Lemhi Settlement Minimum Target Discharge at McFarland Campground

COMPUTATIONS AND FINDINGS

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EXECUTIVE SUMMARY

The mainstem Lemhi River, above the Hayden Creek confluence, is prime salmonid habitat. Maintaining salmonid habitat requires periodic high discharges that 1) flush the overlying fine sediment off the armored layer, and 2) mobilize bed materials to restore and enhance riffle habitat. The Lemhi Settlement Agreement, addressing the high-water diversion applications, is to include a provision requiring a pause in high-flow withdrawals creating a minimum stream flow event in the upper Lemhi River. This analysis identifies the target discharge required to achieve the aquatic habitat goals, computes the quantity and availability of supplemental discharge, determines favorable periods to conduct a minimum stream flow event, and identifies potential flooding threats downstream.

Upper Lemhi River Minimum Stream Flow Event Overview

- The upper Lemhi River reach extends from Leadore to the Hayden Creek confluence.
- Upper Lemhi River discharge = mountain runoff - base water rights - high water diversions (Figure 1A).
- Among other things, diverting high water during this period reduces the Lemhi River's power to move sediment and "flush" fine sediment from pools and riffles, thus limiting the habitat for fish and their prey.
- The proposed Lemhi River minimum stream flow event will temporarily increase river flows by pausing the high-water withdrawals for three consecutive days every two out of every five-year period, sending a pulse of water downstream to mobilize fine sediment and perform channel maintenance (Figure 1B).
- The proposed Lemhi River minimum stream event will occur in the May to July period and will have no effect on base water rights.
- The target discharge to perform the channel maintenance is 420 ft^3/s at the Lemhi River McFarland Campground (LR-MC) gauge.

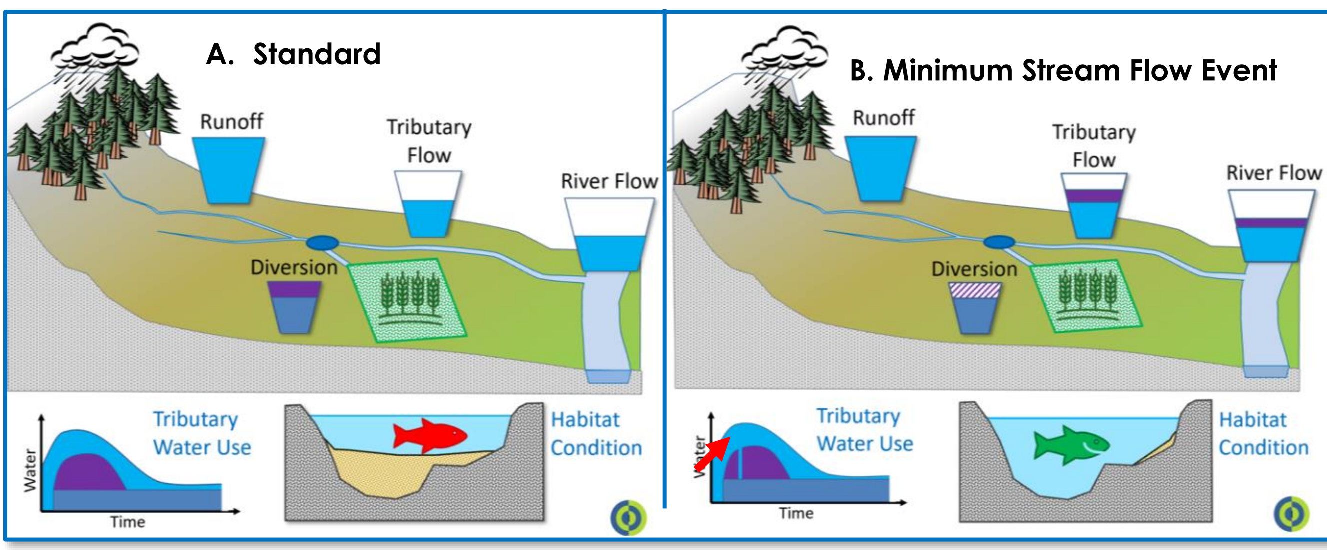

Figure 1. Schematics illustrating diversion practices during Spring runoff for (A) standard irrigation and (B) minimum stream flow event. Red arrow in 1B is points to the gap in high water diversion (purple) when the Lemhi River minimum stream flow event is in operation during the irrigation season.

Minimum Stream Flow Target Discharge

Based on a sediment entrainment analysis for the LR-MC study reach, the estimated minimum flow required to remove surficial fine sediment deposit (objective i) and restore and enhance riffle habitat (objective ii) is 420 ft³/s. Generally, upper Lemhi River flows do not include a minimum stream flow event (Figure 2):

- At 420 ft³/s for three consecutive days, Lemhi River discharges at McFarland Campground occurred 2 in 10, which historically occurred in water years (WY) 2009 and 2011 within the historic period of WY 2008 - 2017.
- Based on historic records, a minimum stream flow event could augment flows at the LR-MC gauge to meet the target discharge 9 out of 10 years.

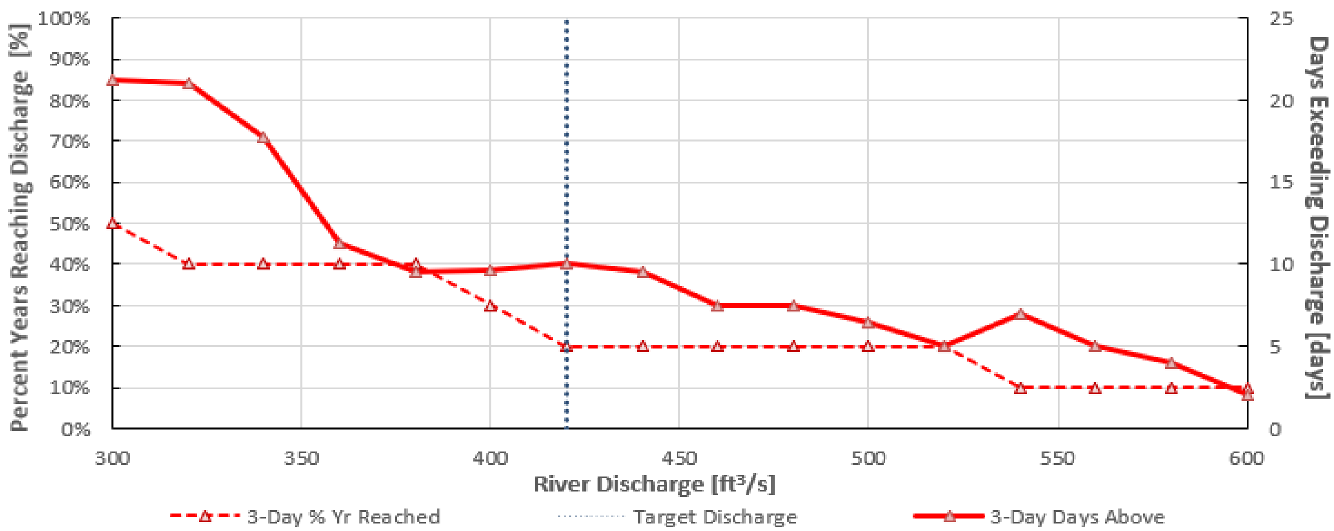

Figure 2. For a range of discharges at the LR-MC, the percentage of years that flows are exceeded and the corresponding average days from WY 2008 - 2017. Target discharge is the 420 ft³/s.

Minimum Stream Flow Event Duration

The lack of site-specific sediment transport measurements and storage of fine sediment in pools makes setting a specific duration difficult to predict or model. For similar systems, minimum stream flow events on the Trinity and Beaverhead Rivers, with similar ecological objectives, use a 5-day event and a 60-hour event, respectively. After each event, the channels are monitored, and based on the findings, the duration and magnitude of future high flow events are adjusted. By agreement, the Lemhi River minimum stream flow event will be a 3-day consecutive day event.

Water Deficiency at the LR-MC Study Reach

Based on historic records from the LR-MC gauge for WY 2008 - 2017, June is the month that requires the least additional discharge to reach the flow target (Figure 3). Given the historic operation of ditches and timing of Spring runoff, June to early July is the most favorable period for conducting a minimum stream flow event. Though favorable, available supplemental discharge from cessation of diversion operations must be matched with the deficiency before identifying favorable periods for conducting the minimum stream flow event.

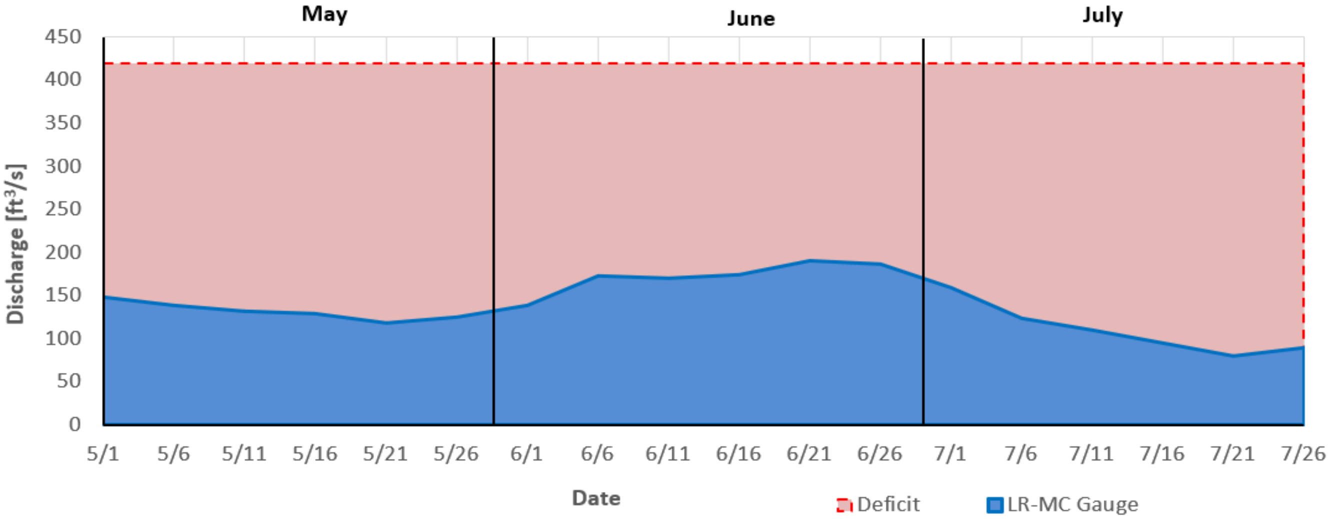

Figure 3. Average daily discharge and deficit below the target discharge at LR-MC gauge for WY 2008 - 2017. Red dashed line is the target discharge at LR-MC.

Supplemental Discharge Available for a Minimum Stream Flow Event

For the Lemhi River minimum stream flow event, the available supplemental discharge was computed for each tributary and the Lemhi River upstream of McFarland Campground. The available inflow is the catchment runoff that exceeds the diverted base water rights and pending applications[1]. The available supplemental discharge is the portion of the available inflow that would be diverted for the Lemhi Basin streamflow maintenance water rights (LBSMWR). For example, Figure 4 presents the total available inflow as the mountain runoff (blue area) minus the base water right diversions and pending applications (red area) in Big Timber and Little Timber Creeks. The available supplemental discharge, under the proposed Lemhi Settlement Agreement, is the estimated LBSMWR withdrawals[2] (orange area). The catchment inflow above the supplemental discharge is the average remaining high-water available for

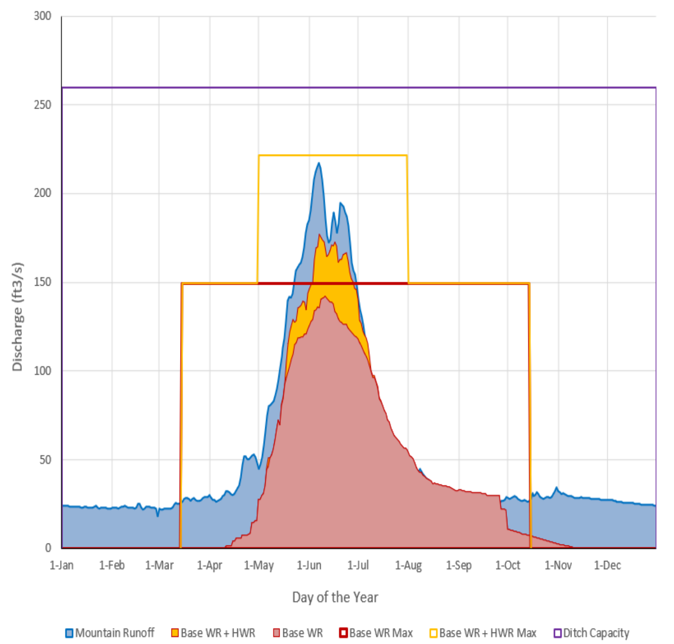

Figure 4. Big Timber Creek average recorded daily catchment inflows, base water rights withdrawals, and estimated high-water diversions for WY 2008-2017.

[1] Base water rights include all prior senior water rights and current pending applications not addressed in the Lemhi Settlement Agreement. Pending applications are listed in Section 1 of the Lemhi Settlement Agreement.

[2] Historically, high-water withdrawals in the tributaries were not recorded by most watermasters; thus, the historic withdrawals are unknown. For diversions that did not record high-water use, the estimated LBSMWR withdrawal rates are based on the lesser of water right rates or ditch capacity.

development in the tributary during high cumulative precipitation conditions.

Upstream of the LR-MC gauge, the estimated maximum supplemental discharge from pausing the LBSMWR withdrawals in the tributaries is 491.27 ft^3/s. Adding Lemhi River and Big Springs, the LBSMWR estimated maximum supplemental discharge increases to 790.47 ft^3/s (Table 7). Accounting for historic diversion operations[1] and catchment inflow, the historic supplemental discharges ranged from 10 ft^3/s to 507 ft^3/s (Table 1). On average, late May through June period, when supplemental discharges is near or above 300 ft^3/s, provides the greatest potential for supplemental discharge. In abundant water years (WY 2009 – 2011), the supplemental discharge exceeds the target discharge in June to early July. These conditions provide greater flexibility in timing a minimum stream flow event as the target flow will be achieved independent of discharge at the LR-MC gauge.

Table 1. Available supplemental discharge[2] at LR-MC to support the minimum stream flow event. Blue cells denote supplemental discharge that exceeds the target discharge

	May						June						July					
WY	**1**	**6**	**11**	**16**	**21**	**26**	**1**	**6**	**11**	**16**	**21**	**26**	**1**	**6**	**11**	**16**	**21**	**26**
2008	10	20	85	209	289	352	309	277	274	252	234	211	177	145	112	107	118	112
2009	120	121	142	244	304	380	*429*	*480*	*451*	*449*	*500*	*472*	*420*	354	309	248	225	252
2010	176	221	233	259	289	372	399	*429*	*448*	*480*	*463*	*443*	*437*	380	312	254	241	267
2011	18	19	48	150	201	204	255	409	*457*	*451*	*497*	*507*	*475*	*460*	*454*	400	355	340
2012	195	293	336	369	357	325	356	388	321	264	254	247	226	228	250	227	202	208
2013	128	222	270	339	312	296	242	216	228	221	250	243	253	233	213	257	217	192
2014	76	200	241	278	328	369	328	265	240	263	218	215	196	191	191	187	194	213
2015	211	204	262	323	292	319	298	258	242	195	150	158	168	171	143	129	152	186
2016	108	167	208	222	273	270	310	319	239	235	185	158	158	144	150	139	155	168
2017	181	258	250	288	317	328	372	359	381	408	363	323	284	254	221	212	217	231
Min.	*10*	*19*	*48*	*150*	*201*	*204*	*242*	*216*	*228*	*195*	*150*	*158*	*158*	*144*	*112*	*107*	*118*	*112*
Ave.	*122*	*173*	*207*	*268*	*296*	*322*	*330*	*340*	*328*	*322*	*311*	*298*	*279*	*256*	*236*	*216*	*208*	*217*
Max.	*211*	*293*	*336*	*369*	*357*	*380*	*429*	*480*	*457*	*480*	*500*	*507*	*475*	*460*	*454*	*400*	*355*	*340*

Less Discharge Available	0	101	203	304	406	507	More Discharge Available

Favorable Periods

The Lemhi Settlement Agreement states that the minimum stream flow event can occur from May 1st to July 31st. Historically, when adding the supplemental discharge from a minimum stream flow event to the LR-MC gauge discharge, the target discharge would be reached in 9 out of 10 years in late May, June, and July (Table 2). During this window, the most favorable periods for conducting the minimum stream flow event span from May 26th and June 10th, with target discharge reached in 60% - 80% of the years. During abundant runoff years (WY 2009 – 2011, WY 2017), the favorable window extends into late June and mid-July. Thus, in low to moderate precipitation years, the minimum stream flow event should be

1 It was assumed that LBSMWR would not be diverted when base water rights were not diverting.

2 For visualizing conditions throughout the year, the year was divided into 5-day intervals within which the historic flows and operations have been averaged. Actual calculations use daily values.

scheduled between late May and mid-June. In water years with abundant precipitation, the favorable period for executing a minimum stream flow event can be extended until mid-July.

Concerning meeting the target discharge twice in 5-year criteria, historically this was not achieved at the LR-MC gauge. With a minimum stream flow event, the criteria are met for each rolling 5-year period (Table 2).

Table 2. Favorable periods to conduct a minimum stream flow event (5-day intervals) for the upper Lemhi River for WY 2008 - 2017.

	May						June						July						Achieved
WY	**1**	**6**	**11**	**16**	**21**	**26**	**1**	**6**	**11**	**16**	**21**	**26**	**1**	**6**	**11**	**16**	**21**	**26**	
2008																			
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% Years	0%	20%	20%	30%	40%	80%	80%	60%	50%	40%	40%	40%	40%	30%	30%	10%	10%	10%	**90%**
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2010-14																			
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% Years	0%	0%	0%	50%	50%	100%	100%	100%	67%	50%	50%	50%	50%	50%	50%	0%	0%	0%	**100%**

Downstream Impacts

The increased discharge associated with the proposed Lemhi River minimum stream flow event has a limited potential flooding risk in Lemhi and Salmon, Idaho. The LBSMWR estimated maximum supplemental discharge (791 ft^3/s) was added to the historic discharge to develop the potential daily discharge during a minimum stream flow event. Flooding risk was estimated using the flood frequency return period of 50-year and 100-year flow events at USGS Gauges Lemhi River at Lemhi (13305310) and Lemhi River at Lemhi (13305000). Additionally, Rick Sager, former Water District 74 water master, indicated that localized flooding can occur along the Lemhi River at 2,500 ft^3/s. Comparing potential daily discharge at the gauges against the 50-year and 100-year flow events and the 2,500 ft^3/s target estimated the potential for flooding impacts at the gauging sites.

Flooding risk at Lemhi (USGS Gauge 13305310 Lemhi River near Lemhi):

- 100-year event is not exceeded.
- 50-year maybe exceeded during June 2009, but the corresponding flow at McFarland Campground is 517 ft^3/s, which is above the target flow so no minimum stream flow event would have been initiated.
- No localized flooding risk is likely to occur.

Flooding risk at Salmon (USGS Gauge 13305000 Lemhi River near L-5):

- 100-year event is not exceeded.
- 50-year event is not exceeded.
- Localized flooding may occur during 3 of the 10 years. However, during June 2009 the corresponding flow at McFarland Campground was 517 ft^3/s, which is above the target flow, so no minimum stream flow event would have been initiated.

Based on the discharge frequency analysis, flooding induced by the proposed Lemhi River minimum stream flow event has no flooding risk for the 50-year and 100-year events, but may have risk of producing localized flooding near L-5

IMPLEMENTATION

Once the minimum stream flow event is deemed feasible and designed, the final step is developing the technical and institutional support for implementation. Implementation of a minimum stream flow event requires i) metrics and indicators to indicate favorable conditions for conducting the minimum stream flow event, ii) organizational infrastructure to coordinate, conduct, and monitor the minimum stream flow event, and iii) a monitoring program to continually assess the impact of the minimum stream flow event on habitat conditions. As these are currently under development, only the methodology will be presented.

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ABBREVIATIONS

Term	Description
BWR	base water rights include all senior water rights and pending applications to the Lemhi Basin streamflow maintenance water rights included in the Lemhi Settlement Agreement
CHaMP	Columbia Habitat Monitoring Program
D_{16}, D_{50}, D_{90}	particle size where 16%, 50%, and 90% of the material is smaller in size
LBSMWR	Lemhi Basin streamflow maintenance water rights
IDFG	State of Idaho, Department of Fish and Game
IDWR	State of Idaho, Department of Water Resources
IRA	Upper Salmon Subbasin Habitat Integrated Rehabilitation Assessment
IWRB	Idaho Water Resources Board
LRBM	Lemhi River Basin Model
LR-MC	Lemhi River at McFarland Campground
OSC	State of Idaho, Office of Species Conservation
POD	point of diversion
POU	place of use
Q	discharge
Sim01 . . Sim10	UI-CER 2D hydrodynamic model simulations 1 through 10
UI-CER	University of Idaho, Center for Ecohydraulics Research
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
WY	water year

1 INTRODUCTION

The mainstem Lemhi River above the Hayden Creek confluence (upper Lemhi River) is prime salmonid habitat for spawning and rearing (NOAA 2017, IRA 2019). Currently the reach experiences impact from excessive fine sediment filling interstitial spaces between gravels and cobbles; patchy, discontinuous riparian corridors; and areas of channel straightening and bridges that locally concentrate flow, causing incision and/or bed armoring (IRA 2019). Depending on the biological objectives, maintaining aquatic habitat requires periodic high discharges that 1) flush the overlying fine sediment off the armored layer, 2) mobilize bed materials flush riffle gravels, and 3) flush pools and build rifles (Kondolf & Wilcock 1996, Reiser et al. 1990, Schmidt & Potyondy 2004). The Lemhi Settlement Agreement, addressing high water diversion applications, proposes a provision requiring a pause in high flow diversions to create a "minimum stream flow event" in the upper Lemhi River, thus removing fine sediment and improving channel conditions. This document details the plan, design, and evaluation of a minimum stream flow event, including setting management objectives, characterizing conditions, designing the event, and evaluating the feasibility of the event. The analysis, design, and evaluation were performed in consultation with IDFG, OSC, and IDWR. Funding was provided by the IWRB and from the Pacific Coast Salmon Recovery Fund through OSC.

1.1 Background

1.1.1 Upper Lemhi River Ecological Conditions

In the mainstem Lemhi River above the Hayden Creek confluence (upper Lemhi River), land use and diversions have degraded the quality of spawning and rearing habitat of summer steelhead (*Oncorhynchus mykiss*) and spring/summer Chinook salmon (*O. tschawytscha*) (NOAA 2017, IRA 2019). In the IRA, Lemhi River geomorphic reaches 1-8 representing the upper Lemhi River, identified human impacts as (IRA 2019):

i. excessive fine sediment filling interstitial spaces between gravels and cobbles;
ii. patchy, discontinuous riparian corridor and associated bank instability, channel widening, plane-bed morphology, and lack of shade;
iii. areas of channel straightening and bridges that locally concentrate flow, causing incision and/or bed armoring.

IDEQ (2012) listed the upper Lemhi River for excessive fine sediment in the TMDL. The primary sources of the fine sediment entering the stream network are agricultural practices that produce sediment-laden runoff that deposits in the channel (IDEQ 2012, IRA 2019). Furthermore, diversions dewater the river, decreasing the stream power to mobilize sediment and thus the ability of the river to flush the excessive fine sediments.

The resulting excess fine sediment limits summer steelhead and spring/summer Chinook salmon habitat for spawning and rearing life stages. Ideally, surface gravels in runs and riffles are "clean" of silts and sands, creating favorable conditions for salmonid spawning and rearing as well as suitable habitat for benthic organisms that the fish feed upon (Figure 5A). Typically, streambeds with clean, 8 mm sized gravel are desirable conditions for salmonid spawning (Mike Edmondson 2020, personal communication). For gravel streams, excessive fine sediment impacts stream habitat by plugging the voids between gravels and cobbles and changing the streambed shape (Figure 5C). Plugging voids eliminates vital refuge for juvenile fish to escape predators and the habitat for aquatic insects upon which the salmonids feed. For spawning fish, the excessive fine sediment can "lock" gravels in place, making it harder to move the gravels when forming a spawning bed or redd. Once a redd is formed and eggs laid, excessive fine sediments plug the voids, thus reducing the oxygenated water flowing through the redd that nurtures the eggs within.

As stated, increased sediment load from agricultural runoff, coupled with a decrease in stream discharge by diversion withdrawal, silts, sands, and gravels deposit in between and on top of larger gravel and armored layer in the upper Lemhi River. Crucial to addressing this issue are discharge events that occur over a short period, such as the proposed minimum stream flow event, to erode fine sediment deposits, coarsening of the streambed, and increase channel morphology complexity (e.g., scour of pools). To design and evaluate the impacts of such a minimum stream flow event, it is necessary to consider sediment transport potential and bed size materials (Kondolf & Wilcock 1996). The following section provides the scientific basis for the minimum stream flow event and computations.

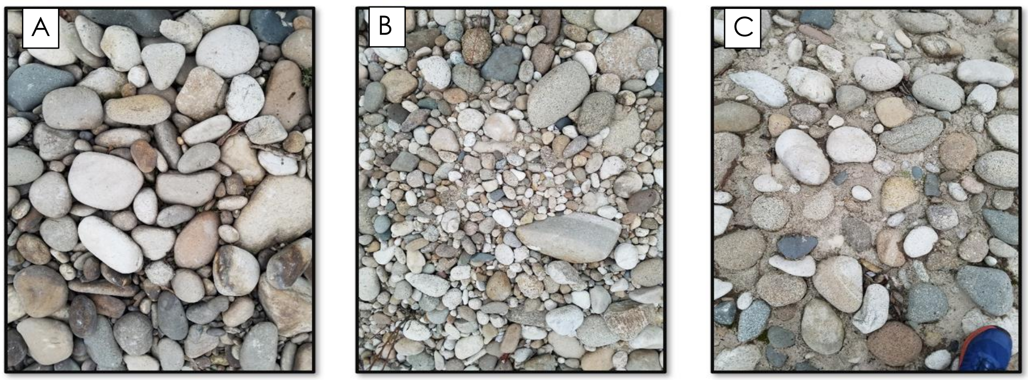


Figure 5. Gravel stream beds exhibiting different levels of sand and gravel inundation: A) surface gravels and cobbles clean of sand and fine gravels, B) a mixture of sand fine gravels over cobbles, and C) sand filling interstitial void in the armored layer.

1.1.2 Channel Form and Maintenance

1.1.2.1 River Mechanics and Sediment Transport Overview

Channel morphology and sediment conditions are a balance between the river's power to move material and the bed materials' resistance to movement. Lane (1955) expressed this relationship as:

$$Q_s * D_{50} \propto Q * S_w \qquad \textit{Equation 1}$$

where: Q_s = sediment transport
D_{50} = the mean size particle diameter
Q = stream discharge
S_w = water surface slope

River systems in dynamic equilibrium, over time, will balance the two sides of the equation. In the short term, if a river system increases the volume of transported sediment and/or the sediment coarsens without a corresponding increase in discharge or water surface slope, the system will deposit sediment and aggrade. Conversely, a streambed will erode if flow volumes increase without a change in sediment transport volume and/or sediment coarsening. Once disturbed, rivers seek to find dynamic equilibrium by adjusting streambed morphology and sediment size to rebalance the equation.

Sediment transport through pool-riffle systems, as is characteristic of the upper Lemhi River, is complicated. During lower discharges, sediment is mobilized and transported from runs and riffles, where flows are the most powerful, and deposited in pools that trap and store mobilized sediment, disrupting the downstream migration of the mobilized particles (Figure 6) (Thompson 2018). As discharges increase, sediment erosion, transport, and deposition change character. Sediment mobilization increases with the changing hydraulics scouring pools and building riffles as the mobilized sediment is moved out of the pool tail and deposited in the downstream riffle (Ashworth & Ferguson 1989, Wilcock & McArdell 1997, Church & Hassan 2002, MacVicar & Roy 2011, Jackson & Beschta 1982, Thompson 2018). As discharges decrease, sediment transport returns to preferentially mobilizing from riffles and depositing in pools. In these systems, bedload is more influential in dictating channel morphology than suspended sediment.

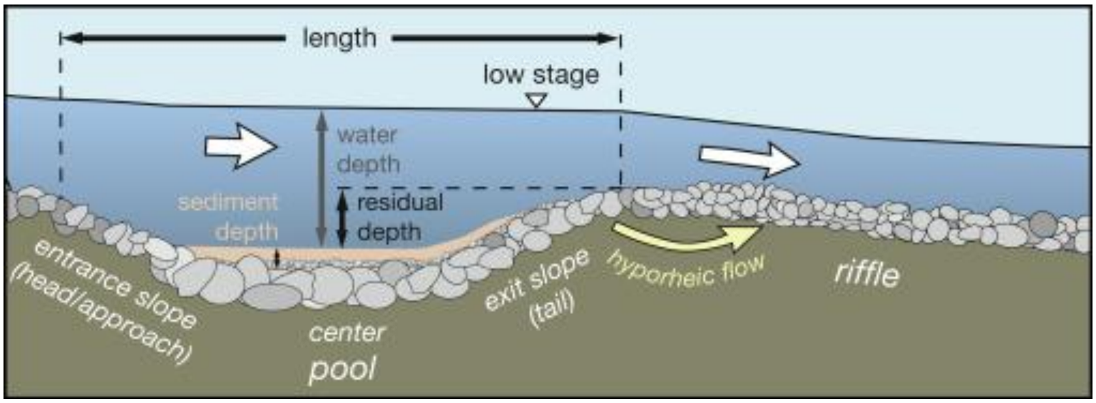


Figure 6. Diagram of a pool-riffle sequence illustrating deposition of fines in the pool and clean gravels in the riffles (source: Thompson 2018).

Adding to sediment transport complexity in gravel-bedded rivers is the disparate transport capacity of fine to coarse material. Bedload transport follows two phases: 1) predominantly sand and fine gravels over a coarse bed and 2) transport of finer materials, gravels, and cobbles (Figure 7) (Schmidt & Potyondy 2004). At low discharges, stream power is insufficient to mobilize materials; therefore, finer material from upstream, riverbanks erosion, tributary inflow, and ditch runoff deposits in low-velocity portions of the stream bed (e.g., pools, sidebars, back channels). As discharge increases, silts, sands, and fine gravels begin to mobilize from the main channel (phase 1). For streams in the Salmon River basin, Idaho, Emmet (1975) observed that bedload movement initiated around 0.4 of the bankfull discharge. The mobilized sands and fine gravels travel over a coarser, "armored" layer that underlies the riverbed (Figure 5B). The armored layer is formed as finer particles are selectively transported and winnowed from immobile, coarser materials after the streambed has been mobilized by a high discharge event or disturbed by anthropogenic activities (*Figure 8*). The armored layer is a lower erosional boundary that will persist until a discharge has sufficient stream power to mobilize the median particle size (D_{50}) in the armored layer.

The movement of the gravels, cobbles, and boulders characterizes Phase 2 (Emmett 1976, Schmidt & Potyondy 2004). At lower discharges in Phase 2, transport concentrates in high-shear stress areas (e.g., riffles) and acts on smaller particles; with increasing discharge, the mobilized area and particle size increase. At higher discharges, the interstitial voids of recently mobilized coarser materials are free silts, sands, and fine gravel (Figure 5A). Full mobilization of the armored layer, as occurs during higher discharges, creates areas that leave the substrate exposed, rapidly transported, and eroded. As the high discharges recede back to Phase 1, coarse material ceases to mobilize and will again, over time, form an armored layer. During low flow conditions, alongside an adequate supply of mobilized silts and coarse sands, the interstitial voids in the armored layer are filled or covered, creating undesirable habitats for salmonids and macroinvertebrates (Figure 5C).

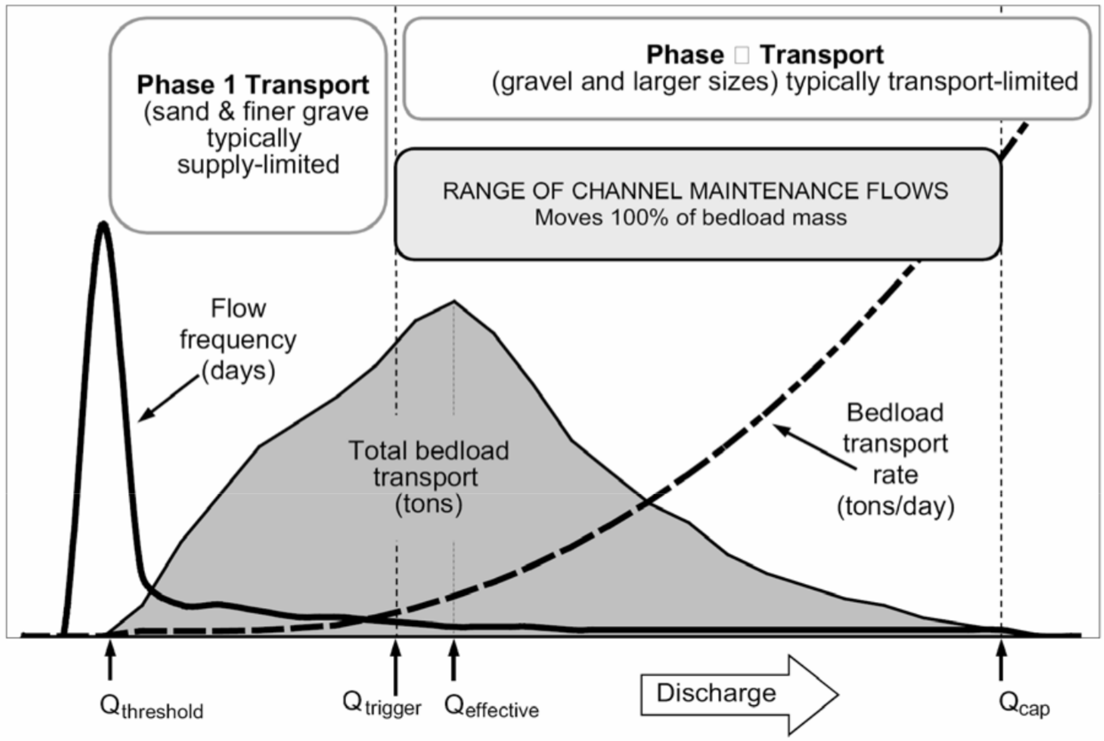


Figure 7. Effective discharge (Wolman & Miller 1966, Schmidt & Potyondy 2004)

In natural systems, long-term channel form is maintained by discharges recurring every 1.5 to 2 years, which is approximately equivalent to the bankfull discharge in alluvial rivers (Wolman & Miller 1960). Effective discharge[1] ($Q_{effective}$ in Figure 7) is the discharge that transports the most bedload over time and is calculated by multiplying the discharge frequency and the bedload transport rate. Effective discharge is often similar in magnitude to bankfull discharge (Wolman & Miller 1960, Schmidt & Potyondy 2004). These flows maintain channel form by scouring pools and building riffles. In natural, gravel-bed rivers with mobile boundaries and a floodplain, systems out of equilibrium will not exhibit bankfull flows or effective discharges with recurring every 1.5 to 2 years (citation).

For rivers such as the upper Lemhi River, managed flow events induced through water management, such as the proposed minimum stream flow event at LR-MC, provide a means of both sediment and channel maintenance. Examples of studies and projects using managed flow events to improve channel and sediment conditions in gravel-bed streams include the removal of fine sediment while retaining and loosening gravel on the Trinity River (Wilcock et al. 1996), removal of accumulated fine silts in pools and riffles below the Iron Gage Dam on the Klamath River (Holmquist-Johnson & Milhous 2010), and removal of fine sediment along Beaverhead River below Clark Canyon Reservoir (Klumpp & Randle 2013). For the upper Lemhi River, the objectives include: i) removing overlying excess fine sediments, ii) mobilizing gravel to remove interstitial fine material and maintain gravel "looseness", and iii) restoring/enhancing pool habitat (IRA 1996). Minimum stream flow events that flush gravels and cobbles are an effective tool for managing these conditions.

[1] Also referred to as dominant discharge.

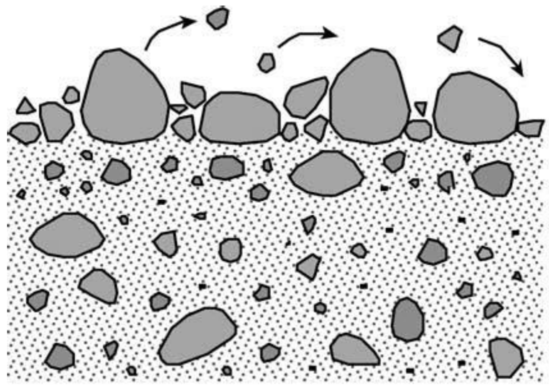


Figure 8. Schematic riverbed cross-section of an armored layer atop a finer substrate (Bunte & Abt 2001).

1.2 Lemhi Settlement Agreement Terms: Minimum Stream Flow Event

The minimum stream flow event criteria in the Lemhi Settlement Agreement stipulate that LBSMWR, associated with the agreement, will be paused for a continuous 3-day period to achieve a minimum stream flow of at least 420 ft^3/s (target discharge) at the LR-MC gauge for at least 2 events in five years. If the target discharge is realized without pausing high water diversions, then that year is considered to have conducted a minimum stream flow event. Furthermore, if withdrawal from LBSMWRs is paused and the target flow is not achieved, the event still counts as conducting a minimum stream flow event. These criteria were derived through the following scientific study.

2 METHODOLOGY

2.1 Overview

Planning and designing a minimum stream flow event involves setting management objectives, characterizing conditions, and evaluating feasibility. If deemed feasible, the next steps involve designing the event, evaluating potential downstream impacts, and establishing the methodology and infrastructure for conducting future events. Specifically, the 6 steps used for setting, designing, and evaluating impacts are:

1. *Set the minimum stream flow objective:* Define how the streambed and channel conditions are to improve and set the desired biological and morphological objective of a minimum stream flow event.

2. *Identify and set the target discharge:* Calculate the discharge volume and duration needed to maintain/enhance sediment and channel form for the desired aquatic habitat. Determine the magnitude, duration, and location of a minimum stream flow event, as well as the frequency and time of year for which these events are to be conducted to reach the objectives.

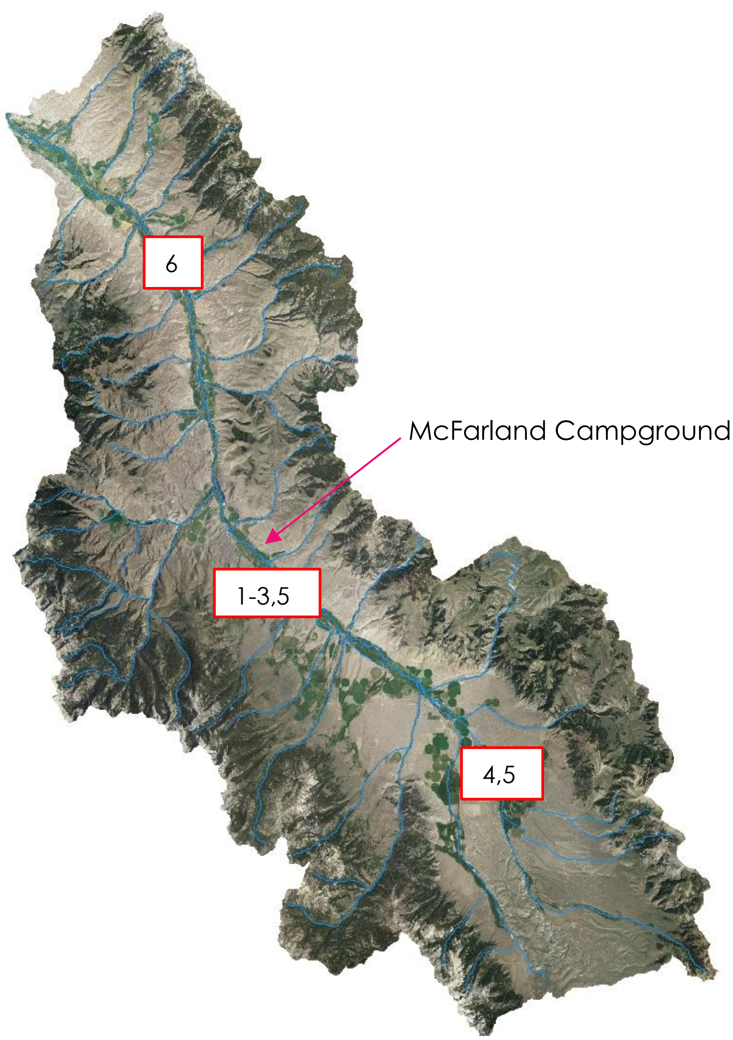


Figure 9. Locations in the Lemhi Basin where steps 1-6 are applied.

3. *Determine discharge deficiency*: Given the desired timing, duration, and magnitude, calculate how much to augment the target reach discharge to achieve the biological and morphological objectives. The equation used is:

   $Q_D = Q_T – Q_G$ *Equation 2*

   where: Q_D = deficit discharge
   Q_T = target discharge
   Q_G = gage discharge

4. *Calculate supplemental discharge availability:* From historic catchment inflows and diversion operations, calculate the volume and timing of the available water supply to support a minimum stream flow event. The equation used is:

   $Q_{AW} = Q_{in} – Q_{BWR}$ if $Q_{AW} < Q_{LBSMWR}$ *Equation 3*

   $Q_{AW} = Q_{LBSMWR}$ if $Q_{AW} \geq Q_{LBSMWR}$

   where: Q_{AW} = available supplemental discharge
   Q_{in} = catchment inflow
   Q_{BWR} = BWR[1] diversion rate
   Q_{LBSMWR} = LBSMWR diversion rate

   For computing Q_{AW}, the LBSMWRs were only considered active when the associated BWRs were historically diverting. Historic BWR activity was based on waster master records or, if none were reported, the BWRs were assumed active from April 15th – Oct 1st [2].

5. *Assess favorable timing:* Given the water deficit (Equation 2) and supplemental discharge availability (4), determine the favorable periods and conditions for conducting a minimum stream flow event at the target reach. Favorable periods are when the historic discharge (Q_G) plus the available supplemental discharge (Q_{AW}) exceeds the target discharge (Q_T). The equations used are:

   $Q_G + Q_{AW} \geq Q_T$ *Equation 4a*
   or
   $Q_{AW} \geq Q_D$ *Equation 4b*

6. *Assess downstream impacts of the minimum stream flow event:* Assess the likelihood and potential location of downstream flooding. If flooding is likely, determine a maximum target discharge to minimize the impacts.

Following a successful design of a minimum stream flow event, the final step is to develop the technical and institutional support for its implementation. Implementation requires developing i) the metrics and indicators to signify favorable conditions for conducting the minimum stream flow event, ii) organizational infrastructure to coordinate, conduct, and monitor the minimum stream flow event, and iii) a monitoring program to continually assess the impact of the minimum stream flow event on habitat conditions. As

[1] Base water rights (BWR) include all senior water rights to the LBSMWR addressed in the Lemhi Settlement Agreement.

[2] For WY 2008-2017, historic diversion records from L-43 through L-63 had an average irrigation start date of May 8th with a few diversions starting as early as April 29th. Thus, the April 15th start date is used as a conservative estimate.

these implementation tasks are currently under development, this document presents only the methodology.

2.2 Determining the Ecological Objectives

The upper Lemhi River is valuable habitat for salmonid spawning and rearing; the habitat is limited, however, due to fine sediment inundating spawning gravels as well as filling pools and clogging interstitial pores that provide refuge for juveniles (NOAA 2017, IRA 2019). In coordination with Jeff Diluccia (IDFG fisheries biologist) and Mike Edmondson (OSC interim director), 3 ecological objectives identified for the minimum stream flow event are:

i. *Removing surficial fine sediment deposit*: Mobilize muds, silts, and sands to expose the underlying gravels and the armored layer (coarser materials) (Figure 5).
ii. *Restoring/enhancing riffle habitat*: Mobilize medium gravel patches as well as local patches of coarse gravels and the armored layer (D_{50} ranging from 21.5 to 54 mm) to clean interstitial muds, silts, and sands from surficial coarse gravels and cobbles.
iii. *Restoring/enhancing pool habitat*: Discharge with sufficient velocity and shear stress to scour pools and flush runs of finer materials depositions.

2.3 Identifying and Setting Target Discharge

This study utilized two assessment methods to set the target discharge: the hydrological event methods and sediment entrainment method (Reiser et al. 1990, Kondolf & Wilcock 1996). The hydrological event[1] calculates the flow frequency of unimpaired discharges at a target reach using norms developed in natural streams based on the dominant discharge or bankfull theories. The hydrological event methods provide an effective approximation for streams with low anthropogenic impacts, as they assume the stream conditions were in equilibrium before the disturbance (e.g., the introduction of a dam) (ibid). For streams significantly altered through diversion, dams, and other hydraulic structures, the hydrological event methods are insufficient. These necessitate applying the sediment entrainment methods that require channel surveys, sediment measurements, and discharge records to assess the impacts of changes in discharge.

2.3.1 LR-MC Study Reach Characterization

The LR-MC study reach was used for designing, evaluating, and monitoring the minimum stream flow event located around the LR-MC gauge (Figure 10). The thalweg is 0.75 miles in length with a river slope of 0.00404 m/m and a sinuosity of 1.5. The valley length of the study reach is 0.5 miles with a valley slope of 0.0606 m/m. The study reach is located within IRA Geomorphic Reach-8, in which the channel morphology is predominantly plane-bed with a lack of instream structure and over-widened in locations without riparian vegetation (IRA 2019). Over-widened sections also observe fine sediment deposits (ibid). No irrigation withdrawals, tributary inflows, or well-defined irrigation outfalls occur within the study reach, so the discharge measured at the LR-MC gauge is assumed constant throughout the study reach.

Baseline (historic) discharge time series used LR-MC gauge data. Gaps in the historic records were filled using a Maintenance of Variance Type II (MOVE II) analysis (Hirsch 1982) with the reference gauge being the Lemhi River gauge at Cottom Lane located approximately 6.2 miles up the valley (Figure 10, Figure 11). Though 3 tributaries and 10 diversions add and withdraw flows in the Lemhi River, concurrent

[1] In Kondolf & Wilcock (1996), referred to as the "set-adjusted channel methods".

discharge measurements have an R^2 of 0.84 indicating that discharge at Cottom Lane and LR-MC share similar hydrologic characteristics (Table 3).

Predictions for unimpaired flow conditions at the study reach used the LRBM by setting all water user nodes, representing POD/POUs, to a "0" diversion rate for the simulation period, thus eliminating irrigation in the simulation. Catchment inflow and reach gains and losses in the stream network remained fixed. The LRBM rainfall-runoff model (NAM) and allocation models simulate a daily time step but do not account for travel time.

Figure 10. LR-MC reach and stream gauge (yellow push pin) (image source: Google Earth)

Table 3. Discharge characteristics of the Lemhi River gauges at Cottom Lane and LR-MC.

Statistics	Cottom Lane Historic	McFarland Campground Historic	McFarland Campground Gap Filled
Operator	IWRB	USBR	
Years	2006 -	1997 -	
Discharge (ft^3/s)			
Minimum	64.8	34.0	34.0
Average	158.5	156.1	155.6
Maximum	609.0	667.1	667.1
Standard deviation	60.2	81.7	71.4
Observations (n)	4110	3138	4110

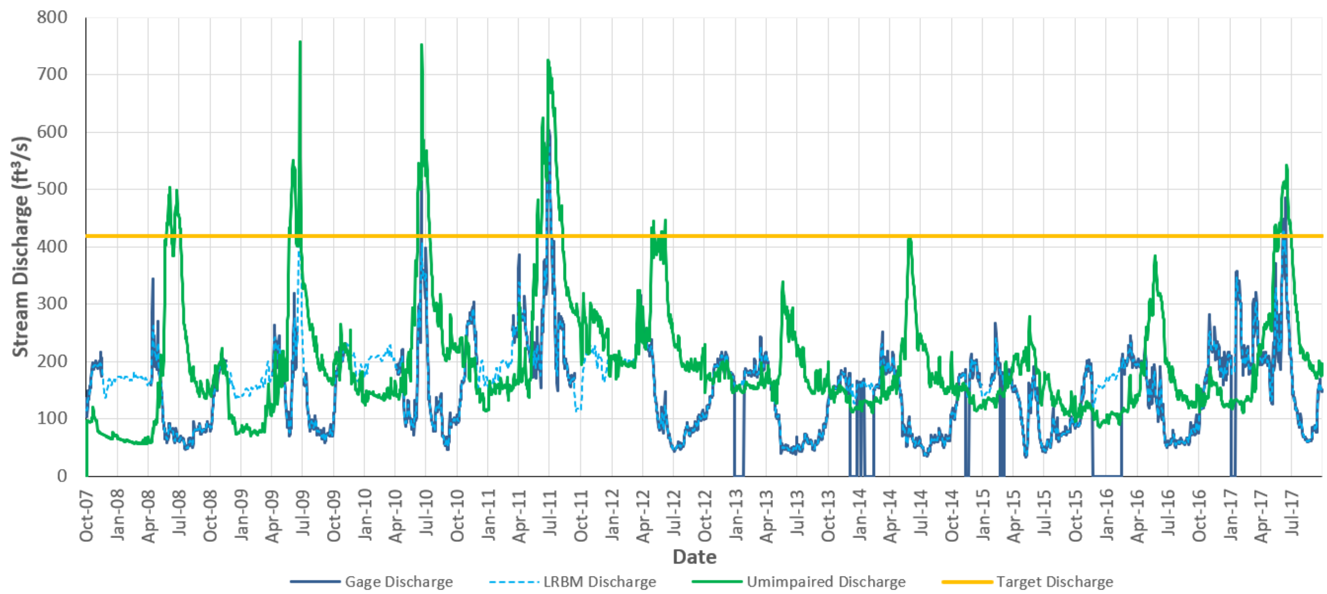


Figure 11. Hydrographs for the LR-MC gauge.

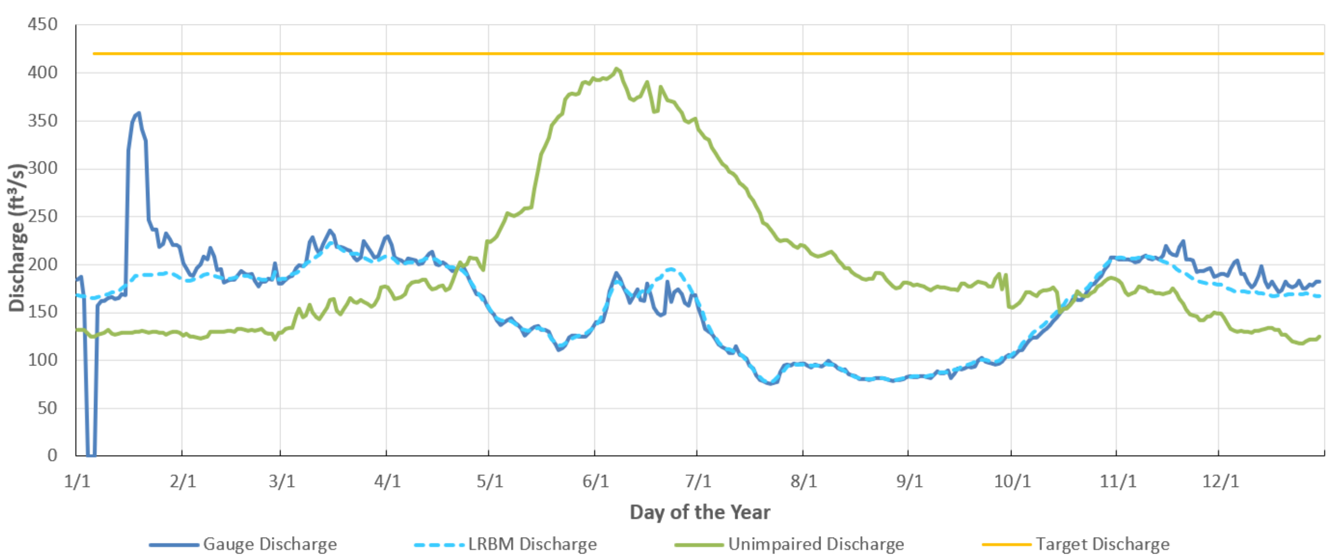


Figure 12. Within year average discharges for the LR-MC gauge.

2.3.2 Additional Study Reaches

For characterizing incipient motion, the Ellsworth, Cottom Lane, and L-46 study reaches were also evaluated providing a range of habitat qualities (Figure 13). The Lemhi River in the Ellsworth study has been straightened and represents poor habitat conditions. The LR-MC and L-46 study reaches are moderate habitat conditions, having moderate complexity. The study reaches below the Cottom Lane stream gauge is desirable habitat with complex channel structure and good riparian vegetation. The hydraulic statistics, particle size distribution, incipient motion potential, and effective discharge calculations for LR-MC reach is presented in the main text and in Appendix A for the Ellsworth, Cottom Lane, and L-46 study reaches.

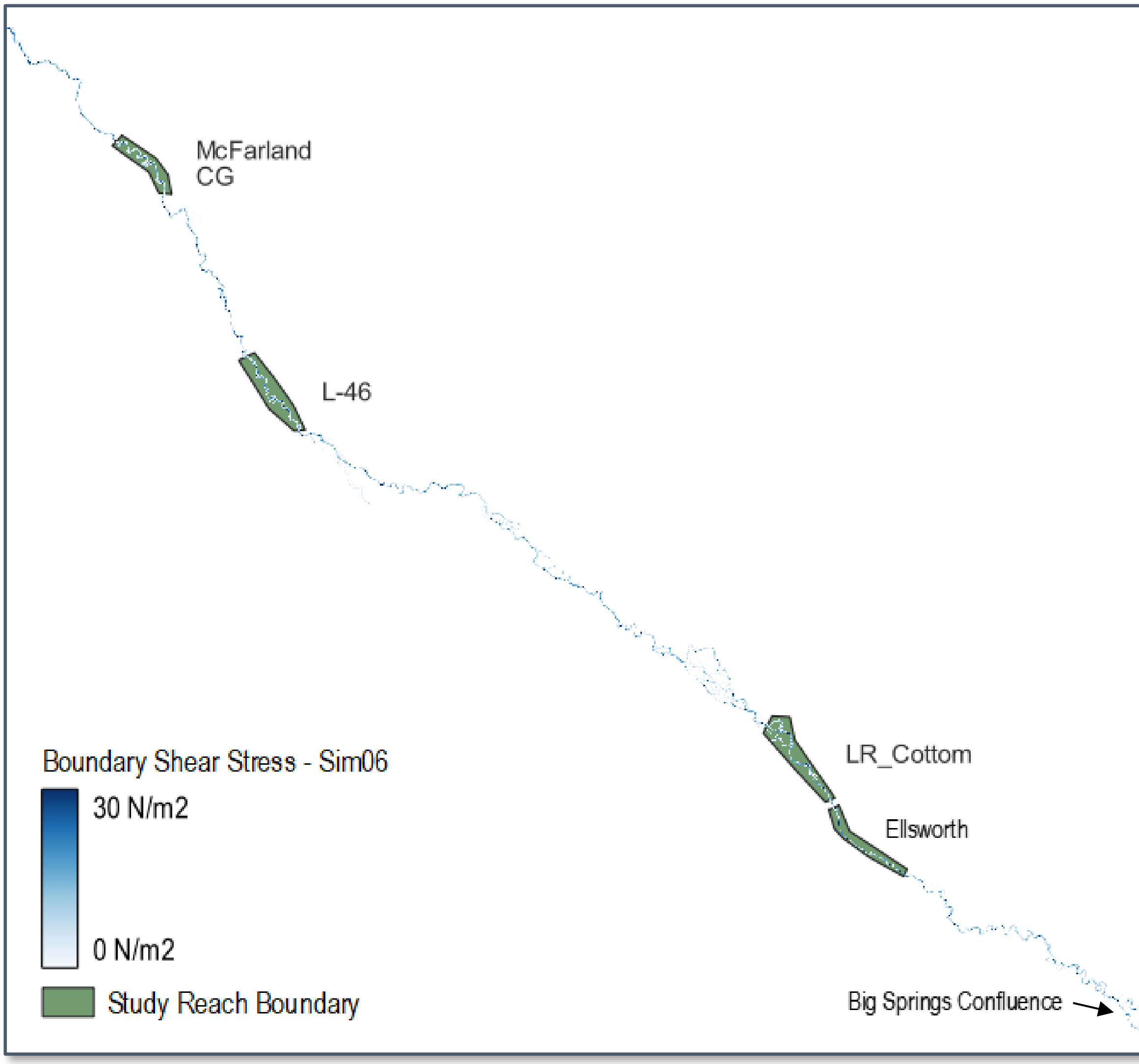


Figure 13. Lemhi River study reaches and boundary shear stress from UI-CER Sim06.

2.3.3 Hydrological Event Methods

The statistical norms applied in this study include:

- 200% mean annual unimpaired flow (Tennant 1976),
- 17% unimpaired flow exceedance (Kondolf & Wilcock 1996),
- Unimpaired flow with a recurrence interval of 1.5 and 2.0 years (Wolman & Leopold 1957, Schmidt & Potyondy 2004, Robinson 2007), providing the typical range of bankfull discharge recurrence intervals is natural streams, and
- Unimpaired flow with a recurrence interval of 25 years (Schmidt & Potyondy 2004), provides an upper threshold to prevent risk to infrastructure.

For each norm, both the baseline historic discharge record and the estimated unimpaired discharge time series were used to compute the channel maintenance statistics for the LR-MC reach. For determining the 1.5-, 2.0-, and 25-year recurrence intervals discharges, the methodology outlined in Bulletin 17B was employed (IACWD 1982).

Beyond calculating a target discharge for stream maintenance norms, additional statistics calculated included the annual recurrence frequency (e.g., how many flows exceeded the target over the last 10 years), the average duration of exceedance (in days), and the discharge exceeding the target discharge. This information provided additional insight into the existing hydrological conditions that were used in the design of the minimum stream flow event.

2.3.4 Sediment Entrainment Analysis

Estimating the channel morphological response to a minimum stream flow event involved computing the Lemhi River's ability to move sediment: calculating the incipient motion of surface D_{50}, substrate D_{50}, and 8 mm particle size[1]; effective discharge; and Rouse number for each study reach. The calculations used channel geometry and hydraulic characteristics (depth, velocity, shear stress) generated from a 2-dimensional (2D) hydrodynamic model and sediment size distribution from field observations.

2.3.4.1 Data

Hydrodynamic Model - Depth, velocity, and boundary shear stress (τ_o) values were derived from the UI-CER 2D hydrodynamic model constructed along the mainstem Lemhi River to evaluate flow and habitat conditions (Rohan Benjankar (University of Southern Illinois professor) and Daniele Tonina (UI-CER professor), personal communication 2020). The 2D hydrodynamic model, constructed with DHI's MIKE21 software, used a 1m x 1m grid covering the Lemhi River channel and its floodplain that extends from Leadore, Idaho to its confluence with the Salmon River at Salmon, Idaho (Tonina et al. 2019, Tonina et al. 2020). The topographic and bathymetric grid forming the surface topography was derived from a green lidar data set flown in 2013 (Tonina et al. 2019). To characterize habitat over a range of stream discharges, 10 scenarios simulated increasing discharge from baseflow to spring runoff conditions. Longitudinally, discharge was increased in 8 reaches along the Lemhi River to represent increased flow contributions from tributaries. Calibrating the model against stage measurements at stream gauges confirmed proper channel roughness (ibid). For each scenario, the model output a 2D grid of depth, velocity, and bed shear for the corresponding discharge throughout the model domain. Gridded hydraulic output post-processed in QGIS provided statistics and a count of cell values for each parameter. Python scripts automated the extraction of velocity, depth, and shear stress distributions for each study reach.

Particle Size Distributions of surface materials were determined by Wolman pebble counts (Bunte & Abt 2001). For the LR-MC and L-46 study reaches, pebble count data from the Amonson and Control Site 3 sites collected by UI-CER were used to characterize the surface materials (Table 4) (Jenna Dustin, UI-CER Doctoral Candidate, personal communication 2020). For the Ellsworth and Cottom Lane study reaches, pebble count data from Natural Reach 2 and Control Site 4 characterize the surface materials that were combined. For the substrate, UI-CER removed a 1 m x 1 m grid of the armored layer, then conducted grid counts on the underlying material (Bunte & Abt 2001). Seven grid counts were conducted from Amonson, Control Site 3, and Control Site 4 by UI-CER; aside from one pebble count near a bridge at Amonson, the particle size distributions were nearly uniform (Jenna Dustin, personal communication 2020).

Table 4. Pebble count data available for the upper Lemhi River.

[1] Favorable size for spring /summer Chinook salmon and summer steelhead spawning and rearing habitat

Site Name	Years Sampled	Average D_{50} [mm]	Source	Location
Site 452047	2013, 2016	20	CHaMP	UTM Zone 12: 311327,4952586
Site 29135	2012, 2015	23	CHaMP	UTM Zone 12: 310467,4953127
Site 20943	2011, 2014	23	CHaMP	UTM Zone 12: 306470,4956223
Natural Reach 2	2020	38	UI-CER	UTM zone 12: 302015,4959738
Control Site 4	2011, 2013, 2017	50	CHaMP, UI-CER	UTM zone 12: 303709, 4958562
Control Site 3	2012-2014, 2020	44	CHaMP, UI-CER	UTM zone 12: 292673, 4971312
Amonson	2013, 2016, 2019	45	CHaMP, UI-CER	UTM zone 12: 301146, 4960397

2.3.4.2 Computations

Incipient Motion: Sediment motion begins when the boundary shear stress exhibited on a particle by flowing water exceeds the forces acting on the particle to remain in place. Boundary shear stress was calculated using:

$$\tau_0 = \gamma\, d\, S \qquad \textit{Equation 5}$$

where: γ = specific weight of water (N/m^3)
d = average water depth (m)
S = water surface slope (m/m)

The critical shear stress required to mobilize a particle was calculated using (Yang 2003):

$$\tau_{crit} = \theta_c\, (\gamma_s - \gamma)\, D_{50} \qquad \textit{Equation 6}$$

where: θ_c = dimensionless Shields parameter
γ, γ_s = specific weight of water and sediment (N/m^3)
D_{50} = mean size particle diameter (m)

For gravel-bed rivers, θ_c ranges from 0.03 for loose sediment to 0.06 for imbricated particles (Buffington & Montgomery 1997). This analysis used a Shields parameter value of 0.0455 and assumes the full force of the fluid is acting on the particle for mobilization.

For streambeds with non-uniform particle size, such as gravel-bed rivers, this assumption overestimates boundary shear stress for smaller particles sheltered from the fluid forces by the larger particles and requires higher boundary shear stresses to mobilize. For particle sizes smaller than the D_{50} of the armored layer, Andrews & Parker (1987) found the correction factor to the Shields parameter to be:

$$\tau^* = \theta_c\, (D_i/D_{50})^m \qquad \textit{Equation 7}$$

where: $\tau^{*'}$ = Shields parameter
θ_c = dimensionless Shields parameter
D_i = size particle diameter (m)
D_{50} = median particle size of the armored layer (m)
m = experimental exponent (from literature -0.9067)

Thus, the critical shear stress required to mobilize finer sediment classes will vary depending on the quantity of fine material inundating the armored layer. More fine material atop the armored layer decreases the shielding effects, and thus the boundary shear stress required to move finer material. As bedload sediment material quantity over the armored layer varies, computing the incipient motion capacity with and without shielding effects provides a range of potential mobilization which reflect the range of shear stress acting on particles less than the D_{50} of the armored layer.

The methodology for calculating incipient motion using the shear stress output grid from 2D hydrodynamic model followed 4 steps:

1. *Calculate τ_{crit} (Equation 6) for 15 size classes ranging from 2 mm (Φ = 1) to 256 mm (Φ = 8).* Given the uncertain quantity and location of finer materials over the armored layer, critical shear stress is computed with and without the influence of shielding. "Without shielding" conditions represent patches of finer material moving over and inundating the armored layer (Figure 5B), while "shielding" represents stream bed conditions where the coarser armored materials are exposed and shield finer materials from bed shear (Figure C). Shielding effects on the Shields parameter (Equation 7) are calculated for particle sizes less than the D_{50} of the armored layer.
2. *Determine the distribution of τ_o (Equation 5) from the gridded results of the 2D hydrodynamic model.* The 2D hydrodynamic model simulates flow conditions over pools, runs, and riffles, thus providing the boundary shear stress at every wetted grid cell across different channel types. Counting the frequency of boundary shear stresses from all wetted grid cells provides the distribution of mobilization potential within the study reach. Each of the 10 hydrodynamic model simulations has a gridded boundary shear stress output.
3. *Per particle size class, compare τ_{crit} to the τ_o distribution to calculate the percentage of the streambed that can be mobilized.* For a given size class, the percentage of the channel that can be mobilized is calculated by dividing the number of grid cells with boundary shear stresses greater than the critical shear stress of that size class, divided by the number of wetted gridded cells (Figure 14). Incipient motion potential of both unshielded and shielded conditions is assessed for each particle size.
4. *Assess target thresholds.* As desirable conditions are "clean" sediments in riffles and runs, the target discharge is when 50% of the stream bed can mobilize the 8 mm size class.

Effective Discharge - Effective discharge calculations used the discharge frequency analysis from the LR-MC gauge record with potential sediment transport rates to determine the channel maintaining discharge (Knighton 1998, Schmidt & Potyondy 2004, Doyle et al. 2005, Robinson 2007). Sediment transport calculations used the Meyer Peter-Müller equation (MPM) (Yang 2003)

$$\gamma\left(\frac{K_s}{K_r}\right)^{3/2} RS = 0.047\,(\gamma_s - \gamma)D_i + 0.25\rho^{1/3}{q_b}^{2/3}$$ *Equation 8*

where: q_b = bedload transport rate for incipient motion (metric ton/s)/m
K_s, K_r = energy loss from the channel, grain roughness
R = hydraulic radius (m)
ρ = fluid density (m/s)

Strickler's formula was used to derive K_s:

$$S = \frac{V^2}{K_s^2 R^{4/3}}$$ *Equation 9*

where: V = flow velocity (m/s)

From experiments, Muller determined the K_r as:

$$K_r = \frac{26}{{D_{90}}^{1/6}}$$ *Equation 10*

where: D_{90} = particle size where 90% material is finer (m)

Input for the MPM used reach averaged hydrological information extracted from the 2D hydrodynamic model and the substrate D_{50} and D_{90} from the UI CER particle size distribution analysis. The MPM equation works well in mid-sized gravel-bed rivers with D_{50} from 0.4-29 mm (Reid & Dunne 1996).

Rouse Number: Once mobilized into the flow, fine sediment will travel as either washload, suspended load, and/or bedload. The Rouse number is the ratio of lifting and buoyancy forces to gravitational forces and informs the transport model of a particle size. The Rouse number is calculated using (Whipple 2004):

$$P = \varpi_s/ku^* \qquad \textit{Equation 11}$$

where: P = dimensionless Rouse number

ϖ_s = fall velocity (m/s)

k = von Kármán constant, o.4

u^* = shear velocity (m/s)

Fall velocity is calculated using Rubey's formula (Yang 2003):

$$\omega_s = F\left[dg\left(\frac{\gamma_s - \gamma}{\gamma}\right)\right]^{0.5} \qquad \textit{Equation 12}$$

where: ϖ_s = fall velocity (m/s)

γ, γ_s = specific weight of water and sediment

d = sediment diameter (m)

g = gravitational force (m/s²)

F = 0.79 for particles ≥ 1mm

$$F = \left[\frac{2}{3} + \frac{36v^2}{gd^3\left(\frac{\gamma_s-\gamma}{\gamma}\right)}\right]^{0.5} - \left[\frac{36v^2}{gd^3\left(\frac{\gamma_s-\gamma}{\gamma}\right)}\right]^{0.5} \text{ for particles < 1mm}$$

Sediment particles with a Rouse number less than 0.8 travel as washload, 0.8 - 1.2 as 100% suspended load, 1.2 - 2.5 as 50% suspended/50% bedload, and greater than 2.5 as bedload (Whipple 2004).

As the suspended load travels with the stream flow velocity, estimations of the travel time to the confluence[1] used the average downstream velocity at Cottom Lane and McFarland Campground. Particle sizes of less than 2 mm were evaluated. This helped inform the minimum stream flow event duration and the fate of sediment upon mobilization.

2.3.5 Minimum Stream Flow Event Duration

Without detailed channel surveys, sediment monitoring and characterization, and hydraulic and sediment modeling, predicting the channel response to different flow conditions is very difficult (Kondolf & Wilcock 1996). Literature searches on similar case studies informed the duration analysis in the absence of analytical data. The effort resulted in 4 case studies with 2.5- to 5-day minimum stream flow events. Averages of deficit discharge, water availability, and favorable periods were compared for WY 2008 - 2017 to evaluate the feasibility of a minimum stream flow event with a 3-, 4-, and 5-day duration. As the Lemhi Settlement proposes a minimum stream flow event with a 3-day duration, this document only presents the 3-day results.

[1] Travel time to confluence determines how quickly suspended particles, should they remain entrained, would take to exit the basin.

2.4 COMPUTING WATER DEFICIT (Q_D)

The water deficit (Q_D) was calculated by subtracting the historic gauge discharge (Q_G) records from the target discharge (Q_T) (Equation 2). The gauge discharge used the gap-filled, LR-MC gauge records for WY 2008 - 2017.

2.5 QUANTIFYING SUPPLEMENTAL DISCHARGE AVAILABILITY (Q_{AW})

Quantifying supplemental discharge availability in the tributaries and mainstem Lemhi River upstream was a two-step process: i) linking an LBSMWR to the correct BWR[1] per diversion and ii) estimating the availability of LBSMWR given the catchment inflow and BWR activities. The former used the LBSMWR list generated by Craig Saxon (IDWR) (File: Lemhi High Flow Claims List.xlsx), which lists the LBSMWR number, diversion rate, associated tributary, owner, supplemental information, and comments. If ambiguous, such as the LBSMWRs listed for the Lemhi Irrigation District, the individual LBSMWR was reviewed on IDWR's online water rights database[2] and the associated BWR was identified. Summing all the upstream LBSMWR diversions provided the maximum available LBSMWR discharge at each study reach (Table 13).

Calculating the available supplemental discharge involved computing 1) the total high-water streamflow and then 2) the portion of the high-water streamflow that could be used for the minimum streamflow event (Equation 3). Total high-water streamflow was calculated as the difference between catchment inflows and historic BWR withdrawals, including the pending applications, in a tributary. Catchment inflows were determined from historic gauge records or, for ungagged catchments, estimated using DHI's NAM model, the rainfall-runoff module in the LRBM (DHI 2006). For Lemhi River Reaches, catchment inflow was determined by a stream gauge or discharge output from the LRBM. Historic diversion records were extracted from the water master records and reported to IDWR. Gaps in the water master records were filled using methods in LRBM development (DHI 2003, DHI 2006, Borden 2016). For diversions without water master records, the diversion rate was set at the BWR from April 15th to October 15th to represent the irrigation season[3]. The available supplemental discharge is the portion of the total high water that could be diverted by LBSMWR withdrawals. To account for historic diversion operations, an LBSMWR withdrawal was added only when the associated BWR was historically diverting water. For each Lemhi River reach or tributary, the available supplemental discharge was the lesser of the sum of the active LBSMWR withdrawals or the total high-water streamflow. The total available at the LR-MC was the sum of the supplemental discharge from the tributaries and Lemhi River reaches.

2.6 IDENTIFYING FAVORABLE PERIODS ($Q_{AW} \geq Q_D$)

Favorable periods were calculated by adding the computed available water to the historic discharge time (Equation 4a). Favorable periods are defined when the combined discharge, base discharge plus pulse flow, exceeds the flow target for 3-day, 4-day, and 5-day periods for 2008 - 2017. The available water supply assumes 100% of the individuals holding LBSMWR sign the Lemhi Settlement Agreement. For testing the minimum stream flow event sensitivity to the adoption rates of potential signees to the Lemhi Settlement Agreement, LBSMWR water availability was multiplied by a percentage of adoption to decrease the available LBSMWR discharge as it is assumed that irrigators not participating would be

[1] BWR, base water rights, are decreed water rights senior to the proposed high-water rights.
[2] https://research.idwr.idaho.gov/apps/waterrights/wrajsearch/wradjsearch.aspx
[3] For WY 2008-2017, historic diversion records from L-43 through L-63 had an average irrigation start date of May 8th with a few diversions starting as early as April 29th. Thus, the April 15th start date is used as a conservative estimate.

irrigating during this period. For display, the acceptable periods were aggregated into 5-day periods (e.g., Table 14).

Frequency Analysis: Aside from irrigation diversions, the upper Lemhi River is an unregulated system and as such, the exact volume of water for a minimum stream flow event is unknown for each event. Therefore, a frequency analysis over a range of Lemhi River discharges was conducted to determine i) how many years the discharge was exceeded, ii) how many 3-day, 4-day, and 5-day averages exceeded the discharge, and iii) how much additional flow was above the discharge. This analysis was performed with and without a minimum stream flow event to establish the necessity of the minimum stream flow event and to quantify the minimum stream flow event's impact on reaching ecological flows. Only the 3-day average results are presented in this document.

2.7 Assessing Potential Downstream Flood Risk

The downstream flooding risk was assessed by comparing the potential discharge during the minimum stream flow event to the flood frequency return period of 50-year and 100-year flow events at USGS gauges Lemhi River at Lemhi (13305310) and Lemhi River at Lemhi (13305000). Additionally, Rick Sager, former water master for Water District 74, indicated local flooding can occur at discharges at 2,500 ft^3/s (personal communication 2021). To estimate the potential discharge during a minimum stream flow event, the maximum available high-water supply (790 ft^3/s[1]) was then added to the existing USGS gauge data. Note, that this flood analysis is a statistical analysis based on flow events. It does not include flood modeling/mapping to route floodwaters nor evaluates the potential for increased flooding in Salmon due to backwater effects from a flooded Salmon River.

2.8 Developing the Implementation Methodology

2.8.1 Indicators and Metrics for Implementation

To enhance habitat benefits, limit impacts on high water irrigation diversions, and reduce the chance of downstream flooding, minimum stream flow events will only be conducted during periods of favorable conditions. To forecast favorable conditions for implementing a minimum stream flow event, scientifically based, easily obtained snowpack, precipitation, and streamflow data and forecasts from the NWS, NRCS, USGS, and IDWR inform the development of associated indicators. Currently, three forecasting periods are being examined for their effectiveness. Seasonal water supply indicators, evaluated on April 1st and May 1st, predict if a sufficient water supply is available in the upper Lemhi Basin to allow a minimum stream flow event. If seasonal water supply indicators are positive, they will be rechecked in mid-May, alongside the NWS Climate Prediction Center's monthly precipitation prediction for June. Finally, if mid-May conditions are still favorable, weekly forecasts will be checked from late May through June to identify the dates for implementation. Once the indicators are selected and the methods developed, instituting tools and protocols will aid minimum stream flow event organizers in evaluating and scheduling minimum stream flow events.

[1] 790 ft^3/s represents the maximum LBSMWR diversion given a 100% adoption rate to the Lemhi Settlement Agreement.

2.8.2 Organizational Infrastructure Plan

Implementation of the minimum stream flow event requires, monitoring stream conditions, and adapting the process moving forward with input from the steering committee. Organizationally, elements to be considered are:

- *Business processes* how the minimum stream flow event will be implemented, , internal and external communications, and how funding will integrate into the decision-making and mission in the Lemhi Basin.
- *Technical infrastructure* on monitoring conditions (e.g., stream gauging, channel reference reach, tracking diversions); hardware and software to support the data acquisition, processing, and dissemination; network access for the data; and tools supporting the minimum stream flow event program.
- *Social infrastructure* assessing the staffing requirements and associated training required to support the minimum stream flow event program.

The developing Organizational Infrastructure Plan will cohesively coordinate the organizations and combine this information.

2.8.3 Monitoring Minimum stream flow events

To assess the habitat response to the Lemhi River minimum stream flow events, a channel reference reach will be established and monitored to detect trends in hydrologic and fluvial geomorphic conditions over time in the upper Lemhi River. The monitoring reach will ideally be located near LR-MC with the exact location identified during the finalization of the monitoring program. The monitoring program will follow the Columbia Habitat Monitoring Program (CHaMP) 2014 protocols[1]. In the CHaMP protocols, the data collected from a reference reach includes discharge, channel geometry, substrate (a.k.a., stream bed materials), riparian and in-channel vegetation, water quality, and biotic activity. Once collected, analyzed, and combined, the data describes the habitat in a series of metrics. With repeated visits to a channel reference reach, these metrics detect trends in-stream habitat conditions. As the CHaMP protocol is extensive, a modified protocol is being developed for annually assessing habitat conditions at the LR-MC reference reach. The responsible agency and funding source for the implementation of this protocol is currently under consideration.

[1] In 2010, the Bonneville Power Administration (BPA) established CHaMP; a Columbia River basin-wide habitat status and trends monitoring program built around a single protocol with a programmatic approach to data collection and management (RM&E Workgroup 2010).

3 COMPUTATIONS AND RESULTS

3.1 TARGET DISCHARGE (Q_T)

3.1.1 Hydrological Event Method

Statistical analyses of the unimpaired discharge (a.k.a., natural discharge) record produces a range of discharges from 272 ft^3/s to 490 ft^3/s, with an average of 395 ft^3/s for the daily measurements (Table 5). If the17% unimpaired flow exceedance is excluded, as it is an outlier, the average is 436 ft^3/s and 427 ft^3/s for the daily and 3-day intervals, respectively. The average 3-day interval discharge, excluding 17% unimpaired flow, is exceeded in 60% of the water years for 33 days and at an average of 95.8 ft^3/s above the target discharge rate. Thus, a naturally occurring system reaches the channel maintaining discharge roughly 6 out of 10 years for over a month duration. The unimpaired discharge of 395 ft^3/s and 436 ft^3/s (excluding the 17% unimpaired flow statistic) is approximately the target discharge of 420 ft^3/s.

Comparing the baseline discharge record to the unimpaired flow time series reveals the impacts of diversion operations. The baseline discharge record yields a range of target discharges from 208 ft^3/s to 350 ft^3/s with an average of 300 ft^3/s for the daily measurements (Table 5). If the17% unimpaired flow exceedance is excluded, the average is 331 ft^3/s and 317 ft^3/s for the daily and 3-day intervals, respectively. The average daily is exceeded in 27% of the water years for 8.1 days and at an average above target discharge rate of 78.2 ft^3/s. As unimparied discharge represents the required flows to maintain aquqtic habitat, baseline discharge metrics illustrate that the current flow regime provides less discharge for a 25% duration period with half the frequency of the unimpaired (natural) flows. Thus, augmenting streamflow with a minimum streanflow event can increase the stream power and frequency of discharges required to maintain aquqtic habitat.

Table 5. Baseline and impaired discharge hydrological event for LR-MC reach. The term "3D" denotes a 3-day average.

		Baseline Discharge					Unimpaired Discharge				
No.	**Criteria**	**Daily**	**3D interval**	**% WY > Target (3D)**	**Average Days (3D)**	**Average Discharge Above Target (3D)**	**Daily**	**3D interval**	**% WY > Target (3D)**	**Average Days (3D)**	**Average Discharge Above Target (3D)**
Statistical Analysis											
1	200% mean annual unimpaired flow	313	313	30%	10.3	81.5	399	399	70%	39.9	90.2
2	17% unimpaired flow exceedance	208	208	50%	34.2	72.6	272	272	90%	69.0	124.1
3	Unimpaired flow recur. interval: 1.57 yrs.	330	311	30%	7.3	91.7	420	419	60%	36.0	93.1
4	Unimpaired flow recur. interval: 2.0 yrs.	350	328	20%	6.5	61.3	490	463	50%	23.2	76.0
	Average	**300**	290	33%	14.6	76.8	**395**	388	68%	42.0	95.8
	Average excluding #2	**331**	317	27%	8.1	78.2	**436**	427	60%	33.0	86.4
5	Unimpaired flow recur. interval: 25 yrs.	709					892				

3.1.2 Sediment Entrainment Method

3.1.2.1 Sediment Size Distribution and Critical Shear Stress

In the LR-MC reach, the average particle size (D_{50}) in the surface and substrate sediments is 51.3 mm and 14.6 mm, respectively (Figure 14, Table 6), which indicates that the streambed is armored. The substrate material, which is assumed to be representative of the bedload particle size distribution, is comprised of 23% very coarse sand and finer (≤ 2 mm) (Yang 2003). The author is unaware of sediment transport measurements collected in the upper Lemhi River that quantify transport rates and characterize the particle size distributions of bedload material.

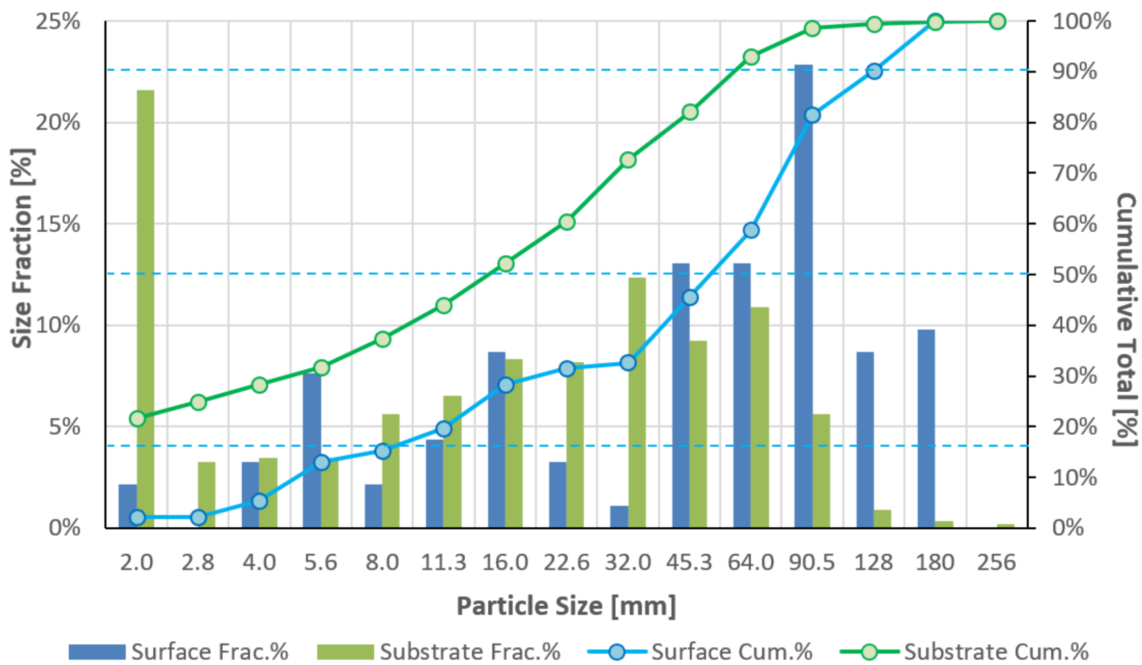


Figure 14. Particle size distribution and cumulative percent finer for the surface and substrate materials in the LR-MC. Dashed lines represent D_{16}, D_{50}, and D_{90}. Source data: UI-CER 2020.

Table 6. Particle size distribution and critical shear stress for D_{16}, D_{50}, and D_{90}. Source data UI-CER 2020.

	Surface Sediment			Substrate Sediment		
% finer	Particle Size [mm]	Critical Shear Stress-No Shielding [N/m^2]	Critical Shear Stress-Shielding [N/m^2]	Particle Size [mm]	Critical Shear Stress-No Shielding [N/m^2]	Critical Shear Stress-Shielding [N/m^2]
16%	8.5	6.3	31.9	2.0	1.5	27.9
50%	51.3	37.8	37.8	14.6	10.8	33.6
90%	127.1	93.5	93.5	58.9	43.3	43.3

Critical shear stress values needed to mobilize the 2.0 mm and 256 mm size classes for unshielded conditions ranged from 1.5 N/m^2 to 188.3 N/m^2, respectively with 37.8 N/m^2 required for the D_{50} of the armored layer (Table 6). Accounting for the shielding effects of larger particles, the critical shear stress required to mobilize a 2.0 mm and 8.5 mm particle increases to 27.9 N/m^2 and 31.9 N/m^2, respectively. Thus, as the abundance of finer materials wanes over the armored layer, the remaining particles require considerably higher discharges to mobilize.

3.1.2.2 LR-MC Reach Hydraulics

At the LR-MC reach, the 2D hydrodynamic model simulated 10 discharges ranging from 71 ft^3/s (Sim01) to 850 ft^3/s (Sim10) producing gridded results of the wetted area, depth, velocity, and bed shear stress (Table 7, Figure 15). Comparing Sim01 and Sim10, reach average depth, velocity, and bed shear stress increased by 90%, 132%, and 247%, respectively. The wetted area ranged from 10,468 m^2 to 26,218 m^2 over the 0.75-mile study reach; a 152% increase. Trends in the average water depth and wetted area illustrate that between 354 ft^3/s (Sim05) to 460 ft^3/s (Sim06), channel inundation transitions from expanding laterally to vertically increasing depth (Figure 15). For discharges greater than 460 ft^3/s, depths increase with limited lateral expansion occurring in low-lying areas along the riverbanks. Figure 16 depicts the inundation patterns around the LR-MC gauge at 71 ft^3/s and 460 ft^3/s.

Table 7. Discharge and accompanying average channel depth, velocity, width, and boundary shear stress for the LR-MC reach from the UI-CER 2D hydrodynamic model.

UI CER Sim	Discharge [m^3/s]	Discharge [ft^3/s]	Wetted Cells	Average Depth [m]	Average Velocity [m/s]	Average Width [m]	Average Boundary shear stress [N/m^2]
1	2.0	71	10489	0.52	0.51	7.54	3.24
2	3.5	124	14291	0.57	0.66	9.41	5.12
3	5.5	195	18986	0.58	0.75	12.66	6.60
4	7.5	266	20801	0.61	0.82	14.81	7.38
5	10.0	354	23070	0.66	0.89	16.91	8.31
6	13.0	460	23902	0.72	0.98	18.38	9.32
7	15.5	549	24571	0.78	1.05	18.86	10.03
8	18.5	656	25430	0.87	1.10	19.27	10.51
9	21.5	761	25975	0.95	1.14	19.92	10.98
10	24.0	850	26218	0.99	1.18	20.45	11.24

The average boundary shear stress increased from 3.24 N/m^2 to 11.24 N/m^2 for Sim01 to Sim10, respectively (Table 7, Figure 15). The rate of boundary shear stress increases by 0.0271 $N/m^2/ft^3/s$ for Sim01 to Sim03, 0.0093 $N/m^2/ft^3/s$ for Sim03 to Sim07, then levels off to 0.0038 $N/m^2/ft^3/s$ for Sim07 to Sim10. Figure 17 depicts the change in magnitude and location and magnitude of boundary shear stress within the LR-MC reach. The inundation pattern with increasing discharge is reflected in the distribution of shear stress in Figure 18. Capacity to mobilize increasingly large particles increases until 460 ft^3/s (Sim06), then levels off for discharges greater than 549 ft^3/s (Sim07).

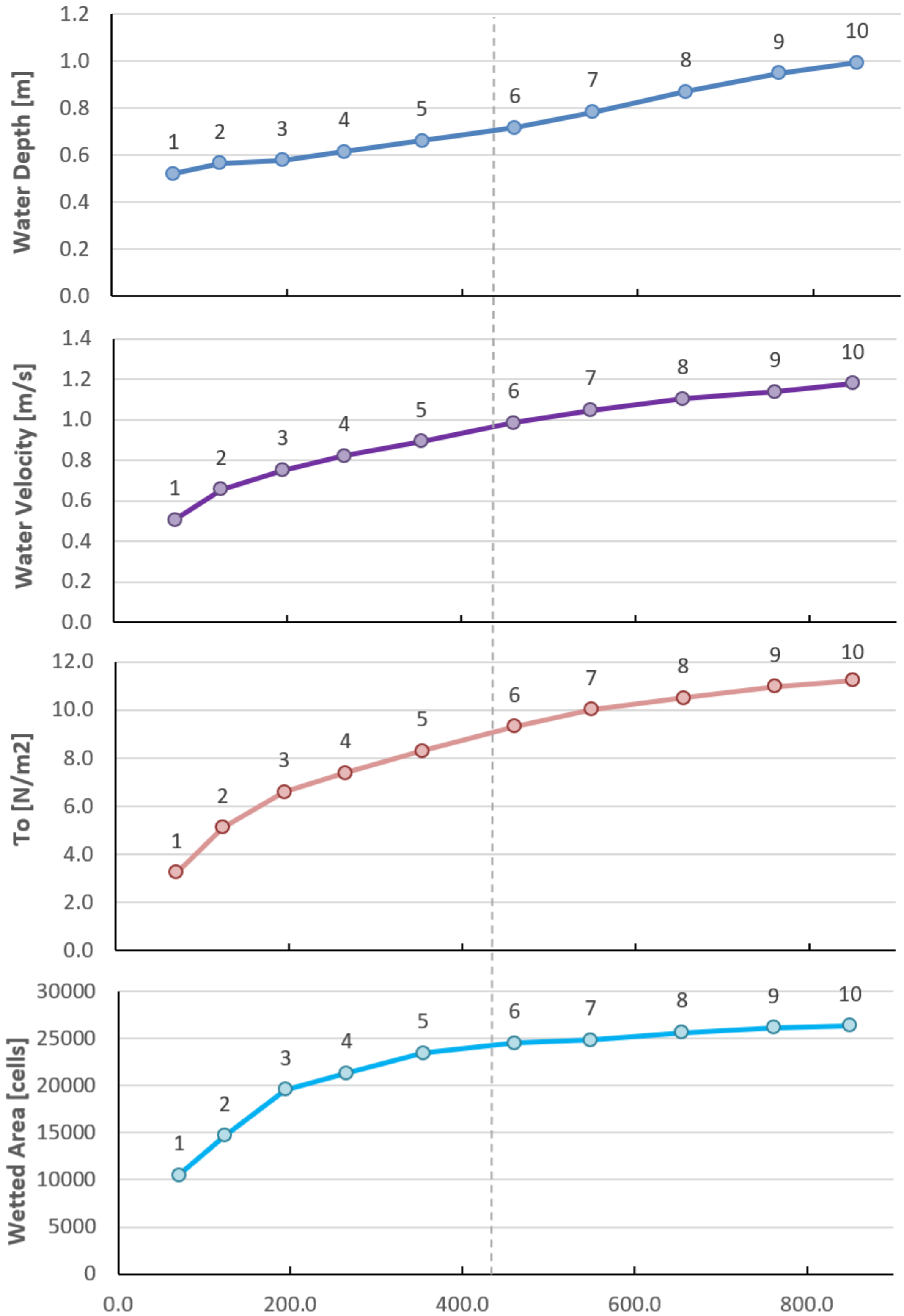


Figure 15. LR-MC reach average water depth, velocity, boundary shear stress (τ_o) as well as wetted area from the 2D hydrodynamic model simulations (1-10). Target discharge is denoted by the vertical dashed grey line.

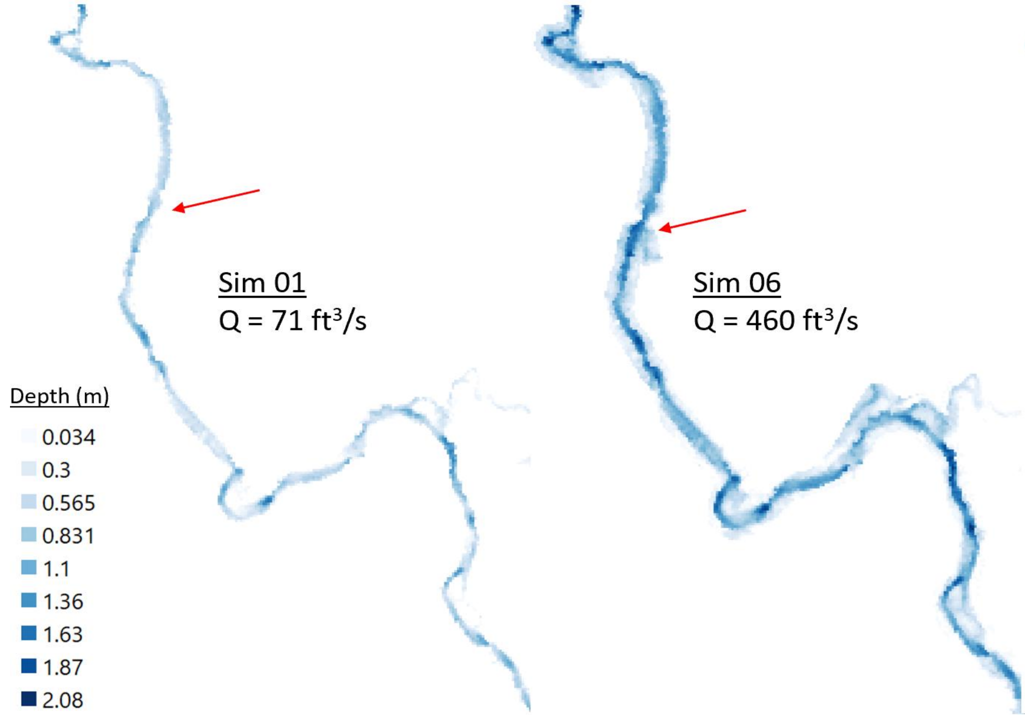


Figure 16. Simulated depths of the Lemhi River up and downstream of the LR-MC gauge (red arrow) for Sim01 and Sim06. Note, the depth color scale represents Sim06, but Sim01uses a similar scale.

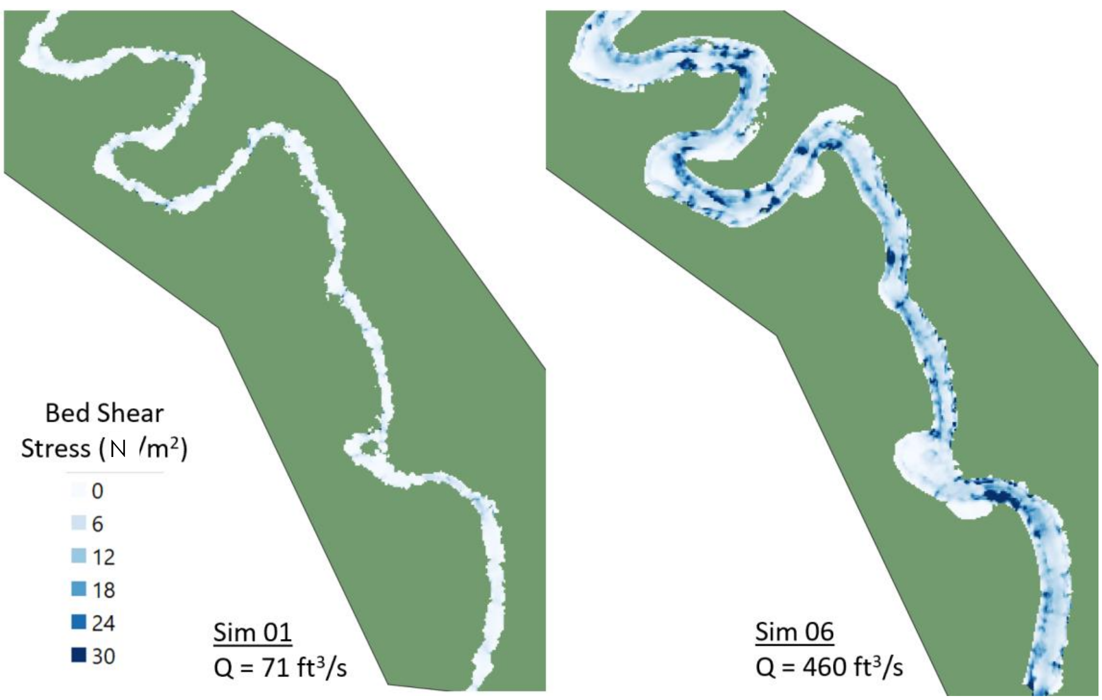


Figure 17. Boundary shear stress in the LR-MC reach from the UI-CER 2D hydrodynamic model for Sim01 and Sim06.

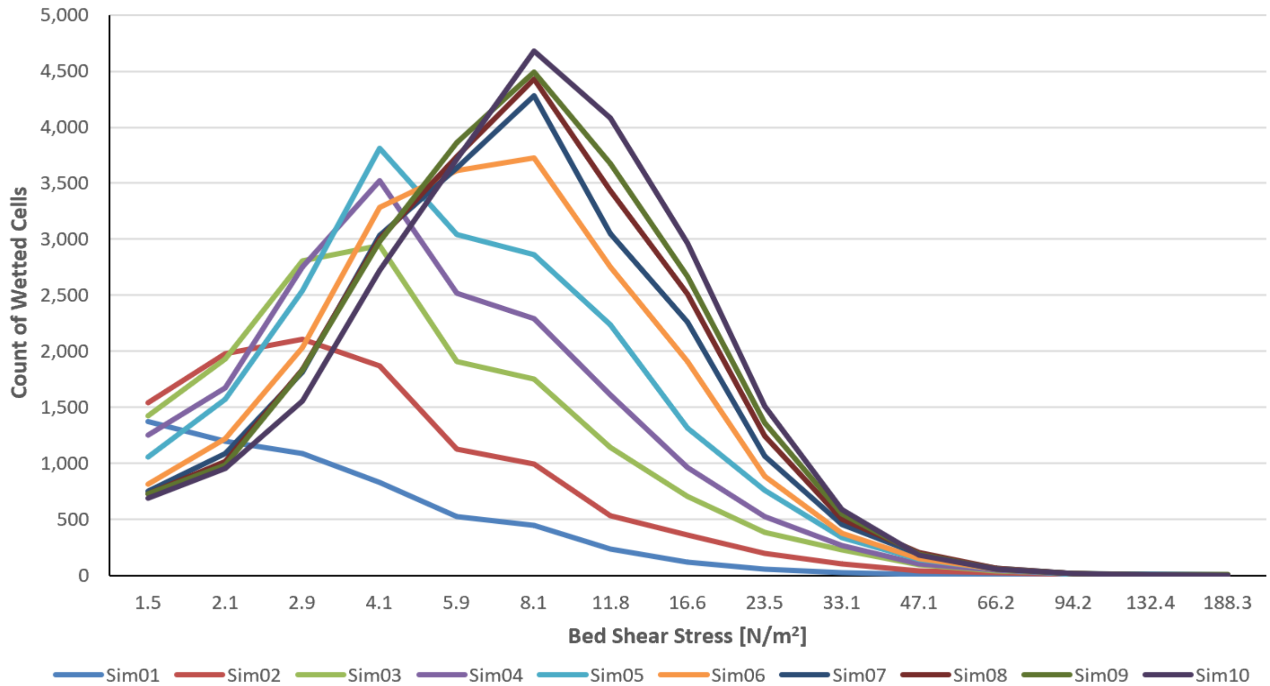


Figure 18. Count of wetted cells (proxy for area) by boundary shear stress for the LR-MC reach. Note the boundary (bed) shear stress values correspond to the incipient motion shear stress for particle sizes without shielding effect.

3.1.2.3 Incipient Motion

LR-MC Study Reach: Based on the boundary shear stress distribution for the 10 simulations, sand particles (2.0 mm) without shielding mobilize 50% and 75% of the riverbed is 159 ft^3/s and 354 ft^3/s, respectively (Table 9A). Reflecting the shift in boundary shear stress between 354 ft^3/s (Sim05) and 549 ft^3/s (Sim07) (Table 8A, Figure 18), the potential bed mobilization has the greatest shift to particle sizes 5.6 mm to 11.3 mm. Particle sizes 5.6 mm, 8.0 mm, and 11.3 mm mobilize from greater than 50% of the stream for discharges of 306 ft^3/s, 445 ft^3/s, and 731 ft^3/s (Table9A). 16.0 mm particle sizes, characteristic of the substrate D_{50} and bedload materials, mobilize 24% of the bed at 460 ft^3/s and 36% at 850 ft^3/s (Sim10). Coarse surface materials, 45.3 mm and greater, are only locally mobilized with a maximum of 3% bed mobilized at discharge greater than 549 ft^3/s. Thus, the armored layer is stable for all discharges except in very localized areas of very high boundary shear stress.

Shielded conditions for particle sizes less than 45.3 mm indicate a drastic decrease in the mobilization potential across the LR-MC study reach (Table 8B, Table 9B). Sand drops from a maximum of 91% in unshielded conditions to 14% when resting amongst the armored layer cobbles. For 8.0 mm gravels, the potential bed mobilization for 354 ft^3/s and 549 ft^3/s is 6% to 8% with a maximum mobility potential of 11% at 850 ft^3/s. At the same discharges, the mobilization potential for 16 mm gravels is 5% and 7% with a maximum of 9% at 850 ft^3/s. Thus, the volume of bedload material over the coarse, armored surface greatly dictates the mobilization potential of smaller particle sizes.

Table 8. For Sim01 to Sim10, percentage surface area of the LR-MC study reach with boundary shear stresses cable of mobilizing particle sizes ranging from 2 to 256 mm. Tables A and B are mobilization potential with and without shielding effects, respectively. The 8 mm particle size is important for salmonids, and the 16 mm and 45 mm particle sizes correspond to the D_{50} in the substrate (14.6 mm) and surface (51.3 mm). Units for shear stress values (τ_{crit}) are N/m^2 and discharge values are ft^3/s.

A. Percentage Surface Area Mobilized without Shielding

Size [mm]	Critical Shear T*cri	Tcri	Sim01 71	Sim02 124	Sim03 195	Sim04 266	Sim05 354	Sim06 460	Sim07 549	Sim08 655	Sim09 761	Sim10 850	Color Scale
2.0	0.046	1.5	23%	42%	59%	67%	75%	80%	83%	87%	89%	91%	0%
2.8	0.046	2.1	17%	36%	53%	62%	71%	76%	80%	84%	87%	88%	7%
4.0	0.046	2.9	13%	28%	46%	56%	65%	72%	76%	80%	83%	84%	14%
5.6	0.046	4.1	9%	20%	35%	45%	56%	64%	69%	73%	76%	78%	21%
8.0	0.046	5.9	5%	13%	24%	32%	41%	51%	57%	62%	64%	68%	29%
11.3	0.046	8.3	3%	9%	17%	22%	30%	38%	43%	47%	50%	54%	36%
16.0	0.046	11.8	2%	5%	10%	14%	19%	24%	27%	30%	33%	36%	43%
22.6	0.046	16.6	1%	3%	6%	7%	10%	13%	15%	17%	19%	20%	50%
32.0	0.046	23.5	0%	1%	3%	4%	5%	6%	7%	8%	8%	9%	57%
45.3	0.046	33.3	0%	1%	1%	2%	2%	2%	3%	3%	3%	3%	64%
64.0	0.046	47.1	0%	0%	1%	1%	1%	1%	1%	1%	1%	1%	71%
90.5	0.046	66.6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	79%
128	0.046	94.2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	86%
180	0.046	132.4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	93%
256	0.046	188.3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%

B. Percentage Surface Area Mobilized with Shielding

Size [mm]	Critical Shear T*cri	Tcri	Sim01 71	Sim02 124	Sim03 195	Sim04 266	Sim05 354	Sim06 460	Sim07 549	Sim08 655	Sim09 761	Sim10 850	Color Scale
2.0	0.863	27.9	1%	2%	4%	5%	7%	9%	11%	12%	13%	14%	0%
2.8	0.636	28.8	1%	2%	4%	5%	7%	8%	10%	11%	12%	13%	7%
4.0	0.460	29.8	0%	2%	4%	5%	6%	8%	9%	10%	11%	12%	14%
5.6	0.339	30.7	0%	2%	4%	4%	6%	7%	9%	10%	10%	11%	21%
8.0	0.245	31.8	0%	2%	3%	4%	6%	7%	8%	9%	10%	11%	29%
11.3	0.179	32.8	0%	2%	3%	4%	5%	6%	7%	8%	9%	10%	36%
16.0	0.131	33.9	0%	1%	3%	4%	5%	6%	7%	8%	8%	9%	43%
22.6	0.096	35.0	0%	1%	3%	3%	5%	5%	6%	7%	8%	8%	50%
32.0	0.070	36.1	0%	1%	3%	3%	4%	5%	6%	6%	7%	8%	57%
45.3	0.051	37.3	0%	1%	1%	2%	2%	2%	3%	3%	3%	3%	64%
64.0	0.037	38.6	0%	0%	1%	1%	1%	1%	1%	1%	1%	1%	71%
90.5	0.027	39.8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	79%
128	0.020	41.1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	86%
180	0.015	42.5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	93%
256	0.011	43.9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%

Ellsworth, Cottom Lane, and L-46 Study Reaches: Expanding the analysis to the Ellsworth, Cottom, and L-46 study reaches, for unshielded conditions discharges predicted to mobilize sand (2.0 mm) from 50% of the riverbed are 108 ft^3/s, 384 ft^3/s, and 225 ft^3/s, respectively (Table 10). At 80% of the riverbed, the discharges able to mobilize sand increase to 406 ft^3/s, 602+ ft^3/s, and 407 ft^3/s with an average discharge is 471 ft^3/s when including the LR-MC study reach. As surficial deposits erode and expose surficial coarser gravels and cobbles, the discharge required to mobilize sands is greatly increased. At the maximum simulated discharge for each reach, on average only 19% of the riverbed could be mobilized. Thus, the mobility of sand and fine gravels is highly dependent on the volume of finer sediment atop the coarser armored layer. Therefore, mobilizing coarser gravels and cobbles is required to clean finer materials from interstitial voids

Table 9. Discharges predicted to mobilize 10%, 25%, 50%, 75%, and 90% surface area of the LR-MC reach for particle sizes ranging from 2 to 256 mm. The 8 mm particle size is important for salmonids, and the 16 mm and 45 mm particle sizes correspond to the D_{50} in the substrate (14.6 mm) and surface (51.3 mm). Discharge values are in ft^3/s.

A. Discharge for Bed Movement - No Particle Shielding *					
Size	10%	25%	50%	75%	90%
2.0	71	78	159	354	811
2.8	71	93	182	430	-
4.0	71	113	236	531	-
5.6	77	147	306	731	-
8.0	124	204	445	-	-
11.0	138	299	775	-	-
16.0	195	497	-	-	-
22.6	351	-	-	-	-
32.0	-	-	-	-	-
45.0	-	-	-	-	-
64.0	-	-	-	-	-
90.0	-	-	-	-	-
128	-	-	-	-	-
180	-	-	-	-	-
256	-	-	-	-	-
* Linearly interpolated between model simulation discharges					

B. Discharge for Bed Movement - Particle Shielding*					
[mm]	10%	25%	50%	75%	90%
2.0	505	-	-	-	-
2.8	549	-	-	-	-
4.0	655	-	-	-	-
5.6	708	-	-	-	-
8.0	761	-	-	-	-
11.0	850	-	-	-	-
16.0	-	-	-	-	-
22.6	-	-	-	-	-
32.0	-	-	-	-	-
45.0	-	-	-	-	-
64.0	-	-	-	-	-
90.0	-	-	-	-	-
128	-	-	-	-	-
180	-	-	-	-	-
256	-	-	-	-	-
* Linearly interpolated between model simulation discharges					

Mobilizing 8.0 mm particles from 50% of the riverbed requires 259 ft^3/s, 557 ft^3/s, and 421 ft^3/s, for unshielded conditions, in the Ellsworth, Cottom, and L-46 study reaches (Table 10). The average from all study

reaches, including the LR-MC, is 420 ft³/s. With shielding effects, 8.0 mm particles cannot be mobilized from 50% of the riverbed with the simulated discharges. In both shielded and unshielded conditions, the surface and substrate D_{50} particle size cannot be mobilized from 50% of the riverbed for the simulated discharges.

Table 10. Incipient motion, effective discharge, and transport method results for the Ellsworth, Cottom Lane, L-46, and LR-MC study reaches. For the Ellsworth, Cottom Lane, and L-46 study reaches, the hydraulic, particle size distribution, and boundary shear stress data is reported in Appendix A.

					Average		Ellsworth		Cottom		L-46		LR-MC	
Analysis No.	Criteria			Grain Size [mm]	Target Discharge [cfs]	Years > Target	Target Discharge [cfs]	Years > Target	Target Discharge [cfs]	Years > Target	Target Discharge [cfs]	Years > Target	Target Discharge [cfs]	Years > Target
Channel Morphology Discharge														
*Incipient Motion Calculations**														
12	Gravels: 8	no shielding	50%	8.0	420	28%	259	70%	557	10%	421	10%	445	20%
13	Gravels: 8	shielding	50%	8.0	Max	0%	602+	0%	602+	0%	850+	0%	850+	0%
14	D_{50} Surface Layer		50%	16.0	Max	0%	602+	0%	602+	0%	850+	0%	850+	0%
15	D_{50} Substrate		50%	45.3	Max	0%	602+	0%	602+	0%	850+	0%	850+	0%
Effective Discharge (Gage/LRBM baseline)														
16	D_{50} Surface Layer				Max	0%	602+	0%	602+	0%	850+	0%	850+	0%
17	D_{50} Substrate				Max	0%	602+	0%	602+	0%	850+	0%	850+	0%
Recommended Threshold														
22	*Sand Removal*		50%	2.0	**206**	83%	108	100%	384	30%	212	100%	120	100%
23	*Sand Removal*		80%	2.0	**472**	15%	406	30%	602+	0%	407	10%	471	20%
24	*Flushing Gravels*		50%	8.0	**420**	33%	259	90%	557	10%	421	10%	445	20%
25	*Mobilizing Pavement*		50%	45.3	**Max**	0%	602+	0%	602+	0%	850+	0%	850+	0%
26	*Target 1*				**420**	23%	420	30%	420	30%	420	10%	420	20%

** Percentage area of riverbed capable of mobilization*

3.1.2.4 Suspended Load

Using reach average velocity and depth for the LR-MC study reach, fine sands (0.25 mm) will be entrained and transported in the suspended load for discharges greater than 77 ft³/s (Table 11). Grain sizes of medium sand (0.50 mm) and coarse sand (1.00 mm) will be transported in both the suspended and bedload portions depending on the local hydraulic conditions. On average, 1.50 mm sand grains will travel as bedload for discharges up to 850 ft³/s, the maximum discharge simulated by the 2D hydrodynamic model. For 420 ft³/s target discharge at LR-MC gauge, silts and sands that are entrained and remain suspended in the main channel (e.g., does not attenuate on the floodplain or in a slow-moving reach) could be transported 41.8 miles to the mouth of the Lemhi River within 20 hours. This transport time assumes that the water velocity is approximately constant in the Lemhi River from the LR-MC study reach to the confluence.

Table 11. Sediment transport method (suspended, bedload) for different sand sizes at the LR-MC study reach.

Particle Size [mm]	Suspended [ft³/s]	50% Bedload [ft³/s]	Bedload [ft³/s]
0.25 (find sand)	> 77	0 - 77	-
0.50 (medium sand)	-	> 77	0 - 77
0.75 (coarse sand)	-	> 206	0 - 206
1.00 (coarse sand)	-	> 592	0 - 592
1.50 (very coarse sand)	-	-	< 850

3.1.2.5 Effective Discharge

Given the substrate D_{50} and the reach average water depth, velocity, and width for all study reaches, the reach average sediment transport rate was 0 metric tons/s over the simulated discharges, therefore the effective discharge could not be used as a target flow (Table 10, Figure 19). The transport rate is consistent with the substrate D_{50} the incipient motion calculations which indicate that less than 50% of the streambed will mobilize.

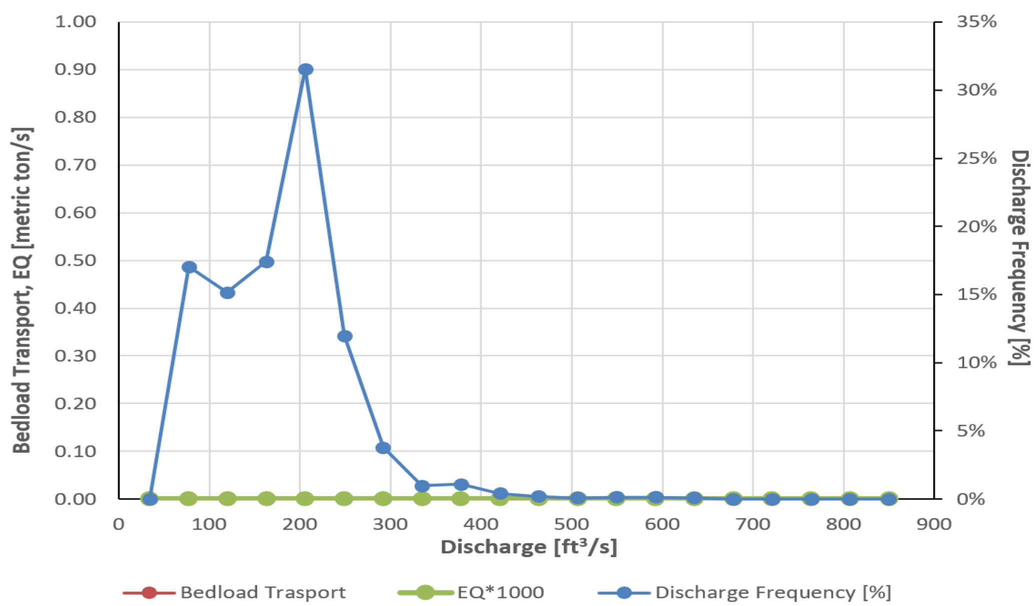


Figure 19. Effective discharge (EQ) calculated at LR-MC study reach.

3.1.2.6 Management Goal Implications

To provide a range of habitat qualities, management decisions were based on incipient motion analysis from the Ellsworth, Cottom Lane, L-46, and LR-MC study reaches. Unless otherwise specified, the discharges reported below are an average from the study reaches' analyses.

Removing Surficial Fine Sediment Deposits: Mobilization of mud, silt, and sand deposits to expose the underlying gravels and cobble in riffles and runs (50% percent of the riverbed) requires average discharges of 206 ft³/s, assuming unshielded conditions (Table 10). Fine sands mobilized at these discharges will be transported out of the study reach as suspended load with medium and coarse sands transported as both suspended and bedload (Table 11). At 472 ft³/s, fine sediment is predicted to be mobilized from 80% of the riverbed, thus exposing the gravels and cobbles and channel structure adding channel complexity to improve rearing habitat. Using the LR-MC study reach as a proxy for the monitoring reach, the required discharges to mobilize 50% and 80% of the riverbed are 102 ft³/s and 471 ft³/s. Based on boundary shear stress distribution, 471 ft³/s at LR-MC will flush riffles and runs, but larger pools will remain a sediment sink (Figure 17). As the deposits erode and the substrate is exposed (Figure 5C), the ability to entrain fine sediments decreases to 11% at 471 ft³/s (Table 8B, Table 21B, Table 23B, Table 25B).

As gravel bed rivers are generally supply limited during mid-range discharges (Figure 7)(Wolman & Miller 1966, Schmidt & Potyondy 2004), the coarser surficial materials remain exposed as the Spring runoff decreases. However, lower discharges in the Summer are incapable of mobilizing fine sediments, thus non-point source sediment-laden runoff from agricultural fields and roads will over time, again deposit on the gravels and cobble in the riffles and runs. Thus, the periodic high flow events will benefit the system by flushing the fine sediments from atop the coarser surface materials.

Restoring/Enhancing Riffle Habitat: Loosening and cleaning spawning gravels requires mobilizing gravels to allow entrainment of the finer, interstitial sediments (e.g., silts, sands). The average discharge to mobilize 8 mm gravels in riffles and runs (50% percent of the riverbed) is 420 ft³/s, assuming that patches of gravel are not shielded from boundary shear stress by coarser gravels and cobbles (Table 10, Figure 5A). For sediment patches with a mixture of 8 mm gravels and coarser particles where shielding impacts incipient motion (Figure 5B), for Sim10 the average mobilization of 8.0 mm gravels is 15% (Table 8B, Table 21B, Table 23B, Table 25B). For the LR-MC study reach, shielded 8.0 mm particles at a discharge of 850 can mobilize 11% of the stream bed. This percentage drops to 6.5% for the target discharge of 420 ft³/s.

TARGET DISCHARGES

- ***Removing Surficial Fines***: 206 ft³/s and 472 ft³/s will mobilize silts and sands from 50% and 80% of the riverbed, assuming unshielded conditions.
- ***Restoring/Enhancing Riffle Habitat***: 420 ft³/s is required to loosen and clean 8.0 mm spawning gravels in riffles and runs.

Restoring/enhancing pool and channel complexity: Scouring pools and reworking the channel bathymetry requires mobilization of the armored layer. In the study reaches, gravels and cobbles of the armored layer are virtually immobile for discharges up to the maximum simulated discharges (620 ft³/s for the Ellsworth, Cottom Lane study reaches and 850 ft³/s for L-46, LR-MC study reaches). Mobilization of 45 mm particles at the maximum discharge averages 3% of the bed. Except for very local regions in the study reach, the armored layer is immobile and thus bedload of smaller-sized materials travels over this coarser base. For patches of the armored layer with particles sized 32 mm or greater, the interstitial voids are unlikely to be flushed of finer sediment or loosened due to their immobility.

3.1.2.7 Calculation Limitation and Assumptions

- As stated, sediment transport measurements are unavailable to quantify the volume and the particle size distribution of the bedload materials transported in the LR-MC study reach. Furthermore, channel surveys of bathymetry and sediment facies mapping were unavailable to characterize the existing sediment conditions in the study reaches. Monitoring of the LR-MC will provide a long-term record of the effectiveness.
- Inherent in the incipient motion, effective discharge and rouse number calculations are the

limitations and assumptions from the gauge records, particle size distribution data, and 2D hydrodynamic modeling results upon which they rely. 2D hydrodynamic model errors include the input data (bathymetry, discharge, water depths) and the numeric parameters (e.g., eddy viscosity, channel roughness). The Lemhi River 2D hydrodynamic model was calibrated to RMSE of 0.03 m for water depth and 0.2 m/s for water velocity (Tonina et al. 2020).

- The bathymetric surface used in the 2D hydrodynamic model is fixed and thus does not account for aggradation and deposition of the riverbed over the range of flow conditions. Changes in the bathymetric surface will have local impact on the hydraulic parameters simulated in the model. In the future, 2D hydrodynamic models with mobile boundaries could be applied in the future but will require detailed channel reach surveys and measurement of bedload transport over a range of discharges.
- In natural systems, sediment transport is episodic given supply fluctuations, and the complexity of hydraulics, and thus the data collected and equations upon which they are developed have large error bars. The MPM equation employed in the effective discharge analysis uses reach average water depth, velocity, and width as well as the substrate D_{50} to provide a reach average transport rate. This transport rate does not reflect potential local sediment transport during higher discharges. Furthermore, sediment transport is episodic and sediment transport equations
- As the typical depths of the mud, silt, and sand deposits are unknown, the duration of high flows to erode the deposits cannot be predicted across the study reach. Continued monitoring of the LR-MC reference reach will enable implementing agencies and irrigators to determine the effectiveness of the 3-day minimum stream flow event at flushing fine sediments and loosening gravels.

3.2 LR-MC Discharge Characterization and Deficit (Q_D)

Historically at the LR-MC gauge, a target discharge of 420 ft³/s continuing 3 consecutive days occurred 2 in 10 years from WY 2008 – 2017 (Figure 20, Table 12A). These events occurred in WY 2009 and WY 2011 and exceeded the target discharge for 6 days. Figure 20 provides insight the frequency and duration exceeded of river discharges from 300 to 600 ft³/s.

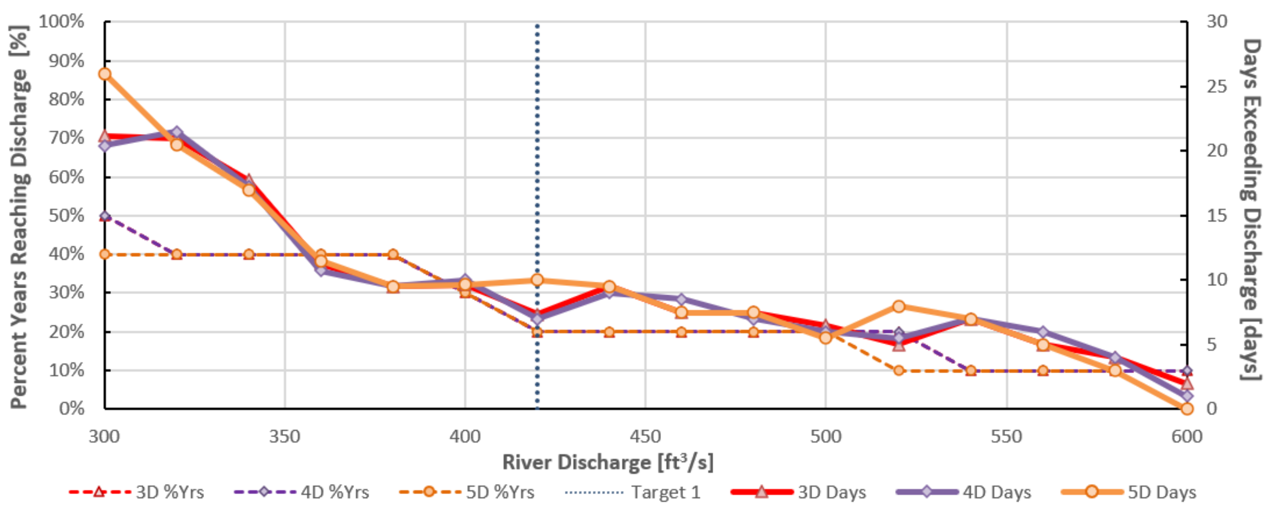


Figure 20. Per discharge, frequency of years reached and number of days it is exceeded at the LR-MC gauge for WY 2008 – 2017.

Table 12. Average discharge and deficit generated from a 3-day running average discharge for the LR-MC gauge. To expedite viewing, the 3-day average discharge is reported in 5-day intervals. All values are in ft³/s.

A. Average LR-MC Discharge

WY	May						June						July					
	1	6	11	16	21	26	1	6	11	16	21	26	1	6	11	16	21	26
2008	201	164	127	89	71	67	83	81	78	66	70	68	63	67	65	57	50	52
2009	205	181	127	99	83	103	187	255	218	282	**508**	381	228	171	161	123	91	93
2010	96	116	110	94	89	99	118	228	276	363	359	348	326	193	126	102	87	88
2011	212	217	202	209	204	219	191	217	284	349	405	**589**	**533**	415	353	286	193	238
2012	185	141	114	91	91	104	91	117	92	72	62	52	46	48	53	57	52	55
2013	105	101	69	50	50	52	50	47	46	46	48	47	52	51	46	50	62	71
2014	145	101	83	71	63	89	77	68	57	59	57	61	55	50	42	38	41	47
2015	57	38	64	132	131	163	169	143	124	79	59	48	46	49	61	57	64	94
2016	145	143	148	163	169	131	112	154	134	100	66	55	57	57	64	70	58	59
2017	138	189	280	290	229	229	313	415	398	327	271	222	180	141	124	112	94	95
Minimum	57	38	64	50	50	52	50	47	46	46	48	47	46	48	42	38	41	47
Average	149	139	132	129	118	126	139	173	171	174	191	187	159	124	110	95	79	89
Maximum	212	217	280	290	229	229	313	415	398	363	**508**	**589**	**533**	415	353	286	193	238
						Less Discharge	38	148	258	369	479	589	More Discharge					

B. Average LR-MC Deficit

WY	May						June						July					
	1	6	11	16	21	26	1	6	11	16	21	26	1	6	11	16	21	26
2008	219	256	293	331	349	353	337	339	342	354	350	352	357	353	355	363	370	368
2009	215	239	293	321	337	317	233	165	202	138	**-88**	39	192	249	259	297	329	327
2010	324	304	310	326	331	321	302	192	144	57	61	72	94	227	294	318	333	332
2011	208	203	218	211	216	201	229	203	136	71	15	**-169**	**-113**	5	67	134	227	182
2012	235	279	306	329	329	316	329	303	328	348	358	368	374	372	367	363	368	365
2013	315	319	351	370	370	368	370	373	374	374	372	373	368	369	374	370	358	349
2014	275	319	337	349	357	331	343	352	363	361	363	359	365	370	378	382	379	373
2015	363	382	356	288	289	257	251	277	296	341	361	372	374	371	359	363	356	326
2016	275	277	272	257	251	289	308	266	286	320	354	365	363	363	356	350	362	361
2017	282	231	140	130	191	191	107	5	22	93	149	198	240	279	296	308	326	325
Minimum	*208*	*203*	*140*	*130*	*191*	*191*	*107*	*5*	*22*	*57*	***-88***	***-169***	***-113***	*5*	*67*	*134*	*227*	*182*
Average	*271*	*281*	*288*	*291*	*302*	*294*	*281*	*247*	*249*	*246*	*229*	*233*	*261*	*296*	*310*	*325*	*341*	*331*
Maximum	*363*	*382*	*356*	*370*	*370*	*368*	*370*	*373*	*374*	*374*	*372*	*373*	*374*	*372*	*378*	*382*	*379*	*373*
						Less Deficiency	**0**	76	153	229	305	382	More Deficiency					

Based on the LR-MC gauge records, the periods with the least deficit occur from June 6th – 31st (Figure 21, Table 12B), with average deficits 241 ft³/s. During high water years (WY 2009 - 2011), the favorable window for augmenting discharge extends into the beginning of July. Dry years such as WY 2013, the deficit is over 350 ft³/s throughout the period for conducting a minimum stream flow event. As ditches are in operation and snowmelt runoff is augmenting tributary inflows, June is the most favorable period for conducting a minimum stream flow event only considering stream flow deficiencies.

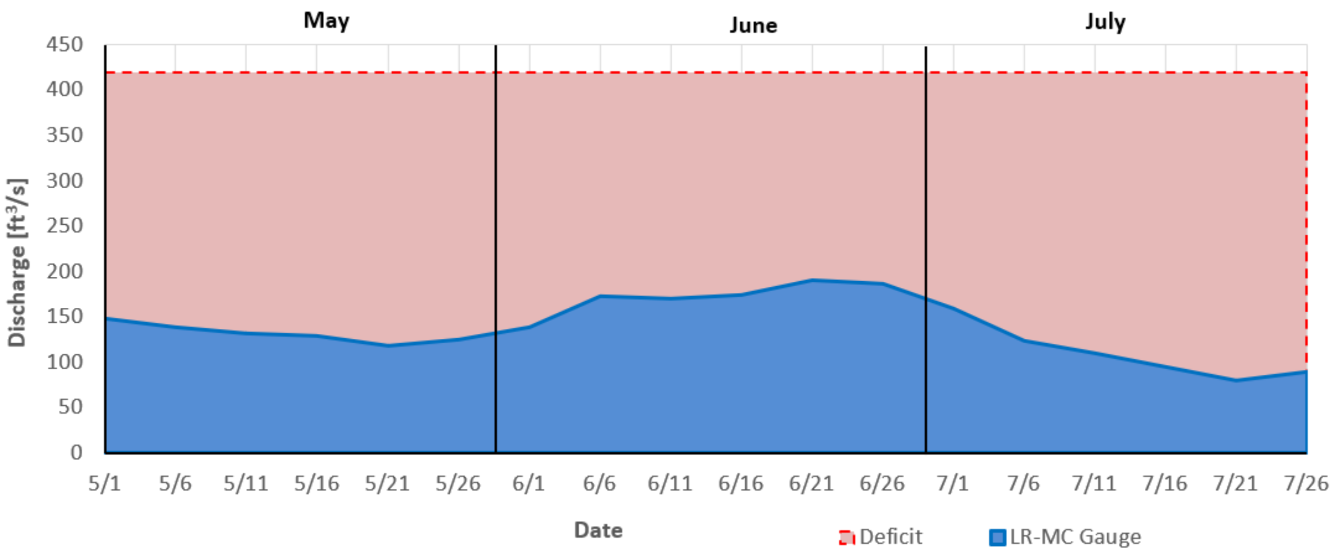


Figure 21. The 3-day average deficit discharge for the LR-MC reach for WY 2008 – 2017. The 3-day average discharge is reported in 5-day intervals.

3.3 Supplemental Discharge Availability (Q_{AW})

At the LR-MC gauge, the estimated supplemental discharge from pausing LBSMWR withdrawals in the tributaries is 491.27 ft³/s. Adding the LBSMWR withdrawals from the Lemhi River, Lemhi Big Springs, and Lemhi Little Springs diversions, the available supplemental discharge increases to 790.47 ft³/s (Table 13).

Table 13. Available of LBSMWR supply from the Lemhi River and per tributary at each study reach.

Tributary/Lemhi Reach		No of HWR	HWR Tributary (ft3/s)	No of HWR	HWR Total (ft3/s)
Texas Creek		8	42.02	8	42.02
Big Timber Creek & Little Timber Creek		12	85.66	12	85.66
Hawley Creek		3	25.58	3	25.58
Canyon Creek		5	43.74	5	43.74
Big Eightmile Creek		15	109.04	15	109.04
Jakes Canyon Creek		3	24.00	3	24.00
Lemhi River				4	41.00
Above Big Springs	**Total**	**46**	**330.04**	**50**	**371.04**
Little Eightmile Creek		3	58.54	3	58.54
Lemhi Big Spring Creek				6	47.50
Lemhi River				3	40.30
Ellsworth	**Total**	**49**	**388.58**	**62**	**517.38**
Lee Creek		1	3.40	1	3.40
Lemhi River				2	15.20
Cottom	**Total**	**50**	**391.98**	**65**	**535.98**
Lemhi Little Spring Creek				2	22.50
Mill Creek		15	99.29	15	99.29
Lemhi River				9	132.70
L-46, McFarland	**Total**	**65**	**491.27**	**91**	**790.47**

This represents the full potential LBSMWR withdrawal rates and does not consider historic diversion practices where diversions are off due to operational requirements (e.g., haying, irrigation repairs), insufficient capacity (e.g., irrigation system has been converted from flood to sprinkler), or personal matters unrelated to irrigation (e.g., illness, family matters).

Based on the historic diversion practices, on each tributary the available supplemental discharge is the catchment runoff that exceeds the diverted BWR withdrawals up to the total LBSMWR rate (Equation 3). For example, Figure 22 presents the total available high-water diversion is the average catchment runoff (blue area) minus the average BWR diversions[1] (red area) in Big Timber and Little Timber Creeks. The predicted average available supplemental discharge, under the proposed Lemhi Settlement Agreement, is the predicted average high-water withdrawals (orange area). The average catchment inflow above the average high-water withdrawals is the remaining high-water for exploitation. However, as this is the average conditions, this water will only be available during high cumulative precipitation conditions.

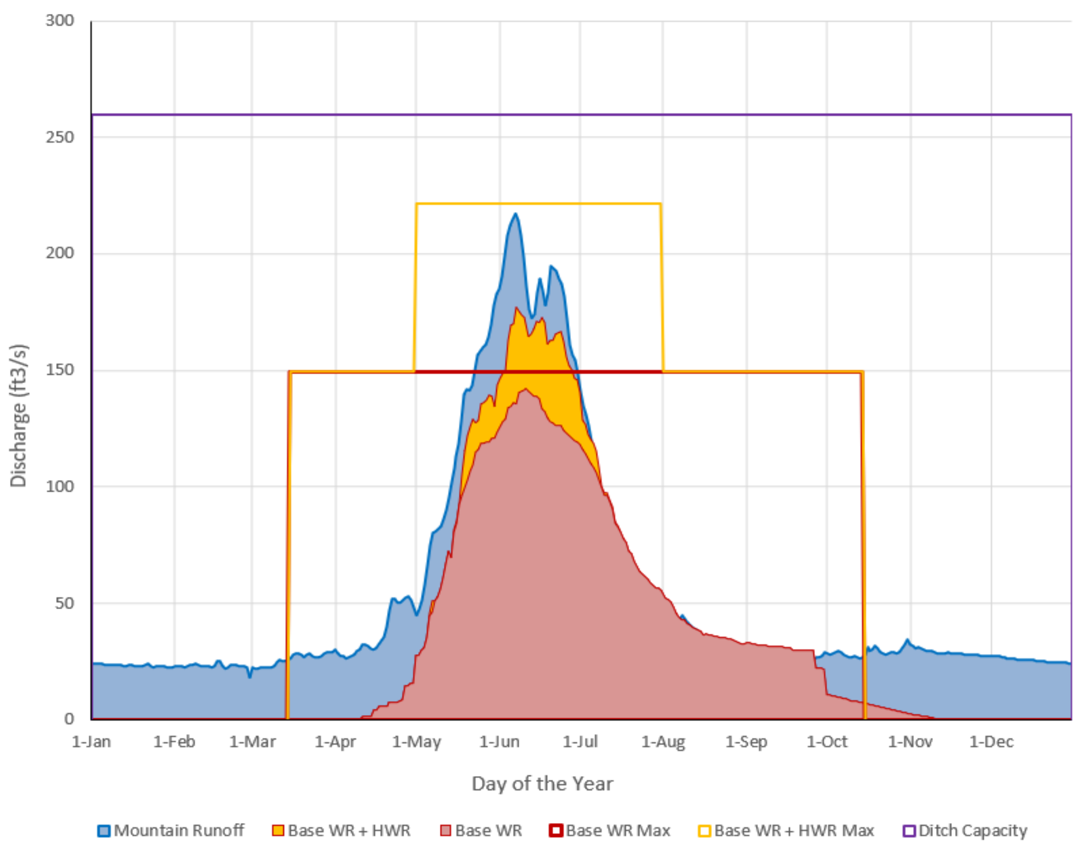


Figure 22. Big Timber Creek and Little Timber Creek average recorded daily inflows and base water rights as well as predicted high water diversions for WY 2008 - 2017.

Applying the calculations to all tributaries and the Lemhi River reaches, the available supplemental discharge from the cessation of LBSMWR withdrawals upstream of LR-MC, ranges from 77 ft^3/s to 513 ft^3/s, with averages for May, June, and July being 289 ft^3/s, 357 ft^3/s, and 274 ft^3/s, respectively (Table 14B). The

[1] Historically, high-water diversions were not recorded by many watermasters, thus their activity was unknown. The high-water diversion was estimated in the tributaries, based on ditch capacities and gauge data. The estimated LBSMWR diversions represent current conditions

supplemental discharge exceeds the target discharge in WY 2008 – 2011 and WY 2017(Figure 23). On average, the source of the available supplement discharge is largely even between the tributaries and Lemhi River diversions from April through June with the Lemhi River Tributaries contributing more during July (Figure 24). Supplemental discharge exceeding the target discharge occurred during abundant water years of 2009-2011 and 2017 and generally occurred early June through middle of July. During these periods, pausing LBSMWR withdrawals would still reach the target discharge regardless of the existing discharge at the LR-MC gauge.

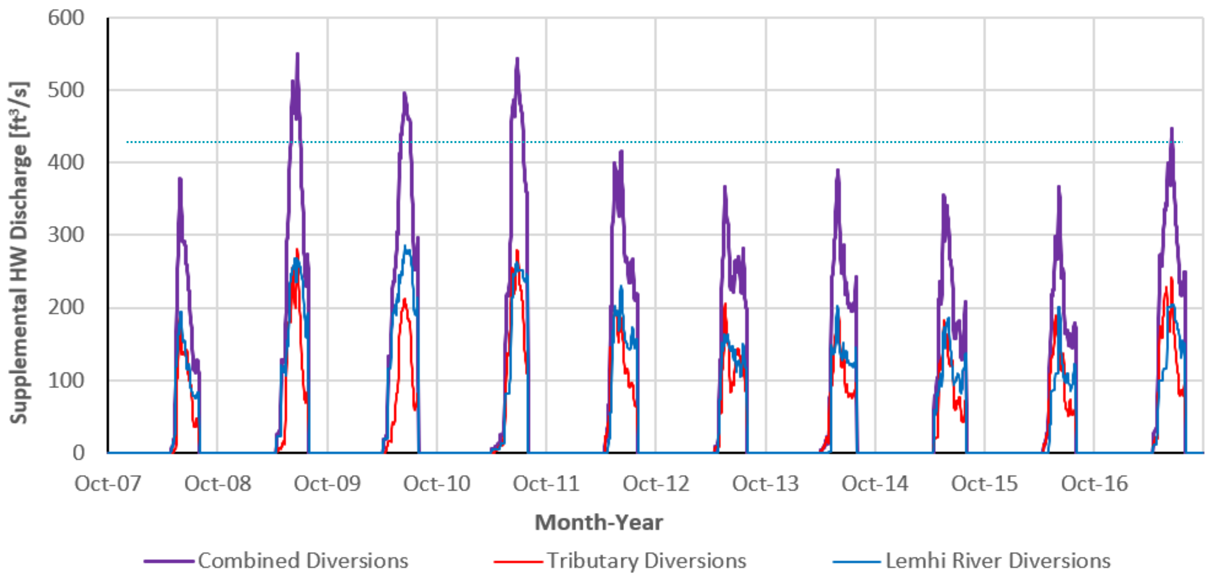


Figure 23. Estimated supplemental LBSMWR discharge at the LR-MC gauge for WY 2008 - 2017. The dotted line represents the LR-MC target flow.

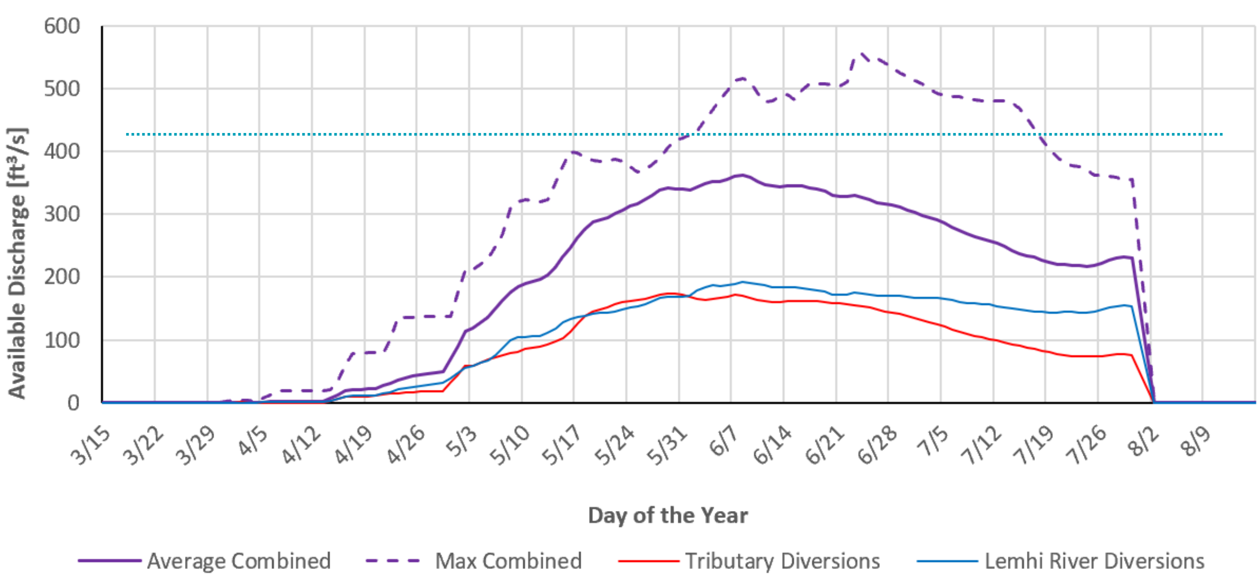


Figure 24. Daily average and maximum estimated supplemental LBSMWR discharge at the LR-MC gauge for WY 2008 - 2017. average high-water withdrawals. The dotted line represents the LR-MC target flow.

Table 14. Discharge, available supplemental discharge, and combined discharge periods at the LR-MC gauge for WY 2008-2017. Yellow cells exceed the target discharge. All values are in ft³/s and represent

the running 3-D average values for each 5-day period. As the 5-day period is averaged, individual 3-D average values will vary.

A. LR-MC Gauge Discharge

	May						June						July					
WY	**1**	**6**	**11**	**16**	**21**	**26**	**1**	**6**	**11**	**16**	**21**	**26**	**1**	**6**	**11**	**16**	**21**	**26**
2008	201	164	127	89	71	67	83	81	78	66	70	68	63	67	65	57	50	52
2009	205	181	127	99	83	103	187	255	218	282	508	381	228	171	161	123	91	93
2010	96	116	110	94	89	99	118	228	276	363	359	348	326	193	126	102	87	88
2011	212	217	202	209	204	219	191	217	284	349	405	589	533	415	353	286	193	238
2012	185	141	114	91	91	104	91	117	92	72	62	52	46	48	53	57	52	55
2013	105	101	69	50	50	52	50	47	46	46	48	47	52	51	46	50	62	71
2014	145	101	83	71	63	89	77	68	57	59	57	61	55	50	42	38	41	47
2015	57	38	64	132	131	163	169	143	124	79	59	48	46	49	61	57	64	94
2016	145	143	148	163	169	131	112	154	134	100	66	55	57	57	64	70	58	59
2017	138	189	280	290	229	229	313	415	398	327	271	222	180	141	124	112	94	95
Min.	*57*	*38*	*64*	*50*	*50*	*52*	*50*	*47*	*46*	*46*	*48*	*47*	*46*	*48*	*42*	*38*	*41*	*47*
Ave.	*149*	*139*	*132*	*129*	*118*	*126*	*139*	*173*	*171*	*174*	*191*	*187*	*159*	*124*	*110*	*95*	*79*	*89*
Max.	*212*	*217*	*280*	*290*	*229*	*229*	*313*	*415*	*398*	*363*	*508*	*589*	*533*	*415*	*353*	*286*	*193*	*238*

Less Discharge	38	148	258	369	479	589	More Discharge

B. Available Supplemental Discharge

	May						June						July					
WY	**1**	**6**	**11**	**16**	**21**	**26**	**1**	**6**	**11**	**16**	**21**	**26**	**1**	**6**	**11**	**16**	**21**	**26**
2008	11	21	89	220	305	371	325	291	289	265	246	222	186	153	117	113	125	118
2009	127	128	149	257	320	400	451	506	475	473	526	497	442	373	325	261	237	265
2010	185	233	246	273	304	392	420	451	471	506	488	466	460	400	328	267	254	281
2011	19	20	50	158	211	215	269	430	482	475	523	534	500	484	478	421	374	358
2012	205	309	353	389	376	342	375	409	338	277	267	260	237	240	264	239	212	219
2013	134	233	285	357	328	312	255	228	240	233	263	256	266	245	225	271	228	202
2014	80	211	254	293	346	388	346	279	252	277	230	227	207	201	201	197	205	224
2015	222	215	276	340	307	336	314	271	254	206	158	166	177	180	151	136	160	196
2016	114	176	219	234	288	285	327	335	251	248	195	166	166	151	158	147	163	176
2017	191	271	263	303	333	345	392	377	401	429	382	340	299	267	233	223	228	243
Min.	*11*	*20*	*50*	*158*	*211*	*215*	*255*	*228*	*240*	*206*	*158*	*166*	*166*	*151*	*117*	*113*	*125*	*118*
Ave.	*129*	*182*	*218*	*282*	*312*	*339*	*347*	*358*	*345*	*339*	*328*	*314*	*294*	*270*	*248*	*227*	*219*	*228*
Max.	*222*	*309*	*353*	*389*	*376*	*400*	*451*	*506*	*482*	*506*	*526*	*534*	*500*	*484*	*478*	*421*	*374*	*358*

Less Discharge Available	0	107	214	320	427	534	More Discharge Available

C. Combined LR-MC Gauge and Supplemental Discharge

	May						June						July					
WY	**1**	**6**	**11**	**16**	**21**	**26**	**1**	**6**	**11**	**16**	**21**	**26**	**1**	**6**	**11**	**16**	**21**	**26**
2008	211	185	217	309	376	438	409	372	367	332	316	291	249	220	183	170	174	170
2009	332	309	276	356	404	502	638	761	693	755	1034	879	670	544	486	384	329	359
2010	281	349	355	367	393	491	538	680	748	869	847	815	786	593	455	369	341	369
2011	232	238	253	368	415	433	460	648	766	824	928	1123	1034	900	831	707	567	596
2012	390	450	467	480	466	446	466	526	430	350	329	312	284	288	316	296	265	274
2013	240	335	353	407	378	364	305	275	286	279	311	303	319	296	271	321	291	274
2014	225	312	337	364	409	477	423	347	309	336	287	287	262	252	243	235	245	271
2015	279	253	340	472	438	499	483	415	378	285	217	215	223	229	212	192	224	290
2016	259	320	367	397	457	415	438	490	385	348	261	221	223	209	221	217	222	235
2017	329	461	543	593	563	575	705	792	800	756	653	562	479	408	357	335	323	338
Min.	*211*	*185*	*217*	*309*	*376*	*364*	*305*	*275*	*286*	*279*	*217*	*215*	*223*	*209*	*183*	*170*	*174*	*170*
Ave.	*278*	*321*	*351*	*411*	*430*	*464*	*486*	*530*	*516*	*513*	*518*	*501*	*453*	*394*	*358*	*323*	*298*	*318*
Max.	*390*	*461*	*543*	*593*	*563*	*575*	*705*	*792*	*800*	*869*	*1034*	*1123*	*1034*	*900*	*831*	*707*	*567*	*596*

Less Discharge	151	346	540	734	928	1123	More Discharge

3.4 Favorable Periods ($Q_{AW} \geq Q_D$)

The Lemhi Settlement Agreement states that the minimum stream flow event can occur from May 1st to July 31st. Historically, the LR-MC gauge met the target discharge (Q_T) from late June to early July in WY 2011 and early June in WY 2017 (Table 14A). When adding the supplemental discharge from a minimum stream flow event to the LR-MC gauge discharge, the target discharge would be reached in 9 out of 10 years with the exception being WY 2013. From May 1st to July 31st, the most favorable periods for conducting the minimum stream flow event span from May 26th and June 10th, with target discharge reached in 60% - 80% of the years (Table 14C, Table 15). During abundant runoff years (WY 2009 – 2011, WY 2017), the favorable window extends into late June and mid-July. Thus, in low to moderate precipitation years, the minimum stream flow event should be scheduled between late May and mid-June. In water years with abundant precipitation, the favorable period for executing a minimum stream flow event can be extended until mid-July.

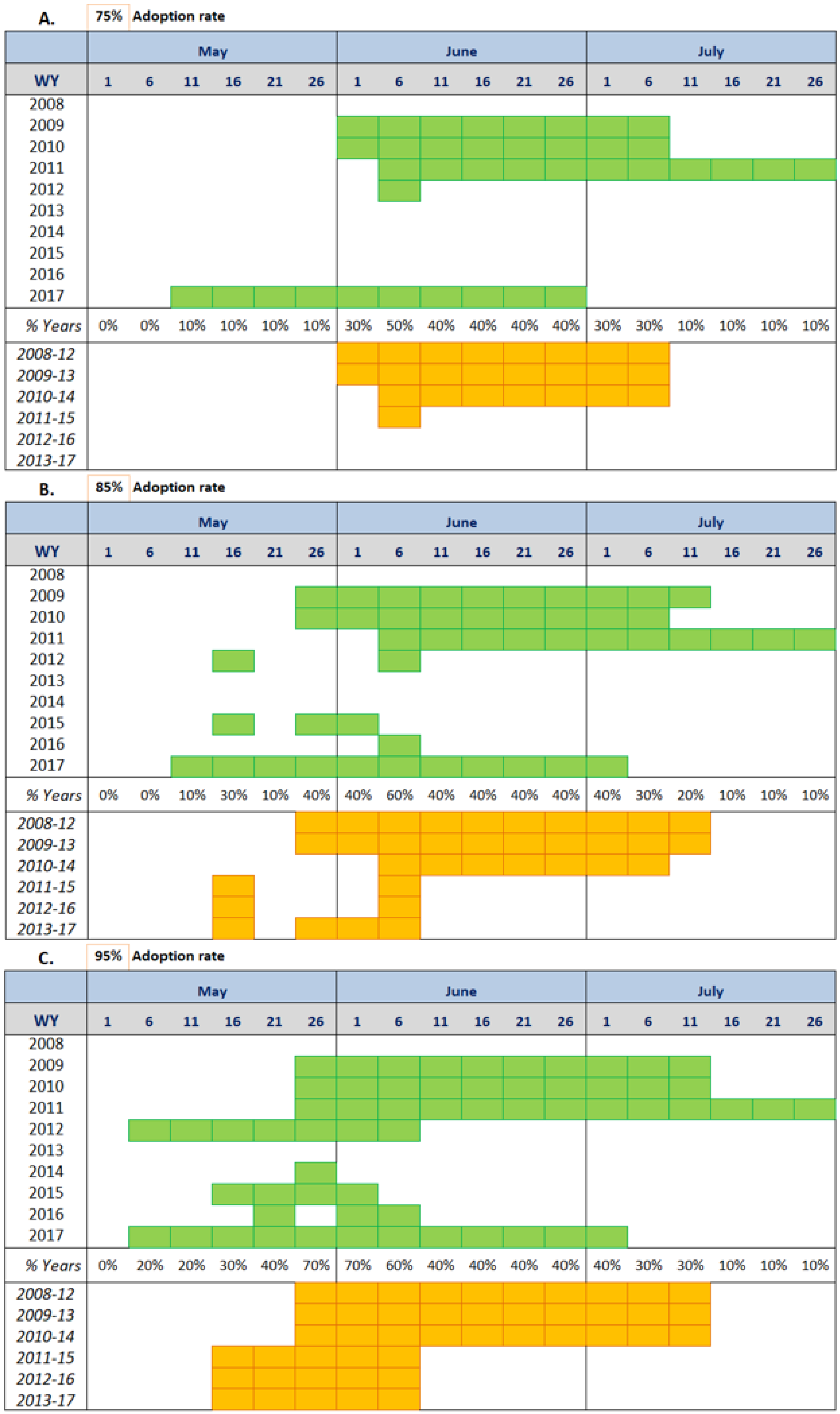
> **Favorable Periods**
>
> In low to moderate precipitation years, the minimum stream flow event should be scheduled between late May and mid-June. In water years with abundant precipitation, the favorable periods for executing a minimum stream flow event can be extended until mid-July.

Concerning meeting the target discharge twice in 5-year criteria, historically this was not achieved at the LR-MC gauge (Table 14A). With a minimum stream flow event, the criteria are met for each rolling 5-year period (Table 15). If minimum flow exercised between May 26th and June 10th the 240 cfs minimum flow is consistently achieved twice in 5-years.

Table 15. Favorable 5-day periods for conducting the three consecutive day minimum stream flow event. Top are the periods that exceed the target discharge. Bottom are periods when the twice in 5-year period criteria is met.

	May						June						July						Achieved
WY	**1**	**6**	**11**	**16**	**21**	**26**	**1**	**6**	**11**	**16**	**21**	**26**	**1**	**6**	**11**	**16**	**21**	**26**	
2008																			
2009																			
2010																			
2011																			
2012																			
2013																			
2014																			
2015																			
2016																			
2017																			
% Years	0%	20%	20%	30%	40%	80%	80%	60%	50%	40%	40%	40%	40%	30%	30%	10%	10%	10%	**90%**
2008-12																			
2009-13																			
2010-14																			
2011-15																			
2012-16																			
2013-17																			
% Years	0%	0%	0%	50%	50%	100%	100%	100%	67%	50%	50%	50%	50%	50%	50%	0%	0%	0%	**100%**

Table 16. Favorable periods if 75% (A), 85% (B), and 95% (C) of total available supplemental flow from pausing LBSMWRs is available. For each, the top and bottom graphs represent 5-day periods when the 420 ft³/s target flow was met per water year and when the twice in 5-year period criteria is met.



***Lemhi Settlement Agreement Adoption Rate**: The above analysis assumes 100% of the eligible irrigators sign the Lemhi Settlement Agreement. If the fewer parties sign the Lemhi Settlement Agreement, then the available supplemental discharge during a minimum stream flow event is decreased and, correspondingly, the frequency and favorable periods for reaching the target discharge, thus limiting management alternatives. As a proxy for fewer parties signing the Agreement, the available supplemental discharge was reduced by 75%, 85%, and 95% (*

Table 16). At a 75% available supplemental discharge, the target discharge is reached in only 5 of the 10 years and the twice in 5-years criteria is not met between 2012 – 2017. For an 85% available supplemental discharge, the target discharge is reached in 6 of the 10 years in early June and the twice in 5-years criteria is met, albeit with a narrow window. Finally, at a 95% available supplemental discharge, the target discharge is reached in 7 of the 10 years from late May to mid-June with a wider window to meet the twice in 5-years criteria. Thus, an 85% available supplemental discharge is the minimum to achieve the benefits of hitting the target discharge and meeting the twice in 5-year criteria. These metrics improve greatly as the available supplemental discharge reaches 95% – 100%.

Limitations and assumptions associated with quantifying the deficit and available supplemental discharge as well as determining the favorable periods include:

- The LR-MC gauge discharge record includes an error in measuring discharge to create a rating curve that can be 7% with an ADCP and 15% with a flow meter. Fitting a rating curve to the measurements provides greater uncertainty as does the extrapolation of the rating curve to discharges beyond what has been measured.
- Gap filling in the LR-MC gauge records used the Lemhi River at Cottom Lane gauge records Plotting the concurrent Cottom Lane and LR-MC gauge data yielded an $R^2 = 0.84$. Applying the MOVE Type II method, the concurrent Cottom Lane gauge and estimated LR-MC discharge yielded an $R^2 = 0.89$. The estimated LR-MC discharge was only used when no historic records were available.
- Catchment inflow from gauged basins includes errors associated with measurement and fitting the rating curve. Ungauged basins that use the NAM model in the LRBM incorporate errors associated with input data (distributed precipitation, temperature from Climate Engine) and the DEM. Catchment inflow for Eightmile Creek and Texas Creek was particularly challenging due to the presence of large spring complexes above the gauges and the lack of water master records to estimate historic diversions.
- The use of high water was not historically recorded by many water masters; thus the high-water withdrawals have been estimated. For diversion without withdrawal records, the diversion rate was assumed to be the full water right throughout the irrigation season and thus is the maximum potential high-water withdrawal. Actual high-water withdrawals may not have been active when based water rights were being diverted. Thus, the method used to estimate high-water right withdrawal could overestimate the available supplemental discharge.
- Travel time within the stream network and pausing the LBSMWR withdrawals are assumed to be instantaneous. Assuming the LR-MC study reaches average velocity is constant in the upper Lemhi River, travel times for 200 and 460 ft^3/s from Leadore to the gauge are approximately 11 to 9 hours, respectively, which is well within a daily time step that the analysis is based.

While these limitations introduce uncertainty into the computations, the estimates are based on the best available data. Monitoring of future minimum streamflow events, high water diversions, and improved gauging as LR-MC will allow for continued refinement of the analysis.

3.5 Downstream Flood Potential

The increasing discharge associated with the proposed Lemhi River minimum stream flow event has a limited potential flooding risk in Lemhi and Salmon, Idaho. The flooding risk was estimated using the flood frequency return period of 50-year and 100-year flow events at USGS Gauges Lemhi River at Lemhi (13305310) and Lemhi River at Lemhi (13305000) (Table 17). Additionally, Rick Sager, the former Water District 74 water master, indicated that localized flooding can occur along the Lemhi River at 2500 ft3/s.

Table 17. Flood frequency analysis for the Lemhi River. All values in ft³/s.

Gauge	USGS Gauge	Period of Record	Frequency Return Period		
			25-yr	50-yr	100-yr
Lemhi River nr Lemhi	13305000	1956-2020	1,986	2,209	2,410
Lemhi River at L5	13305310	1993-2020	3,495	4,007	4,526

Assuming that the minimum stream flow event travels downstream unaltered (e.g., no change in historic diversion operations, no travel attenuation by floodplain storage), then the full potential of pausing all LBSMWR withdrawals (791 ft³/s) would be added to the existing flows at the USGS Gauges. Comparing historic daily maximum discharges plus the minimum stream flow event against the 50-year and 100-year flow events and the 2,500 ft³/s benchmark indicates the potential impacts at the gaging sites.

Flooding risk at Lemhi (USGS Gauge 13305310 Lemhi River near Lemhi (Table 18)):

- 100-year event is not exceeded.
- 50-year was exceeded during June 2009, but this would not occur as the discharge at McFarland Campground was 517 ft³/s, which is already above the target flow. If the target discharge is reached naturally, irrigators would not have been required to pause LBSMWR diversions.
- No localized flooding risk is likely to occur.

Table 18. Flooding potential with the proposed Lemhi River minimum stream flow event comparison for the USGS Gauge 13305000 Lemhi River near Lemhi for WY 2008 - 2017. All values are the maximum observed flow during the 5-day interval with 790 ft³/s added. All values are in ft³/s.

Water Year	April						May						June						July					
	1	6	11	16	21	26	1	6	11	16	21	26	1	6	11	16	21	26	1	6	11	16	21	26
2008	990	990	1205	1103	1063	1144	1059	1080	995	1276	1181	1134	1211	1166	1097	1231	1374	1283	1250	1143	1040	985	971	944
2009	1056	1136	1125	1145	1230	1115	1103	1103	1009	1257	1353	1638	1774	1871	1456	1674	2381	1941	1459	1306	1212	1128	1044	1018
2010	1033	1028	1021	1048	1082	998	948	959	952	1041	1081	1181	1616	1735	1595	1941	1730	1851	1861	1349	1297	1170	1084	1056
2011	1170	1093	1091	1122	1074	1059	1043	1111	1242	1208	1263	1248	1186	1504	1642	1656	2111	1951	1745	1688	1514	1413	1280	1179
2012	1149	1097	1118	1102	1306	1432	1131	1026	1116	1169	1174	1100	1488	1364	1112	1155	1072	1064	993	966	947	951	913	906
2013	1072	1059	1026	1007	993	943	919	941	1030	983	944	968	957	1124	1143	1021	1016	1053	1012	969	927	916	910	924
2014	1044	1104	1110	1048	1072	1053	1026	988	973	1136	1454	1532	1296	1281	1210	1151	1111	1209	1130	1110	1029	974	947	936
2015	1041	1011	1004	984	948	938	966	971	1105	1198	1211	1311	1473	1424	1421	1119	1037	991	975	945	953	950	948	1000
2016	1069	1110	1167	1127	1212	1140	1020	1179	1269	1345	1294	1134	1282	1623	1360	1145	1047	1008	1012	951	951	935	913	906
2017	1126	1147	1126	1122	1111	1095	1173	1448	1646	1340	1416	1469	2091	2141	1733	1640	1735	1524	1353	1272	1153	1096	1013	1014

Localized Flooding: 2500 50-yr event 2209 00-Yr Event 2410

Flooding risk at Salmon (USGS Gauge 13305000 Lemhi River near L-5 (Table 19)):

- 100-year event is not exceeded.
- 50-year event is not exceeded.

- Localized flooding may occur during 3 of the 10 years. However, June 2009 would not occur. During this period the corresponding flow at McFarland Campground is 517 ft^3/s, which is above the target flow so irrigators would not be required to pause LBSMWR.

Based on the discharge frequency analysis, flooding induced by the proposed Lemhi River minimum stream flow event is not a risk at L-5.

Table 19. Flooding potential comparison with the proposed Lemhi River minimum stream flow event for the USGS Gauge 13305310 Lemhi River at L-5 for WY 2008 - 2017. All values are the maximum observed flow during the 5-day interval with 790 ft^3/s added. All values are in ft^3/s.

	April						May						June						July					
Water Year	1	6	11	16	21	26	1	6	11	16	21	26	1	6	11	16	21	26	1	6	11	16	21	26
2008	1024	1024	1283	1144	1093	1163	1038	1018	937	1451	1348	1222	1377	1308	1241	1410	1658	1476	1329	1200	1064	959	922	878
2009	1078	1202	1174	1198	1361	1172	1130	1099	973	1317	1725	2141	2191	2341	1647	2001	2821	2041	1515	1338	1211	1073	963	906
2010	1058	1039	1009	1011	1020	935	876	871	853	956	1191	1319	1941	2241	1991	2611	2301	2461	2221	1575	1385	1185	1018	950
2011	1220	1127	1124	1164	1124	1095	1073	1124	1515	1476	1516	1500	1415	2011	2031	2101	2331	2231	2141	2111	1698	1559	1316	1183
2012	1250	1152	1178	1118	1276	1554	1162	996	1036	1148	1216	1216	1547	1547	1183	1132	1031	1020	920	905	899	915	852	833
2013	1085	1054	997	972	948	844	819	818	904	943	917	930	893	981	1072	1041	1096	1043	976	941	824	820	817	817
2014	1084	1111	1119	1065	1075	1046	958	940	925	1181	1534	1633	1392	1336	1259	1292	1177	1310	1179	1065	968	861	825	819
2015	1078	1046	1007	960	834	828	893	916	1150	1283	1285	1394	1548	1424	1433	1164	1059	908	879	830	839	839	825	917
2016	1152	1223	1294	1219	1278	1196	1030	1239	1342	1529	1471	1265	1356	1618	1423	1223	1012	974	929	858	858	831	818	818
2017	1173	1183	1181	1191	1236	1210	1212	1619	1861	1646	1757	1831	2551	2681	2641	2041	2071	1561	1369	1220	1048	1001	922	908

Localized Flooding: 2500 50-yr event 4007 .00-Yr Event **4526**

4 CONCLUSION

Based on this analysis, a minimum stream flow event is feasible and can maintain and enhance the Steelhead and Chinook rearing habitat in the upper Lemhi River. Based on incipient motion analysis of 4 study reaches, the fine sediments can be flushed, and gravels loosen given discharges of 420 ft^3/s and greater. This is the basis for the target discharge for the Lemhi River minimum stream flow event. Historically, the target flow of 420 ft^3/s at the LR-MC would occur naturally 2 in 10 years with an average discharge deficit of 282 ft3/s from May through July.

Given an absolute pause in high-water diversion withdrawals, the maximum supplemental discharge from the tributaries and Lemhi River diversions is 790.97 ft^3/s. Accounting for the historic catchment inflow and diversion practices in the upper Lemhi Basin, the average available supplemental discharge is 263 ft^3/s. Though the average discharge deficit is greater than the average available supplemental discharge supplemental, favor periods within May – July exist to reach or exceed the target discharge. In low to moderate precipitation years, the minimum stream flow event should be scheduled between late May and mid-June. In water years with abundant precipitation, the favorable periods for executing a minimum stream flow event can be extended until mid-July. Adding the supplemental discharge to the existing discharge at the LR-MC gage, the target discharge can be attained 9 out of the 10 years and the twice in 5-year criteria reached every rolling 5-year period.

The increasing discharge associated with the proposed Lemhi River minimum stream flow event has a limited potential flooding risk in Lemhi and Salmon, Idaho. The flooding risk was estimated using the flood frequency return period of 50-year and 100-year flow events at USGS Gauges Lemhi River at L-5 (13305310) and Lemhi River at Lemhi (13305000). Additionally, Rick Sager, former Water District 74 water master, indicated that localized flooding can occur along the Lemhi River at 2,500 ft^3/s. Comparing historic daily maximum discharges plus the maximum available supplemental discharge (790.97 ft^3/s) there is no flood risk at the Lemhi River at Lemhi gauge and potential localized flooding at the Lemhi River at L-5.

The final step in the minimum stream flow event development is creating the technical and institutional protocol for implementation. Implementation requires i) metrics and indicators to indicate favorable conditions for conducting the minimum stream flow event, ii) organizational infrastructure to coordinate, conduct, and monitor the minimum stream flow event, and iii) a monitoring program to continually assess the impact of the minimum stream flow event on habitat conditions. These are currently under development.

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APPENDIX A. STUDY REACH INCIPIENT MOTION CALCULATIONS

5.1 Ellsworth Study Reach

Table 20. Discharge and accompanying average channel depth, velocity, width, and boundary shear stress for the Ellsworth Study Reach from the UI-CER 2D hydrodynamic model.

UI CER Sim	Discharge [m³/s]	Discharge [ft³/s]	Wetted Cells	Average Depth [m]	Average Velocity [m/s]	Average Width [m]	Average Boundary shear stress [N/m²]
1	1.5	53	6735	0.35	0.62	6.89	5.06
2	3.0	106	7821	0.42	0.76	9.49	6.83
3	5.0	177	8908	0.48	0.91	11.41	8.92
4	7.0	248	10061	0.55	1.01	12.64	10.34
5	9.0	319	10490	0.59	1.09	13.94	11.45
6	11.0	389	11223	0.62	1.16	15.19	12.63
7	12.5	443	11969	0.67	1.17	16.09	12.44
8	14.5	513	12579	0.71	1.19	17.19	13.32
9	16.5	584	13436	0.74	1.22	18.34	13.81
10	17.0	602	13636	0.74	1.25	18.31	13.99

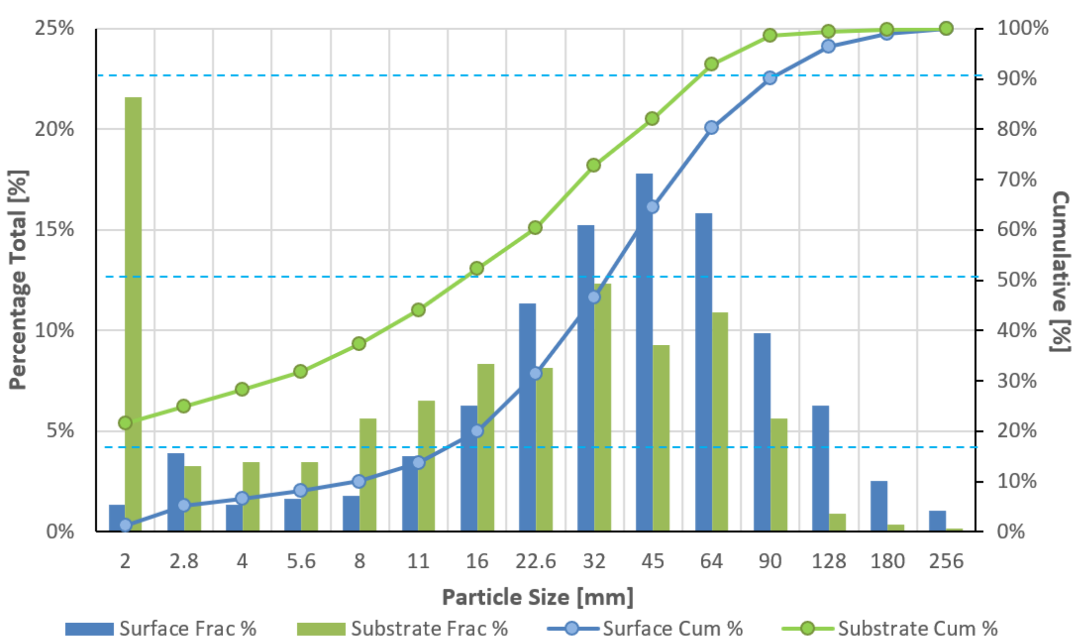

Figure 25. Surface and substrate particle size distribution and cumulative percent finer used in the Ellsworth study reach computations. Dashed lines represent D_{16}, D_{50}, and D_{90}. Source data: UI-CER 2020.

Table 21. For Sim01 to Sim10, percentage surface area of the Ellsworth study reach with boundary shear stresses cable of mobilizing particle sizes ranging from 2 to 256 mm. The 8 mm particle size is important for salmonids. Units for shear stress values (τ_{crit}) are N/m² and discharge values are ft³/s.

A. Percentage Surface Area Mobilized without Shielding

Size [mm]	Critical Shear T*cri	Tcri	Sim01 53	Sim02 106	Sim03 177	Sim04 248	Sim05 319	Sim06 389	Sim07 443	Sim08 513	Sim09 584	Sim10 602	Color Scale
2.0	0.046	1.5	38%	50%	59%	68%	71%	75%	82%	86%	91%	92%	0%
2.8	0.046	2.1	33%	46%	57%	67%	70%	74%	80%	84%	89%	90%	7%
4.0	0.046	2.9	27%	41%	53%	64%	67%	72%	78%	82%	87%	88%	14%
5.6	0.046	4.1	20%	33%	47%	59%	64%	69%	75%	79%	84%	85%	21%
8.0	0.046	5.9	13%	23%	38%	49%	57%	63%	69%	73%	78%	80%	29%
11.3	0.046	8.3	8%	15%	27%	38%	47%	55%	58%	64%	68%	70%	36%
16.0	0.046	11.8	4%	8%	15%	21%	28%	32%	36%	44%	48%	49%	43%
22.6	0.046	16.6	2%	4%	8%	11%	14%	17%	19%	23%	26%	27%	50%
32.0	0.046	23.5	1%	2%	4%	5%	6%	9%	9%	11%	12%	13%	57%
45.3	0.046	33.3	0%	1%	1%	2%	2%	3%	4%	4%	5%	6%	64%
64.0	0.046	47.1	0%	0%	0%	1%	1%	1%	1%	2%	2%	2%	71%
90.5	0.046	66.6	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	79%
128	0.046	94.2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	86%
180	0.046	132.4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	93%
256	0.046	188.3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%

B. Percentage Surface Area Mobilized with Shielding

Size [mm]	Critical Shear T*cri	Tcri	Sim01 53	Sim02 106	Sim03 177	Sim04 248	Sim05 319	Sim06 389	Sim07 443	Sim08 513	Sim09 584	Sim10 602	Color Scale
2.0	0.601	19.4	2%	3%	6%	8%	10%	13%	14%	16%	19%	20%	0%
2.8	0.443	20.1	1%	3%	5%	7%	9%	12%	13%	15%	17%	18%	7%
4.0	0.321	20.7	1%	3%	5%	7%	9%	12%	12%	14%	16%	17%	14%
5.6	0.236	21.4	1%	3%	4%	6%	8%	11%	11%	13%	15%	16%	21%
8.0	0.171	22.1	1%	2%	4%	6%	8%	10%	10%	12%	14%	15%	29%
11.3	0.125	22.8	1%	2%	4%	6%	7%	9%	9%	11%	13%	14%	36%
16.0	0.091	23.6	1%	2%	4%	5%	6%	8%	9%	10%	12%	13%	43%
22.6	0.067	24.4	1%	2%	3%	5%	6%	8%	8%	10%	11%	12%	50%
32.0	0.049	25.2	1%	2%	3%	5%	5%	7%	7%	9%	10%	11%	57%
45.3	0.036	26.0	1%	2%	3%	4%	5%	7%	7%	8%	10%	10%	64%
64.0	0.026	26.9	1%	1%	3%	4%	5%	6%	6%	8%	9%	9%	71%
90.5	0.019	27.7	1%	1%	2%	4%	4%	5%	6%	7%	8%	9%	79%
128	0.014	28.7	1%	1%	2%	3%	4%	5%	5%	6%	8%	8%	86%
180	0.010	29.6	1%	1%	2%	3%	3%	5%	5%	6%	7%	7%	93%
256	0.007	30.6	1%	1%	2%	3%	3%	4%	4%	5%	6%	7%	100%

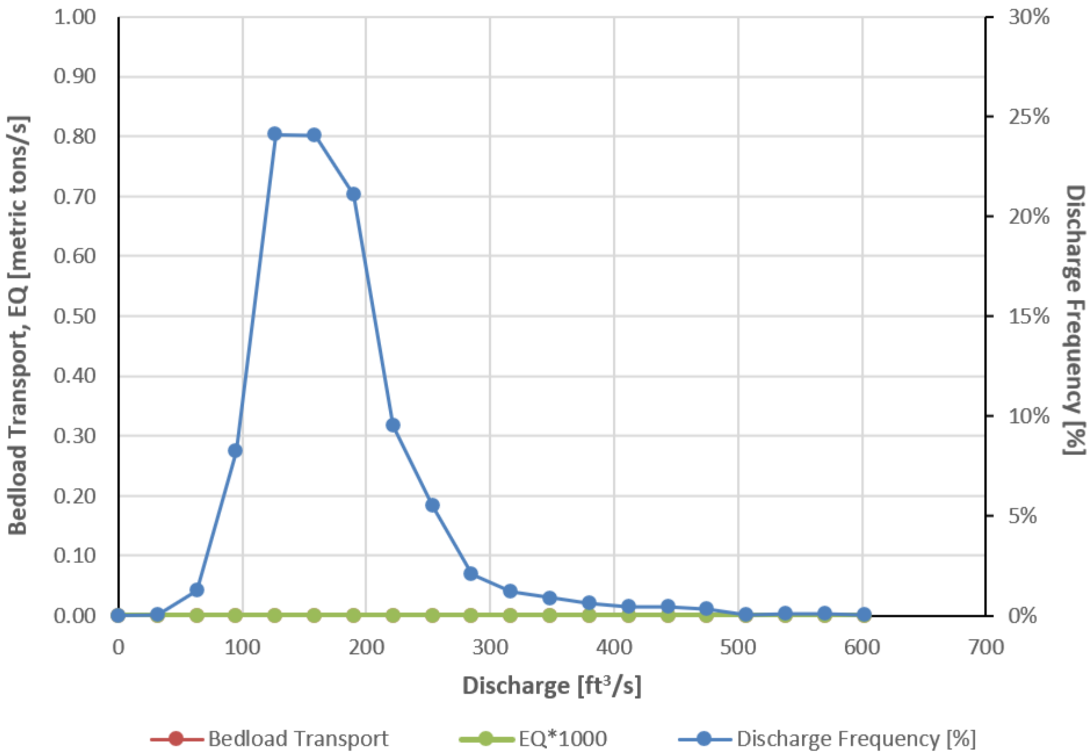

Figure 26. Effective discharge calculated at Ellsworth study reach.

5.2 Cottom Lane Study Reach

Table 22. Discharge and accompanying average channel depth, velocity, width, and boundary shear stress for the Cottom Lane study reach from the UI-CER 2D hydrodynamic model.

UI CER Sim	Discharge [m^3/s]	Discharge [ft^3/s]	Wetted Cells	Average Depth [m]	Average Velocity [m/s]	Average Width [m]	Average Boundary shear stress [N/m^2]
1	1.5	53	17061	0.30	0.57	8.87	4.70
2	3.0	106	19120	0.33	0.67	13.52	5.77
3	5.0	177	22017	0.37	0.79	17.07	7.40
4	7.0	248	26049	0.41	0.82	21.00	7.98
5	9.0	319	28092	0.44	0.90	22.72	9.06
6	11.0	389	32572	0.45	0.94	25.88	10.09
7	12.5	443	36776	0.47	0.96	27.86	10.17
8	14.5	513	42814	0.47	0.96	32.42	10.53
9	16.5	584	48581	0.47	0.96	37.03	10.76
10	17.0	602	52359	0.47	0.95	38.15	10.93

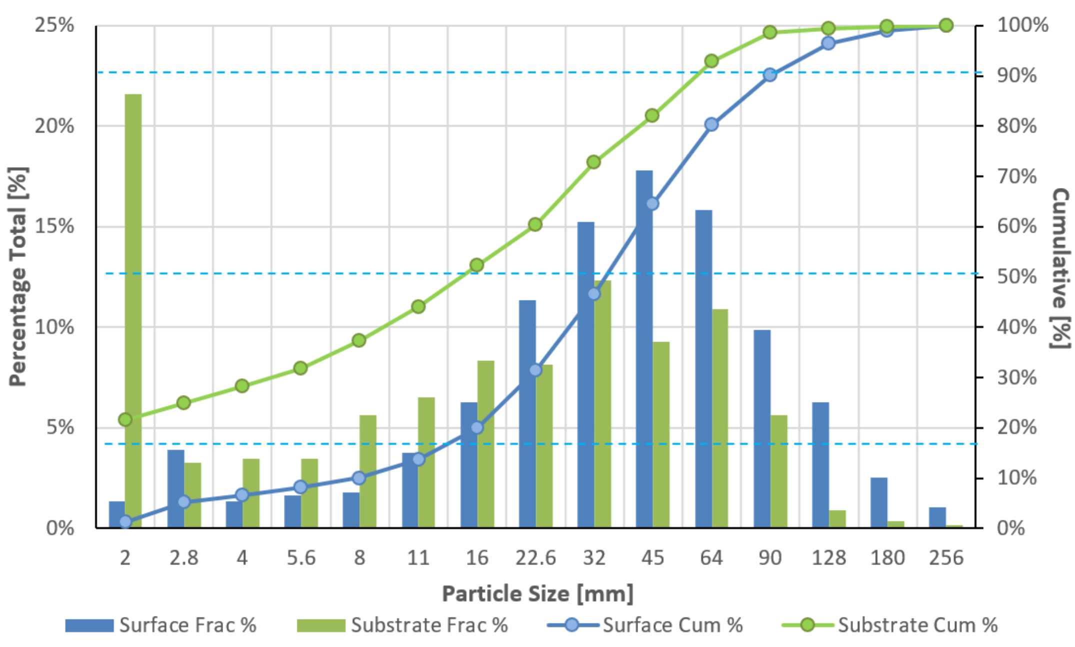

Figure 27. Surface and substrate particle size distribution and cumulative percent finer used in the Cottom Lane study reach computations. Dashed lines represent D_{16}, D_{50}, and D_{90}. Source data: UI-CER 2020.

Table 23. For Sim01 to Sim10, percentage surface area of the Cottom Lane study reach with boundary shear stresses cable of mobilizing particle sizes ranging from 2 to 256 mm. The 8 mm particle size is important for salmonids. Units for shear stress values (τ_{crit}) are N/m^2 and discharge values are ft^3/s.

A. Percentage Surface Area Mobilized without Shielding

Size	Critical Shear		Sim01	Sim02	Sim03	Sim04	Sim05	Sim06	Sim07	Sim08	Sim09	Sim10	Color
[mm]	T*cri	Tcri	53	106	177	248	319	389	443	513	584	602	Scale
2.0	0.046	1.5	23%	28%	35%	41%	45%	51%	58%	65%	73%	79%	0%
2.8	0.046	2.1	20%	25%	33%	39%	43%	49%	56%	63%	69%	74%	7%
4.0	0.046	2.9	17%	22%	30%	36%	40%	46%	53%	59%	65%	70%	14%
5.6	0.046	4.1	13%	18%	26%	32%	36%	42%	48%	54%	59%	63%	21%
8.0	0.046	5.9	9%	13%	20%	26%	31%	37%	41%	47%	52%	55%	29%
11.3	0.046	8.3	6%	9%	14%	19%	24%	31%	34%	39%	43%	46%	36%
16.0	0.046	11.8	3%	5%	8%	11%	15%	21%	23%	28%	32%	35%	43%
22.6	0.046	16.6	1%	2%	4%	5%	8%	12%	14%	18%	21%	24%	50%
32.0	0.046	23.5	1%	1%	2%	2%	3%	5%	6%	8%	10%	12%	57%
45.3	0.046	33.3	0%	0%	0%	1%	1%	2%	2%	3%	4%	5%	64%
64.0	0.046	47.1	0%	0%	0%	0%	0%	0%	1%	1%	2%	2%	71%
90.5	0.046	66.6	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	79%
128	0.046	94.2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	86%
180	0.046	132.4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	93%
256	0.046	188.3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%

B. Percentage Surface Area Mobilized with Shielding

Size	Critical Shear		Sim01	Sim02	Sim03	Sim04	Sim05	Sim06	Sim07	Sim08	Sim09	Sim10	Color
[mm]	T*cri	Tcri	53	106	177	248	319	389	443	513	584	602	Scale
2.0	0.601	19.4	1%	1%	3%	4%	5%	9%	10%	13%	16%	18%	0%
2.8	0.443	20.1	1%	1%	2%	3%	5%	8%	9%	12%	15%	17%	7%
4.0	0.321	20.7	1%	1%	2%	3%	4%	7%	8%	11%	14%	16%	14%
5.6	0.236	21.4	1%	1%	2%	3%	4%	7%	7%	10%	13%	15%	21%
8.0	0.171	22.1	1%	1%	2%	3%	4%	6%	7%	9%	12%	14%	29%
11.3	0.125	22.8	1%	1%	2%	2%	3%	5%	6%	9%	11%	13%	36%
16.0	0.091	23.6	1%	1%	2%	2%	3%	5%	6%	8%	10%	12%	43%
22.6	0.067	24.4	1%	1%	1%	2%	3%	4%	5%	7%	9%	11%	50%
32.0	0.049	25.2	0%	1%	1%	2%	2%	4%	5%	7%	9%	10%	57%
45.3	0.036	26.0	0%	1%	1%	2%	2%	4%	4%	6%	8%	9%	64%
64.0	0.026	26.9	0%	1%	1%	1%	2%	3%	4%	5%	7%	9%	71%
90.5	0.019	27.7	0%	1%	1%	1%	2%	3%	4%	5%	7%	8%	79%
128	0.014	28.7	0%	0%	1%	1%	2%	3%	3%	5%	6%	7%	86%
180	0.010	29.6	0%	0%	1%	1%	1%	2%	3%	4%	5%	7%	93%
256	0.007	30.6	0%	0%	1%	1%	1%	2%	3%	4%	5%	6%	100%

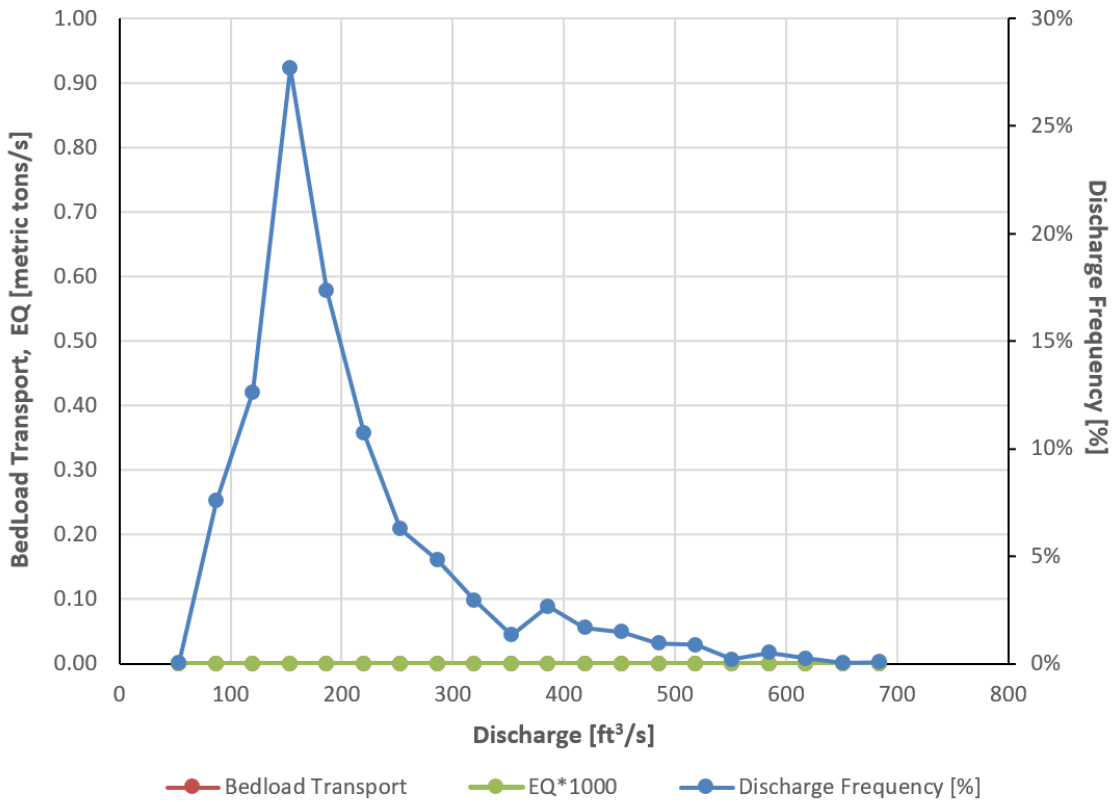

Figure 28. Effective discharge calculated at Cottom Lane study reach.

5.3 L-46 Study Reach

Table 24. Discharge and accompanying average channel depth, velocity, width, and boundary shear stress for the L-46 study reach from the UI-CER 2D hydrodynamic model.

UI CER Sim	Discharge [m³/s]	Discharge [ft³/s]	Wetted Cells	Average Depth [m]	Average Velocity [m/s]	Average Width [m]	Average Boundary shear stress [N/m²]
1	2.0	71	12976	0.41	0.56	8.7	4.2
2	3.5	124	16747	0.47	0.70	10.7	6.0
3	5.5	195	21638	0.48	0.77	14.9	7.1
4	7.5	266	24673	0.49	0.84	18.3	8.1
5	10.0	354	29109	0.50	0.90	22.0	9.3
6	13.0	460	31218	0.54	0.98	24.3	10.5
7	15.5	549	32719	0.58	1.05	25.4	11.3
8	18.5	655	34148	0.65	1.10	26.0	12.3
9	21.5	761	34980	0.70	1.15	26.6	13.1
10	24.0	850	35416	0.74	1.21	26.8	13.6

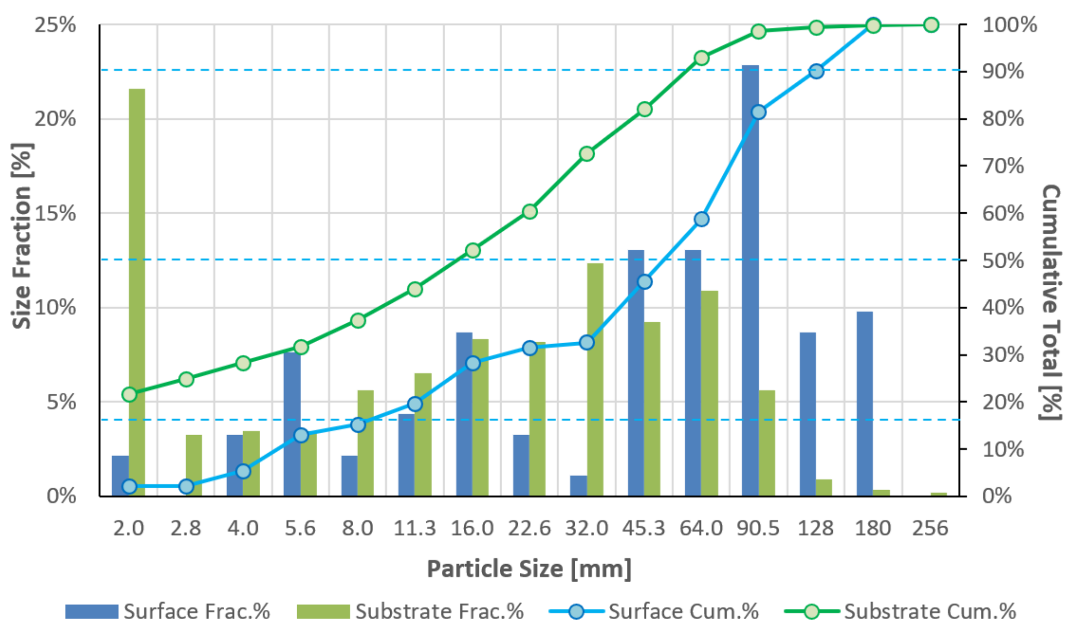

Figure 29. Surface and substrate particle size distribution and cumulative percent finer used in the L-46 study reach computations. Dashed lines represent D_{16}, D_{50}, and D_{90}. Source data: UI-CER 2020.

Table 25. For Sim01 to Sim10, percentage surface area of the L-46 study reach with boundary shear stresses cable of mobilizing particle sizes ranging from 2 to 256 mm. The 8 mm particle size is important for salmonids. Units for shear stress values (τ_{crit}) are N/m² and discharge values are ft³/s.

A. Percentage Surface Area Mobilized without Shielding

Size	Critical Shear		Sim01	Sim02	Sim03	Sim04	Sim05	Sim06	Sim07	Sim08	Sim09	Sim10	Color
[mm]	T*cri	Tcri	71	124	195	266	354	460	549	655	761	850	Scale
2.0	0.046	1.5	23%	36%	49%	58%	70%	77%	81%	86%	88%	89%	0%
2.8	0.046	2.1	20%	33%	46%	54%	66%	73%	78%	83%	85%	86%	7%
4.0	0.046	2.9	16%	28%	41%	50%	61%	68%	73%	78%	81%	83%	14%
5.6	0.046	4.1	11%	23%	35%	43%	55%	62%	67%	72%	75%	76%	21%
8.0	0.046	5.9	8%	16%	26%	34%	45%	53%	58%	62%	65%	67%	29%
11.3	0.046	8.3	5%	11%	18%	25%	35%	43%	49%	53%	55%	58%	36%
16.0	0.046	11.8	3%	6%	11%	15%	22%	29%	34%	39%	41%	44%	43%
22.6	0.046	16.6	2%	3%	6%	8%	13%	17%	21%	25%	27%	30%	50%
32.0	0.046	23.5	1%	2%	3%	4%	7%	9%	11%	13%	15%	17%	57%
45.3	0.046	33.3	0%	1%	1%	2%	3%	3%	4%	6%	7%	7%	64%
64.0	0.046	47.1	0%	0%	1%	1%	1%	1%	1%	2%	2%	3%	71%
90.5	0.046	66.6	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	79%
128	0.046	94.2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	86%
180	0.046	132.4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	93%
256	0.046	188.3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%

B. Percentage Surface Area Mobilized with Shielding

Size	Critical Shear		Sim01	Sim02	Sim03	Sim04	Sim05	Sim06	Sim07	Sim08	Sim09	Sim10	Color
[mm]	T*cri	Tcri	71	124	195	266	354	460	549	655	761	850	Scale
2.0	0.618	20.0	1%	2%	4%	6%	10%	13%	16%	19%	21%	23%	0%
2.8	0.455	20.6	1%	2%	4%	6%	9%	12%	15%	18%	20%	22%	7%
4.0	0.329	21.3	1%	2%	4%	5%	9%	11%	14%	17%	19%	21%	14%
5.6	0.243	22.0	1%	2%	4%	5%	8%	11%	13%	16%	18%	20%	21%
8.0	0.176	22.7	1%	2%	3%	5%	8%	10%	12%	15%	17%	19%	29%
11.3	0.128	23.5	1%	2%	3%	4%	7%	9%	11%	14%	16%	18%	36%
16.0	0.094	24.2	1%	2%	3%	4%	7%	9%	11%	13%	15%	16%	43%
22.6	0.069	25.0	1%	1%	3%	4%	6%	8%	10%	12%	14%	15%	50%
32.0	0.050	25.9	1%	1%	2%	3%	6%	7%	9%	11%	13%	14%	57%
45.3	0.036	26.7	1%	1%	2%	3%	5%	7%	8%	11%	12%	13%	64%
64.0	0.027	27.6	0%	1%	2%	3%	5%	6%	7%	10%	11%	12%	71%
90.5	0.019	28.5	0%	1%	2%	3%	5%	6%	7%	9%	10%	12%	79%
128	0.014	29.4	0%	1%	2%	2%	4%	5%	6%	8%	9%	11%	86%
180	0.010	30.4	0%	1%	2%	2%	4%	5%	6%	7%	9%	10%	93%
256	0.008	31.4	0%	1%	2%	2%	3%	4%	5%	7%	8%	9%	100%

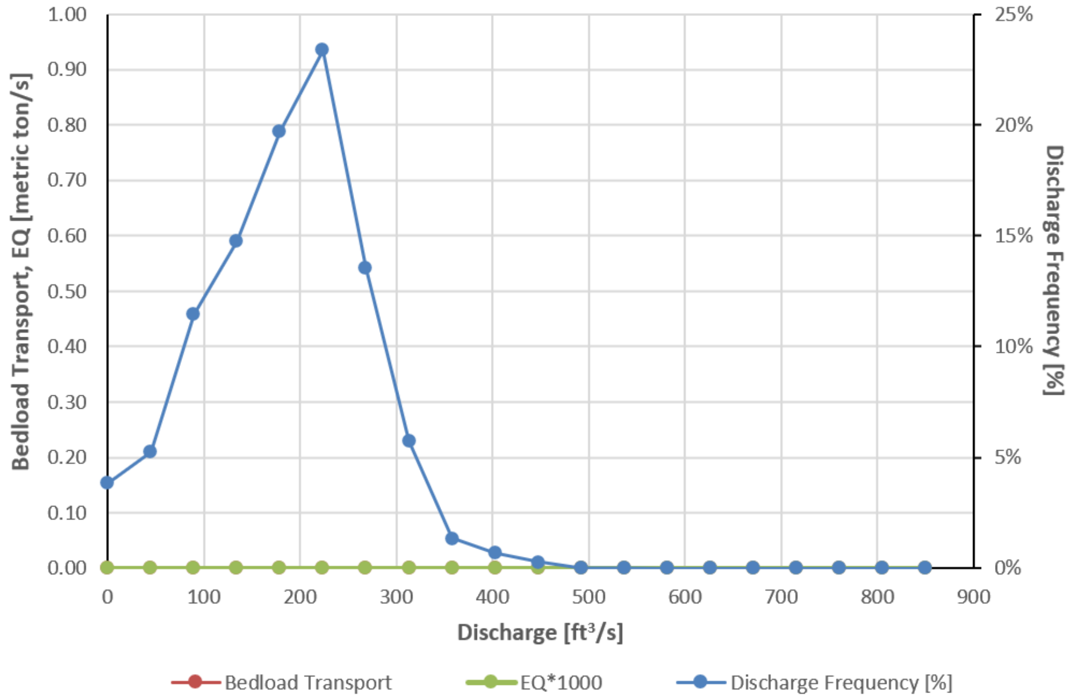

Figure 30. Effective discharge calculated at L-46 study reach.