \times (\gamma_s - \gamma_w)$$

	<b>Design Value</b>	<b>Units / Notes</b>
$V_{backfillsub} =$ volume of backfill over LWM members	6,939	ft <sup>3</sup>
$\gamma_s =$ unit weight of backfill material		See design plans 110 lb/ft <sup>3</sup>
<b><math>F_{backfillsub}</math> (lb)</b>		<b>-330,296</b>

***Pile Skin Friction***

Accounts for the vertical resistance provided by piles within the LWM structure. USBR document equation modified by Inter-Fluve to match industry pile design standard formulations.

$$F_{piles-v} = N_{piles} \times \pi \times d_{piles} \times L_{piles} \times (k_s \times \tan \frac{2}{3}\theta \times \sigma')$$

	<b>Design Values</b>	<b>Units</b>
$N_{piles}$ = number of piles	10.5	number
$L_{piles}$ = length of pile embedded below potential scour depth	15	ft
$d_{piles}$ = nominal diameter of the piles	1.30	ft
$\sigma' = (L_{piles} \times (\gamma_{sat} - \gamma_w)) / 2$	357	lb/ft <sup>2</sup>
$K_s$ = coefficient of lateral earth pressure (0.5 to 1.0)	1.0	unit less
$\theta$ = internal friction angle of soils	36	deg.
<b><math>F_{piles-v}</math> (lb)      -102,241</b> <i>Negative values resist upward displacement.</i>		

***Piles Only Buoyancy Factor of Safety***

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bPiles} = \frac{F_{piles-v}}{F_{LWMS} + F_L}$$

**$FOS_b$  2.7**

*Note this value does not include the backfill assuming it's all lost but the piles are holding.*

***Backfill Only Buoyancy Factor of Safety***

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bBackfill} = \frac{F_{backfillsub}}{F_{LWMS} + F_L}$$

**$FOS_b$  8.9**

*Note this value does not include the piles.*

***Net Buoyancy Factor of Safety***

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bNet} = \frac{F_{backfillsub} + F_{piles-v}}{F_{LWMS} + F_L}$$

**$FOS_b$  11.6**

*Note this value includes the piles and backfill.*

**Resistance to Sliding | 6.4.3**

LWM structures are also susceptible to failure through sliding.

**Drag Force**

LWM structures are pushed downstream by the fluid drag forces acting upon the wood by the flowing water.

$F_d = \frac{C_D \times A_{LWM} \times \gamma_w \times U_c^2}{2 \times g}$		<b>Design Value</b>	<b>Units / Notes</b>
$C_D =$ drag coefficient		1	Per Equations 23 and 24
$A_{LWM} =$ area of wetted wood normal to the flow direction		$A_{LWM} =$ See Design Plan	
		<b><math>A_{LWM}</math> (ft<sup>2</sup>)</b>	<b>75</b>
$U_c =$ velocity adjacent to the LWM structure		6	ft/s Velocity value is conservative for all LWS locations. Value from 100-yr event 2D model results for main channel.
$g =$ acceleration due to gravity		32.2	ft/s <sup>2</sup>
<b><math>F_d</math> (lb) 2,616</b>			

**Hydrostatic Force**

Hydrostatic forces act on the upstream and downstream faces of a LWM structure. They account for differences in the upstream and downstream water depths against the structure.

$F_{hu} = \frac{1}{2} \times \gamma_w \times Y_u \times A_u$	$F_{hd} = \frac{1}{2} \times \gamma_w \times Y_d \times A_d$	<b>Variable Design Value</b>
$F_{hu}$ , $F_{hd} =$ hydrostatic force on upstream and downstream side of the wood structure		$Y_u$ (ft) 9
$Y_u$ , $Y_d =$ water depth upstream and downstream of the structure		$A_u$ (ft <sup>2</sup> ) 75 Post racking area
$A_u$ , $A_d =$ area projected to flow direction on the upstream and downstream of the structure		$Y_d$ (ft) 9
		$A_d$ (ft <sup>2</sup> ) 75 Plan downstream area
<b><math>F_{hu} + F_{hd} = F_h</math> (lb)</b>		<b>N/A</b>

**Impact Force**

The impact force associated with debris impacting a large wood structure can be estimated by the impact force equation.

$$F_i = \frac{w_{debris}}{g} \times \frac{V_{channel}^2}{2 \times \Delta x} \times C_i \times C_o \times C_d \times C_b \times R_{max}$$

$w_{debris}$  = weight of debris

$V_{channel}$  = channel approach velocity

$\Delta x$  = deceleration distance

Coefficients (see Table 6 and Figures 11, 12 for values)

$C_i$  = importance,  $C_o$  = orientation = 0.8,  $C_d$  = depth,  $C_b$  = blockage,  $R_{max}$  = impulse response ratio

Variable Design Value	
$W_{debris}$ (lb)	3,774
$V_{channel}$ (ft/s)	6
$\Delta x$ (ft)	5
$C_i$	0.5
$C_o$	0.8
$C_d$	1.0
$C_b$	1.0
$R_{max}$	0.8

<b><math>F_i</math> (lb) 135</b>
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**Friction Force**

Accounts for the friction force between the LWM and the channel bed. Restraint force from piles is not included as it does not exert a pressure on the LWS / bed interface.

$$F_f = -\mu_{bed} \times (F_{LWMS} + F_L + F_{bouldersub} + F_{backfillsub})$$

	Design Value Units / Source
$\mu_{bed}$ = coefficient of bed friction = $\tan(\theta)$	0.78 unit less
$\theta$ = internal friction angle (degrees)	38 Table 5, (Knutson et. al. 2014)

<b><math>F_f</math> (lb) -228,981</b>
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Negative values resist downstream displacement.

**Lateral Resistance From Piles**

Accounts for the lateral resistance provided by piles within the LWM structure. Assumes soil resistance is limiting, i.e. the pile pushes over before it breaks.

$$F_{piles-h} = N_{piles} \times \frac{L_{pile}^3 \times \frac{1}{2} \times (\gamma_s - \gamma_w) \times d_{pile} \times K_p}{h_{load} \times L_{pile}}$$

	Design Values Units
$N_{pile}$ = number of piles	10.5 number
$L_{pile}$ = length of pile embedded below potential scour depth	15 ft
$d_{pile}$ = diameter of the pile	1.30 ft
$h_{load}$ = applied load height above the potential scour depth	2.5 ft
$K_p = \frac{1 + \sin \theta}{1 - \sin \theta}$	4.2 unit less

<b><math>F_{piles-h}</math> (lb) -122,910</b>
-----------------------------------------------

Negative values resist downstream displacement.

**Sliding Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{sliding} = \frac{F_f + F_{piles-h}}{F_d + F_{nu} + F_{hd} + F_i}$$

**FOS<sub>sliding</sub> 127.9**

**Pile Strength Factor of Safety**

The factor of safety for the timber bending stress capacity of the pile. This evaluates the potential for the pile(s) to break under load prior to the pile pushing over in the ground.

		<b>Design Values Units</b>
$F_b =$ Timber Bending Stress Capacity per Timber Pile Manual Table 3-1 or AWC NDS Supplement Table 4D		1,200 psi 172,800 psf
$d_{pile} =$ diameter of the pile		1.30 ft
$I =$ circular cross – sectional moment of inertia	$I = \frac{\pi B^4}{4}$	2.24 ft <sup>4</sup>
$S =$ circular section modulus	$S = \frac{\pi B^3}{32}$	0.216 ft <sup>3</sup>
$C_F =$ strength reduction size factor for diameters greater than 12"	$C_F = \frac{1}{B}^{(1/9)}$	0.971 --
$M_p =$ applied moment per pile	$M_p = \frac{(F_d + F_i + F_h) \times h_{load}}{N_{piles}}$	655 ft-lb
$f_b =$ applied pile bending stress	$f_b = \frac{M_p}{S}$	3,037 psf
$F_{bx} =$ Pile bending stress capacity	$F_{bx} = F_b \times C_F$	1,166 psi 167,835 psf
$FOS_{pile\ strength} = \frac{F_{bx}}{f_b}$		
	<b>FOS<sub>pile strength</sub> 55.3</b>	

**References**

Large Woody Material - Risk Based Design Guidelines  
M. Knutson, J. Fealko. 2014. *Large Woody Material - Risk Based Design Guidelines*. U.S. Department of the Interior Bureau of Reclamation Pacific Northwest Region & Technical Services. Boise, Idaho. September 2014. Online at: <http://www.usbr.gov/pn/fcrps/documents/lwm.pdf>

ASTM D25. Allowable Stress Values for Treated Round Timber Piles.

Timber Pile Design and Construction Manual, Timber Piling Council, 2015.

American Wood Council (2018) National Design Specifications for Wood Construction, Design Supplement.

**Nason Floodplain - Large Woody Structure Stability Evaluation**

**Structural Stability | 6.4**

Structural stability of large woody material placements is evaluated herein using the procedures, formulas, and recommendations provided in the Reclamation's *Large Woody Material - Risk Based Design Guidelines* (Knutson et. al. 2014) along with insight gained from professional experience and general engineering judgment.

**Factors of Safety | 6.4.1**

Safety factors for structural stability were selected from *Table 4. Minimum recommended factors of safety* given the site specific public safety and property damage risk levels.

<b>Public Safety Risk</b> Moderate	Criteria: <b>FOS<sub>sliding</sub></b> 1.5
<b>Property Damage Risk</b> Moderate	<b>FOS<sub>buoyancy</sub></b> 1.75
<b>Stability Design Flow Criteria</b> 50-year	<b>FOS<sub>rotation</sub></b> 1.5

**Resistance to Flotation | 6.4.2**

Flotation is typically caused by the buoyant force and the lift force acting on the wood material from water passing over its surface.

**Large Wood Material Force**

Accounts for the vertical buoyant force of submerged large wood and the vertical weight force of unsubmerged large wood.

$$F_{LWMS} = V_{LWMS} \times (\gamma_{wood} - \gamma_w)$$

$V_{LWMS}$  = total volume of submerged large wood material

$$V_{LWMS} = \sum N_{LWMi} \times V_{LWMi}$$

Variable	Design Value Units
$\gamma_{wood}$ = unit weight of wood	38 lb/ft <sup>3</sup>
$\gamma_w$ = unit weight of water	62.4 lb/ft <sup>3</sup>
$V_{LWMS}$	348 ft <sup>3</sup>

<b><math>F_{LWMS}</math> (lb) 8,482</b>	<i>Positive values are upward forces.</i>
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**Lift Force**

Accounts for the lift force of large wood in flowing water. Not applicable to LWS where the bed will deform around the leading edges.

$F_L = \frac{C_L \times A_{LWM} \times \gamma_w \times U_o^2}{2 \times g}$	<b>Design Value</b>	<b>Units / Notes</b>
$C_L = \text{lift coefficient}$		0.2 typ. LWM value
$A_{LWM} = \text{area of large woody material perpendicular to flow}$		$A_{LWM} = \text{See Design Plan}$
$U_u = \text{upstream channel velocity at design event}$		<b><math>A_{LWM} \text{ (ft}^2\text{) 70}</math></b> For pre-racking condition
$g = \text{acceleration due to gravity}$		5 ft/s
		32.2 ft/s <sup>2</sup>
	<b><math>F_L \text{ (lb)}</math></b>	<b>N/A</b>

**Boulder Ballast Force**

Accounts for the ballasting force of large boulders directly attached to or placed over LWM.

$F_{bouldersub} = N_{bouldersub} \times \pi/6 \times d_{bouldersub}^3 \times (\gamma_{boulder} - \gamma_w)$	<b>Design Value</b>	<b>Units / Notes</b>
$N_{bouldersub} = \text{number of submerged boulders}$		0 number
$d_{bouldersub} = \text{effective diameter of submerged boulders}$		0 ft
$\gamma_{boulder} = \text{unit weight of boulders}$		165 lb/ft <sup>3</sup>
	<b><math>F_{bouldersub} \text{ (lb)}</math></b>	<b>N/A</b>

**Backfill Ballast Force**

Accounts for the ballasting force of backfill placed directly over LWM members. Volume is based on the fill area over the log(s) and a the effective cover depth shown on the Drawings.

$F_{backfillsub} = V_{backfillsub} \times (\gamma_s - \gamma_w)$	<b>Design Value</b>	<b>Units / Notes</b>
$V_{backfillsub} = \text{volume of backfill over LWM members}$		1,125 ft <sup>3</sup>
$\gamma_s = \text{unit weight of backfill material}$		See design plans 110 lb/ft <sup>3</sup>
	<b><math>F_{backfillsub} \text{ (lb)}</math></b>	<b>-53,550</b>

**Pile Skin Friction**

Accounts for the vertical resistance provided by piles within the LWM structure. USBR document equation modified by Inter-Fluve to match industry pile design standard formulations.

$$F_{piles-v} = N_{piles} \times \pi \times d_{piles} \times L_{piles} \times (k_s \times \tan \frac{2}{3}\theta \times \sigma')$$

	<b>Design Values</b>	<b>Units</b>
$N_{piles}$ = number of piles	6.75	number
$L_{piles}$ = length of pile embedded below potential scour depth	12	ft
$d_{piles}$ = nominal diameter of the piles	1.30	ft
$\sigma' = (L_{piles} \times (\gamma_{sat} - \gamma_w)) / 2$	285.6	lb/ft <sup>2</sup>
$K_s$ = coefficient of lateral earth pressure (0.5 to 1.0)	1.0	unit less
$\theta$ = internal friction angle of soils	36	deg.
<b><math>F_{piles-v}</math> (lb)</b>		<b>-42,065</b>

Negative values resist upward displacement.

**Piles Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bPiles} = \frac{F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 5.0**

Note this value does not include the backfill assuming it's all lost but the piles are holding.

**Backfill Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bBackfill} = \frac{F_{backfillsub}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 6.3**

Note this value does not include the piles.

**Net Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bNet} = \frac{F_{backfillsub} + F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 11.3**

Note this value includes the piles and backfill.

**Resistance to Sliding | 6.4.3**

LWM structures are also susceptible to failure through sliding.

**Drag Force**

LWM structures are pushed downstream by the fluid drag forces acting upon the wood by the flowing water.

$F_d = \frac{C_D \times A_{LWM} \times \gamma_w \times U_c^2}{2 \times g}$		<b>Design Value</b>	<b>Units / Notes</b>
$C_D =$ drag coefficient		1	Per Equations 23 and 24
$A_{LWM} =$ area of wetted wood normal to the flow direction		$A_{LWM} =$ See Design Plan	
		<b><math>A_{LWM}</math> (ft<sup>2</sup>)</b>	<b>70</b>
$U_c =$ velocity adjacent to the LWM structure		5	ft/s Velocity value is conservative for all LWS locations. Value from 100-yr event 2D model results for main channel.
$g =$ acceleration due to gravity		32.2	ft/s <sup>2</sup>
<b><math>F_d</math> (lb) 1,696</b>			

**Hydrostatic Force**

Hydrostatic forces act on the upstream and downstream faces of a LWM structure. They account for differences in the upstream and downstream water depths against the structure.

$F_{hu} = \frac{1}{2} \times \gamma_w \times Y_u \times A_u$	$F_{hd} = \frac{1}{2} \times \gamma_w \times Y_d \times A_d$	<b>Variable Design Value</b>
$F_{hu}$ , $F_{hd}$ = hydrostatic force on upstream and downstream side of the wood structure		$Y_u$ (ft) 4
$Y_u$ , $Y_d$ = water depth upstream and downstream of the structure		$A_u$ (ft <sup>2</sup> ) 70
$A_u$ , $A_d$ = area projected to flow direction on the upstream and downstream of the structure		Post racking area
		$Y_d$ (ft) 4
		$A_d$ (ft <sup>2</sup> ) 70
		Plan downstream area
<b><math>F_{hu} + F_{hd} = F_h</math> (lb)</b>		<b>N/A</b>

**Impact Force**

The impact force associated with debris impacting a large wood structure can be estimated by the impact force equation.

$$F_i = \frac{w_{debris}}{g} \times \frac{V_{channel}^2}{2 \times \Delta x} \times C_i \times C_o \times C_d \times C_b \times R_{max}$$

$w_{debris}$  = weight of debris

$V_{channel}$  = channel approach velocity

$\Delta x$  = deceleration distance

Coefficients (see Table 6 and Figures 11, 12 for values)

$C_i$  = importance,  $C_o$  = orientation = 0.8,  $C_d$  = depth,  $C_b$  = blockage,  $R_{max}$  = impulse response ratio

Variable Design Value	
$W_{debris}$ (lb)	3,774
$V_{channel}$ (ft/s)	5
$\Delta x$ (ft)	5
$C_i$	0.5
$C_o$	0.8
$C_d$	1.0
$C_b$	1.0
$R_{max}$	0.8

<b><math>F_i</math> (lb) 94</b>
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**Friction Force**

Accounts for the friction force between the LWM and the channel bed. Restraint force from piles is not included as it does not exert a pressure on the LWS / bed interface.

$$F_f = -\mu_{bed} \times (F_{LWMS} + F_L + F_{bouldersub} + F_{backfillsub})$$

	Design Value Units / Source
$\mu_{bed}$ = coefficient of bed friction = $\tan(\theta)$	0.78 unit less
$\theta$ = internal friction angle (degrees)	38 Table 5, (Knutson et. al. 2014)

<b><math>F_f</math> (lb) -35,211</b>
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Negative values resist downstream displacement.

**Lateral Resistance From Piles**

Accounts for the lateral resistance provided by piles within the LWM structure. Assumes soil resistance is limiting, i.e. the pile pushes over before it breaks.

$$F_{piles-h} = N_{piles} \times \frac{L_{pile}^3 \times \frac{1}{2} \times (\gamma_s - \gamma_w) \times d_{pile} \times K_p}{h_{load} \times L_{pile}}$$

	Design Values Units
$N_{pile}$ = number of piles	6.75 number
$L_{pile}$ = length of pile embedded below potential scour depth	12 ft
$d_{pile}$ = diameter of the pile	1.30 ft
$h_{load}$ = applied load height above the potential scour depth	2.5 ft
$K_p = \frac{1 + \sin \theta}{1 - \sin \theta}$	4.2 unit less

<b><math>F_{piles-h}</math> (lb) -50,569</b>
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Negative values resist downstream displacement.

**Sliding Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{sliding} = \frac{F_f + F_{piles-h}}{F_d + F_{nu} + F_{hd} + F_i}$$

**FOS<sub>sliding</sub> 47.9**

**Pile Strength Factor of Safety**

The factor of safety for the timber bending stress capacity of the pile. This evaluates the potential for the pile(s) to break under load prior to the pile pushing over in the ground.

		<b>Design Values Units</b>
$F_b =$ Timber Bending Stress Capacity per Timber Pile Manual Table 3-1 or AWC NDS Supplement Table 4D		1,200 psi 172,800 psf
$d_{pile} =$ diameter of the pile		1.30 ft
$I =$ circular cross – sectional moment of inertia	$I = \frac{\pi B^4}{4}$	2.24 ft <sup>4</sup>
$S =$ circular section modulus	$S = \frac{\pi B^3}{32}$	0.216 ft <sup>3</sup>
$C_F =$ strength reduction size factor for diameters greater than 12"	$C_F = \frac{1}{B}^{(1/9)}$	0.971 --
$M_p =$ applied moment per pile	$M_p = \frac{(F_d + F_i + F_h) \times h_{load}}{N_{piles}}$	663 ft-lb
$f_b =$ applied pile bending stress	$f_b = \frac{M_p}{S}$	3,073 psf
$F_{bx} =$ Pile bending stress capacity	$F_{bx} = F_b \times C_F$	1,166 psi 167,835 psf
$FOS_{pile\ strength} = \frac{F_{bx}}{f_b}$		<b>FOS<sub>pile strength</sub> 54.6</b>

**References**

Large Woody Material - Risk Based Design Guidelines  
M. Knutson, J. Fealko. 2014. *Large Woody Material - Risk Based Design Guidelines*. U.S. Department of the Interior Bureau of Reclamation Pacific Northwest Region & Technical Services. Boise, Idaho. September 2014. Online at: <http://www.usbr.gov/pn/fcrps/documents/lwm.pdf>

ASTM D25. Allowable Stress Values for Treated Round Timber Piles.

Timber Pile Design and Construction Manual, Timber Piling Council, 2015.

American Wood Council (2018) National Design Specifications for Wood Construction, Design Supplement.

**Nason Floodplain - Large Woody Structure Stability Evaluation**

**Structural Stability | 6.4**

Structural stability of large woody material placements is evaluated herein using the procedures, formulas, and recommendations provided in the Reclamation's *Large Woody Material - Risk Based Design Guidelines* (Knutson et. al. 2014) along with insight gained from professional experience and general engineering judgment.

**Factors of Safety | 6.4.1**

Safety factors for structural stability were selected from *Table 4. Minimum recommended factors of safety* given the site specific public safety and property damage risk levels.

<b>Public Safety Risk</b> Moderate	Criteria: <b>FOS<sub>sliding</sub></b> 1.5
<b>Property Damage Risk</b> Moderate	<b>FOS<sub>buoyancy</sub></b> 1.75
<b>Stability Design Flow Criteria</b> 50-year	<b>FOS<sub>rotation</sub></b> 1.5

**Resistance to Flotation | 6.4.2**

Flotation is typically caused by the buoyant force and the lift force acting on the wood material from water passing over its surface.

**Large Wood Material Force**

Accounts for the vertical buoyant force of submerged large wood and the vertical weight force of unsubmerged large wood.

$$F_{LWMS} = V_{LWMS} \times (\gamma_{wood} - \gamma_w)$$

$V_{LWMS}$  = total volume of submerged large wood material

$$V_{LWMS} = \sum N_{LWMi} \times V_{LWMi}$$

Variable	Design Value Units
$\gamma_{wood}$ = unit weight of wood	38 lb/ft <sup>3</sup>
$\gamma_w$ = unit weight of water	62.4 lb/ft <sup>3</sup>
$V_{LWMS}$	1115 ft <sup>3</sup>

<b><math>F_{LWMS}</math> (lb) 27,206</b>	<i>Positive values are upward forces.</i>
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**Lift Force**

Accounts for the lift force of large wood in flowing water. Not applicable to LWS where the bed will deform around the leading edges.

$$F_L = \frac{C_L \times A_{LWM} \times \gamma_w \times U_o^2}{2 \times g}$$

	Design Value	Units / Notes
$C_L =$ lift coefficient	0.2	typ. LWM value
$A_{LWM} =$ area of large woody material perpendicular to flow		$A_{LWM} =$ See Design Plan
$U_u =$ upstream channel velocity at design event	8	ft/s
$g =$ acceleration due to gravity	32.2	ft/s <sup>2</sup>
<b><math>F_L</math> (lb)</b>		<b>N/A</b>

**Boulder Ballast Force**

Accounts for the ballasting force of large boulders directly attached to or placed over LWM.

$$F_{bouldersub} = N_{bouldersub} \times \pi/6 \times d_{bouldersub}^3 \times (\gamma_{boulder} - \gamma_w)$$

	Design Value	Units / Notes
$N_{bouldersub} =$ number of submerged boulders	0	number
$d_{bouldersub} =$ effective diameter of submerged boulders	0	ft
$\gamma_{boulder} =$ unit weight of boulders		165 lb/ft <sup>3</sup>
<b><math>F_{bouldersub}</math> (lb)</b>		<b>N/A</b>

**Backfill Ballast Force**

Accounts for the ballasting force of backfill placed directly over LWM members. Volume is based on the fill area over the log(s) and a the effective cover depth shown on the Drawings.

$$F_{backfillsub} = V_{backfillsub} \times (\gamma_s - \gamma_w)$$

	Design Value	Units / Notes
$V_{backfillsub} =$ volume of backfill over LWM members	5,910	ft <sup>3</sup>
$\gamma_s =$ unit weight of backfill material		See design plans 110 lb/ft <sup>3</sup>
<b><math>F_{backfillsub}</math> (lb)</b>		<b>-281,316</b>

**Pile Skin Friction**

Accounts for the vertical resistance provided by piles within the LWM structure. USBR document equation modified by Inter-Fluve to match industry pile design standard formulations.

$$F_{piles-v} = N_{piles} \times \pi \times d_{piles} \times L_{piles} \times (k_s \times \tan \frac{2}{3}\theta \times \sigma')$$

	<b>Design Values</b>	<b>Units</b>
$N_{piles}$ = number of piles	4.5	number
$L_{piles}$ = length of pile embedded below potential scour depth	12	ft
$d_{piles}$ = nominal diameter of the piles	1.30	ft
$\sigma' = (L_{piles} \times (\gamma_{sat} - \gamma_w)) / 2$	285.6	lb/ft <sup>2</sup>
$K_s$ = coefficient of lateral earth pressure (0.5 to 1.0)	1.0	unit less
$\theta$ = internal friction angle of soils	36	deg.
<b><math>F_{piles-v}</math> (lb)</b>		<b>-28,043</b>

Negative values resist upward displacement.

**Piles Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bPiles} = \frac{F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 1.0**

Note this value does not include the backfill assuming it's all lost but the piles are holding.

**Backfill Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bBackfill} = \frac{F_{backfillsub}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 10.3**

Note this value does not include the piles.

**Net Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bNet} = \frac{F_{backfillsub} + F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 11.4**

Note this value includes the piles and backfill.

**Resistance to Sliding | 6.4.3**

LWM structures are also susceptible to failure through sliding.

**Drag Force**

LWM structures are pushed downstream by the fluid drag forces acting upon the wood by the flowing water.

$F_d = \frac{C_D \times A_{LWM} \times \gamma_w \times U_c^2}{2 \times g}$		<b>Design Value</b>	<b>Units / Notes</b>
$C_D =$ drag coefficient		1	Per Equations 23 and 24
$A_{LWM} =$ area of wetted wood normal to the flow direction		$A_{LWM} =$ See Design Plan	
		<b><math>A_{LWM}</math> (ft<sup>2</sup>)</b>	120
$U_c =$ velocity adjacent to the LWM structure		8	ft/s Velocity value is conservative for all LWS locations. Value from 100-yr event 2D model results for main channel.
$g =$ acceleration due to gravity		32.2	ft/s <sup>2</sup>
<b><math>F_d</math> (lb) 7,441</b>			

**Hydrostatic Force**

Hydrostatic forces act on the upstream and downstream faces of a LWM structure. They account for differences in the upstream and downstream water depths against the structure.

$F_{hu} = \frac{1}{2} \times \gamma_w \times Y_u \times A_u$	$F_{hd} = \frac{1}{2} \times \gamma_w \times Y_d \times A_d$	<b>Variable Design Value</b>
$F_{hu}$ , $F_{hd} =$ hydrostatic force on upstream and downstream side of the wood structure		$Y_u$ (ft) 7
$Y_u$ , $Y_d =$ water depth upstream and downstream of the structure		$A_u$ (ft <sup>2</sup> ) 120 Post racking area
$A_u$ , $A_d =$ area projected to flow direction on the upstream and downstream of the structure		$Y_d$ (ft) 7
		$A_d$ (ft <sup>2</sup> ) 120 Plan downstream area
<b><math>F_{hu} + F_{hd} = F_h</math> (lb)</b>		N/A

**Impact Force**

The impact force associated with debris impacting a large wood structure can be estimated by the impact force equation.

$$F_i = \frac{w_{debris}}{g} \times \frac{V_{channel}^2}{2 \times \Delta x} \times C_i \times C_o \times C_d \times C_b \times R_{max}$$

$w_{debris}$  = weight of debris

$V_{channel}$  = channel approach velocity

$\Delta x$  = deceleration distance

Coefficients (see Table 6 and Figures 11, 12 for values)

$C_i$  = importance,  $C_o$  = orientation = 0.8,  $C_d$  = depth,  $C_b$  = blockage,  $R_{max}$  = impulse response ratio

Variable Design Value	
$W_{debris}$ (lb)	3,774
$V_{channel}$ (ft/s)	8
$\Delta x$ (ft)	5
$C_i$	0.5
$C_o$	0.8
$C_d$	1.0
$C_b$	1.0
$R_{max}$	0.8

<b><math>F_i</math> (lb) 240</b>
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**Friction Force**

Accounts for the friction force between the LWM and the channel bed. Restraint force from piles is not included as it does not exert a pressure on the LWS / bed interface.

$$F_f = -\mu_{bed} \times (F_{LWMS} + F_L + F_{bouldersub} + F_{backfillsub})$$

	Design Value Units / Source
$\mu_{bed}$ = coefficient of bed friction = $\tan(\theta)$	0.78 unit less
$\theta$ = internal friction angle (degrees)	38 Table 5, (Knutson et. al. 2014)

<b><math>F_f</math> (lb) -198,533</b>
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Negative values resist downstream displacement.

**Lateral Resistance From Piles**

Accounts for the lateral resistance provided by piles within the LWM structure. Assumes soil resistance is limiting, i.e. the pile pushes over before it breaks.

$$F_{piles-h} = N_{piles} \times \frac{L_{pile}^3 \times \frac{1}{2} \times (\gamma_s - \gamma_w) \times d_{pile} \times K_p}{h_{load} \times L_{pile}}$$

	Design Values Units
$N_{pile}$ = number of piles	4.5 number
$L_{pile}$ = length of pile embedded below potential scour depth	12 ft
$d_{pile}$ = diameter of the pile	1.30 ft
$h_{load}$ = applied load height above the potential scour depth	2.5 ft
$K_p = \frac{1 + \sin \theta}{1 - \sin \theta}$	4.2 unit less

<b><math>F_{piles-h}</math> (lb) -33,713</b>
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Negative values resist downstream displacement.

**Sliding Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{sliding} = \frac{F_f + F_{piles-h}}{F_d + F_{nu} + F_{hd} + F_i}$$

**FOS<sub>sliding</sub> 30.2**

**Pile Strength Factor of Safety**

The factor of safety for the timber bending stress capacity of the pile. This evaluates the potential for the pile(s) to break under load prior to the pile pushing over in the ground.

		<b>Design Values Units</b>
$F_b =$ Timber Bending Stress Capacity per Timber Pile Manual Table 3-1 or AWC NDS Supplement Table 4D		1,200 psi 172,800 psf
$d_{pile} =$ diameter of the pile		1.30 ft
$I =$ circular cross – sectional moment of inertia	$I = \frac{\pi B^4}{4}$	2.24 ft <sup>4</sup>
$S =$ circular section modulus	$S = \frac{\pi B^3}{32}$	0.216 ft <sup>3</sup>
$C_F =$ strength reduction size factor for diameters greater than 12"	$C_F = \frac{1}{B}^{(1/9)}$	0.971 --
$M_p =$ applied moment per pile	$M_p = \frac{(F_d + F_i + F_h) \times h_{load}}{N_{piles}}$	4,268 ft-lb
$f_b =$ applied pile bending stress	$f_b = \frac{M_p}{S}$	19,785 psf
$F_{bx} =$ Pile bending stress capacity	$F_{bx} = F_b \times C_F$	1,166 psi 167,835 psf
$FOS_{pile\ strength} = \frac{F_{bx}}{f_b}$		
	<b>FOS<sub>pile strength</sub> 8.5</b>	

**References**

Large Woody Material - Risk Based Design Guidelines  
M. Knutson, J. Fealko. 2014. *Large Woody Material - Risk Based Design Guidelines*. U.S. Department of the Interior Bureau of Reclamation Pacific Northwest Region & Technical Services. Boise, Idaho. September 2014. Online at: <http://www.usbr.gov/pn/fcrps/documents/lwm.pdf>

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Timber Pile Design and Construction Manual, Timber Piling Council, 2015.

American Wood Council (2018) National Design Specifications for Wood Construction, Design Supplement.

**Nason Floodplain - Large Woody Structure Stability Evaluation**

**Structural Stability | 6.4**

Structural stability of large woody material placements is evaluated herein using the procedures, formulas, and recommendations provided in the Reclamation's *Large Woody Material - Risk Based Design Guidelines* (Knutson et. al. 2014) along with insight gained from professional experience and general engineering judgment.

**Factors of Safety | 6.4.1**

Safety factors for structural stability were selected from *Table 4. Minimum recommended factors of safety* given the site specific public safety and property damage risk levels.

	Criteria:
Public Safety Risk Moderate	FOS <sub>sliding</sub> 1.5
Property Damage Risk Moderate	FOS <sub>buoyancy</sub> 1.75
Stability Design Flow Criteria 50-year	FOS <sub>rotation</sub> 1.5

**Resistance to Flotation | 6.4.2**

Flotation is typically caused by the buoyant force and the lift force acting on the wood material from water passing over its surface.

**Large Wood Material Force**

Accounts for the vertical buoyant force of submerged large wood and the vertical weight force of unsubmerged large wood.

$$F_{LWMS} = V_{LWMS} \times (\gamma_{wood} - \gamma_w)$$

$V_{LWMS}$  = total volume of submerged large wood material

$$V_{LWMS} = \sum N_{LWMi} \times V_{LWMi}$$

Variable	Design Value	Units
$\gamma_{wood}$ = unit weight of wood	38	lb/ft <sup>3</sup>
$\gamma_w$ = unit weight of water	62.4	lb/ft <sup>3</sup>
$V_{LWMS}$	831	ft <sup>3</sup>

<b><math>F_{LWMS}</math> (lb) 20,265</b>	<i>Positive values are upward forces.</i>
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**Lift Force**

Accounts for the lift force of large wood in flowing water. Not applicable to LWS where the bed will deform around the leading edges.

$$F_L = \frac{C_L \times A_{LWM} \times \gamma_w \times U_o^2}{2 \times g}$$

	Design Value	Units / Notes
$C_L =$ lift coefficient	0.2	typ. LWM value
$A_{LWM} =$ area of large woody material perpendicular to flow		$A_{LWM} =$ See Design Plan
$U_u =$ upstream channel velocity at design event	3	ft/s
$g =$ acceleration due to gravity	32.2	ft/s <sup>2</sup>
<b><math>F_L</math> (lb)</b>		<b>N/A</b>

**Boulder Ballast Force**

Accounts for the ballasting force of large boulders directly attached to or placed over LWM.

$$F_{bouldersub} = N_{bouldersub} \times \pi/6 \times d_{bouldersub}^3 \times (\gamma_{boulder} - \gamma_w)$$

	Design Value	Units / Notes
$N_{bouldersub} =$ number of submerged boulders	0	number
$d_{bouldersub} =$ effective diameter of submerged boulders	0	ft
$\gamma_{boulder} =$ unit weight of boulders		165 lb/ft <sup>3</sup>
<b><math>F_{bouldersub}</math> (lb)</b>		<b>N/A</b>

**Backfill Ballast Force**

Accounts for the ballasting force of backfill placed directly over LWM members. Volume is based on the fill area over the log(s) and a the effective cover depth shown on the Drawings.

$$F_{backfillsub} = V_{backfillsub} \times (\gamma_s - \gamma_w)$$

	Design Value	Units / Notes
$V_{backfillsub} =$ volume of backfill over LWM members	1,125	ft <sup>3</sup>
$\gamma_s =$ unit weight of backfill material		See design plans 110 lb/ft <sup>3</sup>
<b><math>F_{backfillsub}</math> (lb)</b>		<b>-53,550</b>

**Pile Skin Friction**

Accounts for the vertical resistance provided by piles within the LWM structure. USBR document equation modified by Inter-Fluve to match industry pile design standard formulations.

$$F_{piles-v} = N_{piles} \times \pi \times d_{piles} \times L_{piles} \times (k_s \times \tan \frac{2}{3}\theta \times \sigma')$$

	<b>Design Values</b>	<b>Units</b>
$N_{piles}$ = number of piles	6	number
$L_{piles}$ = length of pile embedded below potential scour depth	8	ft
$d_{piles}$ = nominal diameter of the piles	1.30	ft
$\sigma' = (L_{piles} \times (\gamma_{sat} - \gamma_w)) / 2$	190.4	lb/ft <sup>2</sup>
$K_s$ = coefficient of lateral earth pressure (0.5 to 1.0)	1.0	unit less
$\theta$ = internal friction angle of soils	36	deg.
<b><math>F_{piles-v}</math> (lb)</b>		<b>-16,618</b>

Negative values resist upward displacement.

**Piles Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bPiles} = \frac{F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 0.8**

Note this value does not include the backfill assuming it's all lost but the piles are holding.

**Backfill Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bBackfill} = \frac{F_{backfillsub}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 2.6**

Note this value does not include the piles.

**Net Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bNet} = \frac{F_{backfillsub} + F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 3.5**

Note this value includes the piles and backfill.

**Resistance to Sliding | 6.4.3**

LWM structures are also susceptible to failure through sliding.

**Drag Force**

LWM structures are pushed downstream by the fluid drag forces acting upon the wood by the flowing water.

$F_d = \frac{C_D \times A_{LWM} \times \gamma_w \times U_c^2}{2 \times g}$		<b>Design Value</b>	<b>Units / Notes</b>
$C_D =$ drag coefficient		1	Per Equations 23 and 24
$A_{LWM} =$ area of wetted wood normal to the flow direction		$A_{LWM} =$ See Design Plan	
		<b><math>A_{LWM}</math> (ft<sup>2</sup>)</b>	140
$U_c =$ velocity adjacent to the LWM structure		3	ft/s Velocity value is conservative for all LWS locations. Value from 100-yr event 2D model results for main channel.
$g =$ acceleration due to gravity		32.2	ft/s <sup>2</sup>
<b><math>F_d</math> (lb) 1,221</b>			

**Hydrostatic Force**

Hydrostatic forces act on the upstream and downstream faces of a LWM structure. They account for differences in the upstream and downstream water depths against the structure.

$F_{hu} = \frac{1}{2} \times \gamma_w \times Y_u \times A_u$	$F_{hd} = \frac{1}{2} \times \gamma_w \times Y_d \times A_d$	<b>Variable Design Value</b>
$F_{hu}$ , $F_{hd} =$ hydrostatic force on upstream and downstream side of the wood structure		$Y_u$ (ft) 4.5
$Y_u$ , $Y_d =$ water depth upstream and downstream of the structure		$A_u$ (ft <sup>2</sup> ) 140 Post racking area
$A_u$ , $A_d =$ area projected to flow direction on the upstream and downstream of the structure		$Y_d$ (ft) 4.5
		$A_d$ (ft <sup>2</sup> ) 140 Plan downstream area
<b><math>F_{hu} + F_{hd} = F_h</math> (lb)</b>		N/A

**Impact Force**

The impact force associated with debris impacting a large wood structure can be estimated by the impact force equation.

$$F_i = \frac{w_{debris}}{g} \times \frac{V_{channel}^2}{2 \times \Delta x} \times C_i \times C_o \times C_d \times C_b \times R_{max}$$

$w_{debris}$  = weight of debris

$V_{channel}$  = channel approach velocity

$\Delta x$  = deceleration distance

Coefficients (see Table 6 and Figures 11, 12 for values)

$C_i$  = importance,  $C_o$  = orientation = 0.8,  $C_d$  = depth,  $C_b$  = blockage,  $R_{max}$  = impulse response ratio

Variable Design Value	
$w_{debris}$ (lb)	3,774
$V_{channel}$ (ft/s)	3
$\Delta x$ (ft)	5
$C_i$	0.5
$C_o$	0.8
$C_d$	1.0
$C_b$	1.0
$R_{max}$	0.8

<b><math>F_i</math> (lb) 34</b>
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**Friction Force**

Accounts for the friction force between the LWM and the channel bed. Restraint force from piles is not included as it does not exert a pressure on the LWS / bed interface.

$$F_f = -\mu_{bed} \times (F_{LWMS} + F_L + F_{bouldersub} + F_{backfillsub})$$

	Design Value Units / Source
$\mu_{bed}$ = coefficient of bed friction = $\tan(\theta)$	0.78 unit less
$\theta$ = internal friction angle (degrees)	38 Table 5, (Knutson et. al. 2014)

<b><math>F_f</math> (lb) -26,005</b>
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Negative values resist downstream displacement.

**Lateral Resistance From Piles**

Accounts for the lateral resistance provided by piles within the LWM structure. Assumes soil resistance is limiting, i.e. the pile pushes over before it breaks.

$$F_{piles-h} = N_{piles} \times \frac{L_{pile}^3 \times \frac{1}{2} \times (\gamma_s - \gamma_w) \times d_{pile} \times K_p}{h_{load} \times L_{pile}}$$

	Design Values Units
$N_{pile}$ = number of piles	6 number
$L_{pile}$ = length of pile embedded below potential scour depth	8 ft
$d_{pile}$ = diameter of the pile	1.30 ft
$h_{load}$ = applied load height above the potential scour depth	2.5 ft
$K_p = \frac{1 + \sin \theta}{1 - \sin \theta}$	4.2 unit less

<b><math>F_{piles-h}</math> (lb) -19,978</b>
----------------------------------------------

Negative values resist downstream displacement.

**Sliding Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{sliding} = \frac{F_f + F_{piles-h}}{F_d + F_{nu} + F_{hd} + F_i}$$

**FOS<sub>sliding</sub> 36.7**

**Pile Strength Factor of Safety**

The factor of safety for the timber bending stress capacity of the pile. This evaluates the potential for the pile(s) to break under load prior to the pile pushing over in the ground.

		<b>Design Values Units</b>
$F_b =$ Timber Bending Stress Capacity per Timber Pile Manual Table 3-1 or AWC NDS Supplement Table 4D		1,200 psi 172,800 psf
$d_{pile} =$ diameter of the pile		1.30 ft
$I =$ circular cross – sectional moment of inertia	$I = \frac{\pi B^4}{4}$	2.24 ft <sup>4</sup>
$S =$ circular section modulus	$S = \frac{\pi B^3}{32}$	0.216 ft <sup>3</sup>
$C_F =$ strength reduction size factor for diameters greater than 12"	$C_F = \frac{1^{(1/9)}}{B}$	0.971 --
$M_p =$ applied moment per pile	$M_p = \frac{(F_d + F_i + F_h) \times h_{load}}{N_{piles}}$	523 ft-lb
$f_b =$ applied pile bending stress	$f_b = \frac{M_p}{S}$	2,424 psf
$F_{bx} =$ Pile bending stress capacity	$F_{bx} = F_b \times C_F$	1,166 psi 167,835 psf
$FOS_{pile\ strength} = \frac{F_{bx}}{f_b}$		
		<b>FOS<sub>pile strength</sub> 69.2</b>

**References**

Large Woody Material - Risk Based Design Guidelines  
M. Knutson, J. Fealko. 2014. *Large Woody Material - Risk Based Design Guidelines*. U.S. Department of the Interior Bureau of Reclamation Pacific Northwest Region & Technical Services. Boise, Idaho. September 2014. Online at: <http://www.usbr.gov/pn/fcrps/documents/lwm.pdf>

ASTM D25. Allowable Stress Values for Treated Round Timber Piles.

Timber Pile Design and Construction Manual, Timber Piling Council, 2015.

American Wood Council (2018) National Design Specifications for Wood Construction, Design Supplement.

**Nason Floodplain - Large Woody Structure Stability Evaluation**

**Structural Stability | 6.4**

Structural stability of large woody material placements is evaluated herein using the procedures, formulas, and recommendations provided in the Reclamation's *Large Woody Material - Risk Based Design Guidelines* (Knutson et. al. 2014) along with insight gained from professional experience and general engineering judgment.

**Factors of Safety | 6.4.1**

Safety factors for structural stability were selected from *Table 4. Minimum recommended factors of safety* given the site specific public safety and property damage risk levels.

<b>Public Safety Risk</b> Moderate	Criteria: <b>FOS<sub>sliding</sub></b> 1.5
<b>Property Damage Risk</b> Moderate	<b>FOS<sub>buoyancy</sub></b> 1.75
<b>Stability Design Flow Criteria</b> 50-year	<b>FOS<sub>rotation</sub></b> 1.5

**Resistance to Flotation | 6.4.2**

Flotation is typically caused by the buoyant force and the lift force acting on the wood material from water passing over its surface.

**Large Wood Material Force**

Accounts for the vertical buoyant force of submerged large wood and the vertical weight force of unsubmerged large wood.

$$F_{LWMS} = V_{LWMS} \times (\gamma_{wood} - \gamma_w)$$

$V_{LWMS}$  = total volume of submerged large wood material

$$V_{LWMS} = \sum N_{LWMi} \times V_{LWMi}$$

Variable	Design Value Units
$\gamma_{wood}$ = unit weight of wood	38 lb/ft <sup>3</sup>
$\gamma_w$ = unit weight of water	62.4 lb/ft <sup>3</sup>
$V_{LWMS}$	231 ft <sup>3</sup>

<b><math>F_{LWMS}</math> (lb) 5,642</b>	<i>Positive values are upward forces.</i>
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**Lift Force**

Accounts for the lift force of large wood in flowing water. Not applicable to LWS where the bed will deform around the leading edges.

$$F_L = \frac{C_L \times A_{LWM} \times \gamma_w \times U_o^2}{2 \times g}$$

	Design Value	Units / Notes
$C_L =$ lift coefficient	0.2	typ. LWM value
$A_{LWM} =$ area of large woody material perpendicular to flow		$A_{LWM} =$ See Design Plan
$U_u =$ upstream channel velocity at design event	3	ft/s
$g =$ acceleration due to gravity	32.2	ft/s <sup>2</sup>
<b><math>F_L</math> (lb)</b>		<b>N/A</b>

**Boulder Ballast Force**

Accounts for the ballasting force of large boulders directly attached to or placed over LWM.

$$F_{bouldersub} = N_{bouldersub} \times \pi/6 \times d_{bouldersub}^3 \times (\gamma_{boulder} - \gamma_w)$$

	Design Value	Units / Notes
$N_{bouldersub} =$ number of submerged boulders	0	number
$d_{bouldersub} =$ effective diameter of submerged boulders	0	ft
$\gamma_{boulder} =$ unit weight of boulders		165 lb/ft <sup>3</sup>
<b><math>F_{bouldersub}</math> (lb)</b>		<b>N/A</b>

**Backfill Ballast Force**

Accounts for the ballasting force of backfill placed directly over LWM members. Volume is based on the fill area over the log(s) and a the effective cover depth shown on the Drawings.

$$F_{backfillsub} = V_{backfillsub} \times (\gamma_s - \gamma_w)$$

	Design Value	Units / Notes
$V_{backfillsub} =$ volume of backfill over LWM members	450	ft <sup>3</sup>
$\gamma_s =$ unit weight of backfill material		See design plans 110 lb/ft <sup>3</sup>
<b><math>F_{backfillsub}</math> (lb)</b>		<b>-21,420</b>

**Pile Skin Friction**

Accounts for the vertical resistance provided by piles within the LWM structure. USBR document equation modified by Inter-Fluve to match industry pile design standard formulations.

$$F_{piles-v} = N_{piles} \times \pi \times d_{piles} \times L_{piles} \times (k_s \times \tan \frac{2}{3}\theta \times \sigma')$$

	<b>Design Values</b>	<b>Units</b>
$N_{piles}$ = number of piles	0.75	number
$L_{piles}$ = length of pile embedded below potential scour depth	8	ft
$d_{piles}$ = nominal diameter of the piles	1.30	ft
$\sigma' = (L_{piles} \times (\gamma_{sat} - \gamma_w)) / 2$	190.4	lb/ft <sup>2</sup>
$K_s$ = coefficient of lateral earth pressure (0.5 to 1.0)	1.0	unit less
$\theta$ = internal friction angle of soils	36	deg.
<b><math>F_{piles-v}</math> (lb)</b>		<b>-2,077</b>
<i>Negative values resist upward displacement.</i>		

**Piles Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bPiles} = \frac{F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 0.4**

*Note this value does not include the backfill assuming it's all lost but the piles are holding.*

**Backfill Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bBackfill} = \frac{F_{backfillsub}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 3.8**

*Note this value does not include the piles.*

**Net Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bNet} = \frac{F_{backfillsub} + F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 4.2**

*Note this value includes the piles and backfill.*

**Resistance to Sliding | 6.4.3**

LWM structures are also susceptible to failure through sliding.

**Drag Force**

LWM structures are pushed downstream by the fluid drag forces acting upon the wood by the flowing water.

$F_d = \frac{C_D \times A_{LWM} \times \gamma_w \times U_c^2}{2 \times g}$		<b>Design Value</b>	<b>Units / Notes</b>
$C_D =$ drag coefficient		1	Per Equations 23 and 24
$A_{LWM} =$ area of wetted wood normal to the flow direction		$A_{LWM} =$ See Design Plan	
		<b><math>A_{LWM}</math> (ft<sup>2</sup>)</b>	<b>20</b>
$U_c =$ velocity adjacent to the LWM structure		3	ft/s Velocity value is conservative for all LWS locations. Value from 100-yr event 2D model results for main channel.
$g =$ acceleration due to gravity		32.2	ft/s <sup>2</sup>
<b><math>F_d</math> (lb) 174</b>			

**Hydrostatic Force**

Hydrostatic forces act on the upstream and downstream faces of a LWM structure. They account for differences in the upstream and downstream water depths against the structure.

$F_{hu} = \frac{1}{2} \times \gamma_w \times Y_u \times A_u$	$F_{hd} = \frac{1}{2} \times \gamma_w \times Y_d \times A_d$	<b>Variable Design Value</b>
$F_{hu}$ , $F_{hd}$ = hydrostatic force on upstream and downstream side of the wood structure		$Y_u$ (ft) 4.5
$Y_u$ , $Y_d$ = water depth upstream and downstream of the structure		$A_u$ (ft <sup>2</sup> ) 20 Post racking area
$A_u$ , $A_d$ = area projected to flow direction on the upstream and downstream of the structure		$Y_d$ (ft) 4.5
		$A_d$ (ft <sup>2</sup> ) 20 Plan downstream area
<b><math>F_{hu} + F_{hd} = F_h</math> (lb)</b>		<b>N/A</b>

**Impact Force**

The impact force associated with debris impacting a large wood structure can be estimated by the impact force equation.

$$F_i = \frac{w_{debris}}{g} \times \frac{V_{channel}^2}{2 \times \Delta x} \times C_i \times C_o \times C_d \times C_b \times R_{max}$$

$w_{debris}$  = weight of debris

$V_{channel}$  = channel approach velocity

$\Delta x$  = deceleration distance

Coefficients (see Table 6 and Figures 11, 12 for values)

$C_i$  = importance,  $C_o$  = orientation = 0.8,  $C_d$  = depth,  $C_b$  = blockage,  $R_{max}$  = impulse response ratio

Variable Design Value	
$W_{debris}$ (lb)	3,774
$V_{channel}$ (ft/s)	3
$\Delta x$ (ft)	5
$C_i$	0.5
$C_o$	0.8
$C_d$	1.0
$C_b$	1.0
$R_{max}$	0.8

**$F_i$  (lb) 34**

**Friction Force**

Accounts for the friction force between the LWM and the channel bed. Restraint force from piles is not included as it does not exert a pressure on the LWS / bed interface.

$$F_f = -\mu_{bed} \times (F_{LWMS} + F_L + F_{bouldersub} + F_{backfillsub})$$

	Design Value Units / Source
$\mu_{bed}$ = coefficient of bed friction = $\tan(\theta)$	0.78 unit less
$\theta$ = internal friction angle (degrees)	38 Table 5, (Knutson et. al. 2014)

**$F_f$  (lb) -12,327**

Negative values resist downstream displacement.

**Lateral Resistance From Piles**

Accounts for the lateral resistance provided by piles within the LWM structure. Assumes soil resistance is limiting, i.e. the pile pushes over before it breaks.

$$F_{piles-h} = N_{piles} \times \frac{L_{pile}^3 \times \frac{1}{2} \times (\gamma_s - \gamma_w) \times d_{pile} \times K_p}{h_{load} \times L_{pile}}$$

	Design Values Units
$N_{pile}$ = number of piles	0.75 number
$L_{pile}$ = length of pile embedded below potential scour depth	8 ft
$d_{pile}$ = diameter of the pile	1.30 ft
$h_{load}$ = applied load height above the potential scour depth	2.5 ft
$K_p = \frac{1 + \sin \theta}{1 - \sin \theta}$	4.2 unit less

**$F_{piles-h}$  (lb) -2,497**

Negative values resist downstream displacement.

**Sliding Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{sliding} = \frac{F_f + F_{piles-h}}{F_d + F_{nu} + F_{hd} + F_i}$$

**FOS<sub>sliding</sub> 71.2**

**Pile Strength Factor of Safety**

The factor of safety for the timber bending stress capacity of the pile. This evaluates the potential for the pile(s) to break under load prior to the pile pushing over in the ground.

		<b>Design Values Units</b>
$F_b =$ Timber Bending Stress Capacity per Timber Pile Manual Table 3-1 or AWC NDS Supplement Table 4D		1,200 psi 172,800 psf
$d_{pile} =$ diameter of the pile		1.30 ft
$I =$ circular cross – sectional moment of inertia	$I = \frac{\pi B^4}{4}$	2.24 ft <sup>4</sup>
$S =$ circular section modulus	$S = \frac{\pi B^3}{32}$	0.216 ft <sup>3</sup>
$C_F =$ strength reduction size factor for diameters greater than 12"	$C_F = \frac{1^{(1/9)}}{B}$	0.971 --
$M_p =$ applied moment per pile	$M_p = \frac{(F_d + F_i + F_h) \times h_{load}}{N_{piles}}$	694 ft-lb
$f_b =$ applied pile bending stress	$f_b = \frac{M_p}{S}$	3,217 psf
$F_{bx} =$ Pile bending stress capacity	$F_{bx} = F_b \times C_F$	1,166 psi 167,835 psf
$FOS_{pile\ strength} = \frac{F_{bx}}{f_b}$		
	<b>FOS<sub>pile strength</sub> 52.2</b>	

**References**

Large Woody Material - Risk Based Design Guidelines  
M. Knutson, J. Fealko. 2014. *Large Woody Material - Risk Based Design Guidelines*. U.S. Department of the Interior Bureau of Reclamation Pacific Northwest Region & Technical Services. Boise, Idaho. September 2014. Online at: <http://www.usbr.gov/pn/fcrps/documents/lwm.pdf>

ASTM D25. Allowable Stress Values for Treated Round Timber Piles.

Timber Pile Design and Construction Manual, Timber Piling Council, 2015.

American Wood Council (2018) National Design Specifications for Wood Construction, Design Supplement.

**Nason Floodplain - Large Woody Structure Stability Evaluation**

**Structural Stability | 6.4**

Structural stability of large woody material placements is evaluated herein using the procedures, formulas, and recommendations provided in the Reclamation's *Large Woody Material - Risk Based Design Guidelines* (Knutson et. al. 2014) along with insight gained from professional experience and general engineering judgment.

**Factors of Safety | 6.4.1**

Safety factors for structural stability were selected from *Table 4. Minimum recommended factors of safety* given the site specific public safety and property damage risk levels.

	Criteria:
Public Safety Risk Moderate	FOS <sub>sliding</sub> 1.5
Property Damage Risk Moderate	FOS <sub>buoyancy</sub> 1.75
Stability Design Flow Criteria 50-year	FOS <sub>rotation</sub> 1.5

**Resistance to Flotation | 6.4.2**

Flotation is typically caused by the buoyant force and the lift force acting on the wood material from water passing over its surface.

**Large Wood Material Force**

Accounts for the vertical buoyant force of submerged large wood and the vertical weight force of unsubmerged large wood.

$$F_{LWMS} = V_{LWMS} \times (\gamma_{wood} - \gamma_w)$$

$V_{LWMS}$  = total volume of submerged large wood material

$$V_{LWMS} = \sum N_{LWMi} \times V_{LWMi}$$

Variable	Design Value	Units
$\gamma_{wood}$ = unit weight of wood	38	lb/ft <sup>3</sup>
$\gamma_w$ = unit weight of water	62.4	lb/ft <sup>3</sup>
$V_{LWMS}$	249	ft <sup>3</sup>

<b><math>F_{LWMS}</math> (lb) 6,085</b>	<i>Positive values are upward forces.</i>
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**Lift Force**

Accounts for the lift force of large wood in flowing water. Not applicable to LWS where the bed will deform around the leading edges.

$F_L = \frac{C_L \times A_{LWM} \times \gamma_w \times U_o^2}{2 \times g}$	<b>Design Value</b>	<b>Units / Notes</b>
$C_L = \text{lift coefficient}$		0.2 typ. LWM value
$A_{LWM} = \text{area of large woody material perpendicular to flow}$		$A_{LWM} = \text{See Design Plan}$
$U_u = \text{upstream channel velocity at design event}$		<b><math>A_{LWM} \text{ (ft}^2\text{) 70}</math></b> For pre-racking condition
$g = \text{acceleration due to gravity}$		32.2 ft/s <sup>2</sup>
	<b><math>F_L \text{ (lb)}</math></b>	<b>N/A</b>

**Boulder Ballast Force**

Accounts for the ballasting force of large boulders directly attached to or placed over LWM.

$F_{bouldersub} = N_{bouldersub} \times \pi/6 \times d_{bouldersub}^3 \times (\gamma_{boulder} - \gamma_w)$	<b>Design Value</b>	<b>Units / Notes</b>
$N_{bouldersub} = \text{number of submerged boulders}$		0 number
$d_{bouldersub} = \text{effective diameter of submerged boulders}$		0 ft
$\gamma_{boulder} = \text{unit weight of boulders}$		165 lb/ft <sup>3</sup>
	<b><math>F_{bouldersub} \text{ (lb)}</math></b>	<b>N/A</b>

**Backfill Ballast Force**

Accounts for the ballasting force of backfill placed directly over LWM members. Volume is based on the fill area over the log(s) and a the effective cover depth shown on the Drawings.

$F_{backfillsub} = V_{backfillsub} \times (\gamma_s - \gamma_w)$	<b>Design Value</b>	<b>Units / Notes</b>
$V_{backfillsub} = \text{volume of backfill over LWM members}$		450 ft <sup>3</sup>
$\gamma_s = \text{unit weight of backfill material}$		See design plans 110 lb/ft <sup>3</sup>
	<b><math>F_{backfillsub} \text{ (lb)}</math></b>	<b>-21,420</b>

**Pile Skin Friction**

Accounts for the vertical resistance provided by piles within the LWM structure. USBR document equation modified by Inter-Fluve to match industry pile design standard formulations.

$$F_{piles-v} = N_{piles} \times \pi \times d_{piles} \times L_{piles} \times (k_s \times \tan \frac{2}{3}\theta \times \sigma')$$

	<b>Design Values</b>	<b>Units</b>
$N_{piles}$ = number of piles	1.5	number
$L_{piles}$ = length of pile embedded below potential scour depth	8	ft
$d_{piles}$ = nominal diameter of the piles	1.30	ft
$\sigma' = (L_{piles} \times (\gamma_{sat} - \gamma_w)) / 2$	190.4	lb/ft <sup>2</sup>
$K_s$ = coefficient of lateral earth pressure (0.5 to 1.0)	1.0	unit less
$\theta$ = internal friction angle of soils	36	deg.
<b><math>F_{piles-v}</math> (lb)</b>		<b>-4,155</b>
<i>Negative values resist upward displacement.</i>		

**Piles Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bPiles} = \frac{F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 0.7**

*Note this value does not include the backfill assuming it's all lost but the piles are holding.*

**Backfill Only Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bBackfill} = \frac{F_{backfillsub}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 3.5**

*Note this value does not include the piles.*

**Net Buoyancy Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{bNet} = \frac{F_{backfillsub} + F_{piles-v}}{F_{LWMS} + F_L}$$

**FOS<sub>b</sub> 4.2**

*Note this value includes the piles and backfill.*

**Resistance to Sliding | 6.4.3**

LWM structures are also susceptible to failure through sliding.

**Drag Force**

LWM structures are pushed downstream by the fluid drag forces acting upon the wood by the flowing water.

$F_d = \frac{C_D \times A_{LWM} \times \gamma_w \times U_c^2}{2 \times g}$		<b>Design Value</b>	<b>Units / Notes</b>
$C_D =$ drag coefficient		1	Per Equations 23 and 24
$A_{LWM} =$ area of wetted wood normal to the flow direction		$A_{LWM} =$ See Design Plan	
		<b><math>A_{LWM}</math> (ft<sup>2</sup>)</b>	70
$U_c =$ velocity adjacent to the LWM structure		3	ft/s Velocity value is conservative for all LWS locations. Value from 100-yr event 2D model results for main channel.
$g =$ acceleration due to gravity		32.2	ft/s <sup>2</sup>
<b><math>F_d</math> (lb) 610</b>			

**Hydrostatic Force**

Hydrostatic forces act on the upstream and downstream faces of a LWM structure. They account for differences in the upstream and downstream water depths against the structure.

$F_{hu} = \frac{1}{2} \times \gamma_w \times Y_u \times A_u$	$F_{hd} = \frac{1}{2} \times \gamma_w \times Y_d \times A_d$	<b>Variable Design Value</b>
$F_{hu}$ , $F_{hd} =$ hydrostatic force on upstream and downstream side of the wood structure		$Y_u$ (ft) 4.5
$Y_u$ , $Y_d =$ water depth upstream and downstream of the structure		$A_u$ (ft <sup>2</sup> ) 70 Post racking area
$A_u$ , $A_d =$ area projected to flow direction on the upstream and downstream of the structure		$Y_d$ (ft) 4.5
		$A_d$ (ft <sup>2</sup> ) 70 Plan downstream area
<b><math>F_{hu} + F_{hd} = F_h</math> (lb)</b>		N/A

**Impact Force**

The impact force associated with debris impacting a large wood structure can be estimated by the impact force equation.

$$F_i = \frac{w_{debris}}{g} \times \frac{V_{channel}^2}{2 \times \Delta x} \times C_i \times C_o \times C_d \times C_b \times R_{max}$$

$w_{debris}$  = weight of debris

$V_{channel}$  = channel approach velocity

$\Delta x$  = deceleration distance

Coefficients (see Table 6 and Figures 11, 12 for values)

$C_i$  = importance,  $C_o$  = orientation = 0.8,  $C_d$  = depth,  $C_b$  = blockage,  $R_{max}$  = impulse response ratio

Variable Design Value	
$W_{debris}$ (lb)	3,774
$V_{channel}$ (ft/s)	3
$\Delta x$ (ft)	5
$C_i$	0.5
$C_o$	0.8
$C_d$	1.0
$C_b$	1.0
$R_{max}$	0.8

<b><math>F_i</math> (lb) 34</b>
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**Friction Force**

Accounts for the friction force between the LWM and the channel bed. Restraint force from piles is not included as it does not exert a pressure on the LWS / bed interface.

$$F_f = -\mu_{bed} \times (F_{LWMS} + F_L + F_{bouldersub} + F_{backfillsub})$$

	Design Value Units / Source
$\mu_{bed}$ = coefficient of bed friction = $\tan(\theta)$	0.78 unit less
$\theta$ = internal friction angle (degrees)	38 Table 5, (Knutson et. al. 2014)

<b><math>F_f</math> (lb) -11,981</b>
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Negative values resist downstream displacement.

**Lateral Resistance From Piles**

Accounts for the lateral resistance provided by piles within the LWM structure. Assumes soil resistance is limiting, i.e. the pile pushes over before it breaks.

$$F_{piles-h} = N_{piles} \times \frac{L_{pile}^3 \times \frac{1}{2} \times (\gamma_s - \gamma_w) \times d_{pile} \times K_p}{h_{load} \times L_{pile}}$$

	Design Values Units
$N_{pile}$ = number of piles	1.5 number
$L_{pile}$ = length of pile embedded below potential scour depth	8 ft
$d_{pile}$ = diameter of the pile	1.30 ft
$h_{load}$ = applied load height above the potential scour depth	2.5 ft
$K_p = \frac{1 + \sin \theta}{1 - \sin \theta}$	4.2 unit less

<b><math>F_{piles-h}</math> (lb) -4,994</b>
---------------------------------------------

Negative values resist downstream displacement.

**Sliding Factor of Safety**

The factor of safety is the absolute value of the sum of resisting forces divided by the sum of driving forces.

$$FOS_{sliding} = \frac{F_f + F_{piles-h}}{F_d + F_{nu} + F_{hd} + F_i}$$

**FOS<sub>sliding</sub> 26.4**

**Pile Strength Factor of Safety**

The factor of safety for the timber bending stress capacity of the pile. This evaluates the potential for the pile(s) to break under load prior to the pile pushing over in the ground.

		<b>Design Values Units</b>
$F_b =$ Timber Bending Stress Capacity per Timber Pile Manual Table 3-1 or AWC NDS Supplement Table 4D		1,200 psi 172,800 psf
$d_{pile} =$ diameter of the pile		1.30 ft
$I =$ circular cross – sectional moment of inertia	$I = \frac{\pi B^4}{4}$	2.24 ft <sup>4</sup>
$S =$ circular section modulus	$S = \frac{\pi B^3}{32}$	0.216 ft <sup>3</sup>
$C_F =$ strength reduction size factor for diameters greater than 12"	$C_F = \frac{1^{(1/9)}}{B}$	0.971 --
$M_p =$ applied moment per pile	$M_p = \frac{(F_d + F_i + F_h) \times h_{load}}{N_{piles}}$	1,074 ft-lb
$f_b =$ applied pile bending stress	$f_b = \frac{M_p}{S}$	4,978 psf
$F_{bx} =$ Pile bending stress capacity	$F_{bx} = F_b \times C_F$	1,166 psi 167,835 psf
$FOS_{pile\ strength} = \frac{F_{bx}}{f_b}$		
	<b>FOS<sub>pile strength</sub> 33.7</b>	

**References**

Large Woody Material - Risk Based Design Guidelines  
M. Knutson, J. Fealko. 2014. *Large Woody Material - Risk Based Design Guidelines*. U.S. Department of the Interior Bureau of Reclamation Pacific Northwest Region & Technical Services. Boise, Idaho. September 2014. Online at: <http://www.usbr.gov/pn/fcrps/documents/lwm.pdf>

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