US Army Corps of Engineers ®
Walla Walla District

SWEETWATER CREEK ECOSYSTEM RESTORATION

Feasibility Report with Integrated Environmental Assessment

Appendix A

Hydrology and Hydraulics

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List of Acronyms

Acronym	Description
BEHI	Bank Erosion Hazard Index
Cfs	Cubic feet per second
D##	Effective diameter of a cumulative sediment grain size distribution
HUC	Hydrologic Unit Code
IQR	Inner Quartile Range (25th to 75th percentiles of a distribution)
Lbf	Pound force
LOID	Lewiston Orchards Irrigation District
LOP	USBR Lewiston Orchards Project
LSC	Lower Sweetwater Creek (below RM 4.0)
NMFS	National Marine Fisheries Service
NPT	Nez Perce Tribe
OLS	Ordinary Least Squares
SOL	Soldiers Meadow Reservoir
SWaM	Sweetwater Creek at Mouth, coincident with USGS#13342340
SWBI	USBR Hydromet Station – zzz
SWCI	USBR Hydromet Station – zzz
Psi (ψ)	Log_2 based sediment scale
Q	Shorthand for hydraulic flow in units of volume per time
TPP	USACE Tribal Partnership Program
USACE	US Army Corps of Engineers
USBR	US Bureau of Reclamation
USGS	US Geological Survey
WAFI	USBR Hydromet Station – Lake Waha Feeder Canal
WBCI	USBR Hydromet Station – Webb Creek above Sweetwater creek
WCCI	USBR Hydromet Station – Webb Creek Canal
WCBI	USBR Hydromet Station – Webb Creek below Diversion
WLS	Weighted Least Squares

1 Introduction

Appendix A summarizes the baseline hydrology and hydraulics and related physical riverine conditions for Sweetwater Creek. Sweetwater Creek historically harbored salmon and steelhead with productive spawning and rearing habitat. The proposed project under the USACE tribal partnership program (TPP) is to implement a suite of integrated ecosystem restoration measures within three sub-reaches (sites) to improve degraded aquatic and riparian habitat. As per ER-1105-2-100, the scope of this task was limited to an assessment of existing baseline conditions to inform the TPP§203 feasibility study. Two key takeaways from the H&H assessment are: 1) that the lower four miles of Sweetwater Creek frequently experience nuisance overbank flooding at return periods as low as the 20%-AEP, and 2) LSC has experienced multiple floods around the 5%-AEP scale that have degraded channel stability in select reaches.

During the subsequent PED phase for the preferred alternative, hydraulic modeling and design analysis will be critical to optimize site specific design parameters including final alignment planform, hydraulic geometry, slope transitions, detailed structure layout, and overbank routing of frequent nuisance flood flows. Measures to reconnect overbank floodplains into a riparian corridor should provide stage progressive grading to maximize volume capture of the spring freshet, increase roughness and sustain riparian processes. Live riparian vegetation components of the restoration are essential “glue” necessary to improve project durability and should be strategically integrated into banklines and structures with rooting depths installed at least below summer baseflow elevations to improve viability and drought resistance. Integrated restoration measures should be designed to optimize hydraulic performance for both stability and ecologic resilience as a composite system. Key components of proposed structural and grading measures should be designed to remain stable at the 1% AEP of 1255 cfs with design criteria and countermeasures that account for localized hydraulic conditions to address known modes of failure including: impingement, overtopping, tear-out, break-apart, and scour. In addition, the project should be designed to meet zero-rise criteria for flows exceeding the 20% AEP of 326 cfs.

2 Hydrology

2.1 Hydrologic Basin

Sweetwater Creek (HUC 170603061205) is a fifth order stream located in north-central Idaho with a drainage area of approximately 78 square miles. Fed by the Craig Mountains between Lewiston and Grangeville Idaho, it flows nearly eighteen miles from headwaters at 4,800 feet to the confluence with Lapwai Creek at 1,100 feet mean sea level. At RM 4.0, Webb Creek (HUC 170603061204) flows into Sweetwater Creek. Combined, the two represent approximately one-third of the Lapwai Creek catchment area (Figure 2-1).

Climate in the Sweetwater Creek watershed is regionally influenced by both maritime and inland weather patterns. The 30-year mean annual precipitation for 1981 to 2010 for the Sweetwater catchment is ~24 inches per year (PRISM 2019), ranging from 32 inches in the headwaters to 16 inches in the lower reach. Much of the annual precipitation occurs between November and March as snow. A summary of Sweetwater Creek basin characteristics is presented in Table 2-1.

Table 2-1. Summary of Sweetwater Creek Basin Characteristics

Parameter	**Value**
Mean basin elevation	3430 feet
Max basin elevation	5020 feet
Basin relief	3920 feet
Mean basin slope	22%
Percent area with slopes > 30%	22.3%
Agricultural basin area	18.4%
Forested basin area	43%
Mean annual basin precipitation for 1981 to 2010 (PRISM)	23.7

Source: USGS Stream Stats version 1.2.22

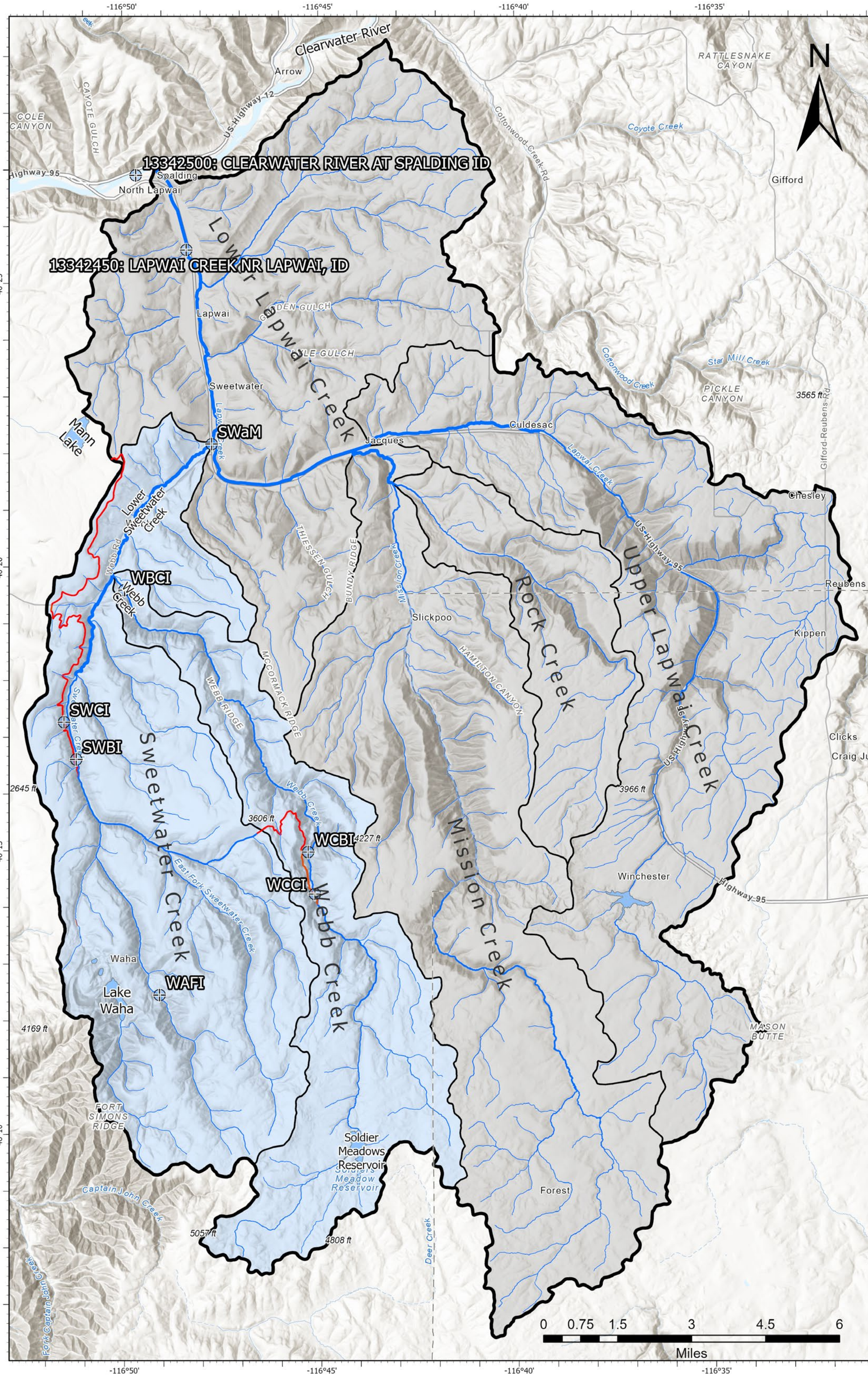

Figure 2-1 Lapwai Creek Watershed (HUC 1706030612) and the six contributing watersheds. *Sweetwater Creek Watershed is highlighted in blue with USBR gage locations. Red paths denote irrigation conveyances.*

Laka Waha is a landslide-dammed lake on the West Fork of Sweetwater Creek without a natural outlet located about 7 miles southeast of Lewiston, ID. As part of the LOP irrigation system, the Lake Waha hydrology has been modified since 1916 and includes both inlet canals and outlet pump station. Above ~RM 9.5, Sweetwater Creek headwaters branch into the East and West Forks. Flows from the West fork of Sweetwater Creek can be diverted out of the basin into Lake Waha to store up to 5.7 kaf nominally which can then be routed to Mann Lake (Reservoir A) via the Sweetwater Canal for use by LOID (Figure 2-3).

Groundwater losses from Lake Waha are hydrologically connected to the Sweetwater Springs complex on Plumb Creek (near WAFI gage) which were historically a significant source of natural stream flows in Sweetwater Creek on Sweetwater Creek downstream of the East and West forks; this flow provided both cold water refugia to steelhead trout during summer months and stable overwintering conditions (NMFS 2010).

The headwaters of Webb Creek include Soldiers Meadow Reservoir (SOL) which is used to store spring (March through June) runoff flows for irrigation up to a nominal capacity of ~2.4 kaf. Irrigation flows from SOL can be transferred to the East Fork of Sweetwater Creek via the Webb Diversion and then subsequently routed via the Sweetwater Diversion and canal near RM 8.5 to Mann Lake.

Figure 2-2 Aerial images of two LOP storage projects. *Left: Soldiers Meadow Reservoir, Right: Mann Lake (Reservoir A). Source: USBR.*

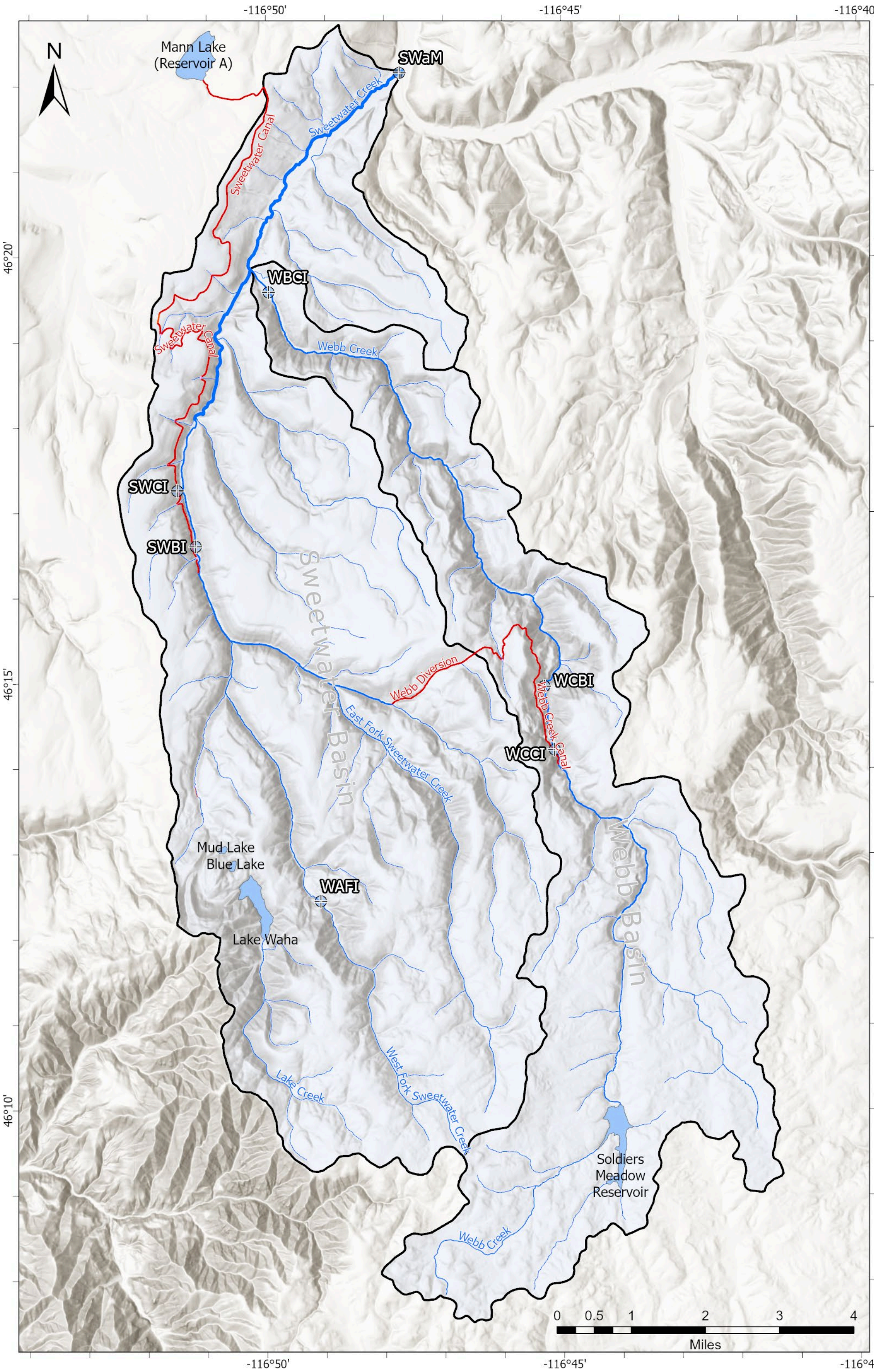

Figure 2-3 Sweetwater Creek watershed map with USBR Hydromet gage locations. *Irrigation conveyances are depicted by labeled red lines.*

2.2 Flow Regime

Stream flow patterns on Sweetwater Creek are characterized by a seasonal snowmelt driven freshet of the basin upper elevations during late winter or early spring (February to May) transitioning to low summer flows for the July through September period. Rain-on-snow events are common and can cause short term flooding. Storm events draining mid and low elevation plateaus in the basin are also common, characterized by short duration flashy peaks. Overbank nuisance flooding on Sweetwater Creek is also common which has resulted in various landowners implementing ad-hoc flood and erosion control measures.

In years with low snowpack, drought conditions can persist through the summer months. Various water diversions from the headwaters of Sweetwater and Webb Creeks to fulfill irrigation demands of the Lewiston Orchards Project (LOP) also influence the flow regime. Since the early 20th century, irrigation diversions for the LOP on Sweetwater Creek, West Fork Sweetwater, and Webb Creek have altered the annual hydrograph of Lower Sweetwater Creek resulting in notable annual flow variations relative to historical conditions. Irrigation diversions and water rights in the Sweetwater drainage have historically been owned by the Bureau of Reclamation (USBR) and operated by the Lewiston Orchards Irrigation District (LOID). Since 2008, the Nez Perce Tribe (NPT) has worked with LOID, USBR and regional stakeholders on developing the Lower Clearwater exchange project to establish in-stream flow to Sweetwater Creek with an objective of improving aquatic and riparian habitat.

The 2010 BiOp established a minimum flow of 2.5 cfs as necessary to maintain connectivity in Sweetwater Creek, and 1.0 cfs in Webb Creek during LOD water diversion operations. As detailed in the 2020 LOP Biological Assessment (USBR, 2020), the USBR and NPT are proceeding to implement a water exchange and title transfer agreement to increase flows in Webb and Sweetwater Creeks for improved conditions to support steelhead trout spawning and juvenile rearing. The agreement includes the transfer of the use of the Soldiers Meadows Reservoir (SOL) from LOID to the NPT. Offsets to surface water that was previously diverted to the LOP began with a pilot well starting in water year 2017 with a second well in 2020. The installation of the two additional wells is projected to incrementally increase over an approximate ten-year period as funding becomes available to construct additional wells as discussed in Section 2.2.4

2.2.1 Seasonal Flows

Sweetwater flows at the mouth (SWaM) were used to characterize the baseline flow regime for the baseline assessment. This location coincides with USGS#13342340 which includes ~17 years of measured stage and flows between WY2003 and 2019. The available record from the USGS gage is mostly complete however, for non-flood periods in the timeseries, select missing data from the SWaM record was interpolated over relatively short gaps less than 12 hours; larger flow gaps for SWaM were provisionally estimated as the sum of the upstream Webb Creek (USGS:13342295) and the Sweetwater below Waha diversion gage (USBR: Hydromet SWBI). Seasonal quantiles for measured mean daily flow at SWaM from WY2003 to 2019 are presented in Figure 2-4, illustrating the typical hydrograph trends since 2002.

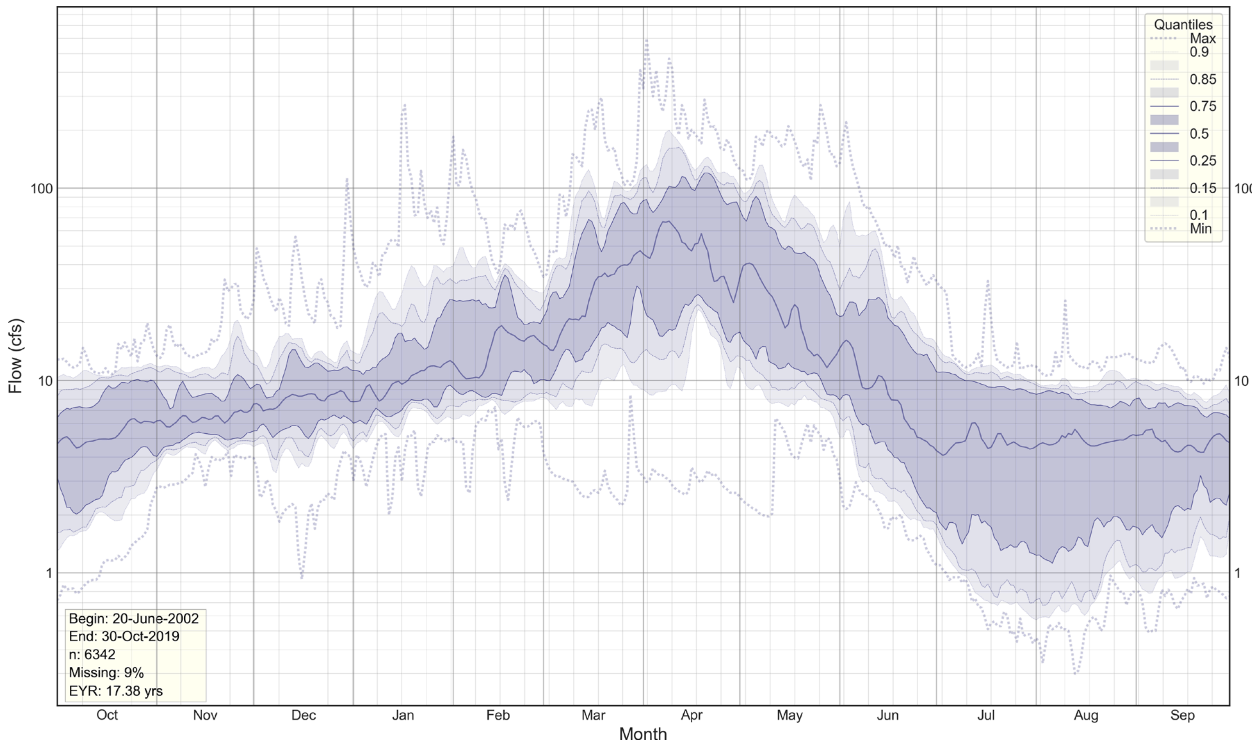

Figure 2-4. Seasonal mean daily flow quantiles for Sweetwater Creek at Mouth (SWAM) from WY 2003 to WY 2019.

To extend the SWaM flow record, an ordinary least squares (OLS) correlation of 5481 paired mean daily flow logarithms on Sweetwater and Lapwai Creeks was completed for water years 2003 to 2019 resulting in an R^2 coefficient of 0.857 (Figure 2-5). This fit balanced the range of low to high flows, resulting in a slight bias above the OLS fit for flows less than 100 cfs that generally fell within the shaded confidence intervals. The correlation was used to hindcast mean daily flow values for SWaM prior to WY 2003 for use in subsequent analyses.

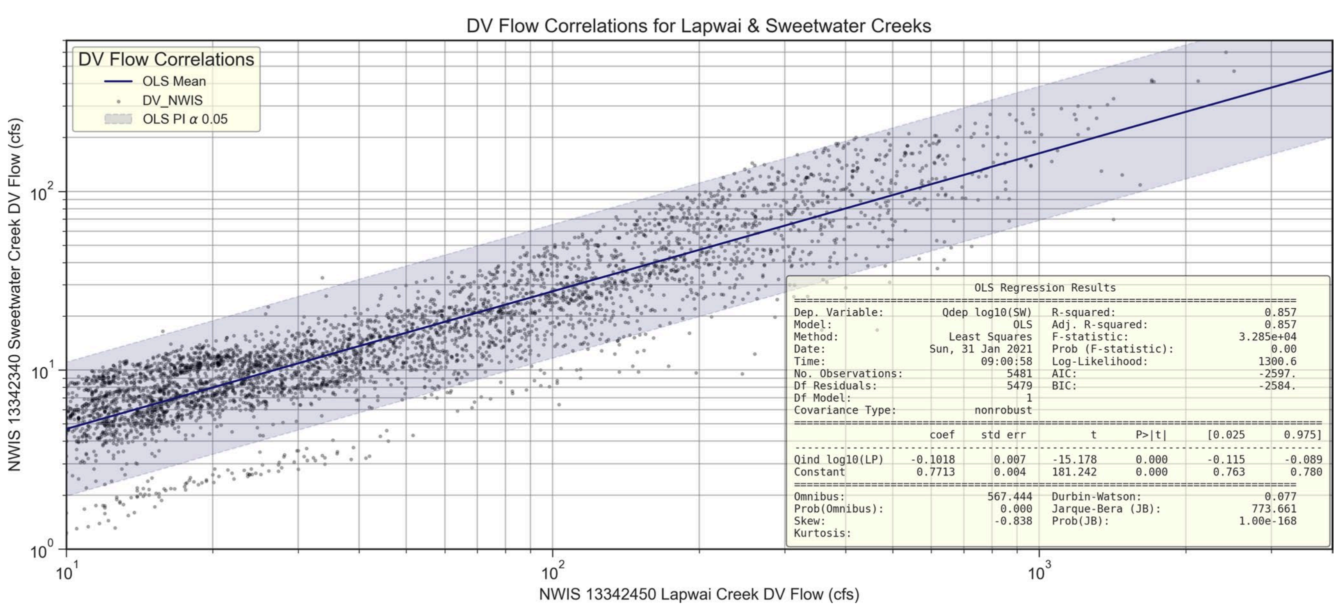

Figure 2-5. Mean Daily Flow Correlations between Lapwai & Sweetwater Creeks with shaded 95% confidence intervals.

2.2.2 Volumetric Yield

Volumetric yield to lower Sweetwater Creek was quantified to distinguish between wet and dry years and evaluate seasonality for shallow groundwater recharge in the riparian corridor. As previously noted, diversions to the Lewiston Orchards Project (LOP) can reduce in-stream flow volumes in lower Sweetwater Creek from February through October each year. The annual contracted diversion amount to LOD is ~8.4 kaf and the volume of water withdrawn from Sweetwater Creek into the LOD for water years 2003 to 2008 was estimated to average approximately 7 kaf per year (NMFS 2010). An ordinary least squares correlation (OLS) between Sweetwater and Lapwai Creek annual flow volume was completed for 14 years between water years 2002 and 2020, resulting in an R^2 coefficient of 0.983 (Figure 2-6).

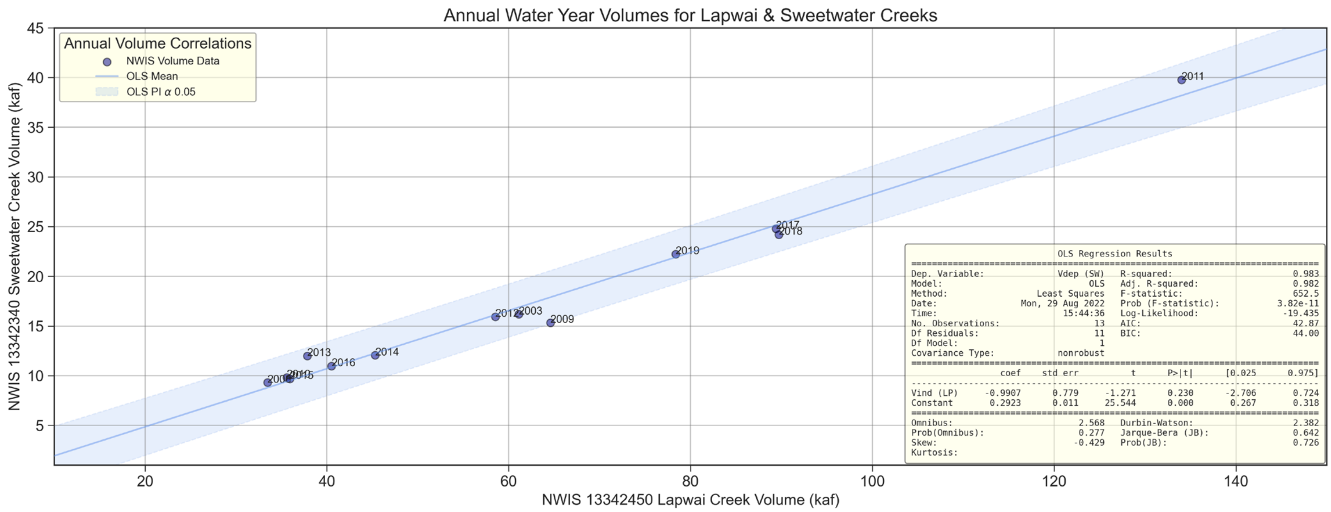

Figure 2-6. Annual Water Year Volume correlations between Sweetwater and Lapwai Creeks with α=0.05

Hindcast estimates of annual volumetric yield at SWaM were developed using the composite mean daily flow record from WY1975 to WY2020. Quantiles of annual yield within the 45-year hydro-period were used to establish volumetric thresholds for relative runoff (Figure 2-7).

Average years are classified as the inner quartile range of the distribution with dry and wet years classified as below the lower 25% and above the upper 25% of the maximum hydroperiod volume (~10kaf and ~21kaf respectively). Figure 2-8 depicts the ranked exceedance for annual water year volume at SWaM. Extreme dry years are classified as the lower 15% (<8 kaf/year), and extreme wet years as the upper 15% (>24 kaf/year).

Figure 2-9 depicts seasonal quantiles of the cumulative volume fraction for SWaM between WY 1975 and WY 2020. A key observation is that the IQR for receiving half the annual volume falls between mid-March and early-April and that by the end of May, only 10% of the annual volume remains for the last third of the water year. From an ecological perspective, this runoff signature illustrates the importance of maintaining a wide riparian corridor with low floodplain surfaces that can inundate annually to recharge shallow groundwater and sustain riparian vegetation through the summer months.

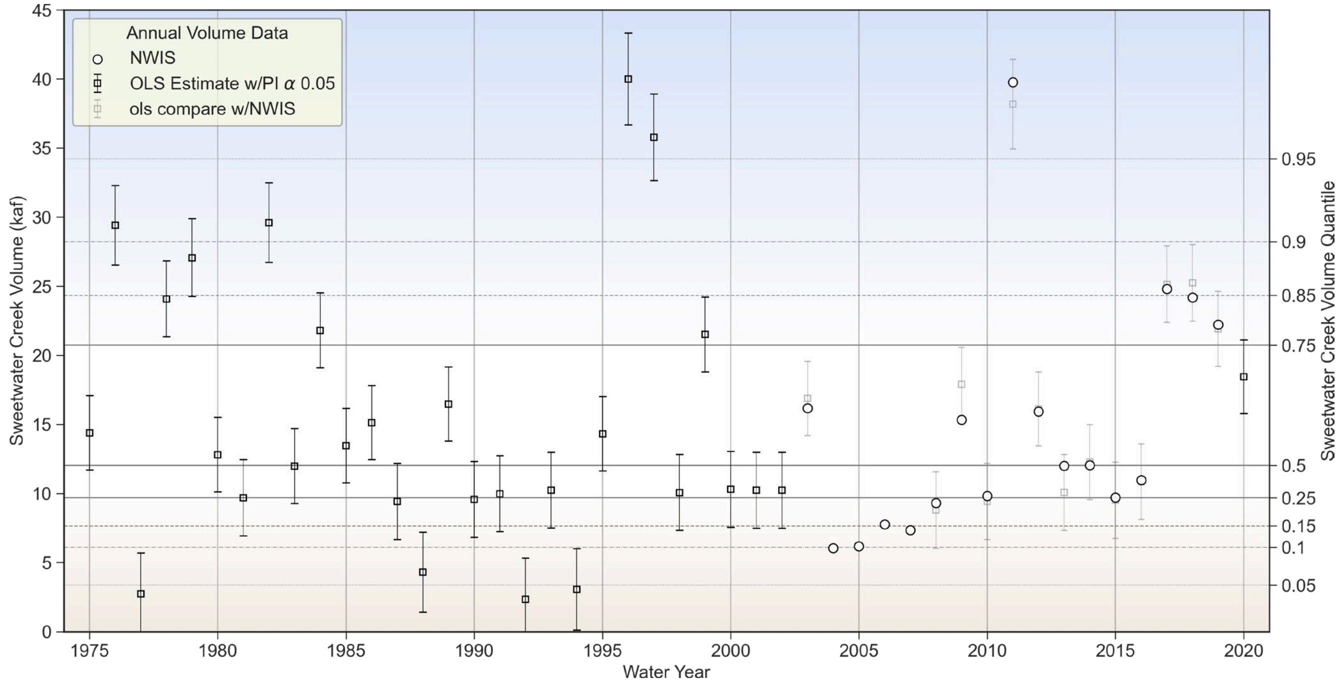

Figure 2-7. Annual Water Year Volume Totals for SWaM. Water year estimates prior to 2003 were hindcast from Lapwai Creek flow correlations with α=0.05.

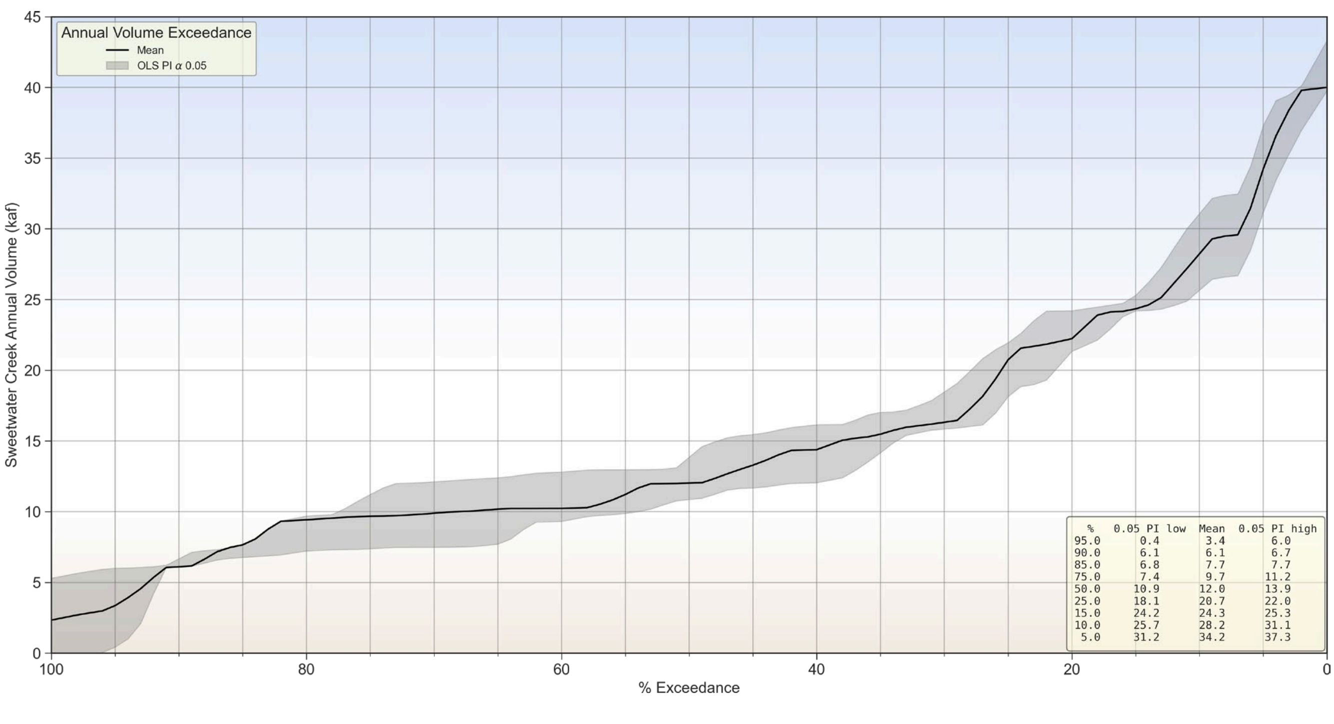

Figure 2-8. Annual Water Year Volume Exceedance for WY 1975 to 2020 at SWaM with α=0.05.

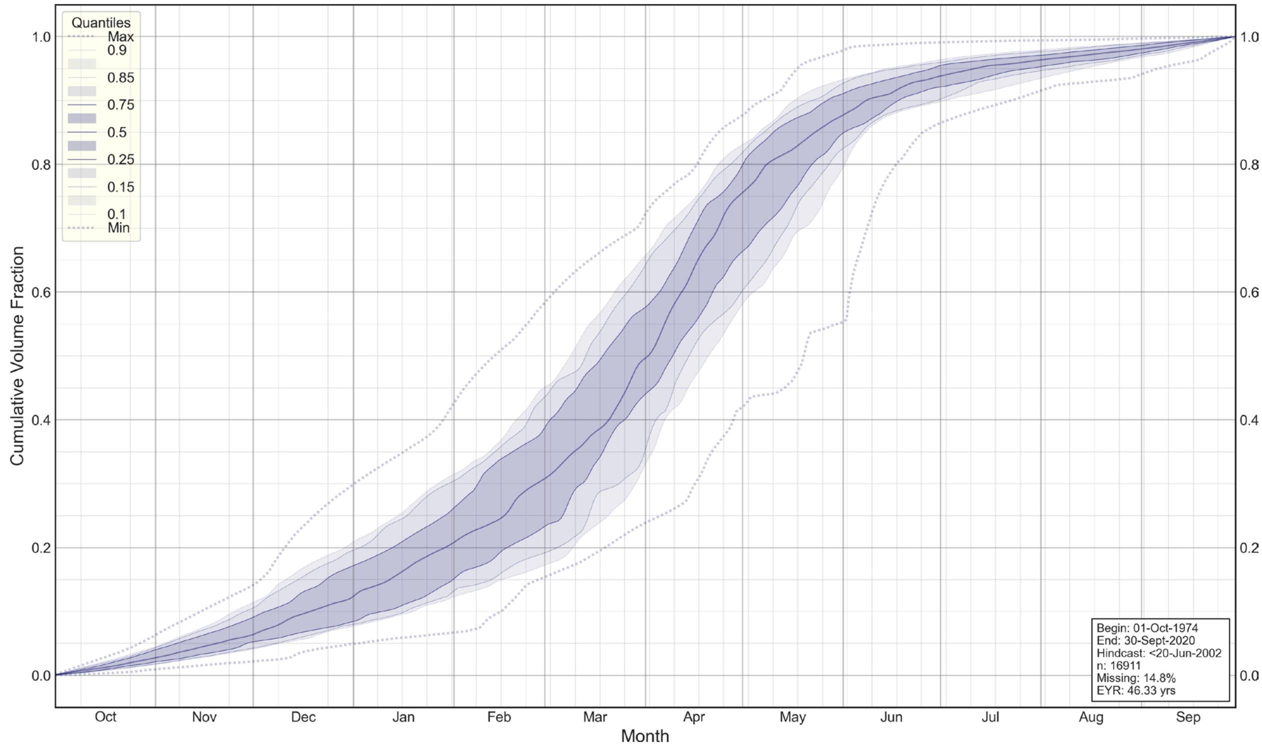

Figure 2-9. Seasonal Volume Trends for Sweetwater Creek at Mouth

2.2.3 Peak Flows

Flooding on Sweetwater and Lapwai Creeks is driven by both snowmelt and precipitation events, and can occur in winter or spring, typically between November and May. The most common month for flooding on Sweetwater Creek is March when mid elevation snowmelt melts quickly with warming seasonal temperatures. Several significant floods have also occurred in April and May. Rain on snow events can cause rapid flow increases. Over twenty percent of measured floods on Lapwai Creek since 1972 have occurred between December and February, with 37% in March, another 37% in April-May, and less than 5% occurring in June.

Measurements of instantaneous peak flows at SWaM are available from WY2002 to WY2019 from USGS Station#13342340 (Figure 2-10). With the exception of the February 1996 rain-on-snow event that is estimated at nearly a 50% AEP, Sweetwater Creek has experienced the next three largest floods of the measurement record in the last decade, in April of 2011 (600cfs) and 2019 (656cfs), and most recently in June of 2022 (~624cfs) (Figure 2-18). The estimated return period for these floods falls on the 5-10% AEP interval (Table 2-5) resulting in significant nuisance flooding (Figure 2-11) and average overbank flow depths of < 0.5 ft (Figure 3-3) with average conveyance rates up to ~20 cfs/ft (Figure 3-5)

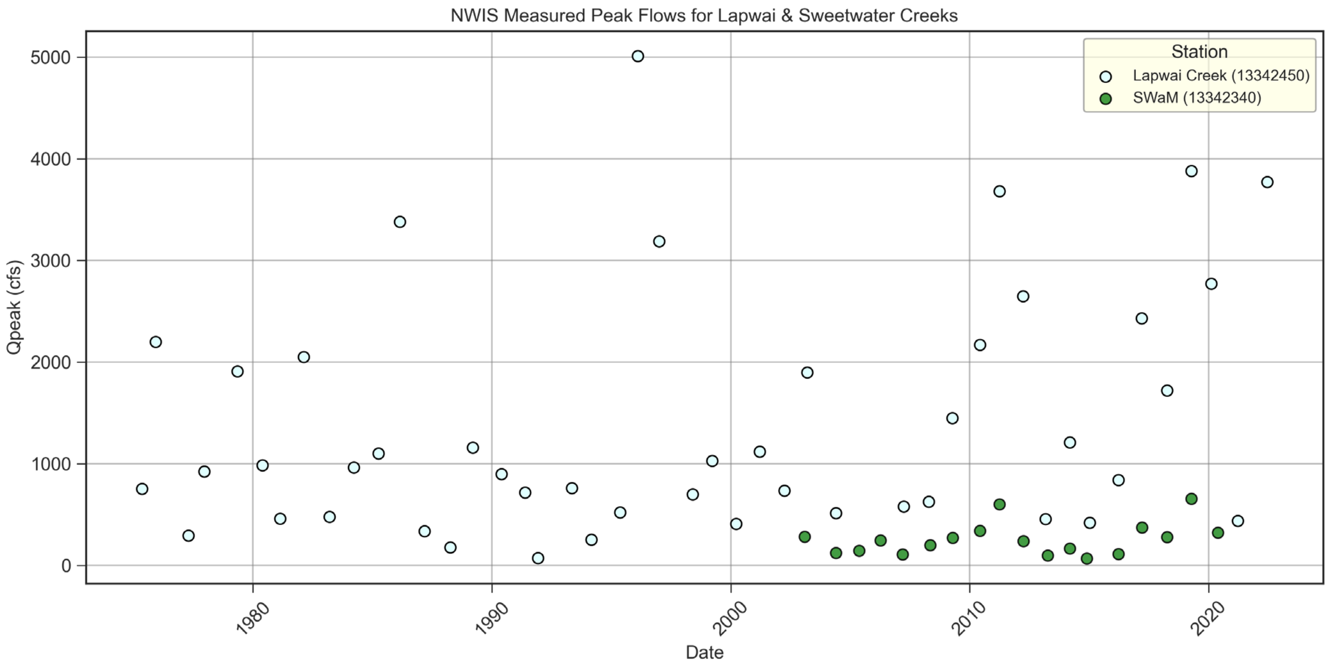

Figure 2-10. Measured peak flows on Lapwai and Sweetwater Creeks. *Note Sweetwater gage active WY2002 to WY2020.*

Figure 2-11. Nuisance flooding on Sweetwater Creek. April-2019 ~650 cfs (5% AEP). *Left: US Hwy95 bridge above Lapwai confluence. Right: Looking South at RM 0.5. Note eroded right bank upstream of bridge that has since had the riprap revetment upgraded by IDT.*

Figure 2-12. Overbank nuisance flooding on Sweetwater Creek. April-2019 ~650cfs (~5% AEP). *Looking Northwest towards RM 0.8. The main channel is behind the line of riparian trees.*

2.2.3.1 Regulatory Floodplain

Flood Risk management on Lower Sweetwater Creek falls within two distinct jurisdictions depending on land ownership. As depicted on the current regulatory FEMA Flood Insurance Rate Maps (FIRM) Panels 160101-0381B & 160101-0400B (Figure 2-13), NPT tribal lands are exempt from participation in the National Flood Insurance program (NFIP). Currently the NFIP and corresponding regulations regarding floodplain development and channel management are applicable to less than 20% of lands in the lower four miles of Sweetwater Creek. Over 80% of lower Sweetwater Creek flows through Nez Perce Tribal (NPT) lands, with both trust and allotment parcels. Within lower Sweetwater Creek there are numerous flood prone structures, and the lack of historical floodplain management has resulted in the construction of various ad-hoc flood response measures such as push-up berms to contain flows, and bank revetments to mitigate localized erosion. While many revetment features have proven effective at stabilizing banklines, the various longitudinal berms to protect various parcels essentially contain up to a 10-year return period (10% AEP) and have been eroded and/or flanked at higher flows.

The USACE TPP§203 ecosystem restoration project is proposing to modify the stream channel and riparian floodplain at three sites within the lower four miles of Sweetwater Creek. Because the proposed restoration actions will be implemented within the active channel and adjacent overbanks, the project design should meet no-rise criteria for all flows exceeding the 20% AEP (5-year return period) flow of 326 cfs. This is not intended to meet an NFIP requirement, but rather to ensure no net increase in relative flood risk as a result of project implementation. The primary project component to ensure no-rise conditions will be the construction of a longitudinally contiguous riparian corridor with inset floodplain features that sufficiently increase the conveyance area to offset the additional roughness introduced by proposed restoration features.

NPT is strongly encouraged to implement a floodplain development permit and compliance framework for Sweetwater Creek to help manage future flood risk in lower Sweetwater Creek. Further, the USGS gage#13342340 for Sweetwater Creek has been inactive since 2021 which introduces uncertainty regarding the magnitude of future flows and potential long-term trends as discussed in Appendix I (Climate Change

Assessment). Further, this uncertainty in flow presents a significant future residual risk to the project, especially in regard to flood events during the post-construction and near-term (0 – 10 years) where project performance under known hydrologic loading conditions should be assessed for risk informed adaptive management.

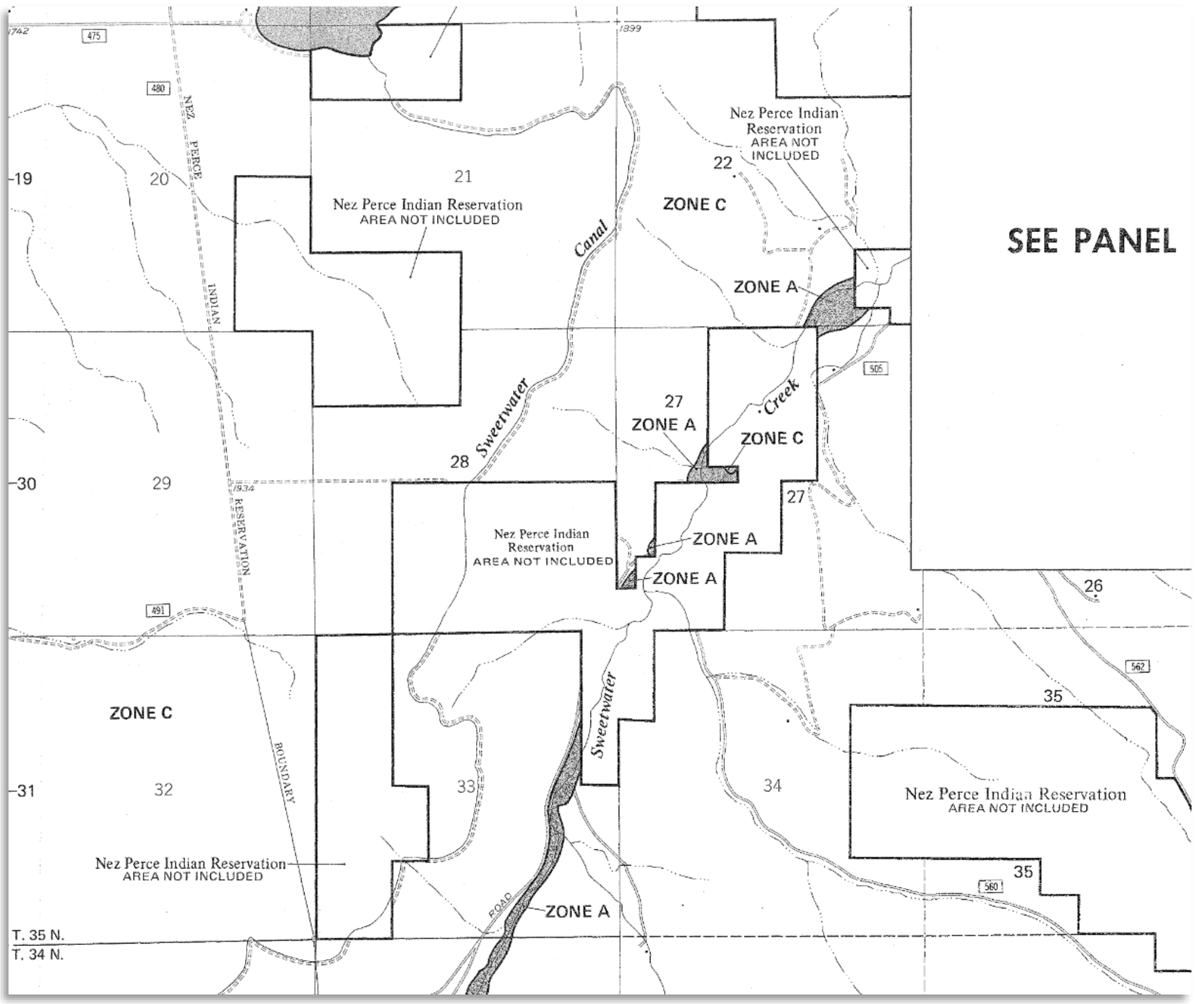

Figure 2-13. Excerpt from Flood Insurance Rate Map Panel 1601010400B effective date (04-April-1983). (*Source: msc.fema.gov*)

2.2.4 Ecologically Significant Flows

Ecologically significant flows include those that influence and sustain various processes related to ecosystem function and health. This includes flows necessary to seasonally inundate the riparian corridor and sustain vegetation, flows related to geomorphic channel processes such as sediment transport, and those related to biologic processes and timing.

Bankfull flow is a threshold corresponding to the dominant channel forming flow that typically fills the active channel up to a point of incipient flooding. The bankfull flow return frequency varies with region and stream type and is commonly less than a 2-year return period (50% AEP) in stable alluvial systems with ample floodplain access. Field observations of vegetation and morphologic indicators were referenced to water surface elevations at various flow levels to establish a range of relevant bankfull flows. As illustrated in Figure 2-4, the IQR of mean daily flows associated with the spring freshet spans from approximately 20cfs to just over 100cfs. Observed low vegetation indicators of bankfull coincide with a flow of ~75cfs with a slightly higher morphologic threshold of ~125cfs tracking with low inset banklines and exposed tree-roots. For incised channel segments, a flow of ~350cfs represents a terrace-full condition whereby the active channel capacity is full and low overbank areas are also active (Figure 2-14).

Figure 2-14. Example bankfull Flow Indicators. *Left: SW1 looking upstream at RM 0.29. Right: SW7 looking upstream at RM 3.55.*

As highlighted in Table 2-2 and Figure 2-4, the spring freshet typically occurs between March and May, with the highest sustained daily flows occurring in April. Low bankfull flows matching vegetation indicators are reached less than 50% of the month, and bankfull geomorphic flows less than 25% of the month. The terrace full flow capacity for incised reaches is exceeded less than 2% of the time. Annually, bankfull vegetation flows are reached less than 10% of the year, and bankfull geomorphic flows less than 5% of the year. On the low flow end of the spectrum, flows less than the monthly targets of the 2010 BiOp and 2020 Biological Assessment (Table 2-3) are not met more than 50% of the month on average for baseline conditions.

Table 2-2. Duration analysis of Mean Daily Flow for Sweetwater Creek at Mouth for Monthly and Annual Hydroperiods

	WY Q1			WY Q2			WY Q3			WY Q4			
	Juvenile Rearing				Spawning			Inc	Juvenile Rearing				
PHE	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Ann**
99	0.8	2.8	1.9	2.9	3.4	2.5	2.6	2.1	1.5	0.5	0.4	0.6	0.6
95	1.3	3.8	3.0	4.7	5.9	3.4	3.3	5.1	1.9	0.6	0.6	0.8	1.1
90	1.8	4.2	4.0	5.3	7.0	6.6	10.4	7.0	2.2	0.8	0.7	0.9	2.0
80	2.3	4.7	5.2	6.6	8.2	12.3	18	9.9	3.1	1.2	1.1	1.6	4.1
50	5.4	6.2	7.8	10.1	14.5	26.7	50.1	21.5	8.0	4.8	4.9	4.7	8.6
25	8.8	9.6	11.5	14.8	25	50.2	98.4	51.5	19.2	9.8	8.4	7.2	17.3
15	10.7	11.5	13.6	24.5	34.4	76.6	125	75.7	27.9	11.3	9.2	8.8	32.2
10	11.1	12.9	15.7	32.7	38.3	92.2	151	98.5	35.9	11.9	10.6	9.7	48.3
5	12.5	16.4	21.2	48.5	54.9	123	191	135	59	12.6	11.6	10.4	84.9
2	14.4	22.1	33.6	72.9	78.1	161	284	182	89.8	15.8	13.2	12.9	135
1	15.7	28.7	44.8	118	106	239	400	195	135	25.0	13.6	14.6	170.6
0.1	19.9	33.5	113	270	185	410	600	270	220	32.9	26.0	15.6	380.6

PHE = Percent of Hydroperiod Exceeded
Inc = Incubation Period (May)
Cell shading indicates flows compared to select thresholds.
{Brown ≤ 2017 BiOp & 2020 BA Monthly Flow Targets, Green ≥ 75cfs, Blue ≥ 125 cfs, and Magenta ≥ 350 cfs}

Future flows in lower Sweetwater Creek are expected to significantly improve relative to baseline conditions as a long-term outcome of a negotiated exchange between USBR and NPT. Per the agreement, inter-basin transfers of water from Sweetwater and Webb Creek to supply the Lewiston Orchards Project will be reduced using approximately four large groundwater wells to offset the demand. The first well was brought online for water year 2017, a second well in 2020, and the two additional wells anticipated to be installed over the subsequent decade pursuant to funding. Based on the 2010 and 2017 NMFS biological opinions, a minimum flow of 2.5 cfs and 1.0 cfs are necessary to maintain connectivity in lower Sweetwater Creek and Webb Creek respectively.

As per USBR, the decision support structure for the future flow regime is divided into minimum flows, target flows, and opportunity flows (see Table 2-3). Minimum flows are based off the 2010 and 2017 Biological Opinions from NOAA Fisheries and are expected to be able to be provided every year. Target flows are derived as the sum of minimum flows and offsets from groundwater well supply to LOID. Opportunity flows are voluntary additions to the target flows when sufficient volume is available within the system. An annual plan is developed each year by USBR, LOID, and NPT to establish flow targets and timing. Automated headgates at LOP diversions are used to maintain flow targets and minimize daily operational variability. In addition, ramping rates will be implemented to more closely mimic natural hydrologic variation and allow water to be used more efficiently to provide optimal spawning habitat in both Webb and Sweetwater creeks. (Table 2-4).

Table 2-3. Instream flow releases (cfs) for Sweetwater & Webb Creeks at their diversions combined. (Source USBR 2020 Biological Assessment)

<table>
<tr><th rowspan="3">Flow Release</th><th colspan="6">No use of stored water to meet flows</th><th colspan="6">Stored water used to meet flows</th></tr>
<tr><th colspan="3">Juvenile Rearing</th><th colspan="3">Spawning</th><th>Incubation</th><th colspan="5">Juvenile Rearing</th></tr>
<tr><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th></tr>
<tr><td>Minimum (up to 5 of 15 years</td><td rowspan="3">I (a)</td><td rowspan="3">I</td><td rowspan="3">I</td><td rowspan="2">15.6-29.8/I (b)</td><td rowspan="2">15.6-29.8/I</td><td rowspan="2">15.6-29.8/I</td><td>4.5</td><td>3.5</td><td>3.5</td><td>3.5</td><td>3.5</td><td>3.5</td></tr>
<tr><td>Target (at least 10 of 15 years)</td><td>8.3</td><td>7.3</td><td>7.3</td><td>7.3</td><td>6</td><td>6</td></tr>
<tr><td>Opportunity (maximum if available)</td><td colspan="3">Natural flow in excess of canal capacity (c)</td><td>22.5</td><td>17</td><td>12.5</td><td>12.5</td><td>12.5</td><td>12.5</td></tr>
</table>

(a) Diversion dams are not operated from November through January. All stream flow reaching the diversion dams will be bypassed. For Webb Creek, the "I" flow is composed of all runoff downstream from Soldiers Meadow Dam; for Sweetwater Creek this value is composed of all runoff downstream from Lake Waha except for runoff diverted by the West Fork diversion.
(b) Months shown with a "[value]/I" specification (February, March and April) are those in which either the specified stream flow will be provided or all inflow (I) to the Webb and Sweetwater diversion dams (as described above) will be bypassed, whichever is less. The specified minimum flow with just the pilot well online is 15.6cfs and will increase up to a potential 29.8cfs as each additional well that comes online is offset.
(c) Natural flows during spring peak flow/spawning (February, March and April) will often exceed canal capacity by more than the target flows. The system does not have means to store this water and it remains in-stream.

Table 2-4. 2020 Ramping Rates for Sweetwater and Webb Creeks

Flows (cfs)	Max Rate (cfs/day)
Ramping Water Into the Sweetwater or Webb Canal	
0.00-4.00	1.00
4.01-8.00	2.00
8.01-15.00	3.00
15.01-30.00	5.00
30.01 or greater	10.00
Ramping Water Out of the Sweetwater or Webb Canal	
0.00-4.00	2.00
4.01-12.00	4.00
12.01-25.00	6.00
25.01 or greater	10.00

Estimates of future flow for the next 50-years were developed from the flow management rules presented in Tables 2-4 and 2-5. The extended mean daily flow record for SWaM (section 2.2.1) was used to hindcast synthetic datasets for three discrete hydroperiods, each with an additional well being brought online. The analysis assumed two wells would be online within the first four years, with another in the next four years, followed by the last well within the next two years. Synthetic timeseries from each hydroperiod (Figure 2-15) were weighted by their duration fraction to compute mean daily flow quantiles for SWaM (Figure 2-16).

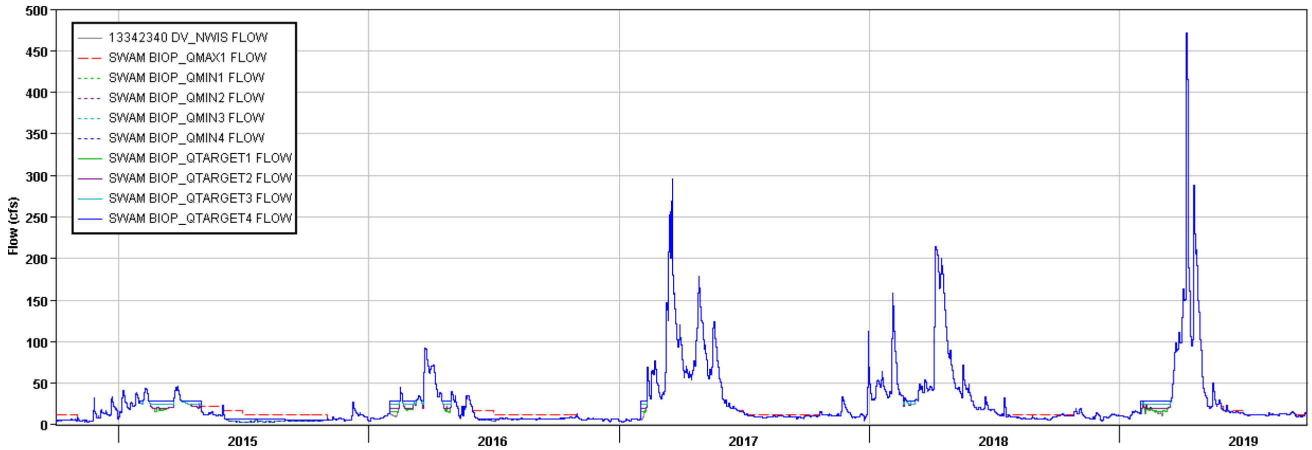

Figure 2-15. Synthetic hindcast timeseries at SWAM with various sets of seasonal flow applied rules per 2020 BA displayed for WY2015-2019

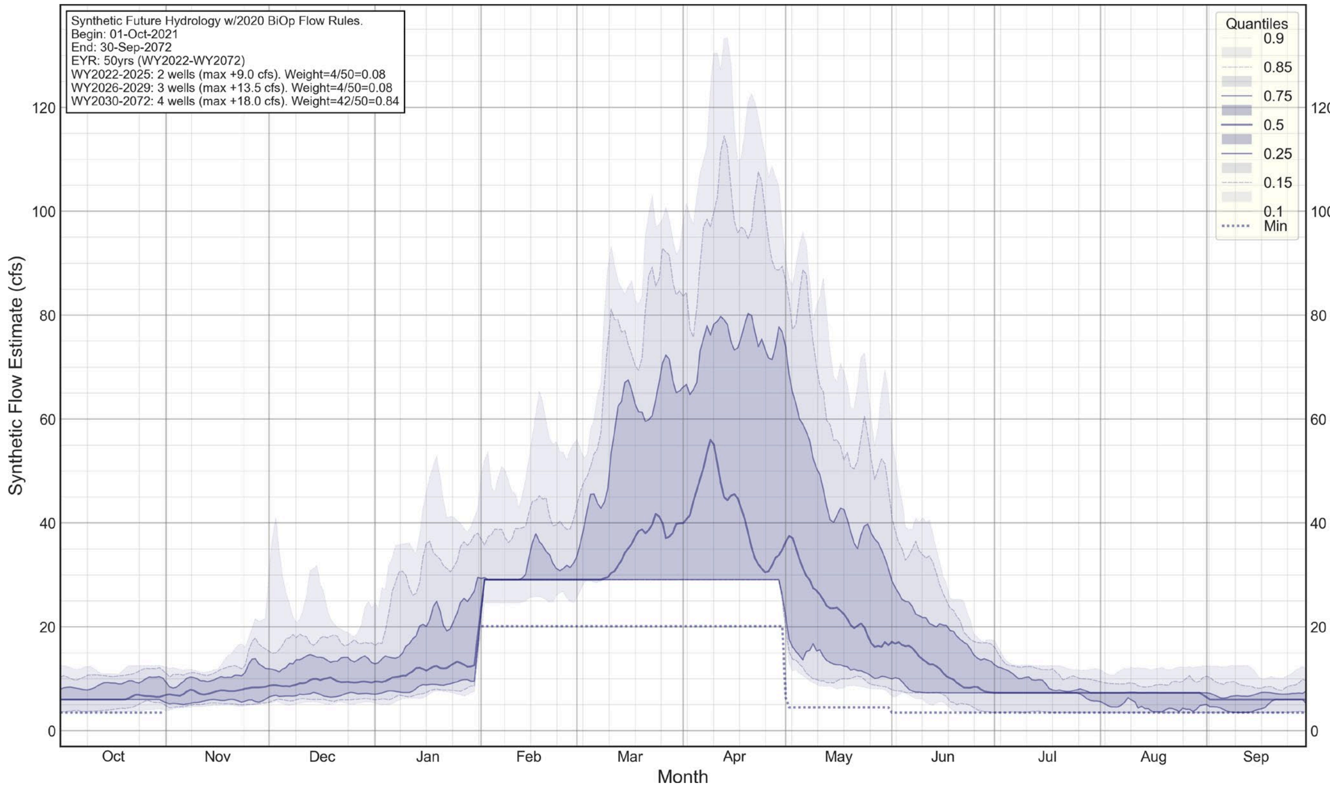

Figure 2-16. Seasonal 50-year future daily flow quantiles for SWaM synthesized from 2020 BiOp flow rules.

2.3 Flood Frequency

Flood frequency estimates for lower Sweetwater Creek include uncertainty due to a relatively short stream gage record (WY 2003 – 2019) at USGS gage#13342340. In addition, before the gage was discontinued and the end of WY 2019, the two largest recorded flood events (600cfs and 656 cfs in April of 2011 and 2019 respectively) were extrapolated above the gage rating value of 342 cfs at 6.20 feet.

Flood frequency estimates for lower Sweetwater Creek at the mouth (SWaM) were computed using Bulletin 17c methods (USGS 2019) for two datasets of instantaneous peak flows. The first dataset included 18 systematic records for the SWaM, which were extended into a second dataset by synthesizing 30 years of additional hindcast peak flows from correlations with Lapwai Creek into a composite peak flow record for WY 1975 to 2022. The distribution of the two peak flow datasets was similar with a mean of (2.33 vs. 2.22) and a station skew of (+0.01 vs -0.01) for the measured and expanded datasets respectively. The computed magnitude of flood frequency estimates from the two datasets was similar with an adopted skew of +0.16 and +0.07 for the measured and expanded datasets respectively. The difference in the 1% AEP estimate between the two datasets was +11.6% and -3.6% for the computed and expected probability curves respectively. Ultimately the flood frequency estimate based on the adjusted (i.e., expected probability) curve of the extended peak flow dataset was adopted for use in this study.

2.3.1 Peak Flow Correlations

Current observations and historical accounts by local landowners indicate that spring peak flows on Sweetwater Creek typically coincide with those on Lapwai Creek within a two-week window. Due to the short record for measured SWaM peak flows, a correlation with coincident peak flows at Lapwai Creek was used to hindcast synthetic peak flows prior to 2002 with 95% prediction intervals to develop a composite annual flood record at SWaM from water years 1975 to 2022 (Figure 2-18). The composite record was then used to update the flood frequency analysis as described in Section 2.3.2 below.

A least squares correlation between Sweetwater and Lapwai Creek annual peak flows was completed for 16 coincident events between water years 2002 and 2020. Ordinary least squares (OLS) fit of the peak flows resulted in an R^2 coefficient of 0.959 and scaling parameter of 0.1505. To better match SWaM peak flows > 200 cfs and improve the prediction interval, the OLS correlation was modified using weighted least squared (WLS) methods. Weights were assigned as the normalized square of the inverse distance from the maximum measured peak flow for SWaM, resulting in a scaling parameter of 0.1655 and an R^2 coefficient of 0.931 (Figure 2-17). Despite a slightly lower R^2 coefficient, the WLS correlation provided a better fit to match the largest measured peak flows in the system.

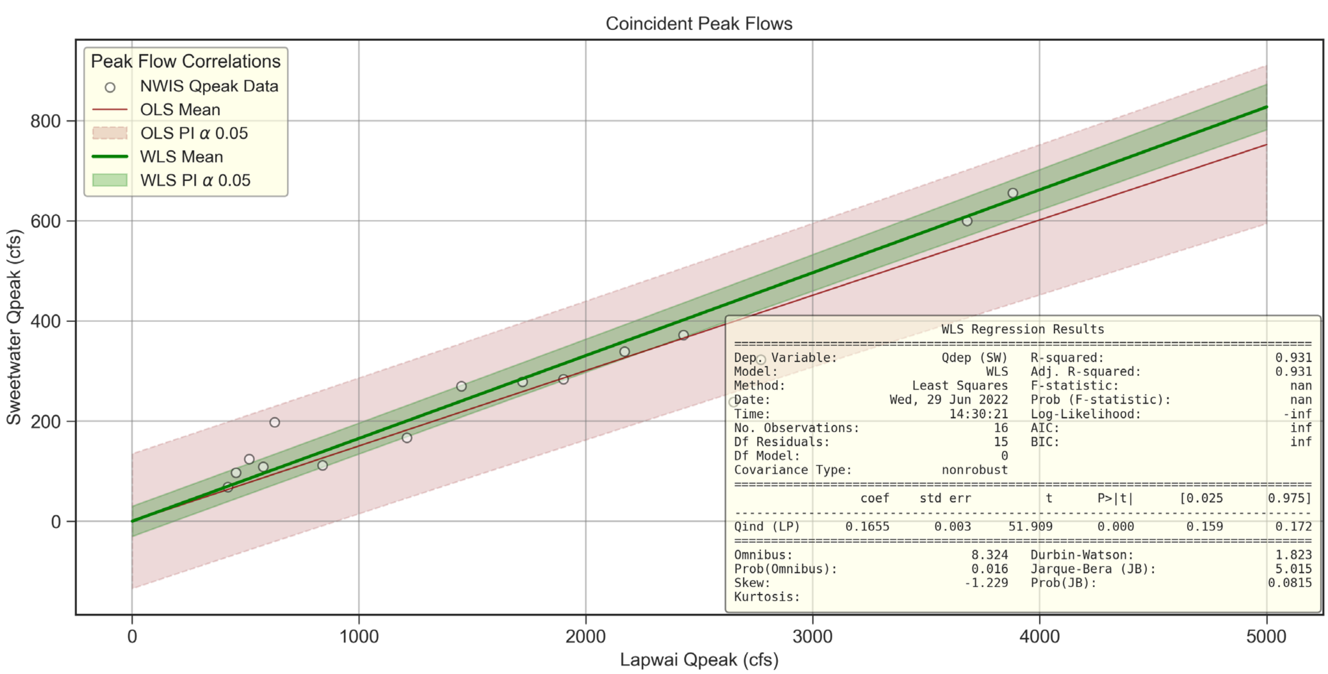

Figure 2-17. Annual Peak Flow Correlations between Lapwai & Sweetwater Creeks

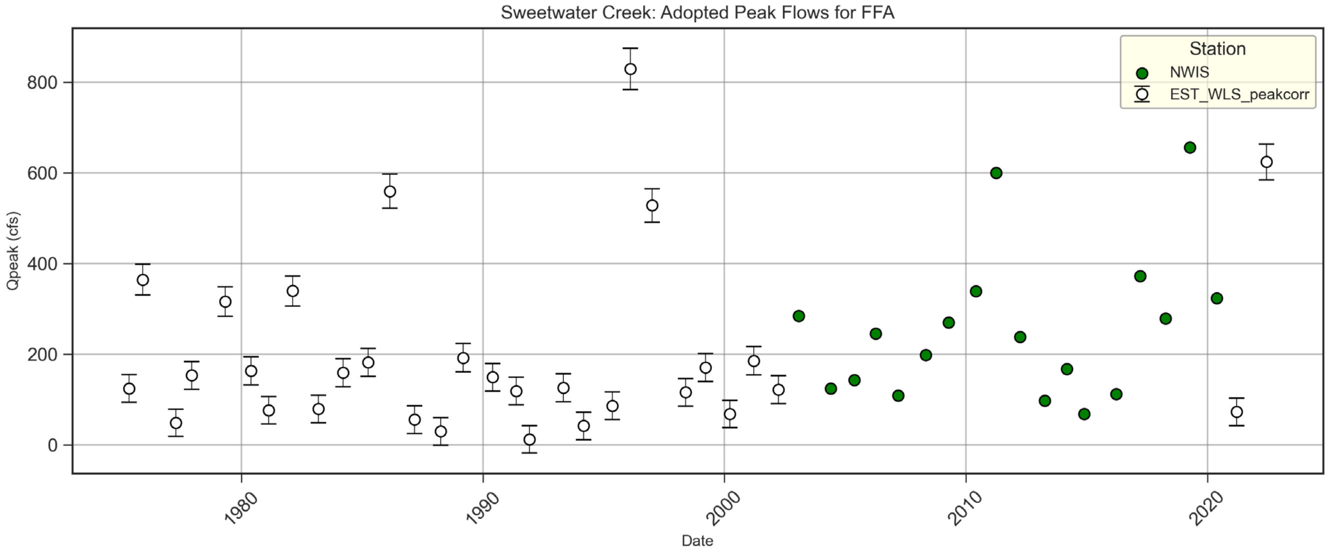

Figure 2-18. Adopted peak flows at SWaM from WY 1975 to WY 2022 with α=0.05 for hindcast correlation.

2.3.2 Flood Frequency Analysis

Bulletin 17C methods with the expected moments algorithm (EMA) (USGS 2019) was used to compute flood frequency estimates at SWaM for this study using HEC-SSP version 2.3 (USACE 2022). The input dataset used a composite record of 48 peak flows at SWaM from WY 1972 to 2022. Flood peaks prior to 2002 and after 2019 were synthesizes using WLS peak flow correlations (see Section 2.3.1) which were entered as systematic data with prediction intervals at α=0.05. The station skew of -0.01 of the composite record was weighted with a regional skew of 0.851 and MSE 1.479 (USGS 2017) for an adopted skew of 0.07 used for this study. Per ER 1105-2-101, to account for uncertainty in the composite SWaM peak flow record, the expected probability curve was adopted to establish design flood criteria for the proposed restoration project and support related risk informed decision making.

Table 2-5. Bulletin 17C EMA adopted Flood Frequency estimate for SWaM based on annual peak estimates from WY1975-2022.

AEP (%)	Return Period (years)	Frequency Curve Values (cfs)			
		Computed Curve	Adopted Expected Probability Curve*	0.95% CL	0.05% CL
0.2	500	1,743	**2,453**	1,052	5,029
0.5	200	1,350	**1,664**	878	3,216
1.0	100	1,094	**1,255**	752	2,267
2.0	50	871	**949**	629	1,578
4.0	25	677	**713**	511	1,081
5.0	20	621	**647**	474	954
10	10	461	**471**	364	637
20	5	322	**326**	260	413
25	4	281	**284**	228	355
50	2	164	**164**	134	202
80	1.25	85	**84**	67	104
90	1.11	60	**59**	45	76

* Adopted values for this study were based on the expected probability curve.

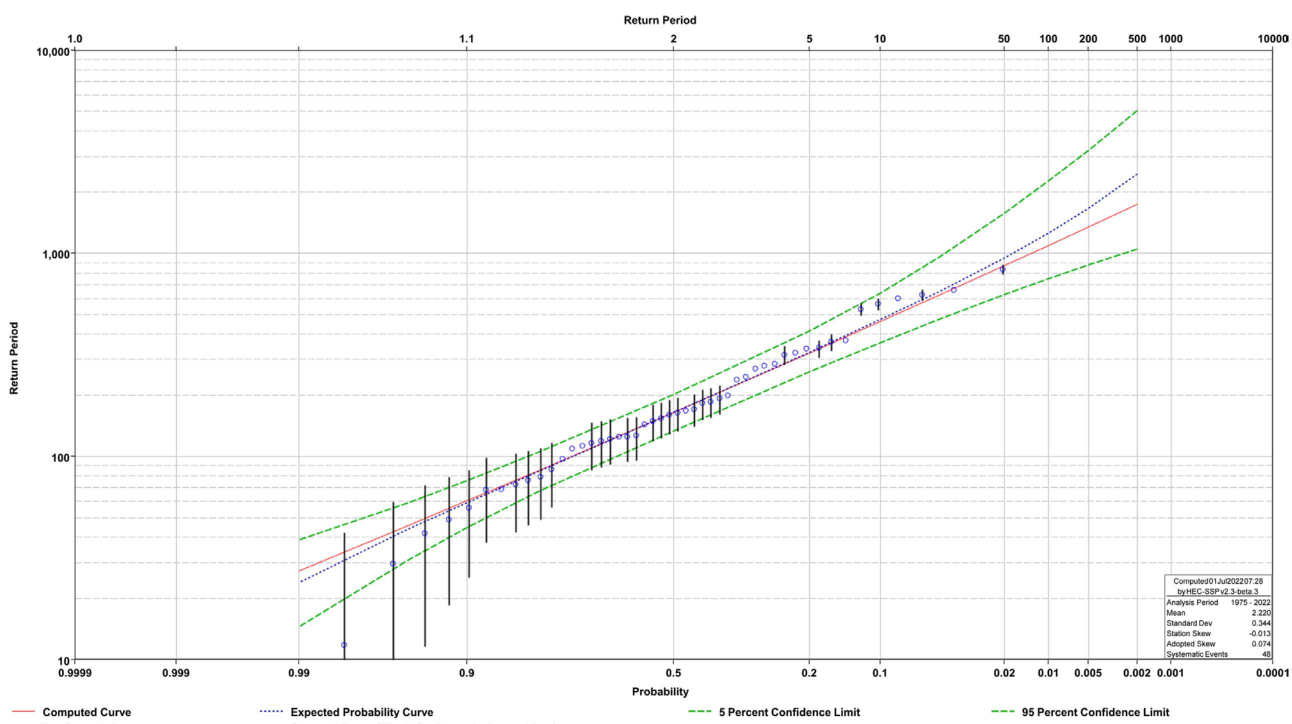

Figure 2-19. Bulletin 17C EMA adopted Flood Frequency estimate for SWaM using WY1975-2022 composite record.

3 Hydraulics

3.1 Hydraulic Model Development

To assess the baseline hydraulic conditions in lower Sweetwater Creek, a two-dimensional depth-averaged planning level model was developed using HEC-RAS version 6. The 2D model domain extent spanned four river miles from the downstream confluence with Lapwai Creek to the upstream confluence with Webb Creek.

Hydraulically corrected terrain for the 2D model was developed by resampling hydro-flattened bare-earth LiDAR point cloud data collected in November 2016 (Quantum Spatial 2016) supplemented with channel breaklines and survey data. All terrain data and hydraulic models utilized the NAVD88 vertical datum.

An orthogonal mesh with a nominal cell size of 3 feet was used for the two-dimensional RAS model, resulting in ~1.89M cells with an average surface area of ~9 square feet. Nominal roughness coefficients for the model were selected based on observed field conditions, recommendations contained in publications RMRS-GTR-323 and FHWA-NHI-01-004, and a comparison with similar streams documented in USGS Water Supply Paper 1849.

3.2 Flooding Assessment

As discussed in section 2.2.3, flooding on Sweetwater Creek most frequently occurs in the March - May timeframe with occasional rain-on-snow events in the through the winter (November – February). In the lower four miles of Sweetwater Creek, the confined active channel is relatively efficient at routing flashy flows down to the confluence with Lapwai Creek with a variable conveyance capacity between 75cfs (lower bankfull) and 125cfs (upper bankfull) before shallow overbank flooding occurs in multiple reaches. For the 50% AEP (2-year return period) flow of ~165cfs the average overbank conveyance is just > 0.5 cfs/ft and increases to ~1.2 cfs/ft for the 20% AEP (5-year return period) flow of ~325cfs. Areas of increased channel confinement, especially where the alignment has been straightened against the valley edge and upstream of undersized bridge crossings, can result in flow bulking that exacerbates channel spillage to the overbanks at lower return periods.

Figures Figure 3-1 and Figure 3-2 depict the flood conveyance within the lower four miles of Sweetwater Creek during the 1% AEP (100-year return period) of 1255cfs. The presence of numerous spill points from the active channel are evident, as well as multiple reaches where overbank flow is routed through relic swales and side channels up to a half-mile before reconnecting with the main channel.

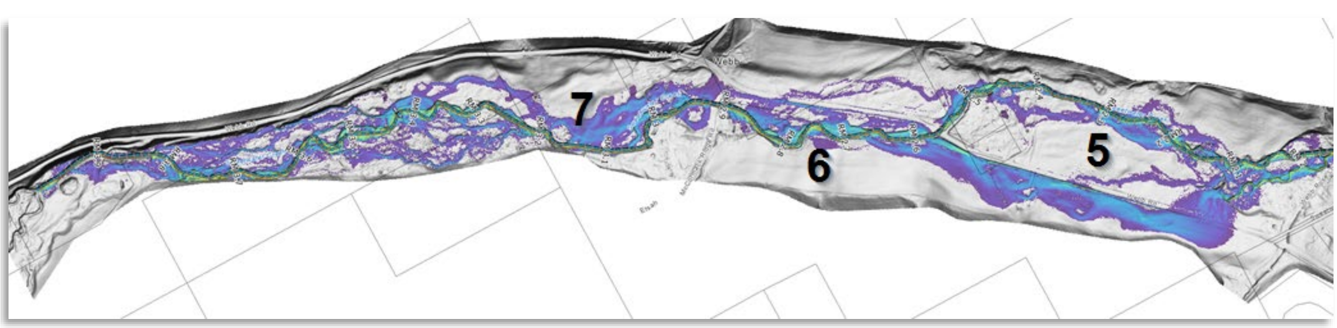

Figure 3-1. Inundated Area for 1% AEP of 1255cfs in Sweetwater Creek from RM 4 upstream to RM 2 downstream with labeled reach numbers. *Flow direction is from left to right.*

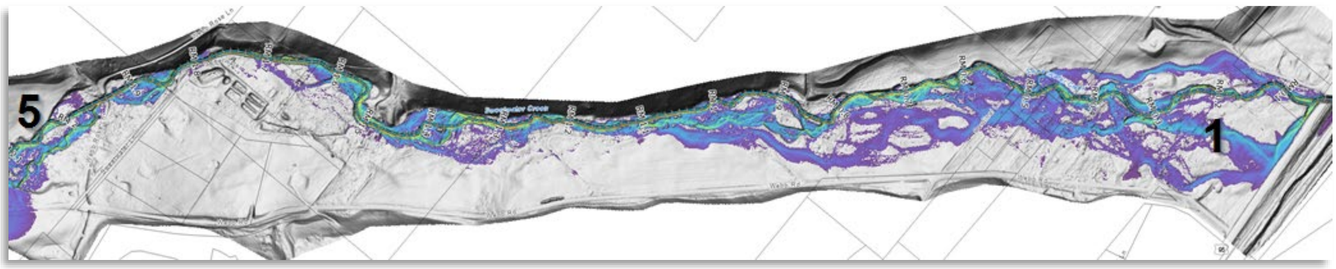

Figure 3-2. Inundated Area for 1% AEP of 1255cfs in lower Sweetwater Creek from RM 2 upstream to US Highway 95 downstream with labeled reach numbers. *Flow direction is from left to right.*

As illustrated in Figure 3-3, at the 50% AEP (2-year) flow of 164 cfs, the inner quartile range of active channel depths ranges from 1.3 to 2.0 feet with 0.1 to 0.5 feet in the overbanks; the corresponding mean velocity is 3.9 ft/sec for the channel and 1.2 feet/sec for the overbanks. This results in an average channel conveyance in lower Sweetwater Creek that ranges from ~7 cfs/ft at the 2-year return period (50% AEP) to ~30 cfs/ft at the 100-year return period (1% AEP). As would be expected, depth, velocity, and unit flow all incrementally increase with discharge. Average overbank conveyance ranges from ~0.4 cfs/ft to ~1.1 cfs/ft for the 2-year and 100-year return periods respectively. Overbank swales that concentrate flows can exceed 10 cfs/ft for events > the 50-year (2% AEP) return period. The inner quartile range for the 100-year return period spans from 23 cfs/ft to 37 cfs/ft for the channel and 0.4 cfs/ft to 2.6 cfs/ft in the overbanks.

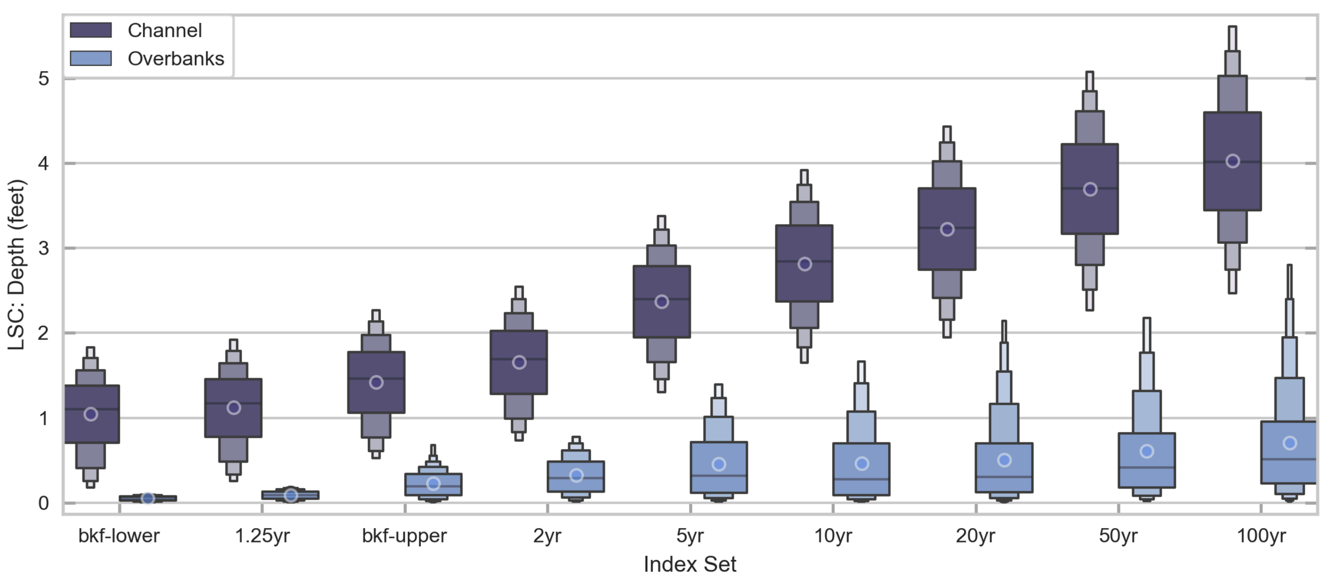

Figure 3-3. Baseline depth distributions in the lower four miles of Sweetwater Creek. *Boxes depict the 10th to 90th percentiles with median and average (circle).*

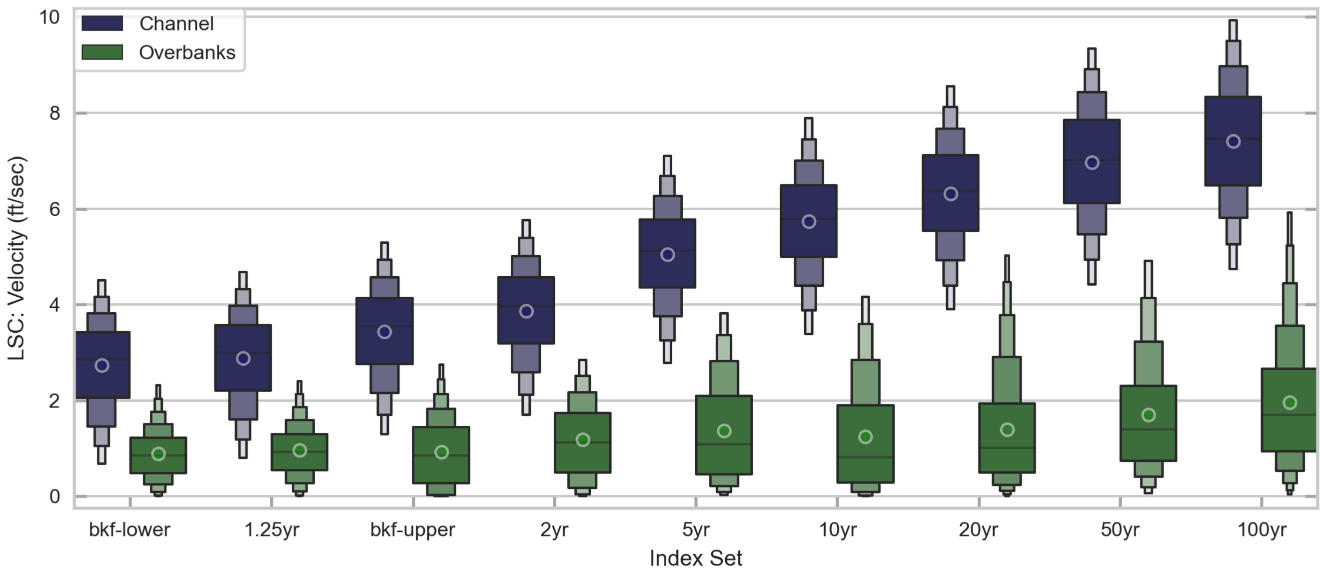

Figure 3-4. Baseline velocity distributions in the lower four miles of Sweetwater Creek. *Boxes depict the 10th to 90th percentiles with median and average (circle).*

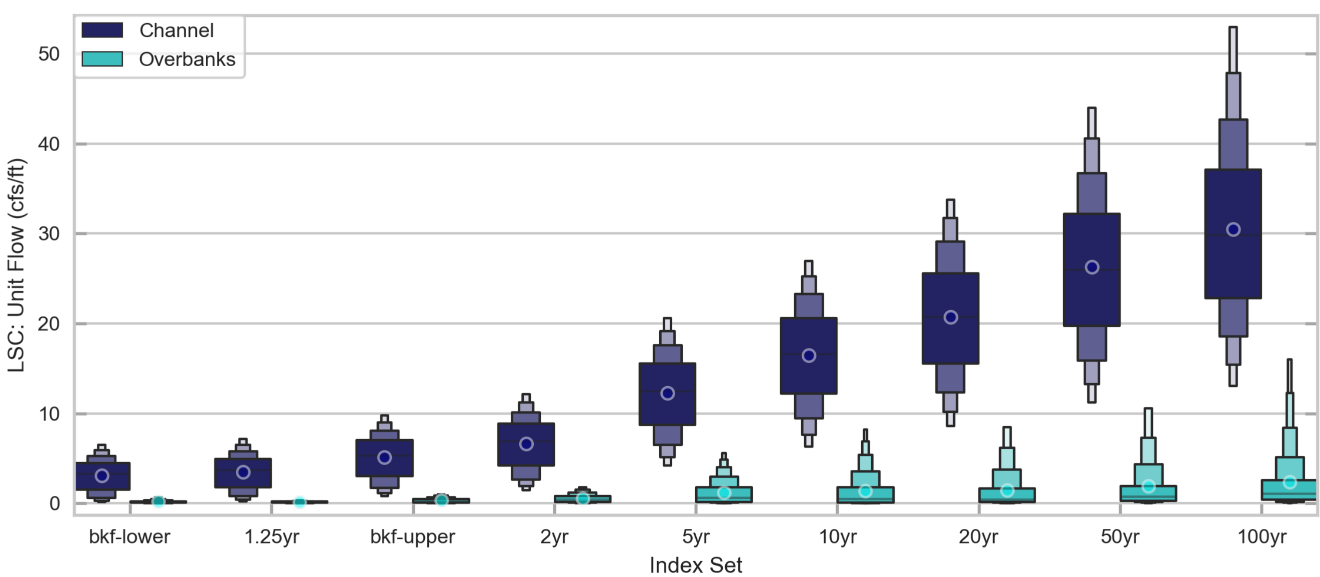

Figure 3-5. Baseline unit flow distributions in the lower four miles of Sweetwater Creek. *Boxes depict the 10th to 90th percentiles with median and average (circle).*

3.2.1 Site SW1 (RM 0.04 to 0.45) Flooding

Site SW1 is the downstream most site in Lower Sweetwater Creek and is immediately upstream of the US-Highway 95 bridge crossing. Although intermittent push up berms are present on both sides of the channel in SW1, overbank flooding frequently occurs upstream of the SW1 site (see Figure 2-11) entering as split flow. Left overbank flows begin to spill from the channel near RM 0.5 (downstream of Cardinal Lane) at <5-year return-period (<20%-AEP) and are routed through a shallow ~80 feet wide that is separate from the main channel, reconnecting ~1500 feet downstream below RM 0.2. On the northwest (left) overbank, a more extensive berm and mound system offset from the channel between RM 0.36 and RM 0.24 provides reasonable protection to what would otherwise be a flood prone home and outbuildings.

Upstream of RM 0.5, right overbank flows spill from the channel at <5-year return-period and are attenuated slightly before overtopping Cardinal Lane at various locations between the 5 and 15 year period-periods. Downstream of Cardinal Lane, the right overbank floodplain is relatively wide at ~500 feet with shallow swales that transition to a deeper ~60 foot wide swale downstream of RM 0.33. This right overbank swale is active at the 2-year return period and diverts flow away from the main channel where it intersects the Highway 95 road prism before flowing parallel to the road down grade to the bridge opening. Immediately upstream of the Highway 95 bridge, the right bank steeply transitions into the road prism (*see Figure 2-11*). This location is frequently prone to erosion, with recently upgraded revetment placed by Idaho Transportation Department (ITD) since the 2019 flood. Of additional note is that backwatering associated with coincident flooding on Lapwai Creek can occur extending more than 200 feet upstream. In addition to a reduction in conveyance capacity under the US Highway 95 bridge, backwater conditions can also result in large sediment deposits supplied by the relatively high transport capacity for gravels and small cobbles.

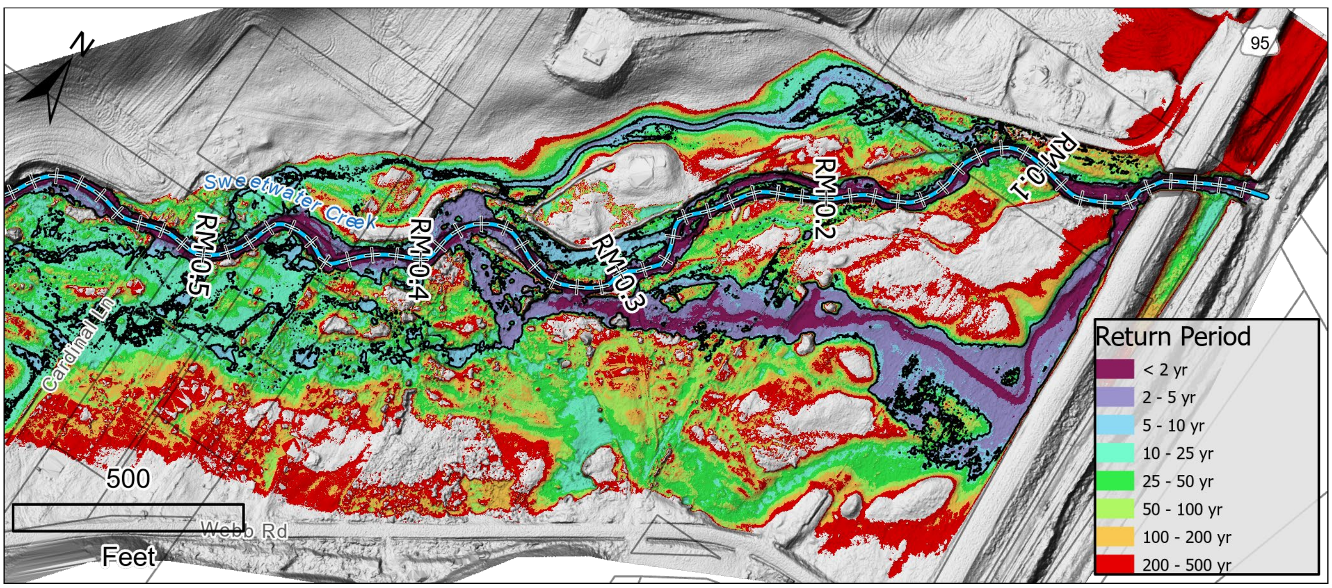

Figure 3-6. Baseline flood inundation frequency at SW1 site. *Contour interval depicts the 10-year return period. Flow direction is from left to right.*

3.2.2 <u>Site SW5 (RM 2.02 to 2.46) Flooding</u>

Site SW5 is located ~600 feet downstream of the Webb Road (Nez Pece County Road#505) crossing and ~600 feet upstream of the Webb Rose Lane bridge crossing. Notable left and right overbank flooding occurs upstream in the SW6 site that directly influences flooding patterns through the SW5 site. The Webb Road bridge crossing is a steel-beam structure with a nominal width of <50 feet and a height <6 feet. With an open area of ~100 ft^2, the conveyance capacity is limited to flows < 600 cfs (<20-year return period) before overbank spillage begins.

Upstream of the Webb Road crossing (adjacent to SW6), left overbank flows impact flood prone structures between creek channel and Webb Road, which does not overtop until ~75-year return period. Conversely, spill to the right overbank upstream of the Webb Rose crossing occurs at low spots near RM 2.67 at less than the 10-year return period. These right overbank flows are conveyed ~700 feet downstream where they intersect the upstream edge of Webb Road at RM 2.57; from this location, right overbank flows follow a shallow roadway ditch on the southeast (uphill) side of Webb Road for another ~2000 feet before spilling over a ~10-year return period low spot and flowing back into the downstream portion of SW5 between RM 2.1 and RM 2.2. This overbank flow pattern frequently occurs during nuisance flooding events, most recently in 2022 which resulted in localized erosion of the road prism that ITD repaired by installing cobble size rock.

Downstream of the Webb Road crossing, there is a private driveway to (address#22499) with a crest elevation exceeding the 1% AEP, and left overbank flooding occurs between RM 2.56 and 2.46 beginning at low flows exceeding the 2-year return period. Downstream of this parcel, Sweetwater Creek enters NPT trust lands where right overbank flooding at RM 2.48 also begins at low flows > 2-year return period; this right bank breach location coincides with a left bank erosion site as discussed in Section 4.3 below. These right overbank flows follow an established shallow swale ~75 feet wide that runs parallel to the SW5 channel (which predominately follows the left valley wall), reconnecting to the main channel ~1300 downstream near RM 2.2.

In the downstream portion of SW5 below RM 2.10, the left overbank flows return to the main channel while right overbank flows (as well as the right overbank flows from SW6 previously noted) flow into an established riparian floodplain, approximately 200 feet wide that extends downstream another 700 feet to the bridge crossing at Webb Rose Lane. This lower subreach above Webb Rose Lane was previously restored in 2016 by notching berms, restoring banklines, and upgrading the flood capacity and erosion protection through the bridge crossing.

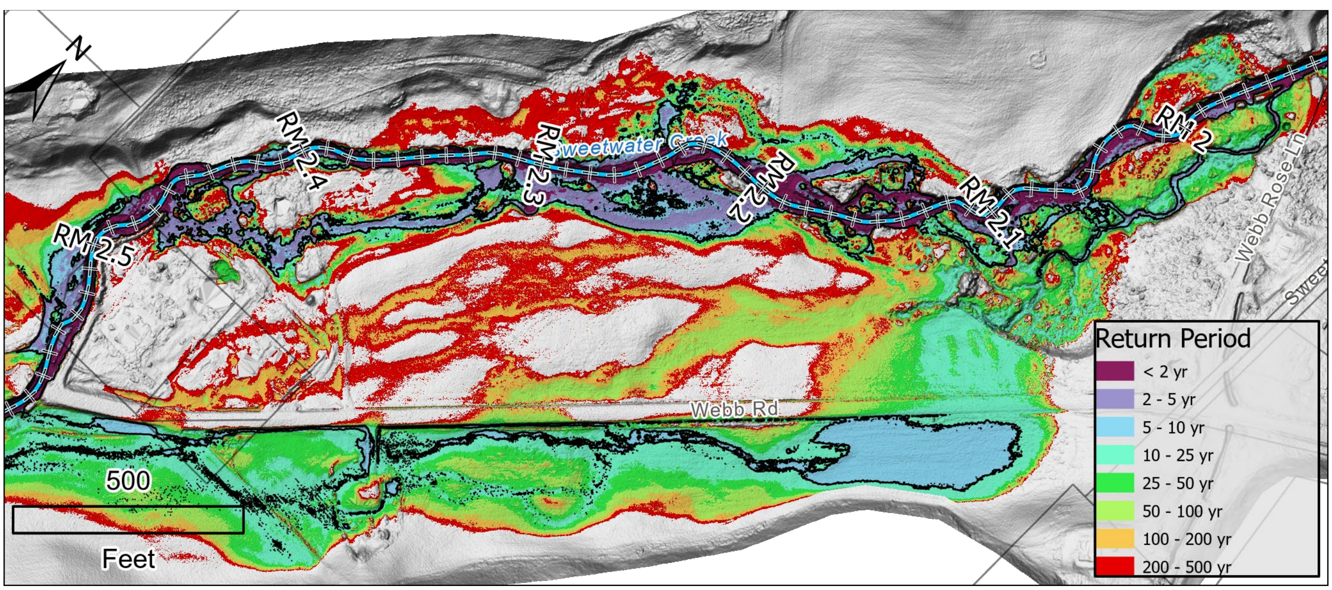

Figure 3-7. Baseline flood inundation frequency at SW5 site. *Contour interval depicts the 10-year return period. Flow direction is from left to right.*

3.2.3 Site SW7 (RM 2.91 to 3.42) Flooding

Site SW7 is the furthest upstream site for Lower Sweetwater Creek, spanning ~2600 feet from the driveway access for 21700 Webb Road upstream to the McCormack Ridge Road downstream. The McCormack Road bridge is a bottomless steel arch with a nominal bankfull width of <20 feet and a height of ~7 feet. With an open area of ~107 ft^2, the crossing conveyance capacity is limited to flows < 600 cfs (<20-year return period) before overbank flooding occurs. Similar to sites SW1 and SW5, overbank flows enter the SW7 site from upstream on both sides of the main channel for relatively frequent events such as nuisance flooding. The subreach upstream of the SW7 boundary is a riparian corridor that spans the ~400 foot wide valley bottom; it is characterized by mature vegetation and established floodplain features including side channels that activate below the 5-year flow and floodplain swales that route larger events above 25-year flow.

Near the top of the SW7 site at RM 3.4, flows in the right overbank follow multiple side channels within a ~300 foot wide floodplain and reconnect to the main channel near RM 3.2. The left overbank flows follow an established swale ~100 feet wide that are forced back towards the main channel near RM 3.0 via an ad-hoc berm extending about 3 feet above the existing floodplain elevation. Despite the presence of the left bank berm, the downstream ~300 feet of the SW7 site is problematic for flooding in that there are two flood-prone structures on the upstream side of McCormack Ridge Road that can be impacted for flows exceeding a 20-year return period. In addition, left overbank flows exceeding a 50-year return period event can overtop McCormack Ridge Road, flowing down into site SW6 and potentially impacting flood prone structures.

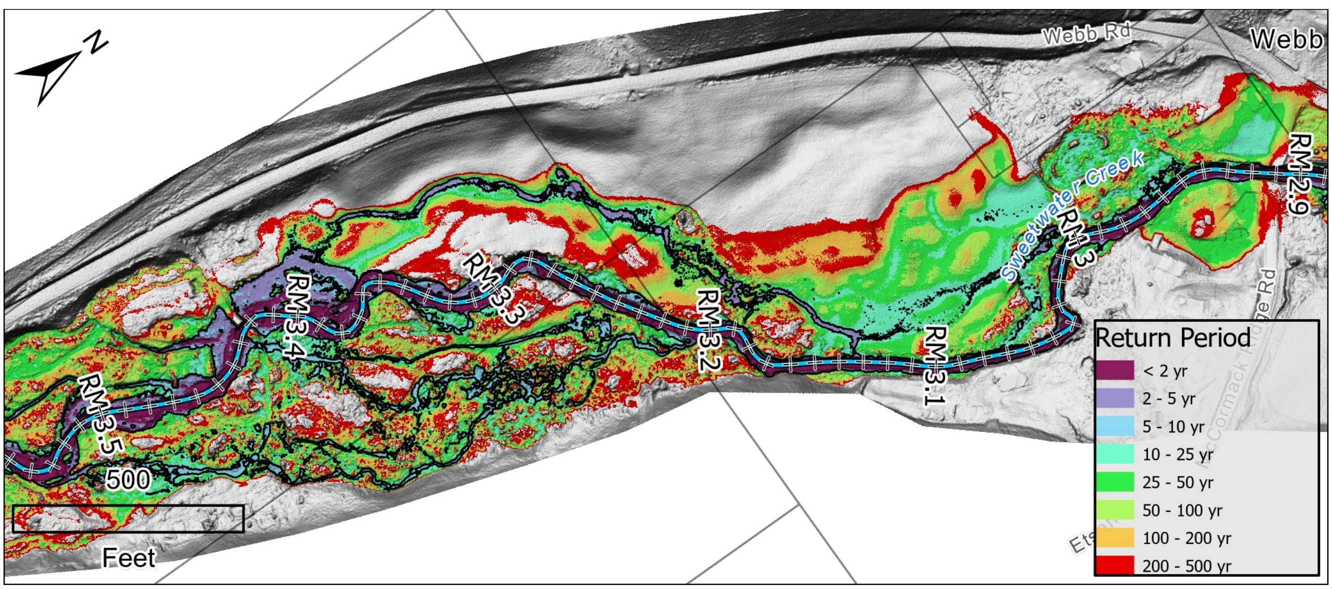

Figure 3-8. Baseline flood inundation frequency at SW7 site. *Contour interval depicts the 10-year return period. Flow direction is from left to right.*

3.3 Channel Stability Assessment

A planning level assessment of channel stability per EM 1110-2-1418 was conducted for this study to identify the dominant fluvial processes in the lower four miles of Sweetwater Creek that could influence the feasibility and functionality of implementing an ecosystem restoration project. Natural stream channels are considered dynamically stable when they can route the incoming flow and sediment without significant changes in: hydraulic geometry (erosion or deposition), reach slope or planform adjustment over medium to long-term time scales (> 5 years). Over short to near-term time scales (<5 years), stable natural channels commonly exhibit a balanced range of dynamic adjustment in response to localized hydraulic and sediment transport conditions, and resilient channel systems are generally capable of trending back towards equilibrium conditions within the near-term following medium-scale seasonal events exceeding the channel forming discharge.

The overall channel stability for the lower four miles of Sweetwater Creek could be generally classified as moderate. Many active channel segments are entrenched up to about the five-year return period flood supported by a coarse cobble and boulder channel framework that is stable up to about a twenty-year return period flood. Lower Sweetwater Creek has experienced multiple overbank flood events in the last twenty years (Figure 2-18) that have resulted in channel adjustment, most recently in 2019 and 2022 which were the second and third ranked floods of record. As would be expected, areas with hardened bank revetment tend to remain more laterally stable while those without have experienced significant bank erosion. Areas where the channel has been aligned against the valley edge tend to have increased bank erosion, especially through areas with poor vegetation coverage and abrupt planform changes that create hydraulic impingement points. Low areas along channel banklines that feed overbank flood swales (see section 3.2) are prone to bank erosion and sculping. Vertically, the lower Sweetwater channel system is generally stable, with average channel slopes exceeding one-percent. This relative streambed stability results from the winnowing of finer sediments from the bed and development of an alluvial armor layer. Although some sub-reaches have stepped offsets in their vertical profile, they still trend with the valley slope, usually resetting at the next bounding hard point such as a riffle or road crossing. Relative to implementation feasibility for ecosystem restoration, channel stability is not considered to be a limiting constraint but will require careful consideration in the design configuration and sizing of proposed alternative measures.

3.3.1 Stream Morphology

The upper elevations of the Sweetwater Creek catchment include the Craig Mountains between Lewiston and Grangeville Idaho which transition to mid-elevation plateaus above 4,100 feet before dropping more than 1,000 feet through steep canyons to a relatively confined alluvial valley (Figure 2-3). Downstream of the confluence with Webb Creek, the Sweetwater valley gradient flattens which historically allowed for some stream meandering, despite steep valley side-slopes that limit the development of a wide floodplain.

The present baseline morphology of lower Sweetwater Creek is characterized as a predominant single thread channel with a high degree of entrenchment, low sinuosity planform (<20%) and relatively steep channel slopes of just under 90 feet per mile (~1% to 2%). From a hydraulic perspective, channel slopes exceeding 1% readily provide sufficient energy to annually transport most fine bed material load (i.e. sands and gravels) through the system. This is especially prominent within straightened sub-reaches with steeper slopes and reduced eddy losses and roughness that are characterized by relatively armored plane bed conditions consisting of small and large cobble. Channel entrenchment in lower Sweetwater Creek is influenced by various lateral constraints, including natural valley topography and historical channelization for land use purposes. Realigned channel segments often follow the valley edge to eliminate historical meander bends within the valley bottom. Existing lateral constraints include earth-moving and berming for agricultural activities and emergency flood-protection, common throughout lower Sweetwater, and multiple mixed materials revetments including large block material, quarried material, differing grades and ages of riprap, and concrete slabs or blocks. Many of these features appear decades old or older, showing a long history in close proximity with Sweetwater Creek.

Floodplain connectivity within lower Sweetwater Creek is quite limited for the range of morphologic bankfull flows (75 cfs to 125 cfs, see section 2.2.4**Error! Reference source not found.**), with average overbank conveyance of ~0.25 cfs/ft (see Figure 3-5). At the 50% AEP (2-year return period) flow of ~165 cfs the average overbank conveyance is ~0.6 cfs/ft, rising to ~1.2 cfs/ft for the 20% AEP (5-year return period) of ~325 cfs. The 5-year event is essentially the morphologic "terrace-full" flow, at which point many overbank swales are activated.

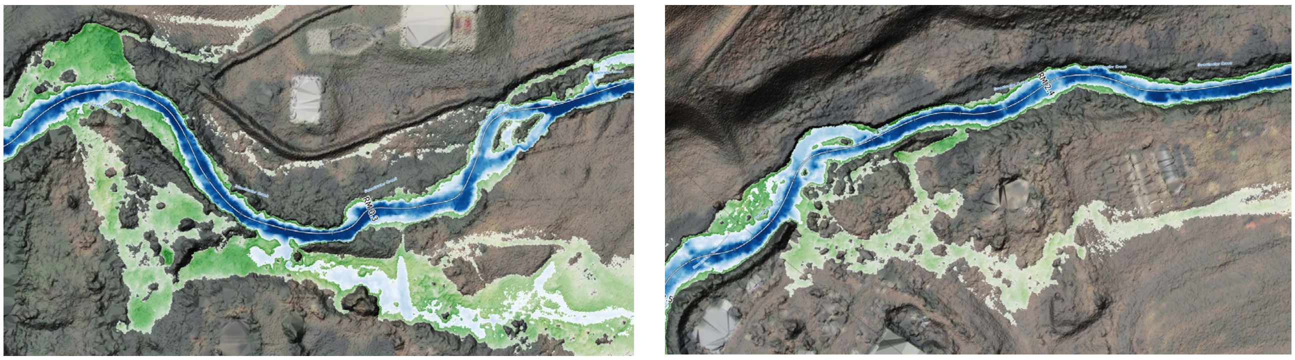

Figure 3-9. Comparison of inundation extents at upper bank-full (125cfs in blue) and terrace-full (325cfs in green). *Left: middle of SW1. Right: upstream end of SW5. Flow is from left to right.*

The lower Sweetwater Creek flooding patterns and morphology are also impacted by undersized bridge crossings, several of which cannot freely pass a 25-year (4% AEP) flow of >700 cfs. While many of the ad-hoc revetment and berm features appear to have been effective at locally controlling lateral erosion and containing some low magnitude nuisance floods, they have resulted in secondary impacts such as upstream and downstream bank erosion, coarsening of the channel bed, and sub-reach degradation that exacerbates floodplain disconnection.

Figure 3-10. Photos of typical LSC channel entrenchment. *Left: Bank revetment in SW1 at RM 0.36 looking downstream. Right: Bank revetment downstream of SW7 at RM 2.94 looking downstream towards McCormack Ridge Road.*

The Bank Erodibility Hazard Index (BEHI) is one of several measures of assessing streambank erosion condition that considers five metrics including: bank heights and angles, rooting depth and density, and surface protection such as revetment. BEHI was assessed with surveyed cross sections, photos and direct observations at five cross section locations representing SW1, SW5, SW6 and SW7 and scours ranged from moderate to very-high. Two notable locations with extreme BEHI are shown in Figure 3-11. Bank heights at both locations were ~7-10 feet with steep bank angles near 90° and undercut in some areas, lack of surface protection, and shallow rooting depth (herbaceous invasive vegetation and adjacent cultivation dominates the riparian community).

Figure 3-11. Photos of extreme BEHI. Left: SW6 right bank @ RM 2.78. Right: SW7 right bank @ RM 3.04.

Arguably the most important lateral constraint in the present-day lower Sweetwater Creek is riparian vegetation in the form of mature, though often narrow, stands of riparian tree species which have recolonized narrow margins along straightened channel segments. In many sub-reaches these trees provide the only protection against additional bank erosion, lateral migration or possible avulsion, so represent a valuable resource for sustaining stream stability and habitat quality in the lower Sweetwater Creek valley. There appears to be a significant enough fraction of fine soils to provide some cohesion in bank materials, and at all sites, riparian vegetation is presently holding significant sections of channel form in place. The contrast between areas with and without vegetation, or where bank areas are eroding behind the line of vegetation, show the beneficial effect that existing vegetation has on these reaches in maintaining relative morphological stability.

Figure 3-12. Site SW5 Bank Erosion Site. Left: RM 2.46 Left Bank looking downstream. Right: RM 2.42 looking upstream across channel.

Vertical grade control through lower Sweetwater Creek is provided primarily by the relative coarseness of colluvium and alluvium bed armor and framework. This overall coarseness of channel bed material has resulted from both a reduction in the upstream supply of gravel due to the LOID irrigation diversion above Webb Creek, as well as the hydraulic geometry of the active channel which provides sufficient hydraulic capacity to transport gravels and sands at less than bankfull flows.

The straightened channel segments with low sinuosity in lower Sweetwater Creek are characterized by relatively armored plane bed conditions consisting of small and large cobble, some with small scour pools localized near intermittent boulders and bank attached or channel spanning riparian debris. Many sub-reaches in lower Sweetwater Creek lack smooth facet slope transitions between geomorphic units (i.e. riffle – run – pool – glide) which can result in localized areas of hydraulic response that can increase bank erosion and subsequent sediment deposition that encroaches into the active channel.

Figure 3-13. Site SW1 photos at RM 0.28. Left: bank erosion looking downstream. Right: Vertical adjustment knickpoint looking upstream.

Despite the combination of a relatively steep slope and entrenchment, the corresponding adjustments in the vertical profile are generally localized to sub-reach level offsets (i.e. steps or knickpoints), which eventually trend back towards the nominal valley slope of 1% to 2% as local head-cuts are arrested at bounding coarse riffle features or road crossings. As a sediment supply limited system, the dynamic equilibrium between the coarse channel framework, hydraulic geometry and flow regime sustains the process of gravel erosion and bed armoring resulting in relative streambed stability, though at the cost of system function.

Figure 3-14. Site SW7 Photos. Left: RM 3.39 Left Bank looking downstream. Right: RM 3.10 Right Bank at eroded terrace looking downstream.

Stream classification based on the commonly used methods from Rosgen (1996, 2014) consider five metrics: entrenchment ratio, bankfull width to depth ratio, water surface slope, sinuosity, and the D_{50} bed surface grain size (Figure 3-15). The first four parameters set the letter designation in the classification and the grain size category sets the number. Based on field measured and GIS derived data, the baseline stream type for lower Sweetwater Creek (below the Webb Creek confluence) is predominately a B3c as per the classification diagram shown below in Figure 3-15. While some reaches with access to slightly wider undeveloped floodplains historically trended towards a C3 stream-type, the C3 features are not well developed under baseline conditions because of localized entrenchment of the active channel and a corresponding low sinuosity alignment.

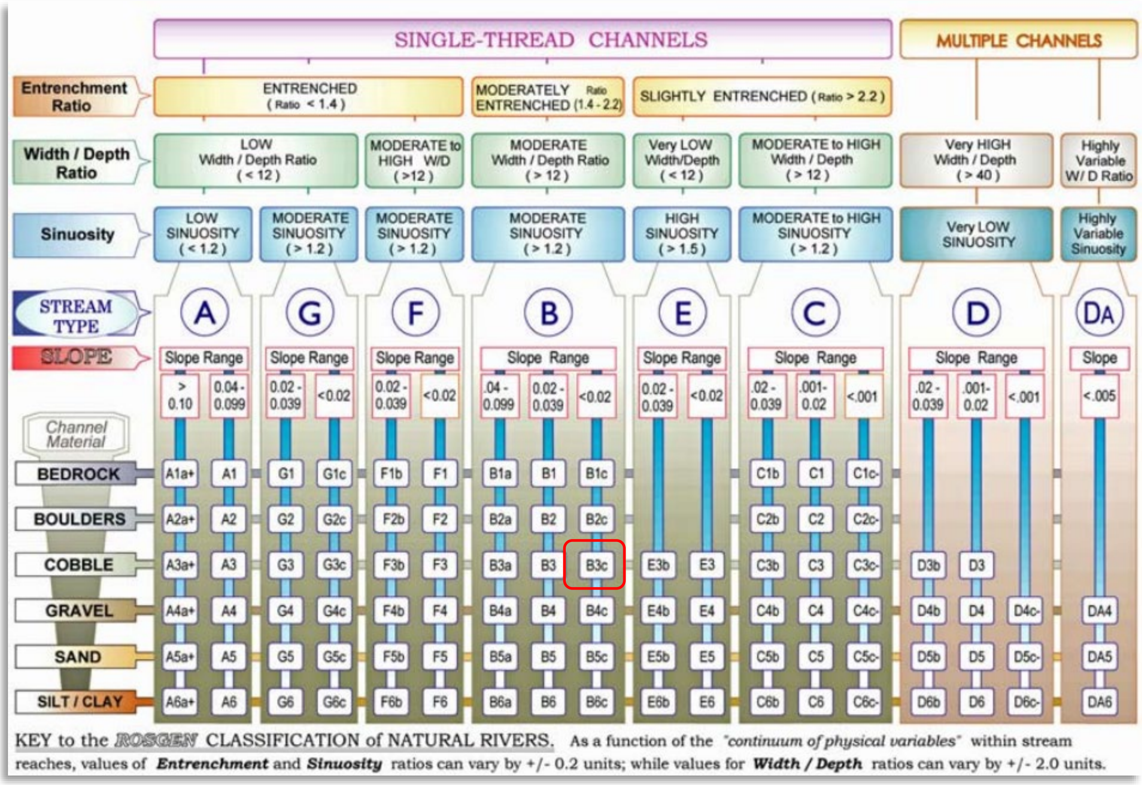

Figure 3-15. Rosgen Stream classification key (source: NEH 654 TS 3E). *The red box outlines the B3c dominant stream type for lower Sweetwater Creek.*

3.3.2 Sediment Regime

The lower Sweetwater Creek valley is situated in Quaternary alluvial deposits consisting of gravel, sand, and silt, with colluvium derived from younger terrace deposits localized to the valley edge. It is underlain by the Columbia River Basalt Group that appears as intermittent bedrock outcrops that intercept the stream channel, typically near the valley edge. The sediment regime in lower Sweetwater Creek is characterized by a relatively coarse alluvial surface layer that serves to armor the active channel which prevents erosion of finer subsurface materials. With the supply of finer sediment sizes (gravels and sands) from the upper watershed cut off due to the LOID irrigation diversion at RM 8.5, the active channel does still recruit some supply of finer material from eroding banklines present in many reaches. Coincident with the B3c stream type (Figure 3-15), depositional lag deposits of sediment are limited to localized patches at planform transitions, and in locations where riparian vegetation dampens the active channel hydraulics. Sediment lag deposits also commonly occur upstream of undersized bridge crossings due to hydraulic backwatering.


Figure 3-16. Sweetwater Creek channel bed material. *Left: SW6 at RM 2.6 above Webb Road crossing. Right: SW7 at RM 2.97 looking upstream*

Because sediment grain sizes can span such a large range, a convenient measure is to use a doubling ($\log_2$) based scale to define equal intervals from very fine to very coarse sediments and is used herein. A simple way to conceptualize this is as a sieve stack whereby the coarsest sieves are at the top (large ψ) incrementally transitioning to finer sieves (small ψ) at the bottom (Figure 3-17). Of interest for this evaluation is the bed material load, which is comprised of sediment sizes coarser than 62.5µm (the sand/silt break) that are present within the system. The compliment to bed material load is washload, representing finer size classes (silts and clays) that transport predominately in suspension due to settling velocities that are much lower than the channel and some overbank velocities.

Grain Class	ψ_{lower}	ψ_{upper}	$Ø_{si}$	$Ø_{bg}$	
MB	9	10	512mm	20.2in	Medium Boulder
SB	8	9	256mm	10.1in	Small Boulder
LC	7	8	128mm	5.0in	Large Cobble
SC	6	7	64mm	2.52in	Small Cobble
VCG	5	6	32mm	1.26in	Very Coarse Gravel
CG	4	5	16mm	0.63in	Coarse Gravel
MG	3	4	8mm	0.315in	Medium Gravel
FG	2	3	4mm	0.157in	Fine Gravel
VFG	1	2	2mm	79mil	Very Fine Gravel
VCS	0	1	1mm	39mil	Very Coarse Sand
CS	-1	0	0.5mm	20mil	Coarse Sand
MS	-2	-1	0.25mm	10mil	Medium Sand
FS	-3	-2	0.125mm	5mil	Fine Sand
VFS	-4	-3	62.5µm	2.5mil	Very Fine Sand

Figure 3-17. Log_2 based stack of sediment grain size classes

Grain size distributions were sampled for both the channel bed, and the channel subgrade immediately below the alluvial armor layer. The bed surface gradation was determined using a systematic random sample following a protocol equivalent to that described Bunte and Abt (2001) and Harrelson et al. (1994) which follow a modified procedure developed by Wolman (1954). Bulk field samples of the shallow subgrade were collected in two-gallon sediment bags and grain size distributions measured using lab sieves via ASTM D6913.

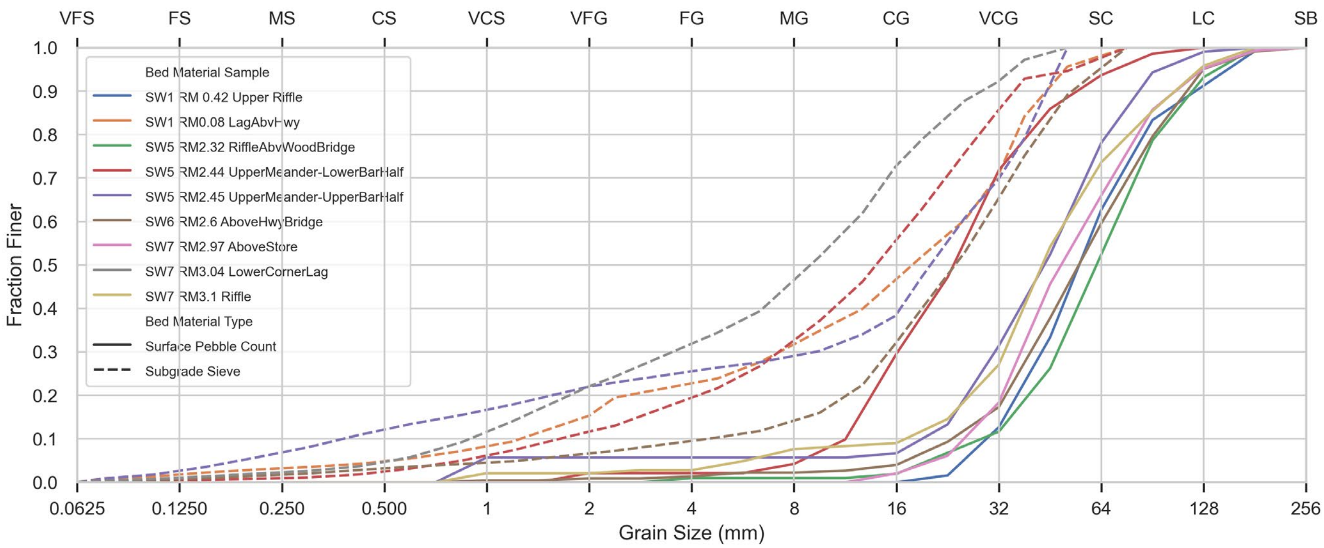

Figure 3-18. Sweetwater bed material gradation by site.

Figure 3-18 depicts grain size distributions at four sites in lower Sweetwater Creek (SW1, SW5, SW6, and SW7). The grain size distribution of the surficial armor layer was relatively consistent across all sites with a D_{84} in the small cobble range (64mm to 128mm) and a D_{50} in the very coarse gravel range (32mm to 64mm). One exception was at site SW5 near RM 2.44, where the sample site was immediately downstream of a bank erosion site (see Figure 3-12) and the surficial gradation was finer by about one grain size interval. The size distribution of subsurface sediments can be considered close to that of sediment in transport during sediment mobilizing events. Some degree of natural coarsening (i.e armoring development) of the active channel bed typically occurs by ongoing winnowing of fine materials, this effect is exagerated and prolonged downstream from impoundments that either limit flows or sequester sediment or both (Kondolf and Piegay 2016, Dietrich et al. 1989). Differences in grain size distribution between surface and subsurface can be used to evaluate sediment supply and transport dynamics.

The distribution variance of the shallow subgrade samples was slightly larger across the sampled sites, with a D_{50} spanning medium and coarse gravel (8mm to 32mm). Fine gravels (<8mm) were present in bar samples at $<D_{35}$, with the D_{16} ranging from coarse sand to very fine gravel (0.5mm to 2mm). The two finest subgrade distributions were measured immediately downstream of bank erosion sites: site SW5 at RM2.45 and a lag deposit at site SW7 RM 3.04 (see Figure 3-11). As illustrated in Figure 3-19, the mean difference between the surficial armor and subsurface layers is roughly 1 grain size class (ψ) at the D_{84}, 1.5 ψ at the D_{50}, and ~4ψ at the D_{16}. The increasing departure for finer sediment sizes is indicative of a high degree of surficial armoring (relative to the subgrade), which tracks with both the limited supply of and sufficient transport capacity for, sand and gravel sediments.

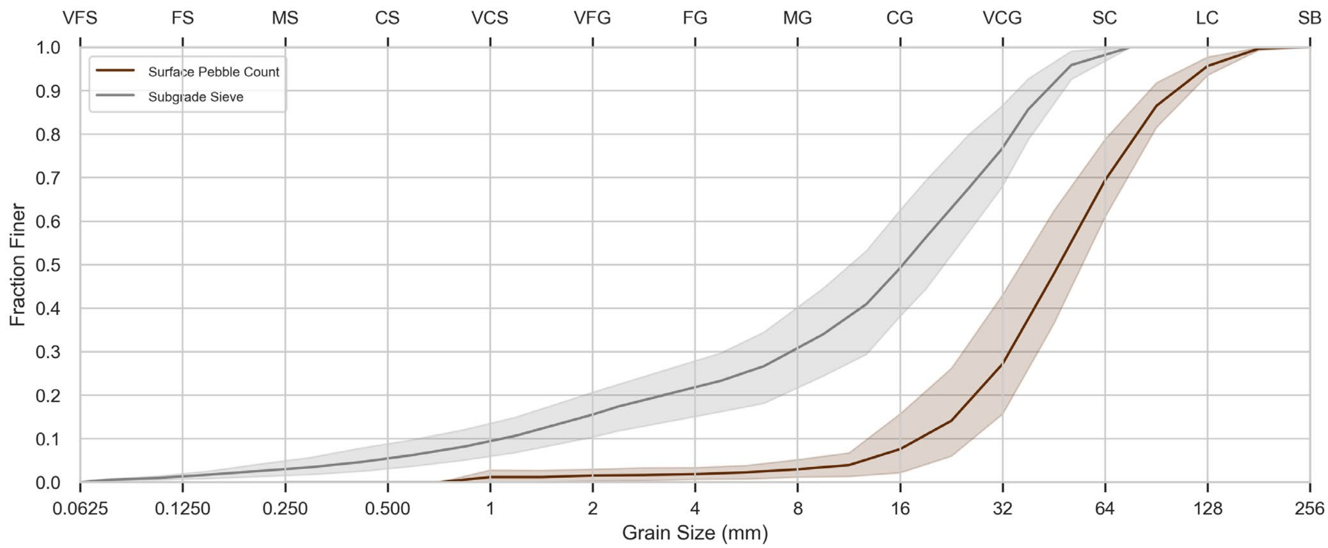

Figure 3-19. Sweetwater bed material gradation with mean and α=0.05 confidence intervals.

3.3.3 Channel Stability

As previously discussed in section 3.3.1, the predominant drivers for hydraulic response that effect channel stability in the lower Sweetwater Creek channel system are:

1. A relatively steep valley slope of ~2% (> 100 feet per mile)
2. A low sinuosity channel (~10%) with a corresponding steep channel slope of ~1.5% and limited energy dissipation from eddy losses.
3. Reaches with entrenched geometry with a low width depth ratio (~20 at bankfull, ~12 at terrace full) and poor floodplain connectivity at morphologic bankfull flows.
4. Abrupt changes planform and local facet slopes causing localized deposition of coarse gravel and cobble sediments.
5. Coarse armored plane bed conditions with limited form drag loss between geomorphic unit transitions.
6. Extended areas of low margin roughness with poor riparian vegetation coverage and localized areas of high near bank stress and low resulting from and abrupt planform transitions.

Friction slope is a hydraulic surrogate that represents the difference in energy head loss normalized by the flow length. Shear stress is derived as a function of depth, velocity, and slope and represents the force per unit area acting on the channel margins (bed and banks). Modeling results of the hydraulic friction slope distribution in lower Sweetwater Creek are illustrated in Figure 3-20. At the 50% AEP (2-year) flow of 164 cfs, the IQR of friction slope ranges from 2% to 3.5%, with 0.7% to 2.7% in the overbanks; the corresponding mean shear stress (Figure 3-23) is 1.4 lbf/ft^2 for the channel and 0.3 lbf/ft^2 for the overbanks.

While incremental increases in channel friction slope across discharge index sets averaged ~14%, the corresponding response in average bed shear stress was slightly higher at ~24%, due to a ~19% increase in channel depth. Conversely, the average overbank friction slope incrementally decreased by an average of ~4% across discharge index sets while the average overbank shear stress incrementally increased by ~18% due to increased overbank depth.

At the 1% AEP (100-year) flow of 1255 cfs, the channel friction slope IQR ranged from 4.2% to 6.2% with the corresponding channel shear stress IQR ranging from ~2.8 lbf/ft^2 to ~4.3 lbf/ft^2.

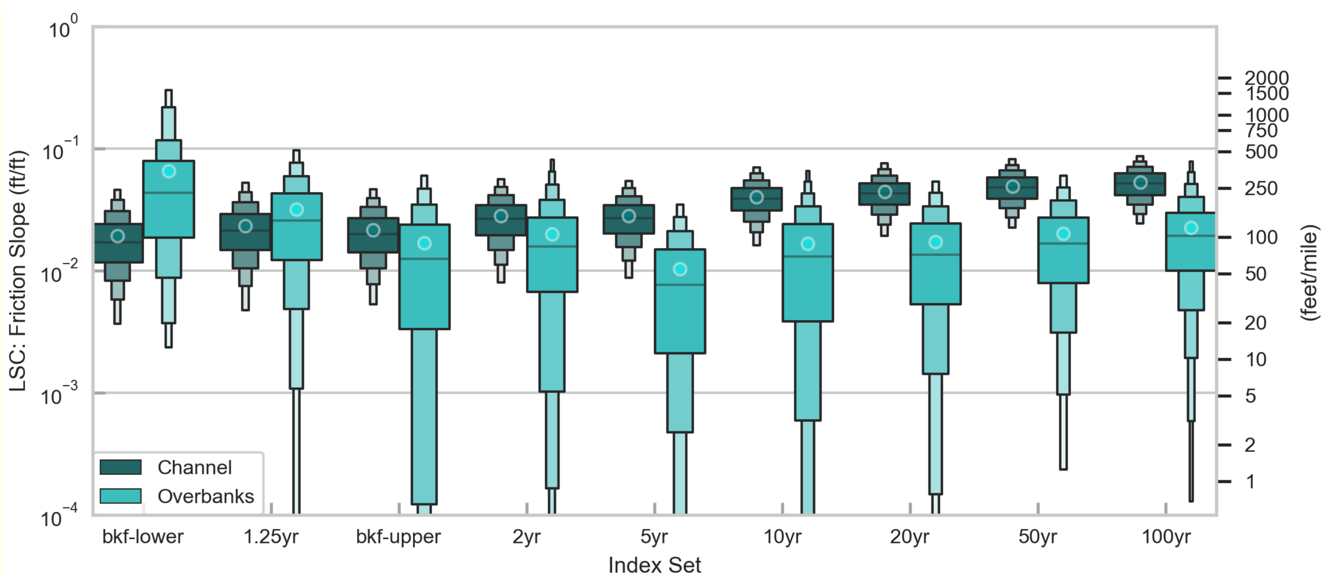

Figure 3-20. Friction Slope distribution for lower four miles of Sweetwater Creek. *Boxes depict the 10th to 90th percentiles with median (ine) and average (circle).*

Channel shear stress values exceeding 1 lbf/ft^2 can begin to transport gravels on the channel bed, and if provided with sufficient depth, erode fine materials from the banks as well. At the 20% AEP (5-year return period) the lower Sweetwater Creek channel system is effectively "full" and there are multiple locations of active overbank flow. The simulated average channel shear stress for these conditions was ~1.6 lbf/ft^2 with an IQR of 1.1 to 2.0 lbf/ft^2 and a 90th percentile of 3.0 lbf/ft^2 in localized areas of steep slope and abrupt planform transitions.

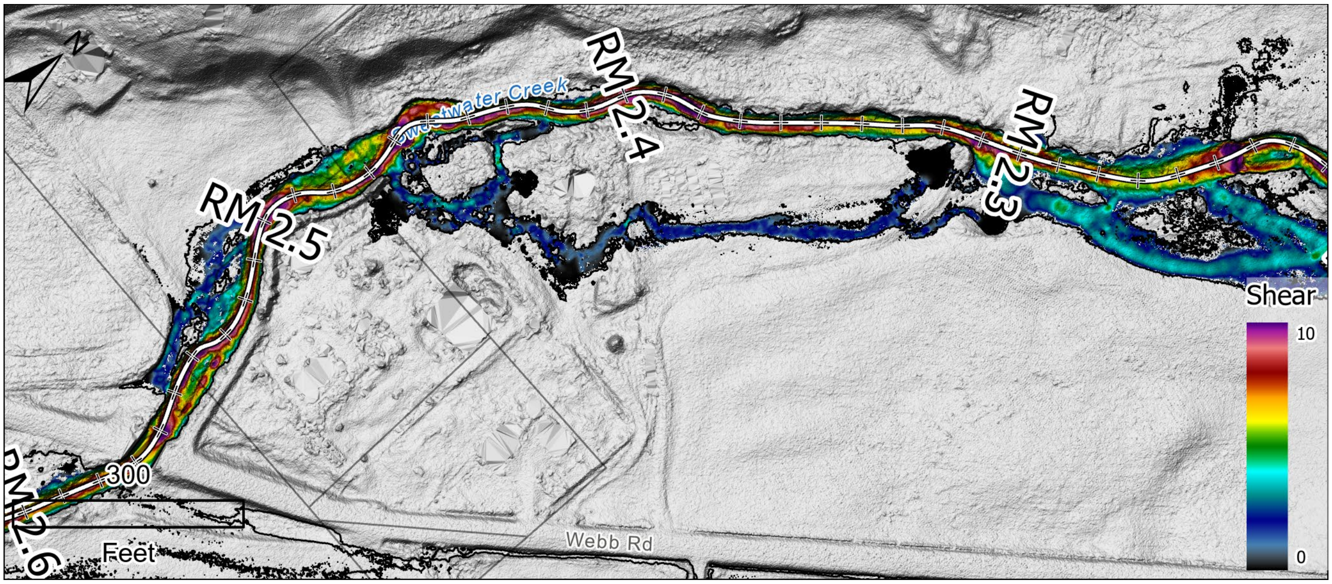

Figure 3-21. Simulated shear stress (lbf/ft^2) for the 20% AEP (5 year return period) of 326 cfs. *SW5 bank erosion site at RM 2.45 (see photos in Figure 3-12).*

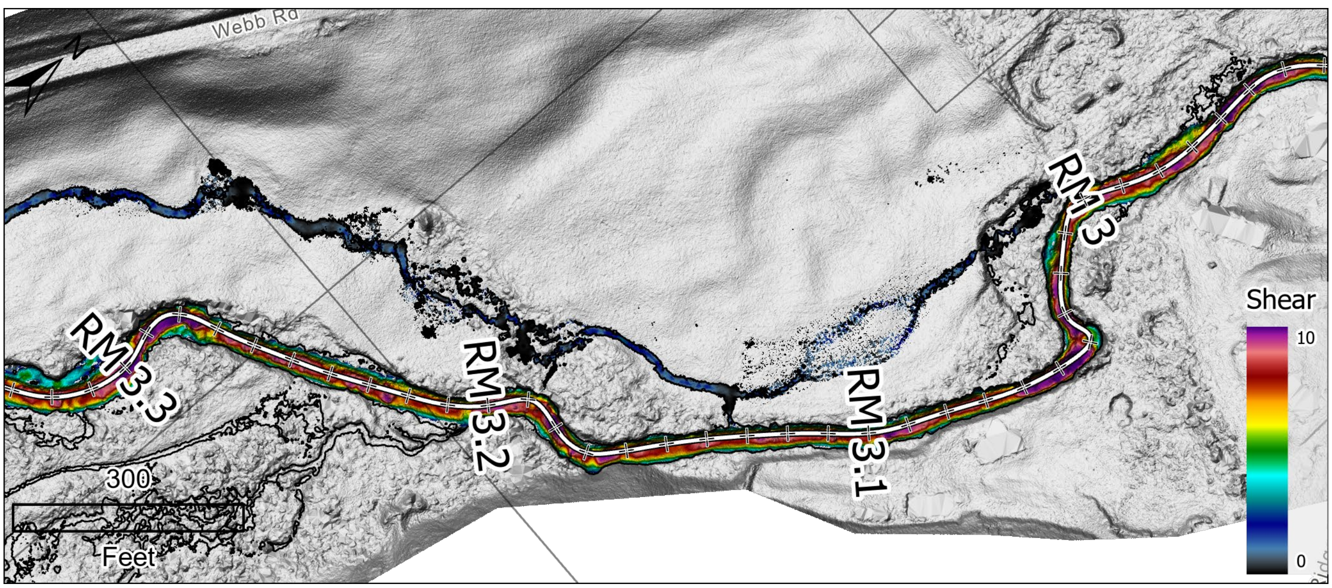

Figure 3-22. Simulated shear stress for the 20% AEP (5-year return period) of 326 cfs. *SW7 bank erosion site at RM 3.05*

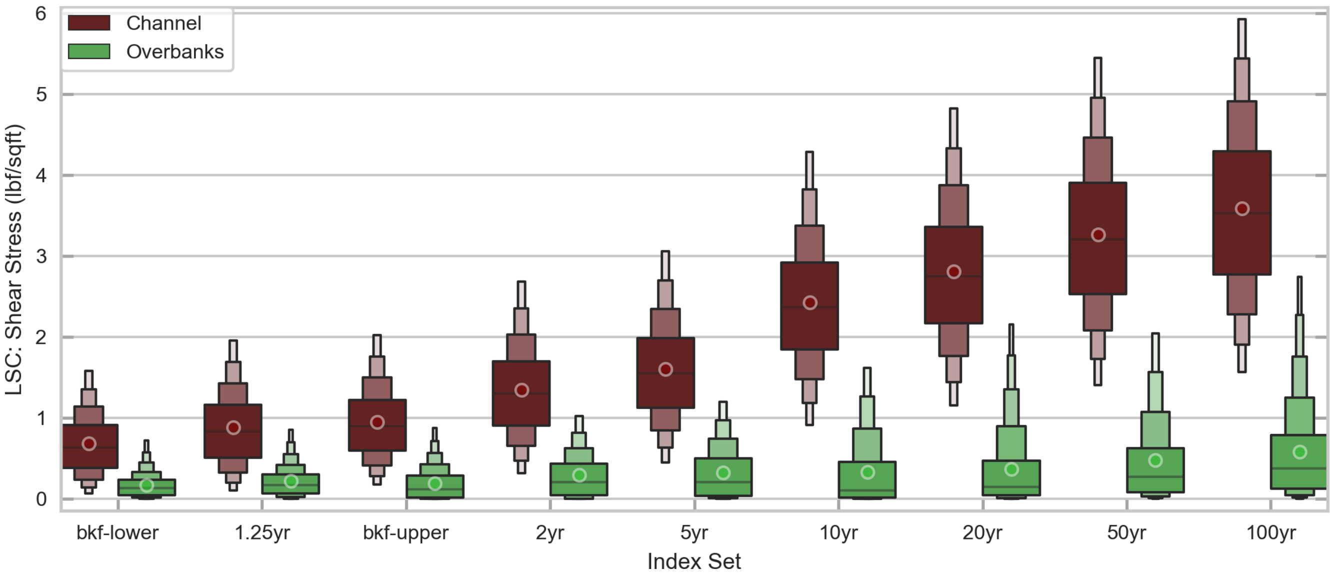

Figure 3-23. Shear Stress distribution for lower four miles of Sweetwater Creek. *Boxes depict the 10th to 90th percentiles with median and average (circle).*

Results from the hydraulic modeling were used to compute the critical sediment size via the Shields (1936) competence-based approach whereby grain mobility is a force balance between applied and resisting forces. For gradually varying flow in an alluvial channel, the applied force results from the hydrodynamics of the flow while the resisting force is related to the submerged weight of a non-cohesive sediment grain. The critical sediment size represents the upper bound for incipient bedload transport, whereby finer grain sizes would also be mobile, and coarser grain sizes would not. Coarse bedload sediments typically move in lagged pulses along the channel bed as a function of tractive force at transport rates significantly lower than those for fines. An important distinction to note is that this is a threshold measure of hydraulic capacity to move a sediment size. If that size is not present in the incoming upstream sediment supply or cannot be eroded from the channel margin, then it would not be in transport despite sufficient hydraulic capacity to move it. The finer bed material (gravels and sands) in LSC is supply limited, with transport rates below equilibrium despite sufficient hydraulic capacity.

Calculations of baseline critical sediment size (Figure 3-24) confirm that that bankfull flows between 75 and 125 cfs can readily erode and transport gravel and finer sized material while not significantly breaking up the coarser alluvial armor framework comprised of large cobble and small boulders (> 128mm). In addition to bedload transport, fine sediment fractions can also be swept up into the active flow increasing their less than equilibrium transport rates which can readily winnow those size classes in supply-limited systems. This tracks with field observations and sediment regime measurements (Figure 3-19).

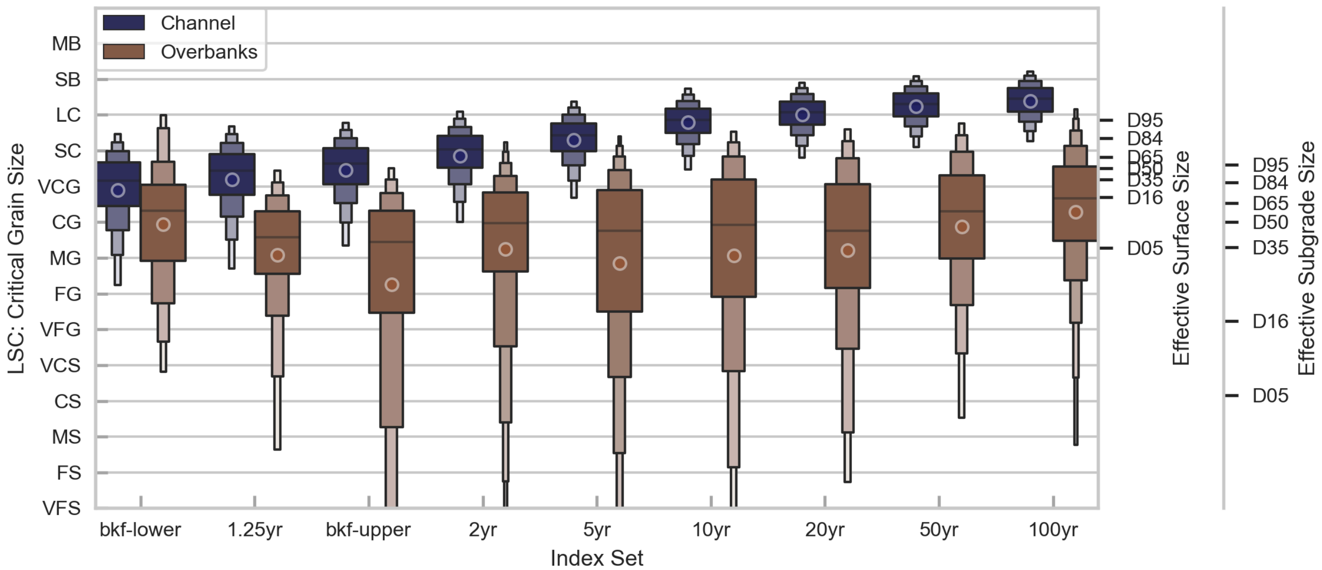

Figure 3-24. Baseline distributions of critical particle size in the lower four miles of Sweetwater Creek. *Boxes depict the 10th to 90th percentiles with median and average (circle). The right axis depicts mean effective particle sizes from Figure 3-19.*

Despite the high degree of channel entrenchment, the cobble armor layer does provide reasonable resistance to erosion over a wide range of frequent flows up to the ~5% AEP flood (20-year return period) of ~650cfs. As flow magnitude increases further, breakup of the large cobble armor and framework begins, and the channel transitions to a live-bed condition, exposing the finer subgrade bed material (gravels and sands) which can dramatically increase overall sediment transport rates. Once exposed, the finer subgrade material can be readily transported by both the active channel and overbank swales with limited deposition in localized areas of hydraulic loss such as fallen trees upstream of under sized road crossings. Under live-bed conditions, localized erosion of the channel bank toe material also occurs, which can result in localized bank erosion, lateral adjustment, and possible channel avulsion to recapture relic alignments.

Coarse material eroded from the channel bed and banks quickly deposits as a large flow event recedes, however instead of forming curvilinear lateral point bars, the low sinuosity, entrenchment and flow-splitting causes these deposits to more commonly lag in the middle of the channel with a longitudinal length of one to three bankfull channel widths and steep cross slope. These mid-channel deposits can reset the top of riffle elevation and create a flow spit or an upstream backwater pool with steep facet slopes between the glide and run. This increases energy through the downstream run which, combined with flow splitting around the channel deposition can increase near bank stress and create impingement points that induce bank erosion and increase the risk of lateral migration and avulsion. While the corresponding upstream backwater pool does help to increase baseflow depth in incised reaches, the steep glide (i.e. backwater pool tailout) results in a relatively unstable feature that is prone to subsequent sub-reach slope adjustment.

Figures Figure 3-25 through Figure 3-27 below depict the critical particle size at the 4% AEP (25-year return period) of 713 cfs. Of note is that at this threshold, both small and large cobble alluvium are mobile and can be eroded from the channel with erosion of gravel and finer materials in the overbank swales

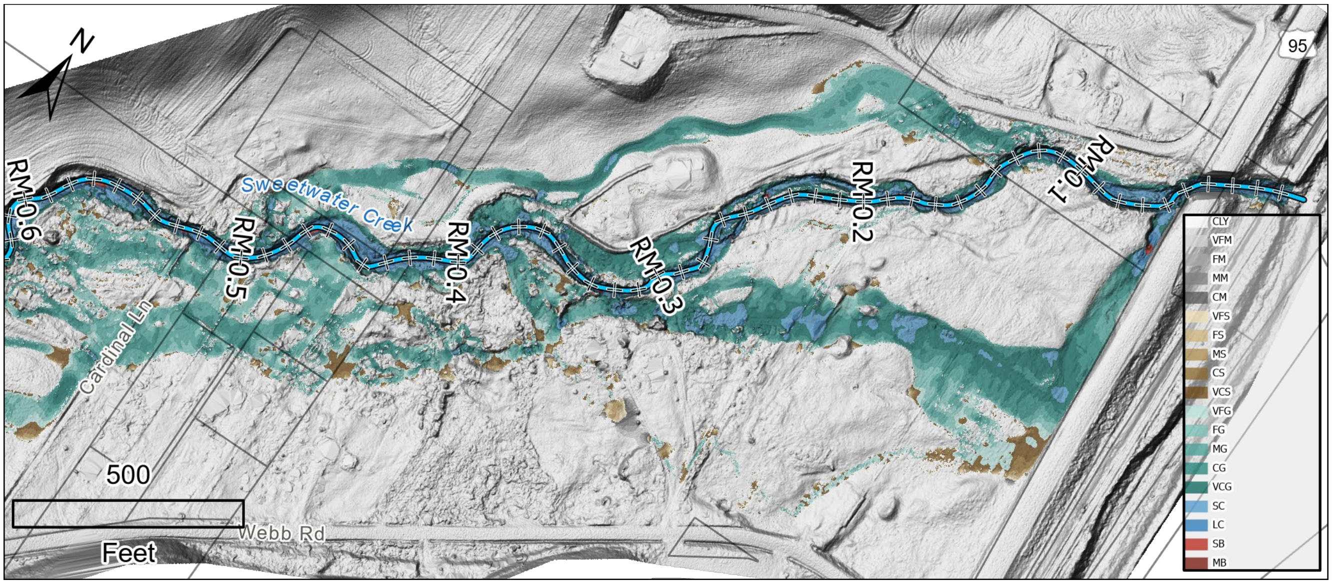

Figure 3-25. SW1 – Mobile Particle Size @ 4% AEP (25-year return period) of 713 cfs.

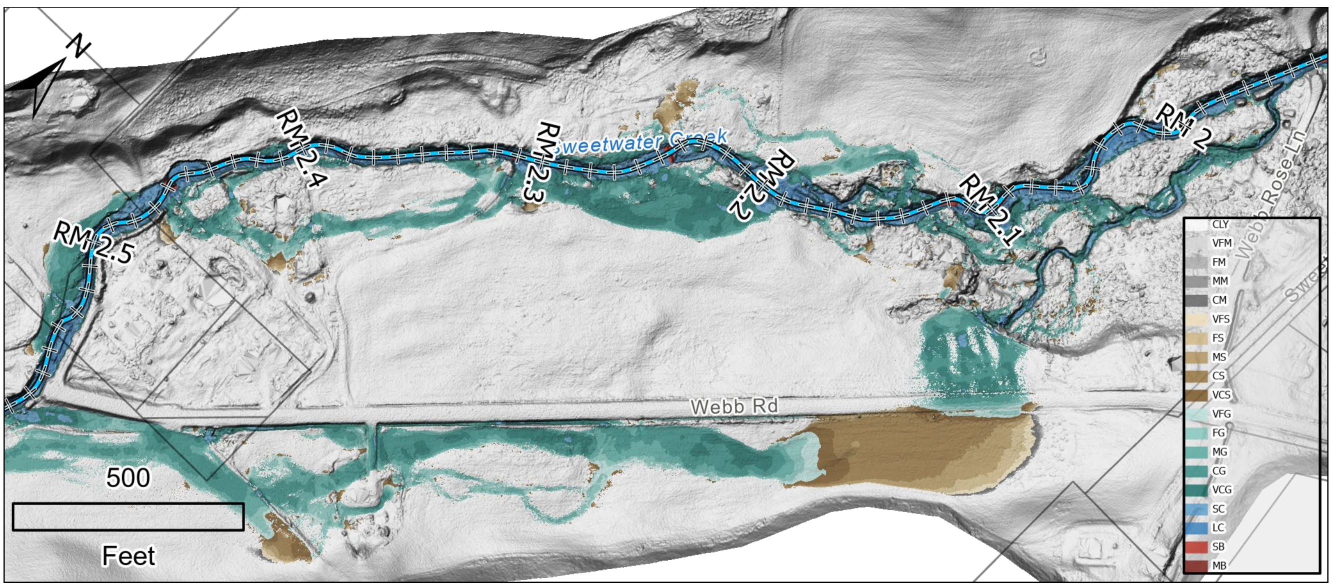

Figure 3-26. SW5 – Mobile Particle Size @ 4% AEP (25-year return period) of 713 cfs.

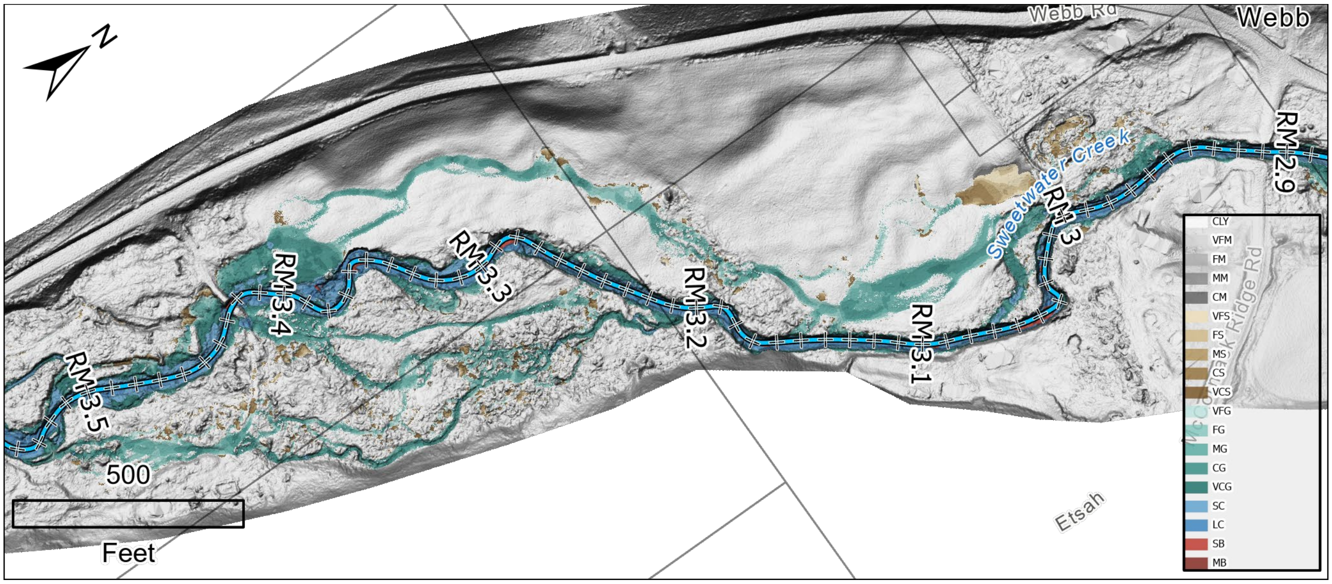

Figure 3-27. SW7 – Mobile Particle Size @ 4% AEP (25-year return period) of 713 cfs.

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