Operating Recommendations
for
Willwood Dam

June, 2019

Contents

Willwood Dam Operating Recommendations Summary Sheet
June, 2019

Fall Draw-Down and Spring Sediment Mobilization

Activity	Dates*	Fisheries and Willwood Irrigation District Objectives	Flow of Shoshone River at Willwood Dam** (cfs)	Average Turbidity (NTUs)	Maximum 24-Hour Average Turbidity (NTUs)
Fall Draw-Down	Oct. 15th – Oct. 31st	Minimize impacts to adult fish/Lower pool to avoid ice damage to canal gates	< 1,000	150	850
Spring Sediment Mobilization	Mar. 28th – Apr. 12th	Minimize impacts to juvenile and adult fish/Controlled release of accumulated sediment	< 1,000	150	850

*Dates are approximate and may need to be modified based on flow conditions, fishery concerns, irrigation demands, etc.

**Flows are estimates; drawing the pool down is contingent upon flows in the Shoshone River at Willwood Dam and the desired pool elevation since all of the water must be passed through the two currently operational sluice gates. The amount of water that can be passed through the sluice gates decreases as the pool elevation is lowered, thus lower flows allow the pool to be lowered further.

Exceptions: When the turbidity of the Shoshone River upstream of Willwood Dam is above the recommendations, turbidity downstream of the dam should not exceed more than 110% of the upstream value (i.e., if upstream turbidity is 400 NTUs, turbidity downstream should not be more than 440 NTUs).

Notifications: When downstream average turbidity is more than 150 NTUs for more than 3 days during the fall draw down or spring sediment mobilization, downstream turbidity is greater than 850 NTUs for more than 24 hours, or circumstances arise that warrant evaluation, Willwood Irrigation District will notify WDEQ/WQD, WGFD, and other partners to discuss potential options.

November 1st through March 27th, Irrigation Season

Dates*	Fisheries and Willwood Irrigation District Objectives	If Upstream Turbidity is < 100 NTUs	If Upstream Turbidity is > 100 NTUs
Nov. 1st – Dec. 31st	Minimize releases of sediment to avoid disruptions to spawning and egg development/Maintain pool below canal gates to avoid ice damage	10 NTU Increase	10% Increase
Jan. 1st – Mar. 27th	Minimize impacts to juvenile and adult fish/Maintain pool below canal gates to avoid ice damage	10 NTU Increase	10% Increase
April 13th – Oct. 14th	Minimize impacts to juvenile and adult fish/Maintain high pool levels for irrigation diversion, release sediment when possible	10 NTU Increase	10% Increase

*Dates are approximate and may need to be modified based on flow conditions, fishery concerns, irrigation demands, etc.

Exceptions: When it is not possible for the dam to operate within the recommendations and maintain the pool elevation below the bottom of the canal gates or deliver water to its users, Willwood Irrigation District will minimize the downstream turbidity to the greatest extent possible.

Notifications: When downstream turbidity is greater than a 10 NTU or 10% increase for more than one week or circumstances arise that warrant evaluation, Willwood Irrigation District will notify WDEQ/WQD, WGFD, and other partners to discuss potential options.

Evaluating Compliance: Compliance with the recommendations will be determined using the USGS monitoring sites upstream and downstream of Willwood Dam or through the collection of samples by the Willwood Irrigation District above and below Willwood Dam a minimum of three times per week.

Rationale for Operating Recommendations for Willwood Dam
to Protect Downstream Shoshone River Fishery
June, 2019

1.0 SUMMARY

In response to a 2016 sediment release from Willwood Dam, in November 2017 the Wyoming Department of Environmental Quality/Water Quality Division (WDEQ/WQD), in cooperation with the Wyoming Game and Fish Department (WGFD), Willwood Irrigation District (WID), the United States Bureau of Reclamation (USBR), the State Engineers Office (SEO), the Wyoming Water Development Office (WWDO), and other stakeholders, developed preliminary recommendations for the operation of Willwood Dam. The recommendations were revised in June 2019 based on public comments, additional data and information, and lessons learned in implementing the November 2017 operating recommendations. The recommendations are intended to maintain suspended sediment and/or turbidity concentrations in the Shoshone River at levels necessary to meet the river's designated use as a cold water fishery while also allowing the WID to deliver water to its users; provide WID with the necessary flexibility to operate the dam in a manner that will protect existing infrastructure such as lowering the reservoir pool each fall to prevent ice damage to the canal gates; allow for gate maintenance when necessary; and minimize the accumulation of sediment behind Willwood Dam. The recommendations include suspended sediment and/or turbidity values aimed at protecting the naturally reproducing Brown Trout and Mountain Whitefish fisheries downstream from the dam since the early life stages of these fish species may be present in the Shoshone River and are more sensitive than stocked trout. In addition, the recommendations encourage WID to time the release of sediment to those periods when the Shoshone River is transporting higher amounts of flow and sediment, most notably during spring and early summer. The operating recommendations and rationale included in this document represent preliminary suggestions of the group and will be updated as new data and information become available.

2.0 BACKGROUND

Willwood Dam is a 70 foot tall concrete diversion dam that was constructed on the Shoshone River in 1924 by the USBR as part of the Shoshone Irrigation Project. The dam has a weir crest length of 271 feet, a total crest length of 476 feet, and was constructed with three sluiceways, each controlled by 3.6 by 4.5 feet cast iron sluice gates to allow the release of water and sediment (Shih 2009). WID provides water to approximately 11,500 acres and 152 users by diverting water from the dam into the Willwood Canal via two 5.5 by 7 feet gates. Willwood Canal was originally constructed to transport approximately 320 cubic feet per second (cfs) but can deliver flows as high as 400 cfs. The main canal is approximately 25 miles long and there are about 53 miles of distribution laterals (Aqua Engineering 2006). In 1950, as part of a contract between WID and USBR, costs and responsibility for operations, maintenance, and repairs were turned over to WID. USBR retained oversight of the dam with responsibility for conducting inspections and identifying mandatory maintenance that WID must address.

The Shoshone River is classified as 2AB by the Wyoming Department of Environmental Quality and is designated for drinking water, cold water fish, nongame fish, aquatic life other than fish, recreation, wildlife, industry, agriculture, and scenic value uses. The river is classified by the WGFD as a blue ribbon trout fishery, as it historically supported a biomass of more than 600 pounds of trout per mile. The river

sustains naturally reproducing populations of Brown Trout and Mountain Whitefish and Rainbow and Cutthroat Trout are regularly stocked. The fishery is important due to the heavy use of the river by anglers.

2.1 Willwood Work Groups

Following a large sediment release from behind Willwood Dam in the fall of 2016, an executive committee and three work groups were formed to restore aquatic life and habitat that had been damaged by the release and reduce and/or eliminate the need for future releases of accumulated sediment from the dam in amounts and of duration that are harmful to riparian and aquatic species and habitats. The executive committee is comprised of the Administrator of the Water Quality Division at WDEQ, the Chief of Fisheries from WGFD, the Director of WWDO, the President of WID, and the Manager for the Wyoming Area Office of the USBR. The intention of the work groups is also to engage stakeholders in identifying workable solutions to achieve the objectives. Work Group 1 was tasked with coordinating a flushing flow and clean-up to remove the sediment and trash that had been deposited downstream from Willwood Dam during the 2016 event. Work Group 2 was tasked with evaluating alternatives for long-term management of the dam while also protecting downstream aquatic and riparian species and habitats. Work Group 3 was tasked with addressing sources of sediment upstream from Willwood Dam.

Work Group 2 is an interagency group composed of WDEQ/WQD, WGFD, WID, USBR, WWDO, SEO, and others. The group has focused on quantifying the annual sediment load entering and exiting Willwood Dam, quantifying the amount of sediment that has accumulated behind the dam, and understanding the Shoshone River fishery and potential impacts of sediment releases to the fishery. This information is critical to determining how to manage the existing accumulated sediment; how much sediment should be released on an annual basis so that additional sediment does not accumulate behind the dam; and how sediment should be released from the dam while also protecting the downstream fishery. Reviewing the operating criteria for Willwood Dam was one of the first tasks addressed by Work Group 2.

2.2 Operating Criteria and Recommendations for Willwood Dam

Prior to the efforts of Work Group 2, the operating criteria for Willwood Dam were last revised in 2011. The 2011 operating criteria were drafted prior to the completion of a number of maintenance and rehabilitation projects for the dam and identified that the criteria would be in effect between January 1, 2012 and December 31, 2014, or until the first phase of the Willwood Dam rehabilitation project was completed. Since the first phase of the rehabilitation project was completed in October/November of 2016, Work Group 2 developed preliminary operating recommendations in November 2017 to replace the previous operating criteria. The recommendations shown in Tables 1 and 2 were revised based on public comments received, additional data and information, and lessons learned implementing the November 2017 operating recommendations.

The recommendations include suspended sediment and turbidity recommendations as well as the rationale and information used to derive the recommendations. It is understood by all parties that the recommendations are based on a limited amount of information and are to be reviewed and updated as more data and information become available. The operating recommendations take into consideration the following minimum requirements for operation of the dam in order to prevent damage to the existing infrastructure:

Table 1. Recommended average and maximum 24-hour average suspended sediment and turbidity for the Shoshone River downstream from Willwood Dam during the fall drawdown and spring sediment mobilization.

Activity	Dates*	Description of Flow Conditions and Sediment Releases	Flow of the Shoshone River at Willwood Dam** (cfs)	Average Suspended Sediment Concentration (mg/L)	Average Turbidity (NTUs)	Maximum 24-Hour Average Suspended Sediment (mg/L)	Maximum 24-Hour Average Turbidity (NTUs)	Newcombe and Jensen (1996) Severity Index
Fall Draw-Down	Oct. 15th – Oct. 31st	Flows tapering to baseflow; minimize impacts to adult fish	< 1,000	325	150	3,000	850	<9
Spring Sediment Mobilization	Mar. 28th – Apr. 12th	Flows starting to increase; minimize impacts to juvenile and adult fish	< 1,000	325	150	3,000	850	<9

*Dates are approximate and may need to be modified based on flow conditions, fishery concerns, irrigation demands, etc.

**Flows are estimates; drawing the pool down is contingent upon flows in the Shoshone River at Willwood Dam and the desired pool elevation since all of the water must be passed through the two currently operational sluice gates. The amount of water that can be passed through the sluice gates decreases as the pool elevation is lowered, thus lower flows allow the pool to be lowered further.

Exceptions: When the suspended sediment and/or turbidity of the Shoshone River upstream of Willwood Dam is above the recommendations, turbidity downstream of the dam should not exceed 110% of the upstream value (i.e., if upstream turbidity is 400 NTUs, turbidity downstream should not be more than 440 NTUs).

Notifications: When downstream turbidity is greater than 150 NTUs for more than 3 days, downstream turbidity is greater than 850 NTUs for more than 24 hours, or circumstances arise that warrant evaluation, Willwood Irrigation District will notify WDEQ/WQD, WGFD, and other partners to discuss potential options.

Table 2. Recommended turbidity for the Shoshone River downstream from Willwood Dam during the Irrigation Season (April 13th through October 14th) and between November 1st and March 27th.

Activity	Dates*	Description of Flow Conditions and Sediment Releases	Mean Discharge (cfs) of Shoshone River at Cody Gage 2007-2016	If Upstream Turbidity is < 100 NTUs	If Upstream Turbidity is > 100 NTUs
Winter Operations	Nov. 1st – Dec. 31st	Baseflow conditions; minimize releases of sediment to avoid disruptions to spawning and egg development	390	10 NTU Increase	10% Increase
	Jan. 1st – Mar. 27th	Baseflow conditions; minimize impacts to juvenile and adult fish	370	10 NTU Increase	10% Increase
Irrigation Season	Apr. 13th – Oct. 14th	Peak flows; minimize sediment accumulation and impacts to juvenile and adult fish	1990	10 NTU Increase	10% Increase

*Dates are approximate and may need to be modified based on flow conditions, fishery concerns, irrigation demands, etc.

Exceptions: When it is not possible for the dam to operate within the recommendations and also maintain the pool elevation below the bottom of the canal gates, the Willwood Irrigation District will minimize the turbidity downstream to the best of their ability without raising the pool elevation above the bottom of the canal gates or deliver waters to its users, Willwood Irrigation District will minimize the downstream turbidity to the greatest extent possible.

Notifications: When downstream turbidity is greater than a 10 NTU or 10% increase for more than one week, Willwood Irrigation District will notify the WDEQ/WQD, WGFD, and other partners to discuss potential options.

Evaluating Compliance: Compliance with the recommendations will be determined using the USGS monitoring sites upstream and downstream of Willwood Dam or by through the collection of samples by the Willwood Irrigation District above and below Willwood Dam a minimum of three times per week.

1. Following the irrigation season and prior to the onset of freezing air temperatures, the pool elevation must be brought below the canal gates to prevent water from freezing within the canal gates and potentially damaging the canal infrastructure.

2. During freezing temperatures, WID must be able to pass all river water through the sluice gates so that water does not overtop the dam and damage the dam apron.

In addition to the above requirements, it is important to note that southernmost sluice gate has been silted in for a number of years, and therefore, the dam cannot be operated as it was originally intended. The center sluice gate was also inoperable for a number of years. A 2009 WWDC report stated that the three sluice gates are over 80 years old and should be replaced in the near future to avoid a potential failure at the dam (Engineering Associates 2009). In 2014, an airlifting operation loosened sediment to regain operation of the center sluice gate that has since provided WID with two functioning sluice gates. Around that time, divers surveyed the two operable gates and dam face and provided graphical data to facilitate proceeding with a suitable design. WID subsequently determined that the sluice gates in place did not require removal and full replacement at that time, but noted that the gates will likely need to be replaced at some point in the future. Instead, the District acquired WWDC Level III construction funding for a 2016 rehabilitation project that replaced the sluice gate stems and gate operators as well as the two canal gates, stems, and operators. The structures housing the operators were replaced, and the gates were automated with remote control and monitoring made possible from the District office via radio based telemetry.

3.0 TURBIDITY, SUSPENDED SEDIMENT, AND BEDLOAD

Turbidity is a measure of the transparency of a liquid and is an expression of the amount of light that is scattered by material in the water when a light is shined through the sample. The higher the intensity of scattered light, the higher the turbidity. Materials that causes water to be turbid include clay, silt, finely divided inorganic and organic matter, algae, soluble colored organic compounds, and other microscopic organisms (USGS 2017). Wyoming's current turbidity criteria, as outlined in the Water Quality Rules and Regulations, Chapter 1, Wyoming Surface Water Quality Standards, provide the following limits: a 10 NTU increase to Class 1 and 2 cold water fisheries and/or drinking water supplies and a 15 NTU increase to Class 1 and 2 warm water or nongame fisheries (WDEQ 2018). Wyoming's current surface water quality standards also include narrative criteria for settleable solids (Chapter 1, Section 15) and floating and suspended solids (Chapter 1, Section 16) that were first included in Wyoming's surface water quality standards in similar form in 1968 (WDPH 1968).

Although Wyoming has historically adopted United States Environmental Protection Agency (USEPA) recommended water quality criteria to protect designated uses, Wyoming's turbidity criteria do not appear to be derived from USEPA's recommendations. USEPA first released recommendations for turbidity in the 1976 Quality Criteria for Water document, known as the Red Book, that were left unchanged in the 1986 Quality Criteria for Water document, known as the Gold Book. The criteria were intended to protect aquatic life and recommended that "settleable and suspended solids should not reduce the depth of compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life" (USEPA 1986).

As of 2019, EPA's current recommendations for "solids suspended and turbidity" reference the 1986 Gold Book and thus updated national recommendations do not currently exist. In an effort to evaluate the current science associated with suspended and bedded sediments, in August, 2003, EPA developed a draft document describing potential approaches to developing water quality criteria for suspended and bedded sediments (SABS; USEPA 2003). USEPA defines SABS as particulate organic and inorganic matter that suspend in or are carried by the water and/or accumulate in a loose, unconsolidated form on the bottom of natural water bodies. SABS is intended to include clean sediment, suspended sediment, total suspended solids, bedload, turbidity, or in common terms, dirt, soils, or eroded materials (USEPA 2017).

USEPA (2003) identified SABS as a unique water quality problem compared to toxic chemicals in that suspended solids and bedded sediments (including the organic fraction) occur naturally in water bodies and are essential to the ecological function of a water body. SABS consist of suspended solids and sediment, nutrients, detritus, and other organic matter which are critical to the health of a water body. Suspended solids and sediment in natural quantities also replenish sediment bedloads and create valuable micro-habitats such as pools and sand bars.

SABS in excessive amounts, however, constitute a major ecosystem stressor that can cause deleterious impacts to aquatic communities. Likewise, sediment starvation caused by dams is also a problem in some ecosystems and can also cause significant changes to aquatic communities. Changes to SABS can alter the structure and function of communities of aquatic plants, algae, benthic invertebrates, as well as fish. Impacts to biota may be directly from SABS acting on organisms or indirectly from SABS through alteration of physical habitat that then cause impacts to biota (USEPA 2003).

USEPA's 2003 review evaluates ways to potentially develop recommended SABS water quality criteria and concludes that the severity of impacts to changes in SABS quantity and timing is a function of many factors that include sediment concentration, duration, particle size, life history stage, temperature, and physical and chemical characteristics of the particles, which are generally site-specific. As such, it can easily be concluded that criteria for SABS should likely be site-specific. Therefore, to avoid deleterious impacts to aquatic communities on the Shoshone River, management of suspended and bedded sediments should, to the greatest extent possible, maintain natural or background levels and timing of SABS that are unique to the Shoshone River. As such, recommendations for the operation of Willwood Dam should follow the natural sediment movement within the Shoshone River. To achieve this, it is recommended that the dam be operated based on the turbidity or suspended sediment concentrations of the Shoshone River upstream of Willwood Dam and that the dam maximize the movement of sediment during higher flows of the Shoshone River that extend from approximately April 1st to August 1st (Figure 1).

The exception to this recommendation would be in circumstances where the dam must be actively managed to fulfill operating requirements such as when the pool elevation must be lowered and maintained below the canal gates in the fall and winter to prevent freezing and damage to infrastructure. During this period, the primary focus of management will be on allowing the dam to lower the pool elevation below the canal gates while minimizing deleterious effects to the downstream naturally reproducing Brown Trout and Mountain Whitefish fisheries. The naturally reproducing fishery is the primary focus because the early life stages of these fish species may be present in the Shoshone River and are likely to be more sensitive than stocked adult salmonids. In addition, the population trends for these species are not directly influenced by stocking and can therefore be used to evaluate the impacts of

various management activities. As such, the proposed recommendations are also intended to be protective of the fishery as a whole.

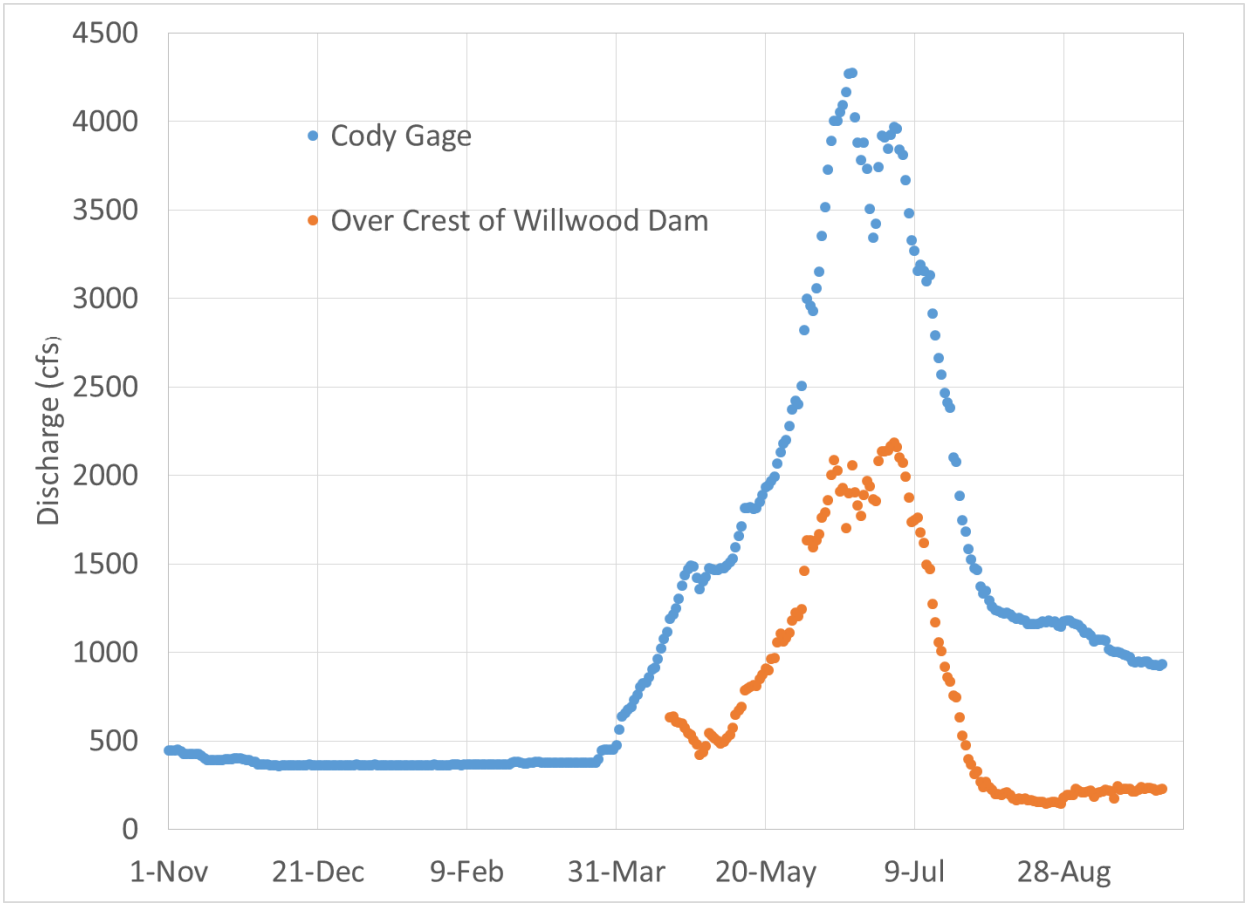

Figure 1. Mean daily discharge of the Shoshone River at the Cody gage below Buffalo Bill Reservoir, September 2007-February 2016, and Over the Crest of Willwood Dam, 2008-2017.

4.0 RECOMMENDATIONS TO PROTECT SHOSHONE RIVER FISHERY

Based on information provided by the Wyoming Game and Fish Department, Brown Trout and Mountain Whitefish naturally reproduce in the Shoshone River downstream of Willwood Dam, while Cutthroat Trout and Rainbow Trout are regularly stocked. To minimize the impacts of SABS to the Brown Trout and Mountain Whitefish fisheries, the non-irrigation season recommendations are intended to protect spawning, juvenile, and adult Brown Trout and Mountain Whitefish, depending on the life stages most likely to be present at a given time.

The main impacts of SABS to fish include behavioral effects such as changes in the natural movements and migrations of fish; inability to see prey or feed normally that can reduce growth rates and reduce resistance to disease; and physiological effects such as decreases in gill functioning or gill clogging. In addition, changes in the quantity and timing of SABS may lead to sediment deposition during critical periods that can result in the loss of spawning habitat along with burial and suffocation of eggs and larvae. Severity of damage is related to the dose of exposure, the duration and exposure, as well as the size and angularity of the particles involved (USEPA 2003).

The sensitive spawning and development periods for Brown Trout and Mountain Whitefish are defined as follows:

Approximate Spawning Period:	October 15th - November 15th
Peak Spawning Period:	November 1st
Egg Development to Hatch:	October 15th - January 1st
Hatch to Juveniles:	January 1st - Unknown

4.1 Recommendations for Fall Pool Draw-Down (October 15th – October 31st)

During irrigation diversions, the reservoir pool elevation at Willwood Dam typically needs to be at or above the dam crest. Irrigation diversions normally conclude each fall around mid-October. Prior to winter and freezing temperatures, the pool elevation behind Willwood Dam must be lowered below the bottom of the canal gates (elevation of approximately 4,487 feet) to prevent ice damage to the gates. It is also critical in the winter that water not be allowed to flow over the top of the dam, as freezing may potentially damage the dam apron. In order to draw the pool elevation down, the entire flow of the river must be passed through the two currently operational sluice gates. The two operational sluice gates can accommodate approximately 500 cfs of flow each when the pool elevation is below the bottom of the canal gates (see Appendix A for gate rating tables), thus, in order to draw the pool down, flows of the Shoshone River at Willwood Dam must be less than approximately 1,000 cfs. The following recommendations are therefore intended to recognize these critical operational requirements for Willwood Dam while minimizing potential impacts to the downstream fishery.

Brown Trout and Mountain Whitefish use interstitial spaces at the bottom of streams to lay or broadcast their eggs. Even thin coverings of fine particles can lead to egg mortality or reduce successful egg hatch and emergence of larvae. As such, the reproductive success of these fish is dependent on limiting the deposition of sediment prior to spawning and also minimizing the deposition of sediment following spawning.

Since Brown Trout and Mountain Whitefish spawn between approximately October 15th and November 15th, it is recommended that the Willwood Irrigation District lower the water level below the canal gates prior to winter between approximately October 15th and October 31st to minimize sediment deposition on potential spawning gravels and eggs during the latter half of the spawning period. During the October 15th to October 31st period, the primary objective would be to operate the sluice gates to lower the pool elevation below the canal gates while also avoiding lethal effects to adult and juvenile Brown Trout and Mountain Whitefish by maintaining average suspended sediment concentrations below 325 mg/L and average turbidity levels below 150 NTUs. It is also recommended that the pool elevation be lowered over the entire 17-day period and that any potential sediment be released over the entire period, rather than in one large pulse, so as to increase the likelihood that the released sediment remains in suspension and is not deposited on spawning habitat. In circumstances where the dam must release concentrations of suspended sediment higher than 325 mg/L and 150 NTUs while lowering the pool elevation, 24-hour average concentrations should be kept below 3,000 mg/L suspended sediment and 850 NTUs turbidity. Exceptions to these recommendations are circumstances where the upstream turbidity exceeds the recommendations; in such cases, the turbidity downstream should not exceed approximately 110% of the upstream concentration.

The 325 mg/L 17-day average and 3,000 mg/L 24-hour average suspended sediment thresholds were selected based on preventing lethal and paralethal effects to juvenile and adult trout using an equation (see equation below) derived from a meta-analysis of fish responses to sediment in streams and estuaries conducted by Newcombe and Jensen (1996). The equations relate the response of fish, represented by a severity index, to different suspended sediment concentrations and durations of exposure (see Table 3 for severity index). The thresholds selected for the Shoshone River downstream of Willwood Dam are intended to maintain a severity index less than nine during the 17-day and 24-hour periods, respectively, for juvenile and adult salmonids in circumstances where particles sizes range from approximately 0.5 – 250 µm (Newcomb and Jensen 1996). The equation for juveniles and adults was selected because it was derived using studies on Mountain Whitefish and Brown Trout and best represents the species and life stages in the Shoshone River downstream of Willwood Dam (see Newcombe and Jensen 1996, Table 2).

$$Severity\ Index = 1.0642 + 0.6068\ (\ln x) + 0.7384\ (\ln y)$$

x = Exposure duration (hours)
y = Sediment Concentration of Predominate Suspended Sediment Size (mg/L)

The equation also seemed applicable based on the expected size of suspended sediment particles on the Shoshone River downstream of Willwood Dam. Suspended sediment particles are expected to be dominated by very fine sand or smaller (<250 µm) based on data collected during the October 2016, sediment release and analyzed by the University of Wyoming (McElroy 2017). McElroy (2017) estimated that the October 2016, event at Willwood Dam liberated 96,000 cubic yards of very fine sand (62-125 µm in diameter) and silt (2.0 – 62 µm in diameter) from behind the dam and that median grain sizes of deposited sediment were approximately 130 µm very fine sand near the dam and 30 µm coarse silt near Byron, WY.

The 150 NTU average and 850 NTU 24-hour average turbidity thresholds are based on the relationship between total suspended solids and turbidity from 21 paired samples collected by WDEQ/WQD at a monitoring site immediately downstream from Willwood Dam (Figure 2). Even though the data set is small, it is recommended that the relationship between total suspended solids and turbidity be used to derive turbidity recommendations for Willwood Dam because turbidity can be measured in real-time and can be used to make immediate changes to dam operations. Turbidity has been shown to have a moderate to strong relationship to suspended sediment concentrations at some sites (Ellison et al., 2013). The correlation between turbidity and suspended sediment concentration is variable based on the particular suspended sediment characteristics of a stream (sediment size, shape, and refractive index all influence turbidity) and therefore the data has been limited to only those collected immediately downstream from Willwood Dam.

It is important to note that the Newcombe and Jensen (1996) relationships are based on suspended sediment concentration, not total suspended solids. The relationship between total suspended solids and turbidity will be used until paired suspended sediment concentration and turbidity data have been collected on the Shoshone River. The current recommendations are considered sufficiently protective, however, because total suspended solids typically underrepresents the amount of suspended sediment. Suspended sediment concentrations can be as much as two times total suspended sediment concentrations (Ellison et al., 2013). It is also not recommended that a correction factor be applied to the suspended sediment concentrations from Newcombe and Jensen (1996) at this time since such correction

factors should be derived using site-specific data and these data do not currently exist. In addition, the current turbidity recommendations are lower than the values would be if a correction factor were applied to the total suspended solids data; this can be considered a margin of safety for the current recommendations.

The suspended sediment and total suspended solids concentrations are likely to be similar in the data set used to develop the relationship because it is expected that the majority of the suspended sediment is comprised of fine material rather than sand or larger particles that can increase differences between total suspended solids and suspended sediment concentrations. This is based in part on the fact that the dam was not likely to be sluicing and mobilizing larger particles at the low total suspended solids (maximum value 173 mg/L) and turbidity values (maximum value 134 NTUs) used to establish the relationship between total suspended solids and turbidity. As noted above, this relationship and the recommendations will be updated as more data becomes available.

There were also concerns about the possibility of the sediment that is released during the fall draw-down may settle into potential spawning habitat. To determine whether this is likely, the particles sizes that would likely be mobilized at a given stream slope and depth were evaluated by calculating the critical shear stress and using the relationship between critical shear stress and grain diameter included in Rosgen (2006). Using the average stream slope of 0.003 for the Shoshone River as identified by McElroy (2017), mean depths between 0.5 feet and 1.5 feet that would be expected during the October 15th to October 31st period in potential spawning habitat, and the unit weight of water (62.4 lbs/ft^3), critical shear stress ranged from 0.09 to 0.28 lbs/ft^2 . Median grain size at these shear stress values were then calculated using the power trendline from Leopold, Wolman, and Miller (1964) that were included in Rosgen (2006). Grain diameter ranged from 6.6 mm at 0.5 feet depth to 20.8 mm at 1.5 feet deep, the smallest of which are gravels. Since the majority of sediment that is likely to be released from Willwood Dam is much, much smaller than gravel during the 17-day period, it is unlikely that this material will be deposited.

Table 3. Severity Index from Newcombe and Jensen (1996).

Effect Category	Severity	Description of Effect
Nil	0	No behavior effects
Behavioral	1	Alarm reaction
	2	Abandonment of cover
	3	Avoidance response
Sublethal	4	Short-term reduction in feeding rates; short-term reduction in feeding success
	5	Minor physiological stress; increase in rate of coughing; increased respiration rate
	6	Moderate physiological stress
	7	Moderate habitat degradation; impaired homing
	8	Indications of major physiological stress; long-term reduction in feeding rate; long-term reduction in feeding success; poor condition
Lethal and Paralethal	9	Reduced growth rate; delayed hatching; reduced fish density
	10	0-20% mortality; increased predation; moderate to severe habitat degradation
	11	>20-40% mortality
	12	>40-60% mortality
	13	>60-80% mortality
	14	>80-100% mortality

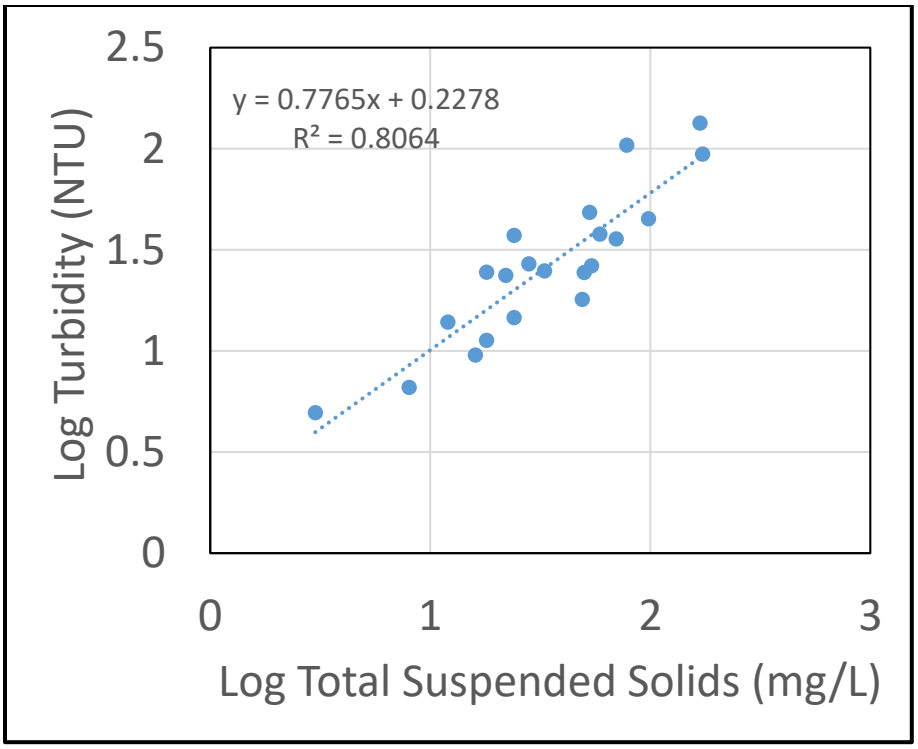

Figure 2. Relationship between total suspended solids and turbidity based on 21 paired samples collected downstream from Willwood Dam in 2008, 2009, and 2016-2018.

It is recognized that there may need to be exceptions to the recommendations in circumstances where the suspended sediment and/or turbidity of the Shoshone River upstream of Willwood Dam are above these thresholds. In these circumstances, the dam should be operated in a manner to maintain similar levels (within 10%) of suspended sediment and/or turbidity in the Shoshone River downstream of Willwood Dam. In such cases, measurements upstream of the dam can be multiplied by 1.1 to derive the recommended water quality downstream of the dam (e.g., 400 NTUs upstream of the dam x 1.1 = 440 NTUs downstream of the dam). It is recommended that the Willwood Irrigation District notify WDEQ/WQD, WGFD, and other partners when downstream turbidity is greater than 150 NTUs for more than 3 days, downstream turbidity is greater than 850 NTUs for more than 24 hours, or in other circumstances that warrant evaluation. Stakeholders will then discuss what potential actions could be taken by WID to mitigate potential impacts to the downstream fishery while also protecting the infrastructure of the dam.

4.2 Recommendations for Spawning and Egg Development Period (November 1st – December 31st)

Once Willwood Dam has lowered the pool elevation between approximately October 15th to October 31st to achieve the winter levels necessary to avoid damage to the dam and canal infrastructure during freezing conditions, the operation of the dam will focus on maintaining the pool elevation below the bottom of the canal gates.

To minimize potential impacts during this sensitive spawning period, it is recommended that the dam minimize the release of suspended sediment between November 1st and December 31st, as this time period represents the later part of the spawning period and the critical egg development period for Brown

Trout and Mountain Whitefish. In addition, the November 1st to December 31st timeframe also occurs as the Shoshone River is approaching baseflow conditions, when flows from Buffalo Bill Reservoir are less than 450 cfs (Figure 1). During this period, the Shoshone River does not have the flows necessary to move substantial amounts of suspended sediment.

As such, the recommended suspended sediment and turbidity levels between November 1st and December 31st are intended to minimize the deposition of sediment in potential spawning gravels that may impede spawning, smother redds, or prevent eggs from developing and hatching normally. Therefore, in order to minimize potential impacts to spawning and reproduction and to recognize that the Shoshone River has minimal flows during this period to keep sediment suspended, it is recommended that turbidity not increase more than 10 NTUs below the dam when the turbidity upstream of the dam is less than 100 NTUs and that the turbidity not increase more than 10% when the turbidity upstream of the dam is greater than 100 NTUs. Exceptions to these recommendations are in circumstances where the pool elevation would need to be raised above the bottom of the canal gates in order to maintain the turbidity recommendations. In these cases, the dam should minimize the downstream turbidity to the greatest extent possible without raising the pool elevation above the bottom of the canal gates. It is recommended that Willwood Irrigation District notify WDEQ/WQD, WGFD, and other partners when turbidity is greater than the 10 NTU or 10% NTU increase for more than one week, downstream turbidity is greater than 850 NTUs for more than 24 hours, or in other circumstances that warrant evaluation. In such cases, Willwood Irrigation District and partners will discuss whether it may be appropriate to raise the pool elevation above the bottom of the canal gates or what other actions may be taken that will best protect the dam as well as the fishery.

4.3 Recommendations for Hatch and Juvenile Fish Development (January 1st – March 27th)

During the January 1st to March 27th period, WID should continue to maintain the pool elevation below the bottom of the canal gates. That said, during the end of this period, air temperatures may not be below freezing, and there may be additional flexibility for the dam to raise the pool elevation above the bottom of the canal gates if it becomes too difficult to maintain the recommended turbidity levels downstream of the dam.

Brown Trout and Mountain Whitefish eggs will hatch in the Shoshone River around early January during baseflow conditions. Baseflow conditions continue until approximately March 31st, at which times flows begin to increase due to snowmelt runoff and increased flows from Buffalo Bill Reservoir. To minimize potential impacts to small, sensitive fish, it is recommended that the dam not increase turbidity more than 10 NTUs when the turbidity upstream of the dam is less than 100 NTUs and not more than 110% of the upstream turbidity when the turbidity upstream is greater than 100 NTUs. Exceptions to these recommendations are in circumstances where the dam would need to raise the pool level above the bottom of the canal gates in order to maintain the downstream turbidity recommendations. In these cases, the dam should minimize the downstream turbidity to the greatest extent possible without raising the pool elevation above the bottom of the canal gates. It is recommended that Willwood Irrigation District notify WDEQ/WQD, WGFD, and other partners when turbidity is greater than the 10 NTU or 10% NTU increase for more than one week, downstream turbidity is greater than 850 NTUs for more than 24 hours, or in other circumstances that warrant evaluation. In such cases, Willwood Irrigation District and partners will discuss whether it may be appropriate to raise the pool elevation above the bottom of the canal gates.

4.4 Recommendations for Spring Sediment Mobilization (March 28th – April 12th)

Since it may not be possible for Willwood Dam to mobilize sufficient sediment during the irrigation season and it is recognized that accumulating sediment behind the dam is not desirable in the long-term, it is recommended that WID employ an approximately 16 day spring sediment mobilization event from approximately March 28th through April 12th, prior to the start of the irrigation season, in order to mobilize sediment that has accumulated behind the dam. This period coincides with the rising limb of the hydrograph, as flows on the Shoshone River start to increase as a result of snowmelt and releases from Buffalo Bill Reservoir have started to increase (Figure 1). The increased flows should help minimize deposition of sediment in the Shoshone River downstream of Willwood Dam. It is also recognized that the March 28th to April 12th timeframe may need to be modified to accommodate flow conditions of the Shoshone River and potential releases of water from Buffalo Bill Reservoir, particularly given that the lower the flows in the Shoshone River at Willwood Dam, the more flexibility WID has to lower the pool elevation and mobilize sediment.

Since the spring sediment mobilization will occur following winter operations when the pool elevation is below the bottom of the canal gates (4,487 feet) and sediment that has accumulated behind Willwood Dam is most effectively mobilized when accumulated sediment is exposed, WID will likely need to lower the pool elevation below 4,487 feet. In order to lower the pool elevation below this point, all of the water must be passed through the two currently operational sluice gates. Since each sluice gate can accommodate approximately 500 cfs of flow at 4,487 feet (see Appendix A for sluice gate rating table), in order to draw the pool down, flows of the Shoshone River at Willwood Dam must be less than approximately 1,000 cfs. Moreover, since the amount of flow that can be released through the sluice gates decreases as the pool elevation is lowered, the lower the flow at Willwood Dam, the more control WID will have to lower the pool elevation and expose and mobilize deposited sediment. For example, at a pool elevation of 4,477 feet, or approximately 10 feet below the bottom of the canal gates, approximately 800 cfs can be passed through the canal gates, whereas at a pool elevation of 4,470 feet, approximately 670 cfs can be passed through the canal gates.

During the spring sediment mobilization, it is recommended that the dam maintain average suspended sediment concentrations of approximately 325 mg/L and turbidity of approximately 150 NTUs and that 24-hour average concentrations not exceed 3,000 mg/L suspended sediment and 850 NTUs. Exceptions to these recommendations are in circumstances where the upstream concentrations are higher than the recommendations. In such cases, the downstream concentrations should not exceed more than 110% of the upstream concentrations. It is recommended that the Willwood Irrigation District notify WDEQ/WQD, WGFD, and other partners when downstream turbidity is greater than 150 NTUs for more than 3 days, downstream turbidity is greater than 850 NTUs for more than 24 hours, or in other circumstances that warrant evaluation.

4.5 Recommendations for Irrigation Season (April 13th – October 15th)

The period of April 13 through October 15 generally has both the highest and lowest flows in the Shoshone River downstream of Willwood Dam. Depending on water supply conditions, spring releases from Buffalo Bill Reservoir often result in flows of more than 2,000 cfs passing Willwood Dam, with peak flows occurring between late May to early July (Figure 1). However, after runoff, between August 1st and October 15th, flows downstream of Willwood Dam typically range from 70 to 100 cfs.

The main goal for the Willwood Irrigation District during the irrigation season is to deliver water to its users. Typically the reservoir pool is maintained at or above the crest of Willwood Dam to provide the necessary depth for diversion of water through the canal gates and into the canal. However, whenever river flows are high enough to meet minimum gate opening requirements and pool elevations are high enough for desired canal diversions, the District can release flow through the operational sluice gates and potentially pass sediment. So although Willwood Irrigation District has not previously received operating recommendations during the irrigation season, it is recommended that the District actively pass sediment during this period, as conditions allow. Movement of sediment during this period is important because it corresponds to the highest flows below Willwood Dam; it is when the Shoshone River is likely to be transporting the most sediment due to higher flows; and mobilizing sediment during the 16-day spring sediment mobilization period alone is likely insufficient to pass the annual sediment load of the Shoshone River. Even with this recommendation, it is recognized that having the sluice gates open while the reservoir pool is up will help keep the sediment immediately upstream of the gates moving, but will not likely pass the heavier sediments that settle far upstream where the river velocity decreases upon entering the reservoir pool. Due to the potential limitations of opportunistically moving sediment during the irrigation season, it is also recommended that WID evaluate their ability to mobilize sediment and determine whether mechanical suspension of sediment may help achieve the desired goal of passing the annual sediment load.

Since potential impacts to the fishery will be minimized if suspended sediment concentrations downstream of the dam are similar to those concentrations upstream of the dam, it is recommended that WID try to maintain turbidity levels downstream of the dam at levels similar to those upstream of the dam. This recommendation is dependent on sufficient flows within the Shoshone River downstream of Willwood Dam to maintain sediment in suspension (i.e., Willwood Irrigation District should not attempt to mobilize sediment if sediment will be deposited downstream). To minimize potential impacts to small, sensitive fish, it is recommended that the dam not increase turbidity more than 10 NTUs when the turbidity upstream of the dam is less than 100 NTUs and not more than 110% of the upstream turbidity when the turbidity upstream is greater than 100 NTUs. Exceptions to these recommendations are in circumstances where the dam would not be able to provide water to its users. In these cases, the dam should minimize the downstream turbidity to the greatest extent possible. It is recommended that Willwood Irrigation District notify WDEQ/WQD, WGFD, and other partners when turbidity is greater than the 10 NTU or 10% NTU increase for more than one week or in other circumstances that warrant evaluation.

5.0 FUTURE RECOMMENDATIONS

In the fall of 2017, WDEQ/WQD contracted with USGS to obtain paired “real-time” turbidity, flow, and suspended sediment concentration data upstream and downstream of Willwood Dam. Turbidity data is currently available and once sufficient suspended sediment and flow data has been collected, the gages will report “real-time” flow and suspended sediment concentrations. These data should help to identify potential deficiencies in the existing total suspended solids and turbidity relationship used to derive the recommendations included above and potentially update these recommendations.

Newcombe and Jensen (1996) noted that the severity index, particularly at low suspended sediment concentrations, has limitations, and that many gaps remain, particularly for the youngest age-classes (eggs through young juveniles). The paper also highlighted that each developmental stage should be identified

and treated separately for the purpose of developing uniquely age-specific and size-specific dose-response profiles, and thresholds for sublethal and lethal effects must be known more precisely. In addition, the authors noted that finding useable data was a challenge and they rejected many studies because they were too vague about sediment concentration, duration of exposure, or the exact nature of the ill effect. Because Model 1, used to develop the recommendations above, does not include impacts to eggs, it is recommended that additional work be conducted to determine recommended suspended sediment concentrations to minimize negative impacts to eggs. Additional data on the impacts of suspended sediment concentrations to the Shoshone River fishery is warranted. This information could be used to evaluate the relationships presented by Newcombe and Jensen on the Shoshone River.

It would also be beneficial to identify Brown Trout and Mountain Whitefish spawning habitat in the Shoshone River so that these areas can be monitored for potential impacts from management recommendations. It would also be helpful to determine more specifically the timing and emergence of Brown Trout and Mountain Whitefish in the Shoshone River so that the fall drawdown recommendations could be refined.

In addition, since the thresholds at which suspended sediment become deposited sediments is highly dependent on flow, additional work should be conducted to develop recommendations for the Shoshone River downstream of Willwood Dam that included a more detailed evaluation of the flow regime and its influence on SABS.

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APPENDIX A. Discharge estimates for one sluice gate per pool elevation at Willwood Dam. For reference: crest of the dam is 4,499.5 feet, bottom of canal gates is 4,487 feet, bottom of power outlet is 4,477 feet and bottom of sluice gates is 4,454 feet.

DISCHARGE FOR ONE GATE
CUBIC FEET PER SECOND

ELEVATIONS ARE 4400 PLUS — Date: January 31, 1971

Gate Open, Ft.	WATER SURFACE ELEVATIONS											
	70.0	71.0	72.0	73.0	74.0	75.0	76.0	77.0	78.0	79.0	80.0	81.0
0.1	10	11	11	11	12	12	12	13	13	13	14	14
.2	21	22	23	23	24	25	25	26	27	27	28	28
.3	32	33	34	35	36	37	38	39	40	41	42	43
.4	43	44	46	47	48	50	51	52	53	55	56	57
.5	53	55	57	59	60	62	64	65	67	68	70	71
.6	64	66	68	70	72	74	76	78	80	82	84	85
.7	74	77	79	82	84	87	89	91	93	95	97	99
.8	85	88	90	93	96	99	101	104	106	108	111	113
.9	95	98	101	104	107	110	113	116	119	122	124	127
1.0	105	108	112	116	119	122	125	128	131	134	137	140
.1	115	119	123	126	130	134	137	141	144	147	150	153
.2	124	129	133	137	141	145	149	153	156	160	163	166
.3	134	139	143	148	152	156	160	164	168	172	176	179
.4	143	148	153	158	163	167	171	176	180	184	188	192
.5	153	158	163	168	173	178	182	187	191	196	200	204
.6	162	167	173	178	183	188	193	198	203	207	212	216
.7	170	176	182	188	193	199	204	209	214	219	223	228
.8	179	185	191	197	203	209	214	219	224	230	234	239
.9	187	194	200	206	212	218	224	230	235	240	245	250
2.0	195	202	209	215	222	228	234	240	245	251	256	261
.1	203	211	218	224	231	237	243	249	255	261	267	272
.2	211	219	226	233	239	246	252	259	265	271	277	282
.3	219	226	234	241	248	255	261	268	274	280	286	292
.4	226	234	242	249	256	263	270	277	283	290	296	302
.5	233	241	249	257	264	272	279	286	292	299	305	312
.6	240	248	257	264	272	280	287	294	301	308	314	321
.7	247	255	264	272	280	287	295	302	309	316	323	330
.8	253	262	271	279	287	295	303	310	317	324	331	338
.9	259	268	277	286	294	302	310	318	325	332	340	347
3.0	265	275	284	292	301	309	317	325	333	340	348	355
.1	271	281	290	299	308	316	324	332	340	348	355	363
.2	277	287	296	305	314	323	331	339	347	355	363	370
.3	282	292	302	311	320	329	338	346	354	362	370	377
.4	288	298	308	317	326	335	344	352	361	369	377	385
.5	293	303	313	323	332	341	350	359	367	375	383	391
.6	298	308	318	328	338	347	356	365	373	382	390	398
.7	302	313	323	333	343	352	362	371	379	388	396	404
.8	307	318	328	338	348	358	367	376	385	394	402	411
.9	312	323	333	343	353	363	372	382	391	399	408	417
4.0	316	327	338	348	358	368	378	387	396	405	414	422
.1	320	331	342	353	363	373	383	392	401	410	419	428
.2	324	335	346	357	368	378	387	397	406	415	424	433
.3	328	339	351	361	372	382	392	402	411	420	430	438
.4	332	343	355	366	376	386	397	406	416	425	434	443
.5	335	347	358	370	380	391	401	411	420	430	439	448

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DISCHARGE FOR ONE GATE
CUBIC FEET PER SECOND

ELEVATIONS ARE 4400 PLUS. Date: January 31, 1971

Gate Open. Ft.	WATER SURFACE ELEVATIONS											
	82.0	83.0	84.0	85.0	86.0	87.0	88.0	89.0	90.0	91.0	92.0	93.0
0.1	14	15	15	15	15	16	16	16	16	17	17	17
.2	29	29	30	31	31	32	32	33	33	34	34	35
.3	44	44	45	46	47	48	48	49	50	51	51	52
.4	58	59	60	61	63	64	65	66	67	68	69	69
.5	73	74	75	77	78	79	81	82	83	84	86	87
.6	87	89	90	92	94	95	97	98	100	101	103	104
.7	101	103	105	107	109	111	112	114	116	118	119	121
.8	115	118	120	122	124	126	128	130	132	134	136	138
.9	129	132	134	137	139	141	143	146	148	150	152	154
1.0	143	146	148	151	154	156	159	161	164	166	168	171
.1	156	159	162	165	168	171	174	176	179	182	184	187
.2	170	173	176	179	182	185	188	191	194	197	200	203
.3	183	186	190	193	196	200	203	206	209	212	215	218
.4	196	199	203	207	210	214	217	220	224	227	230	233
.5	208	212	216	220	224	227	231	235	238	242	245	248
.6	220	225	229	233	237	241	245	248	252	256	259	263
.7	232	237	241	245	250	254	258	262	266	270	273	277
.8	244	249	253	258	262	267	271	275	279	283	287	291
.9	255	260	265	270	274	279	283	288	292	296	301	305
2.0	267	272	277	282	286	291	296	300	305	309	314	318
.1	277	283	288	293	296	303	308	313	317	322	327	331
.2	288	293	299	304	309	314	319	324	329	334	339	344
.3	293	304	309	315	320	326	331	336	341	346	351	356
.4	308	314	320	325	331	336	342	347	352	358	363	368
.5	318	324	330	336	341	347	353	358	363	369	374	379
.6	327	333	339	346	351	357	363	369	374	380	385	390
.7	336	343	349	355	361	367	373	379	385	390	396	401
.8	345	352	358	364	371	377	383	389	395	400	406	412
.9	354	360	367	373	380	386	392	398	404	410	416	422
3.0	362	369	375	382	389	395	401	408	414	420	426	432
.1	370	377	384	391	397	404	410	417	423	429	435	441
.2	377	385	392	399	406	412	419	425	432	438	444	450
.3	385	392	399	407	414	420	427	434	440	447	453	459
.4	392	400	407	414	421	428	435	442	449	455	462	468
.5	399	407	414	422	429	436	443	450	457	463	470	476
.6	406	414	421	429	436	443	450	457	464	471	478	484
.7	412	420	428	436	443	450	458	465	472	479	485	492
.8	419	427	435	442	450	457	465	472	479	486	493	500
.9	425	433	441	449	456	464	471	479	486	493	500	507
4.0	431	439	447	455	463	470	478	485	493	500	507	514
.1	436	445	453	461	469	476	484	492	499	506	513	521
.2	442	450	458	467	475	482	490	498	505	513	520	527
.3	447	456	464	472	480	488	496	504	511	519	526	533
.4	452	461	469	478	486	494	502	509	517	525	532	540
.5	457	466	474	483	491	499	507	515	523	530	538	545

DISCHARGE FOR ONE GATE
CUBIC FEET PER SECOND

ELEVATIONS ARE 4400 PLUS — Date: January 31, 1971

Gate Open.	WATER SURFACE ELEVATIONS											
Ft.	94.0	95.0	96.0	97.0	98.0	99.0	99.5*	00.0**	01.0	02.0	03.0	04.0
0.1	17	18	18	18	18	18	19	19	19	19	19	20
.2	35	36	36	36	37	37	38	38	38	39	39	39
.3	53	53	54	55	56	57	57	57	58	58	59	59
.4	70	71	72	73	74	75	75	76	77	78	78	79
.5	88	89	90	91	92	94	94	95	96	97	98	99
.6	105	107	108	109	111	112	113	113	115	116	117	118
.7	123	124	126	127	129	130	131	132	133	135	136	138
.8	140	141	143	145	147	148	149	150	152	154	155	157
.9	156	158	160	162	164	166	167	168	170	172	174	176
1.0	173	175	177	180	182	184	185	186	188	190	192	194
.1	189	192	194	197	199	201	203	204	206	208	211	213
.2	205	208	211	213	216	218	220	221	223	226	228	231
.3	221	224	227	230	232	235	237	238	241	243	246	249
.4	237	240	243	246	249	252	253	255	257	260	263	266
.5	252	255	258	261	265	268	269	271	274	277	280	283
.6	267	270	273	277	280	284	285	287	290	293	296	300
.7	281	285	288	292	295	299	301	302	306	309	313	316
.8	295	299	303	307	310	314	316	318	321	325	328	332
.9	309	313	317	321	325	329	331	332	336	340	344	347
2.0	322	327	331	335	339	343	345	347	351	355	359	362
.1	335	340	344	348	353	357	359	361	365	369	373	377
.2	348	353	357	362	366	370	373	375	379	383	387	391
.3	361	365	370	375	379	384	386	388	392	397	401	405
.4	373	377	382	387	392	396	399	401	406	410	414	419
.5	384	389	394	399	404	409	411	414	418	423	427	432
.6	396	401	406	411	416	421	423	426	431	435	440	445
.7	407	412	417	422	427	433	435	438	442	447	452	457
.8	417	423	428	433	439	444	446	449	454	459	464	469
.9	427	433	439	444	449	455	457	460	465	470	475	481
3.0	437	443	449	454	460	465	468	471	476	481	487	492
.1	447	453	459	464	470	476	478	481	487	492	497	503
.2	456	462	468	474	480	486	488	491	497	502	508	513
.3	465	472	478	484	489	495	498	501	507	512	518	523
.4	474	480	487	493	499	504	507	510	516	522	527	533
.5	483	489	495	501	507	513	516	519	525	531	537	542
.6	491	497	504	510	516	522	525	528	534	540	546	552
.7	499	505	512	518	524	530	534	537	543	549	555	561
.8	506	513	519	526	532	539	542	545	551	557	563	569
.9	514	520	527	534	540	546	550	553	559	565	571	577
4.0	521	528	534	541	547	554	557	560	567	573	579	585
.1	528	534	541	548	555	561	565	568	574	581	587	593
.2	534	541	548	555	562	568	572	575	581	588	594	600
.3	541	548	555	562	568	575	578	582	588	595	601	608
.4	547	554	561	568	575	582	585	588	595	602	608	615
.5	553	560	567	574	581	588	591	595	602	608	615	621

* Crest of Willwood Dam. ** Elevations are 4500 plus.

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