RECLAMATION

Managing Water in the West

Pilot Study of Reservoir Sustainability–Black Canyon Reservoir

Research and Development Office

Science and Technology Program
Final Report ST-2019-8235-01

Black Canyon Reservoir, looking upstream near Emmett, ID (Sea16)

U.S. Department of the Interior
Bureau of Reclamation
Research and Development Office

September, 2019

Mission Statements

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14. ABSTRACT *(Maximum 200 words)*
Black Canyon Reservoir, located on the Payette River in western Idaho, has lost approximately 64% of its original capacity from sedimentation. We evaluate potential sediment management options to increase reservoir sustainability. Sediment accumulation has been documented through reservoir surveys executed in 1936, 1971, 1983 and 2016 with accumulation rates averaging 300 acre-ft per year. Based on these rates, reservoir operations will be impacted as early as 2047. Empirical data suggests that drawdown (lowering the reservoir pool elevation) and pressure (maintaining reservoir pool elevation) are the most appropriate sediment management options for Black Canyon Dam. Analysis shows that drawdown flushing is the most effective means of removing deposited sediments and restoring reservoir capacity. However, drawdown flushing is limited by the undersized low-level gates. Pressure flushing will extend the life of the useful life of the reservoir. However, annual sediment load is greater than the volume removed; thus, the reservoir will eventually fill. Both flushing operations release sediment laden water to the downstream ecosystem, potentially damaging ecological communities. More analysis is necessary to determine method, timing, duration, and frequency of the necessary flushing operations to sustain Black Canyon Reservoir. Additional studies must consider the impacts to the downstream biological community.

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Pilot Study for Reservoir Sustainability – Black Canyon

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Executive Summary

The Black Canyon Dam, constructed in 1924 on the Payette River, has lost approximately 64% of its original storage capacity due to sedimentation. The average sedimentation rate of about 300 acre-feet per year has resulted of a loss of about 30,000 acre-feet of storage from the initial 44,700 acre-feet of storage when the dam was originally established. At this rate of sedimentation, it is estimated that the penstocks will be buried between 2050 and 2073, and the reservoir will be completely full of sediment between 2062 and 2112, if no change in dam management occurs. To assist in addressing the loss of reservoir function due to sedimentation, this report has been developed to evaluate the ability of Black Canyon dam to pass stored sediment downstream to extend the functional reservoir life while maintaining dam benefits and avoiding negative impacts to downstream ecosystems.

Current dam operations include an annual pressure flush between the months of October and March, on average. However, no data collection accompanies these flushes giving us no additional information on the sediment volumes passed downstream nor the impacts on the river's ecosystem. In addition, two drawdown flushes were conducted for turbine maintenance in 1984 and 2013. Both drawdown flushes occurred during low flow and resulted in temporary negative impacts to the downstream river environment signifying the ability to pass large volumes of sediment downstream and/or the resiliency of the downstream ecosystem to large sediment loads.

Empirical data and previous studies suggest that either drawdown or pressure flushing is likely to be the most suitable sediment management option. Flushing capacity is limited by the irrigation season and withdrawals as well as the capacity of the low-level sluicegates. The low-level gates have a maximum capacity of approximately 2,200 cfs. As peak flows can be as high as 10,000 cfs, drawdown flushing at Black Canyon Dam is only possible during low flow season. Additional low-level gates would need to be constructed to flush during high flows, when the downstream ecosystem is most resilient to high sediment loads.

The predominant concern regarding flushing activities during low flow season is the environmental consequences of the downstream bed, bank, and water quality conditions. Excessive sediment concentrations can threaten the downstream ecological community as biota can die from suffocation, lack of light, and other complications. Any sediment management plan intended to move large volumes of sediment from the reservoir must take into consideration impacts of the concentration, volume, duration, and timing of sediments flushed from the reservoir to downstream ecosystems. The primary sediment management plans examined in this report include drawdown flushing and pressure flushing.

Regardless of flushing method utilized, the system must be understood better to develop a more specific and optimized plan so that unacceptable downstream ecosystem impacts may be avoided. Further planning and research should focus on establishing specific impacts to be avoided, the conditions that produce

negative impacts, and the operational parameters which would pass maximum sediments through the dam with the minimum disturbance to the downstream habitat. Better documentation of future sluicing or flushing activities is necessary for meaningful planning and research development.

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Introduction

Benefits may be enjoyed through applying and improving a preliminary framework for developing reservoir sustainability by planning and evaluating reservoir sediment management options such as drawdown flushing and pressure flushing at dam sites. This study applies the existing framework for reservoir sustainability to Black Canyon Dam which has lost approximately 64% of its original 45,000 acre-feet of storage to sedimentation as of 2016. Through the framework of Reclamation’s Reservoir Sustainability Guidelines (Kimbrel et al., 2014), we evaluate potential sediment management options to assist in developing an operational plan which deals with reservoir sediments in the most acceptable manner to increase reservoir sustainability.

Black Canyon Dam and Reservoir are located on the Payette River in west-central Idaho approximately 4.2 miles northeast of the town of Emmett, Figure 1. Black Canyon Dam diverts water to the Payette Division of the Boise Project and its 8,000 kilowatt powerplant provides power to the Boise, Owyhee, and Minidoka Projects. Since its closure in 1924, Black Canyon Reservoir has also been a popular recreation site for anglers and boaters.

The watershed area is 2,725 square miles, has an annual average precipitation of 40 inches, and an average elevation of 5,600 feet. Land use in the watershed above the reservoir is approximately 33% forested and 4% agriculture and is primarily designated as US Forest Service land. Overall, land use has changed relatively little over the nearly 100 years since the dam was put in place, which likely results in a relatively uniform sedimentation rate over this time. This has resulted in a loss of approximately 30,000 acre-feet, or about 64% of the original 45,000 acre-feet of water storage, by 2016 due to sedimentation.

Previous studies have shown that significant amounts of the sediment may be passed downstream through flushing sediment from the reservoir and could potentially slow the rate or even reverse the trend of storage loss in the reservoir pool. The purpose of this report is to evaluate the ability of Black Canyon Dam to pass stored sediment downstream while fulfilling its purpose of being able to divert water for beneficial uses and generate power. However, if too much sediment is released at the wrong time severe negative impacts on downstream biological communities may occur. This happened in 2013, when the reservoir was drained, and sediment transported downstream to prepare to install a new turbine. The potential biological impacts from releasing large amounts of sediments is beyond the scope of this report but should be investigated before a plan to carry out drawdown and/or pressure flushing operations are finalized.

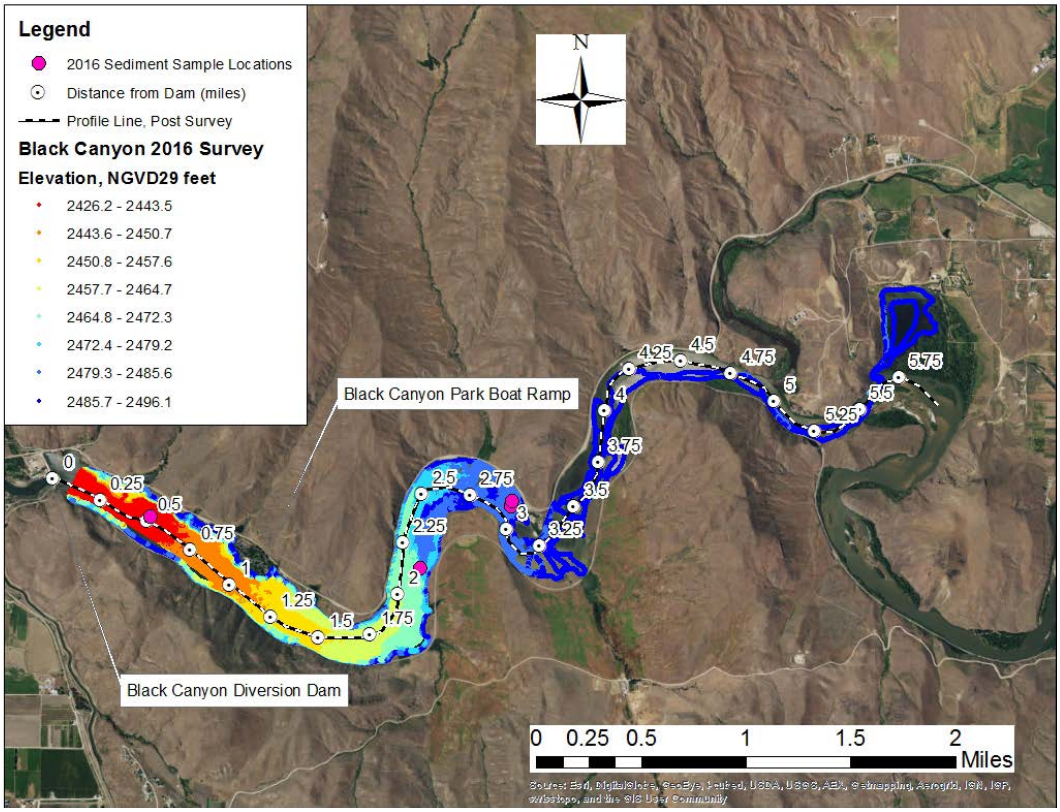

Figure 1. Black Canyon Reservoir and surrounding area. Colored trace represents survey depths collected in May 2016, and the dashed line represents the estimated low flow channel alignment (Kimbrel S. , 2016).

Magnitude of the Sediment Problem

Black Canyon has been identified as a high-risk reservoir due to sedimentation. Dam operation and benefits are likely to be negatively impacted due to its decreasing capacity, high incoming mean annual sediment load and mean annual runoff. This means that sediments are likely to impact operations and accelerate degradation of key structures, such as penstocks and turbines, in the near future. It has been documented that the outlet works already pass measurable amounts of sediments which increases wear on dam components (Kimbrel, Collins, & Randle, 2014). In addition to accelerating degradation of key dam infrastructure, storage capacity at the dam has been reduced which impacts its ability to provide reliable water diversions for irrigation.

Reservoir Surveys

To help document the rate of sedimentation, reservoir surveys were conducted in 1924, when the dam was constructed, 1936, 1971, 1983 and 2016 (Kimbrel S. , 2016). The surveys executed in 1936, 1971, and 1983 were conducted by surveying along range lines and cross sections. Sixty-eight range lines were surveyed in 1936, 49 were surveyed in 1971, and 12 were surveyed in 1983. In 2016, a reconnaissance-level bathymetric survey was performed with an ODOM MB1 multibeam echosounder and Hemisphere real-time kinematic global positioning system (RTK-GPS). Longitudinal profiles for the 1936, 1971, and 2016 surveys are included in Figure 2. Capacity vs elevation curves are presented in Figure 3. The reservoir originally had a water storage capacity of 44,700 acre-feet at full pool in 1924 (Reclamation, 2016), but sedimentation reduced the storage capacity to 29,800 acre-feet by 1971 (Reclamation, 1973), and by 2016 had reduced the usable capacity to 15,300 acre-feet, 34% of the original capacity (Table 1 and Figure 4). The sediment accumulation rate has been relatively stable, except for the period between 1971 and 1983 where the sedimentation rate was significantly smaller. The rate from 1983 to 2016 was 347 acre-ft/yr, which was actually slightly higher than the long term average of 310 acre-ft/yr. The reservoir is expected to continue filling at approximately these same rates into the near future.

Table 1. Reservoir capacity and sediment accumulation based on previous survey data.

Year	Capacity (1,000 acre-ft)	Total Sediment Accumulation (1,000 acre-ft)	Sediment Accumulation Rate (acre-ft / yr)
1924	44.9	0.0	0
1936	40.8	4.0	336
1971	29.8	15.0	314
1983	27.7	17.2	178
2016	15.3	29.5	374

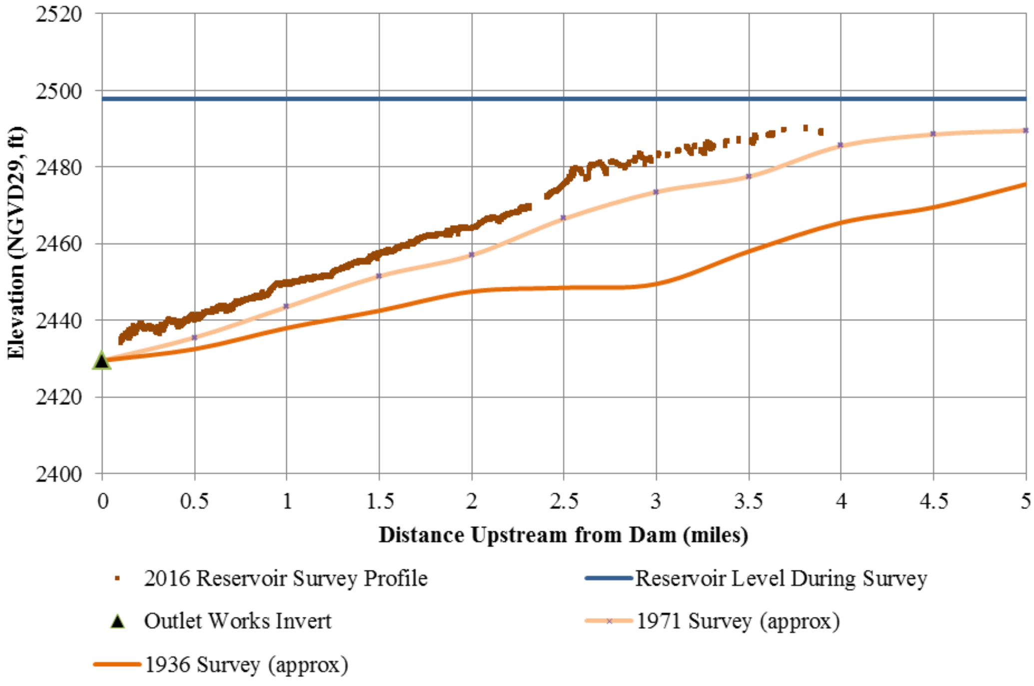

Figure 2. Longitudinal profile of Black Canyon Reservoir (Payette River) from the dam upstream (Kimbrel S. , 2016).

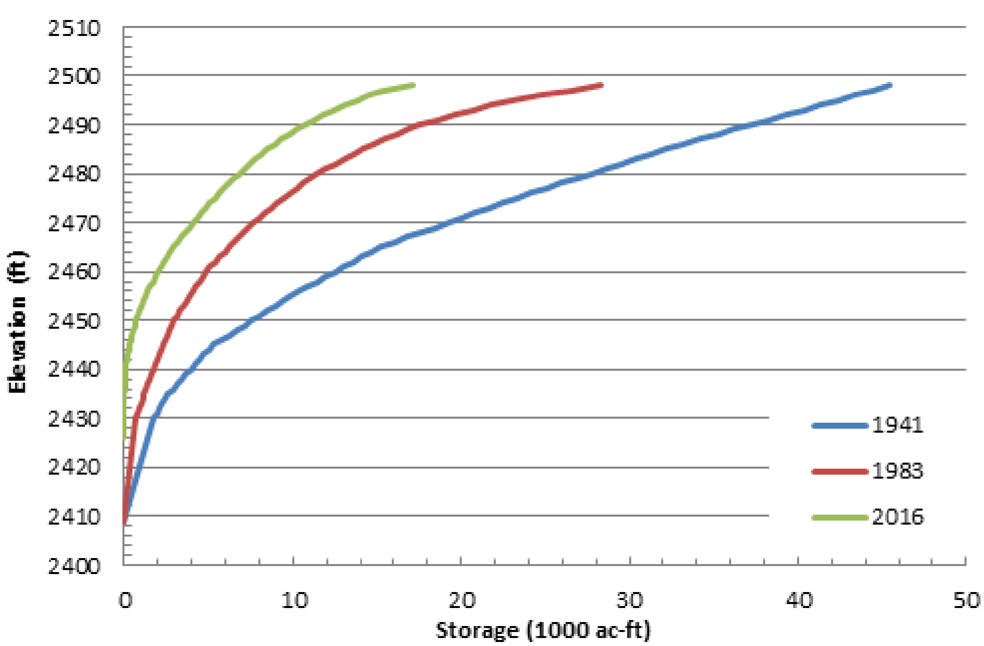

Figure 3. Previously published area capacity curves for Black Canyon Reservoir.

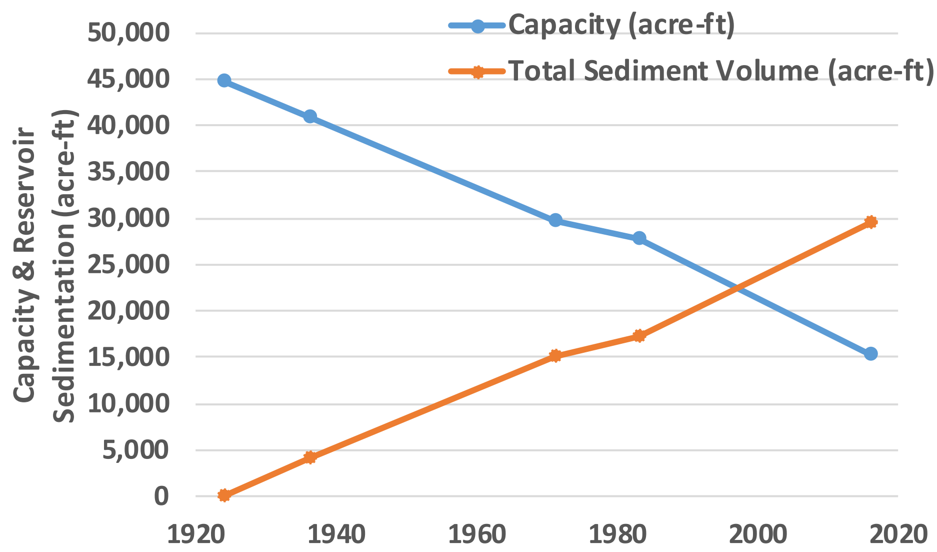

Figure 4. Surveyed reservoir capacity and sediment accumulation.

Future Sediment Volume Predictions

Historical sediment accumulation rates are used to inform future sediment volume predictions. The 1973 Soil Conservation Service survey report details the most recent estimated average annual sediment delivery into Black Canyon Reservoir to be 292 acre-feet (S.C.S., 1973), which is close to the average sedimentation rate displayed in Table 1of 320 acre-feet. Additionally, about 300 acre-feet average annual sediment inflow agrees well with a more recent study of sediment transport in other streams and rivers in Idaho (King, et al., 2004). Of these sediments entering the reservoir each year most of them do not pass the dam, even when accounting for previous flushing operations. Of these sediments the bulk may be classified as sand with median grain diameters (d_{50}) ranging from 1.2 mm for the most upstream locations in the reservoir to 0.02 mm at the location closest to the dam.

As land-use changes are minimal in this basin, we assume that historical sediment accumulation rates will continue. Minimum, average and maximum sedimentation rates were applied to estimate reservoir life.

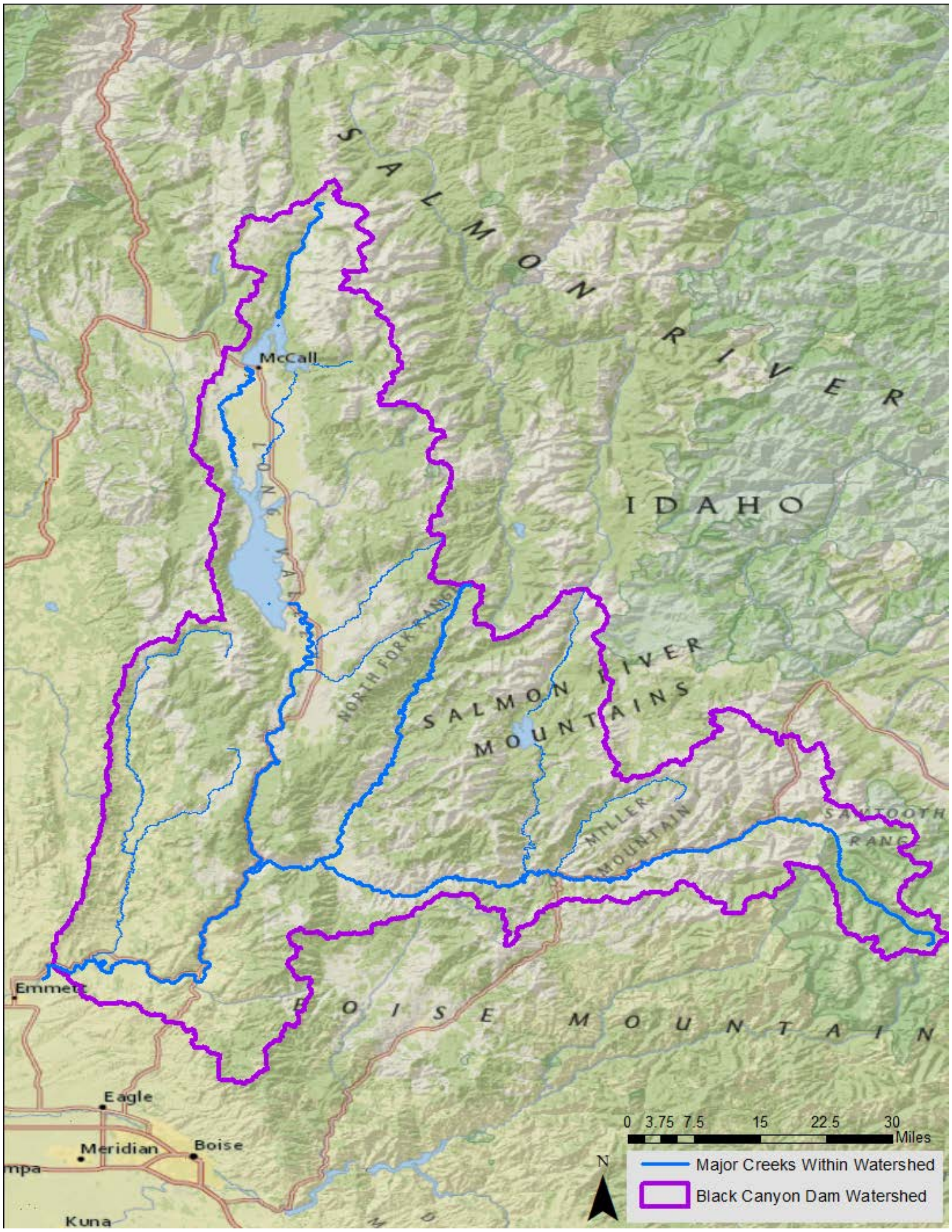

Figure 5. Drainage area of Black Canyon Dam displaying major creeks and waterbodies.

Estimating Reservoir Life

Based on data obtained from reservoir surveys throughout the United States, empirical relationships have been developed to predict sediment distribution within the reservoir (Figure 6). These relationships are useful in predicting where sediment will deposit which helps to determine if key infrastructure (marina, outlet structures, etc.) are at risk. The distribution of sediment is based on: 1) reservoir operations, 2) size and texture of deposited sediment, 3) shape of the reservoir, and 4) volume of sediment already deposited in the reservoir (Strand & Pemberton, 1982). These four factors determine a reservoir type which defines the coefficients used in the empirical equation.

Based on operations, the reservoir can be categorized as a type II (moderate drawdown) reservoir and may be used to estimate the new zero capacity elevation at the dam. The operating pool is relatively stable being a diversion dam, meaning that sediments are always submerged. The reservoir shape factor was calculated to be 2.3 based on equations published in literature (Strand & Pemberton, 1982; Sumi, Kantoush, & Ock, 2017).

The shape of the area capacity curve is known based on the 2016 bathymetric survey. The coefficient values can be modified or calibrated based upon the observed sedimentation from 1983 to 2016 to best predict the measured area capacity curve (Figure 7). The calibrated empirical equations were applied to estimate remaining reservoir life. We assumed that the river delta was completely contained within the reservoir.

By varying the sediment accumulation rate from its minimum to maximum values, we can predict a timeframe in which the penstocks will be buried (sediment elevation at 2472 ft) and the reservoir decommissioned (sediment elevation at 2497 ft; Table 2 and Figure 8). Current calculations estimate that the penstocks will be buried between 2047 and 2063 and the reservoir will completely fill with sediment between 2056 and 2101.

Table 2. Reservoir life estimate

Infrastructure	Sedimentation Rate	Sedimentation Rate (acre-ft/yr)	Impact Year	Useful Life (years)*
Buried Penstocks	Maximum	374	2047	31
Buried Penstocks	Average	321	2052	36
Buried Penstocks	Minimum	178	2063	47
Decommission Reservoir	Maximum	374	2056	40
Decommission Reservoir	Average	321	2063	47
Decommission Reservoir	Minimum	178	2101	85

* The useful life in years begins at the date of the last survey, 2016.

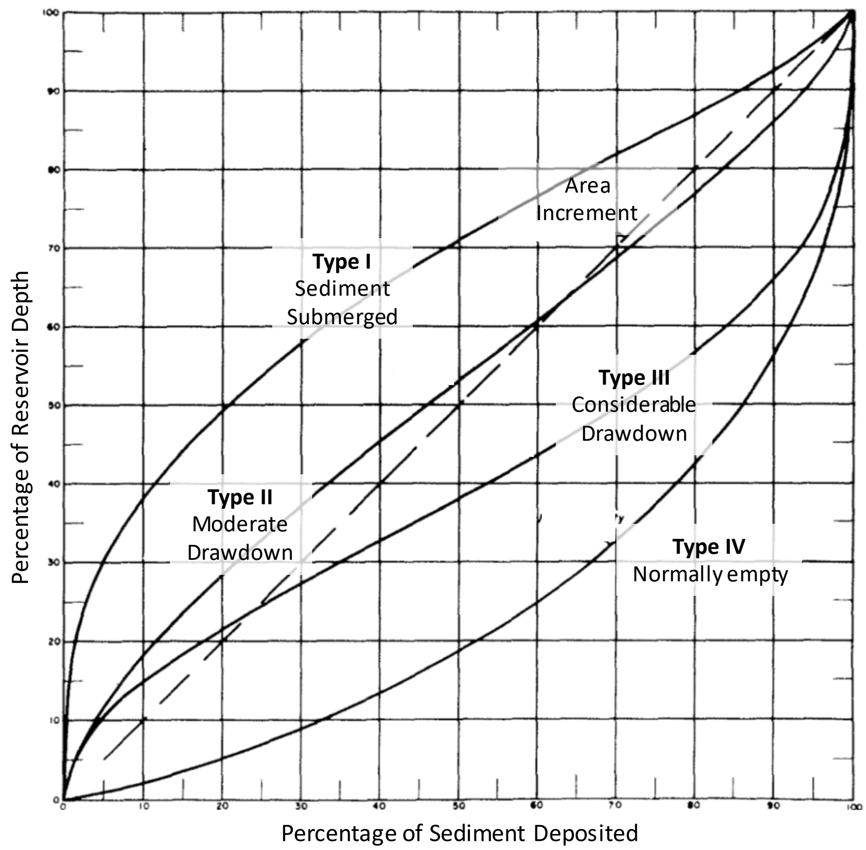

Figure 6. Sediment distribution design curves

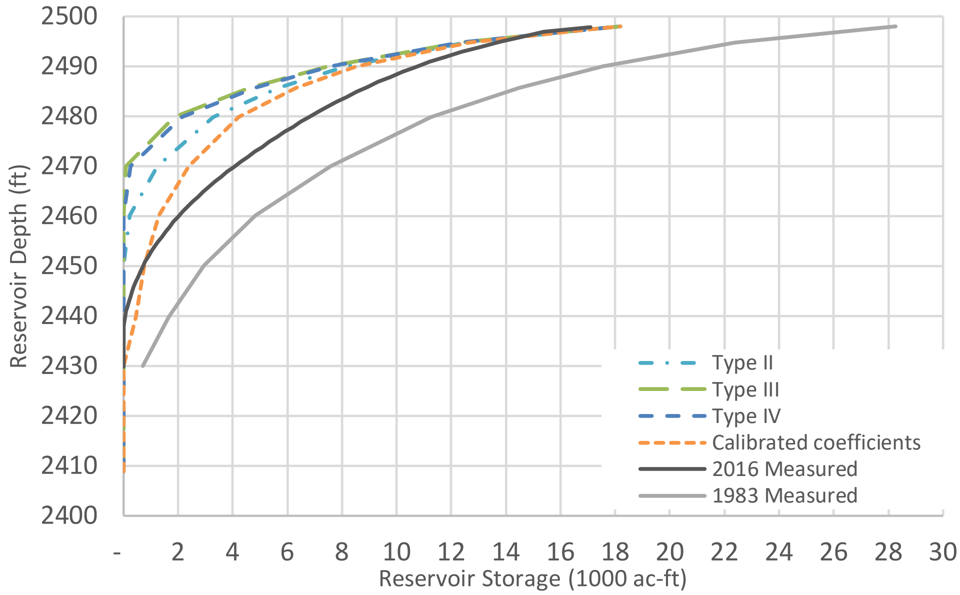

Figure 7. Reservoir storage capacity curve estimate based on reservoir types documented in literature. There was no solution for Reservoir Type I. Calibrated coefficients are represented with the orange square dotted line. The period of calibration was 1983 to 2016.

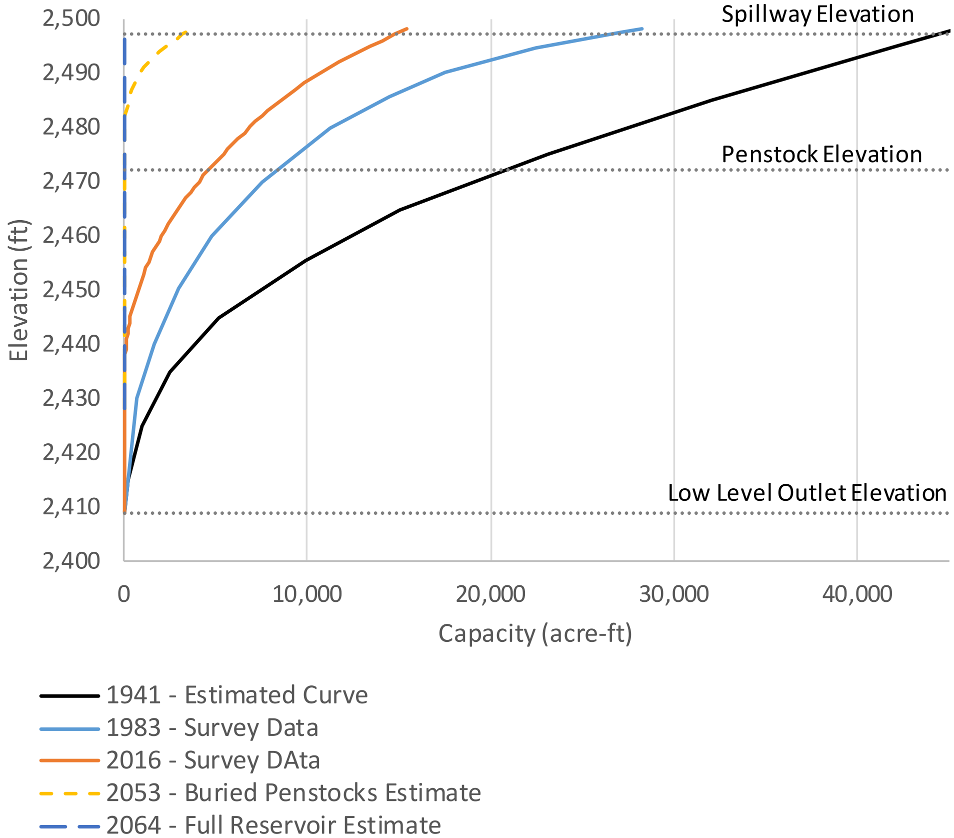

Figure 8. Existing and predicted reservoir capacity curves assuming an average sedimentation rate of 321 acre-ft/year.

Future Sediment Management Options

Sediment management options can be largely classified into three approaches: 1) reduce sediment yield from the watershed, 2) minimize sediment deposition, and 3) increase or recover reservoir capacity (Kondolf, et al., 2014). The preferred sediment management technique(s) for a given reservoir is determined predominantly by reservoir size, reservoir shape, sediment volume, sediment characteristics, and water volume (Sumi, 2008; Annandale, 2013; Kondolf, et al., 2014). For example, small reservoirs can be quickly refilled, making them ideal for a drawdown flush, whereas this same technique is not practical for larger reservoirs where storage operations (such as an off-channel reservoir) may be more successful. Other factors to consider are reservoir purpose, operational constraints, downstream limitations, and environmental concerns.

Empirical data and previous studies suggest that either drawdown or pressure flushing is likely the most suitable sediment management options for Black Canyon (Figure 9). These estimates are based on reservoirs capacity (CAP), mean annual storage (MAS), mean annual runoff volume (MAR), and dam infrastructure limitations such as gate locations and sluiceway capacity.

Sluicing involves releasing high flows through the dam during periods of high inflows into the reservoir. The purpose of sluicing is to release sediment-laden water downstream, preventing sediments from depositing into the reservoir. Some previously deposited sediment may be mobilized, however removing previously deposited sediment is not the goal. Often, the reservoir pool is lowered slightly prior to high flow events and remains low as the sediment laden flows pass. The reservoir typically begins to fill on the tail-end of the hydrograph or when reservoir operations dictates. This approach generally requires high capacity low-level outlets to fully pass a high-flow event without impounding water. Sluicing is not currently possible at Black Canyon because the low-level gates have an approximate maximum capacity of 2,200 cfs at full pool whereas peak flows during the spring snow melt can be 10,000 cfs. Therefore, this option was not analyzed further.

The purpose of drawdown flushing is to scour and re-suspend deposited sediment and transport it downstream. Unlike sluicing, drawdown flushing can be conducted during a low-flow season and can involve completely emptying the reservoir through a low-level outlet, which must be large enough to freely pass the flushing discharge without creating a backwater effect at the dam. Drawdown flushing operations are the most effective in long narrow reservoirs, like Black Canyon (Kondolf, et al., 2014). When drawdown flushing occurs during low-flow season, the hydraulic forces from water leaving the reservoir are not high enough to keep the reservoir sediments in suspension. Therefore, flushed sediments tend to deposit downstream of the dam. During high flow, these sediments would continue to be transported downstream. Drawdown flushing outside of low-flow season is not possible due to the 2,200 cfs sluice-way capacity. However, installation of additional gates would change this.

Pressure flushing involves releasing water through the low-level outlets while maintaining a high water surface elevation. Pressure flushing typically only clears the area near the outlet works (Emamgholizadeh et al., 2006), removing a smaller volume of sediment than drawdown flushing. As the purpose is to remove previously deposited sediments, it can occur at any time of year. However, because the water surface elevation is not significantly reduced, pressure flushing can only transport sediments downstream which are close to the outlet used for flushing.

The advantage of drawdown flushing includes the ability to transport large volumes of sediment downstream. Drawdown flushing has the disadvantage of a higher risk of damaging downstream ecosystems, and water diversions may not occur while the reservoir pool is lowered. The advantage of pressure flushing is that water diversions may occur simultaneously. However, pressure flushing removes a comparatively smaller volume of sediment, only removing sediments close to the dam outlet. The risk of impacting the downstream ecosystem is reduced, but pressure flushing may not be able maintain or restore reservoir capacity.

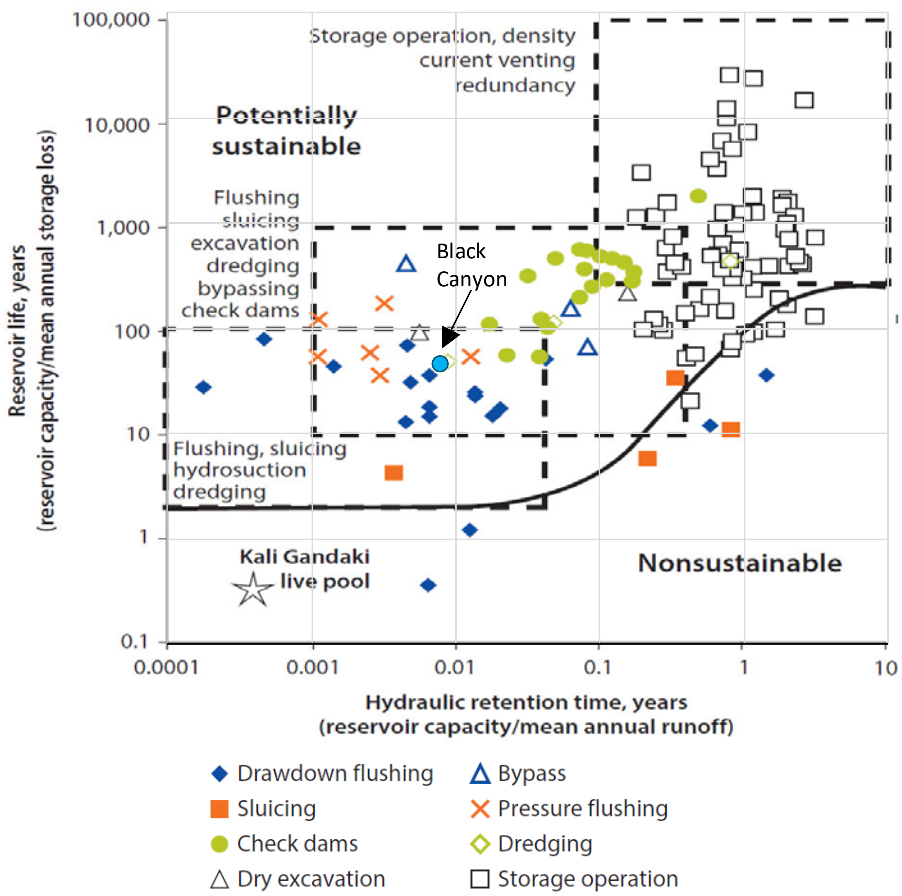

Figure 9. Applicability of sediment management techniques based on hydrologic capacity and sediment loading (Annandale et al., 2016). Black Canyon data (represented as a blue dot) suggests that flushing and sluicing may be a sediment management option based on water and sediment fluxes as well as reservoir capacity.

Historical Sediment Removal Activities

Historically, the reservoir is drawn down an average of about 20 ft almost annually between the months of October and March (Figure 9), this reduction in water surface elevation is not enough to notably influence upstream sediments so these operations are generally regarded as pressure flushes. However, these operations are not strictly regulated, and little data collection occurs, as such limited insights can be developed on sediment volumes passed downstream or other applicable observations. In addition to pressure flushing, two drawdown flushing operations were conducted in 1984 and 2013 and provide historical examples of the potential for the dam to pass larger volumes of sediments.

In December of 1984, a drawdown flushing exercise was conducted to determine the potential to remove reservoir sediment, extending the reservoir's useful life. During the low-flow season, the reservoir was drawn down by 18 feet (to approximately 2479 ft in elevation) for 152 days and beyond that to a minimum elevation of 2426 ft, 71 feet below operating pool, for 54 days (Figure 11). The dual 5-foot by 5-foot sluice gates were opened fully, allowing Payette River flows to transport sediment deposits from the reservoir delta past the dam. The 1984 flushing exercise was halted due to turbulent water downstream of gate. Post flushing surveys indicate that a portion of the flushed sediment deposited in the tailwater area and resulted in an estimated 248 acre-feet of net erosion of reservoir sediment (Kimbrel, 2016), approximately annual supply of sediment to the reservoir. There are no reports of formal biological assessments being conducted downstream of the dam at the time; therefore, impact of drawdown flushing operations to the biological community were inconclusive.

In 2013, a drawdown flushing operation was conducted to install a new turbine. The reservoir was drawn down below operating level at 2497 ft for 178 days and below 2485 ft for 88 days (Figure 12). The minimum reservoir elevation during the drawdown was 2430.5ft, 66.5 ft below operating pool elevation and approximately at the existing reservoir sediment level. As the drawdown flush occurred during lower flows, the sediments settled in the Payette River temporarily damaging much of the fish habitat downstream of the dam and drawing the ire of local communities and concerned state organizations (Tansey, 2013). In the future, any major flushing operations at Black Canyon Dam must take into consideration downstream biological impacts.

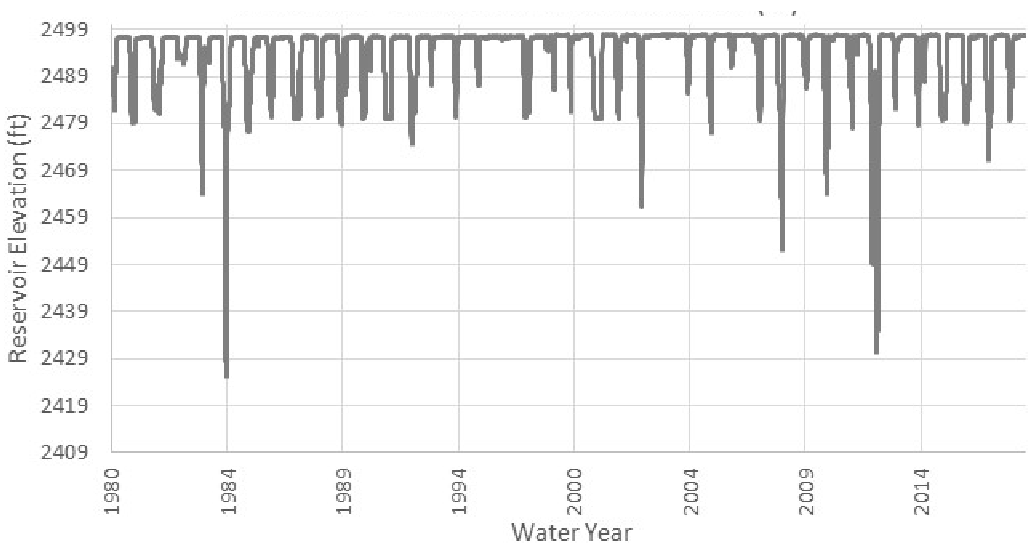

Figure 10. Black Canyon water surface elevation record.

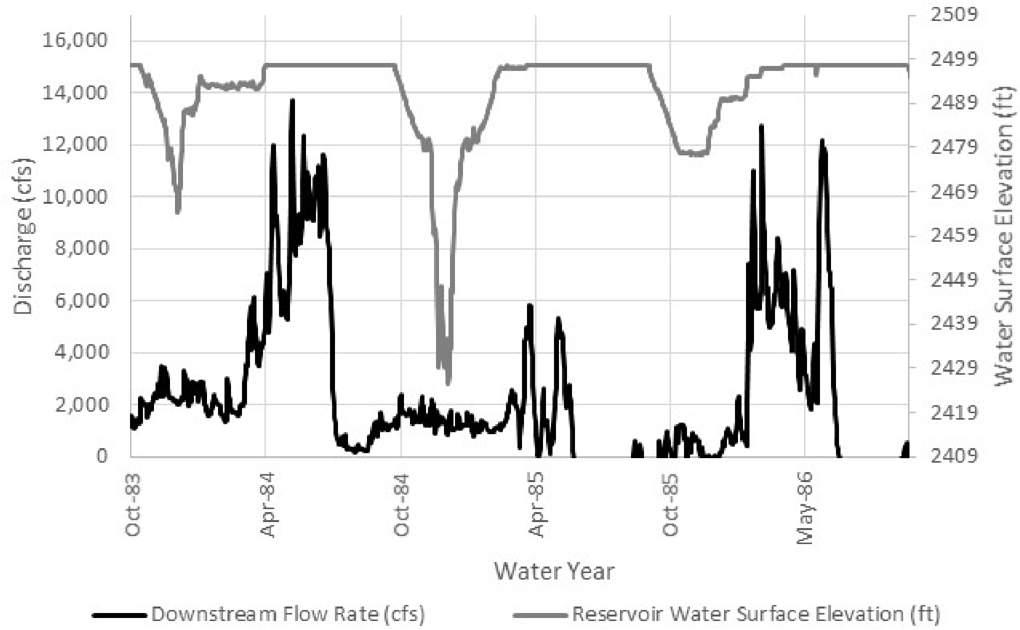

Figure 11. Flow and reservoir water surface elevation surrounding the 1984 drawdown flushing event.

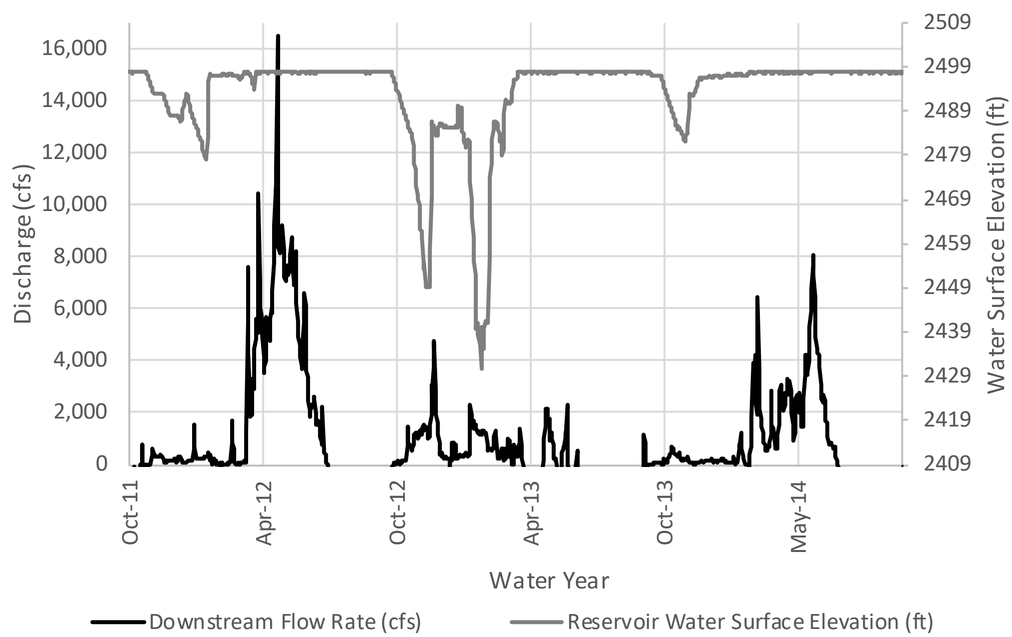

Figure 12. Flow and reservoir water surface elevation surrounding the 2013 drawdown flushing event.

Flow Limitations

The water available for potential flushing operations is limited by the volume of water flowing in the Payette River, and is further reduced through diversions at Black Canyon Dam for irrigation. As displayed in Table 3, potential water used for flushing is greatly reduced in August through October due to diversions. The reservoir is refilling during the spring (April through June) further reducing water available for flushing. Regulations dictate that the reservoir cannot be drawn-down between April 15th to October 15th each year.

The existing low-level outlet works consist of two 5-foot by 5-foot gates. Low-level outlet gate capacity was estimated assuming that the gates behave as two vertical sluice gates, when the reservoir is at full capacity (water surface elevation is 2498 ft) the maximum sluiceway capacity is approximately 2,200 cfs. At this estimated capacity, the sluiceway further limits the flushing/sluicing capacity to November through February on an average year when the entire river flows may be passed. Considering these limitations, flushing operations would be most effective February when flows are highest, but still low enough to pass unimpeded through the low-level outlet.

If the two 5 foot by 5 foot sluice gates were both expanded, or if additional sluice gates were installed, it would increase the volume of sediment which may be passed during each flushing event. Flushing activities could then occur during higher flows, which would increase the ability for flows to pass sediment and potentially reduce downstream impacts.

Table 3. Water available for sluicing operations determined by average streamflow minus the average water diverted for irrigation in cubic feet per second (cfs) each month.

Month	Average Stream Discharge (cfs)	Average Diverted Water (cfs)	Average Water Available for Flushing (cfs)
October	1,155	304	851
November	1,314	1	1,313
December	1,550	1	1,550
January	1,640	1	1,638
February	1,979	1	1,978
March	2,980	8	2,972
April	5,175	593	4,582
May	7,085	1,321	5,764
June	6,606	1,480	5,126
July	2,387	1,584	803
August	1,591	1,558	34
September	1,294	1,101	192

*Gray cells represent the months when flushing and sluicing is not viable due to irrigation.

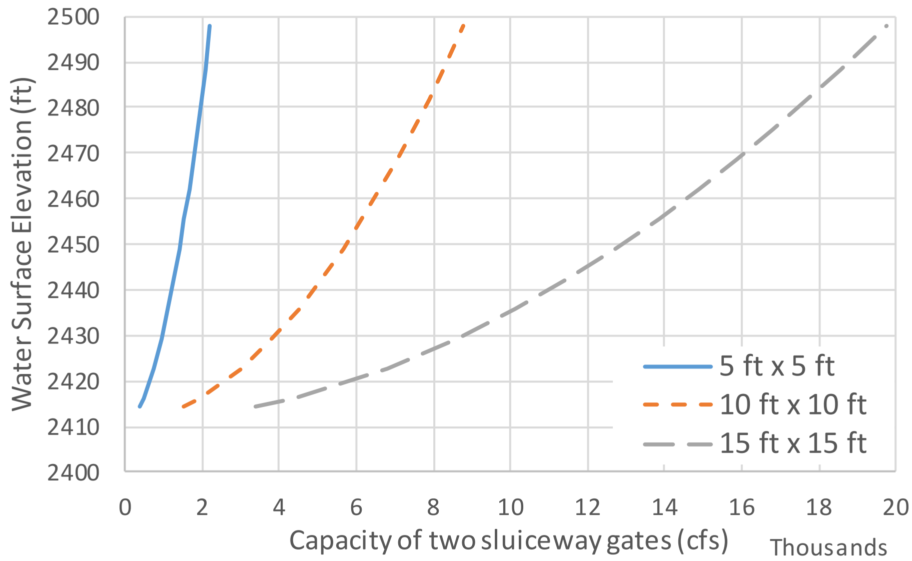

Figure 13. Calculated operating capacity (in thousands of cfs) for two low-level sluiceway gates. Currently, there are two 5 ft x 5 ft gates (solid blue line). However, if these gates could be expanded (orange and gray dashed lines), it would increase the flushing flow capacity and sediment volume.

Relationship between flushing flows and sediment removal

We can determine the feasibility of flushing (both drawdown and pressure) by comparing the ratio of reservoir capacity (CAP) to incoming mean annual runoff (MAR) and mean annual sediment load (MAS) (Figure 13). The estimated sediment flushing efficiency (Fe) is the volume of water consumed compared to the volume of sediment removed during sediment flushing. Reasonable flushing efficiency values range from 1% to 15% depending on stream flow, but if downstream ecological habitat is considered it likely should be about 5% or less (Sumi T. , 2008). Assuming a 5% flushing efficiency, approximately 8,000 acre-ft of water (approximately half of the current reservoir capacity or CAP) will be required to remove the annual sediment load (MAS; 374 acre-ft).

Atkinson (1996) presents an empirical method to predict sediment transporting capacity (Q_s) based on discharge (Q_f), and bedslope (S), channel width (W) and a sediment constant (Ψ). A sediment constant for flushing with low discharge was applied to be conservative. Using this method, the water volume needed to flush the annual sediment load (374 acre-ft) ranged from 4,000 acre-ft to 15,000 acre-ft (27% and 99% of the reservoir capacity, respectively).

$$Q_s = \Psi \frac{Q_f^{1.6} S^{1.2}}{W^{0.6}} \qquad (\#)$$

The above methods to estimate sediment use empirical formulas which do not account for many complexities associated with sediment removal. These values only represent a feasibility estimate and will require further analysis should sediment flushing need to be studied in more detail.

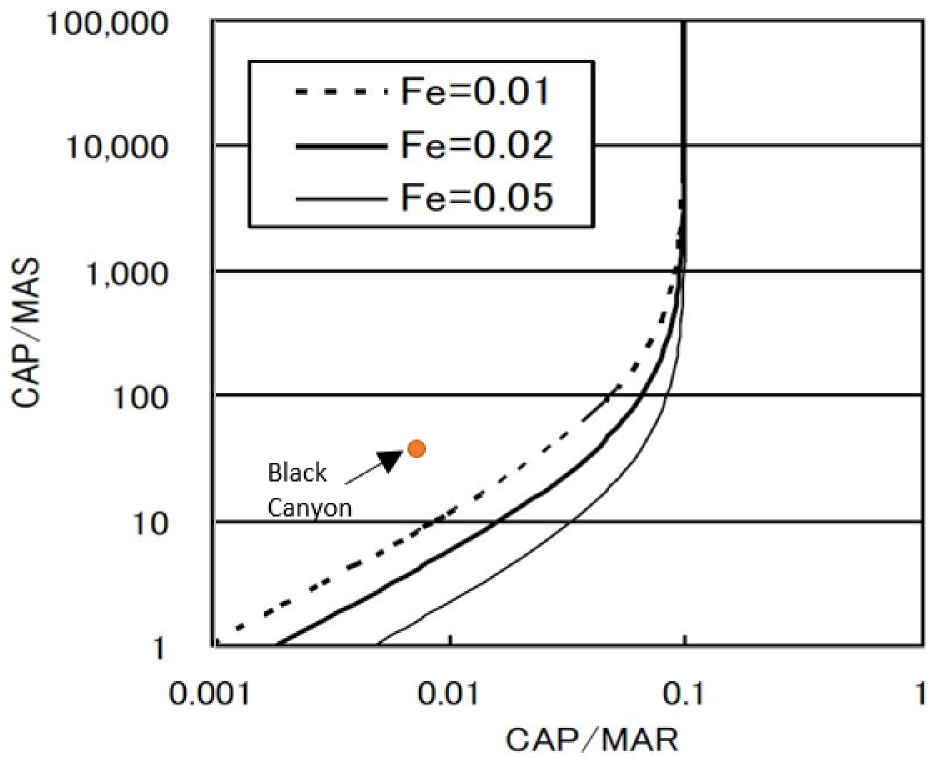

Figure 14. Possible ranges of sediment flushing efficiency (Fe) assuming a constant proportion of reservoir water capacity (CAP) to the mean annual runoff (MAR) volume and mean annual sediment (MAS) load. Black Canyon data are plotted to assess flushing (drawdown or pressure) feasibility, any point to the left of the line is considered feasible.

Timing of Recommended Methods

Because Black Canyon Dam provides diversion water for irrigation from April through September, drawdown flushing of the reservoir is not an option during this period. Furthermore, low-level sluiceway gate capacity limits the volume of water Based upon this, the optimal time for sediment removal using existing facilities is likely the winter months. Previous studies recommended conducting sediment flushing operations during December and January as there will be high enough flows to increase sediment flushed downstream, but still allow time to fill the reservoir (Blanton, 1985). Based on the empirical equations presented in the previous section, flushing the annual sediment load from Black Canyon could take anywhere between 1 and 20 days depending on conditions. Refilling the reservoir could take anywhere between 2 and 10 days depending on incoming stream flow.

As witnessed during the 1983 and 2013 drawdown flushes, flushing during the low flow season can negatively impact the downstream biological environment.

While releasing sediment is a concern to the local biological community, we must remember that historically, the river system was accustomed to passing the annual sediment load. Flushing during the high flow season would likely decrease impact to the downstream community; however, it can only be done if the sluiceway gates are expanded. Releasing sediment during the high flow season more closely mimics the natural sediment regime. A higher volume of water for a given sediment load would result in lower turbidity for a shorter duration. The flow would have a higher capacity to move sediment; therefore, much of the sediment would continue to move downstream, depositing over a longer timeframe and a larger spatial extent.

Assuming the sluiceway gates can be expanded, drawdown flushing should occur during March. High flow values are typical during this time of year, which will lessen the impacts to the downstream community. Furthermore, high flows will continue through the spring, which will allow any residual sediment to be flushed from the downstream environment. Flushing sediments in March will lessen impacts to local communities. Recreation opportunities are minimal during this time of year, and there is enough time to refill the reservoir before irrigation season.

Assess Feasibility & Economic Viability of Options

A program that includes the flushing of reservoir sediment will require significant changes to operations and have environmental considerations.

Define Stakeholders and Constraints

Reclamations jurisdiction in the area includes the reservoir (1,100 surface acres), adjacent lands (1,700 acres), and portions of Montour Wildlife Management Area (1,350 acres). The stated purpose of Black Canyon Dam is for power generation and water diversion. The dam has a power generation capacity of about 10,000 kilowatts of hydropower owned by the Bureau of Reclamation and operated by the Bureau of Reclamation and the Bonneville Power Administration. The plant supplies power to the Southern Idaho Federal Power System for Bureau of Reclamation project uses and for non-project purposes. Surplus power is delivered to BPA for marketing and distribution to regional industries and municipalities.

In addition to producing hydropower the dam serves to divert water to the Payette Division through Black Canyon Canal to serve the Emmett Irrigation District Canal on the north side of the river. The operating organization for the Payette Division is the Black Canyon Irrigation District with headquarters at Notus, Idaho which comprises an area of approximately 60,100 acres The dam is authorized to hold 2,498 acre-feet of water for diversion annually to divert water the reservoir pool needs to be at full between March 15 through September15.

Additional obligations of dam operations besides hydropower generation and water diversion is flow augmentation for wildlife. Since the 1990s, salmon flow augmentation guidelines have dictated facility operations which direct release policies that are different from past downstream discharges (NOAA Fisheries 2008a). Under the current salmon flow augmentation guidelines, up to 165,000 acre-feet of additional stored water is released from June through August, resulting in an additional 920 to 1,340 cubic feet per second (cfs) released during the flow augmentation period. Other downstream species of concern include white fish (stocked), small mouth bass, and trout.

Environmental Considerations

The prime environmental concern associated in flushing or sluicing at Black Canyon Reservoir is the downstream bed, bank, and water quality conditions. As bed load concentrations increase, a stream bed tends to become less armored, and bed grain size decreases. This can be positive if the downstream system is sediment-starved, resulting in artificially high bed sediment. However, excess fine-grained sediment can fill interstitial spaces, suffocating small fish, invertebrates, plants, and other biological life. As sediment concentrations continue to increase a transition from a single-thread stream to a braided channel is common (Mueller & Pitlick, 2013).

Any sluicing or flushing plan intended to move enough sediment from the reservoir to notably increase functional reservoir life must take into consideration impacts of the concentration, volume, duration, and timing of sediments flushed from the reservoir to downstream ecosystems. Currently, there is no guidance on the process or data necessary to analyze the impact of drawdown and pressure flushing on the downstream environment. Literature does exist to help guide the process of evaluating and understanding the biological impacts of sediments in aquatic systems such as the EPA review of biological effects of suspended and bedded sediment (SABS) (Berry, 2003). Timing the release of sediment to be as close as possible to natural conditions will likely result in the least negative consequences downstream.

Releasing sediments to the downstream river during the right time may have positive impacts. If the downstream river is depleted of sediment, as is often the case downstream of a dam, the bed will coarsen and become armored, which creates poor fish and macroinvertebrate habitat. Restoring sands and gravels to the downstream system will have geomorphic benefits such as the creating of point bars One study on found positive long-term effects of passing sediment downstream of reservoir. The study focused on sediment bypass tunnels routing sediment downstream of reservoirs in Japan and Switzerland. A sediment bypass tunnel will have similar impacts to the downstream community as flushing sediment downstream. The study found that passing sediment downstream resulted in finer grain size distribution at dams where the sediment bypass tunnel had been in operation for a long time. Higher microhabitat and invertebrate richness was observed downstream of the dam, largely due to bed disturbance from operating the sediment bypass tunnel (Auel et al., 2017).

RESCON2 Analysis

The Reservoir Conservation Model Version 2 (RESCON2) is an economic and engineering evaluation tool for a variety of sediment management alternatives in a reservoir developed by Fichtner GmbH & Co. under contract by the International Bank for Reconstruction and Development and published in 2017. This tool has been used extensively worldwide to assist in identifying the most feasible reservoir operation methods which have the greatest value (Efthymiou, Palt, Annandale, & Karki, 2017).

RESCON2 provides a preliminary assessment of the technical feasibly of selected sediment management plans based on basic reservoir geometry, hydrology, sediment caliber and load, and economic data. It is not a sediment routing tool and the calculations are based on a simplified reservoir geometry. RESCON2 cannot assess the effects of simultaneous applications of different sediment management techniques. Furthermore, it does not address reservoir infrastructure (penstocks) or the downstream impacts from sediment release. Three scenarios were examined for Black Canyon Reservoir: no action, drawdown flushing, and pressure flushing. The analysis assumes that the reservoir becomes non-sustainable at 5% current storage capacity (less than 765 acre-ft).

This analysis was performed assuming no action or current operations, a two-week drawdown flush or pressure flush, and a one-month drawdown flush or pressure flush operation (Figure 15). Under current operations, the remaining functional life of the reservoir is approximately 58 years. Therefore, continuing with no change in dam operations is technically feasible, but it is not sustainable. This value is within the predicted useful life calculated via Strand & Pemberton (1982).

A two-week seasonal pressure flushing operation will extend the life of the reservoir but will not be sustainable long-term. If conducted every year for 2 weeks, approximately 40 acre-feet of sediment may be removed from the reservoir each year which is 13% average annual sedimentation rate. This would likely result in the reservoir life of approximately 99 years. Pressure flushing for one month is sustainable but, the long-term capacity would be approximately 1,000 acre-ft (2% of the original storage capacity).

Drawdown flushing is feasible and sustainable assuming both two-week and one-month operation every five years. Under this operation, the reservoir is anticipated to have a functional lifespan of over 300 years resulting in a long-term capacity ranging between 22,000 and 30,000 acre-ft of storage. However, drawdown flushing during low-flow seasons is likely to result in undesirable downstream impacts.

As these results are based on empirical data, general reservoir geometry, hydrology and sediment characteristic information these results could have an order of magnitude of error or more and are only indicative of possible beneficial dam management changes. More analysis is necessary to refine the volume of sediment that can be removed by pressure and drawdown flushing.

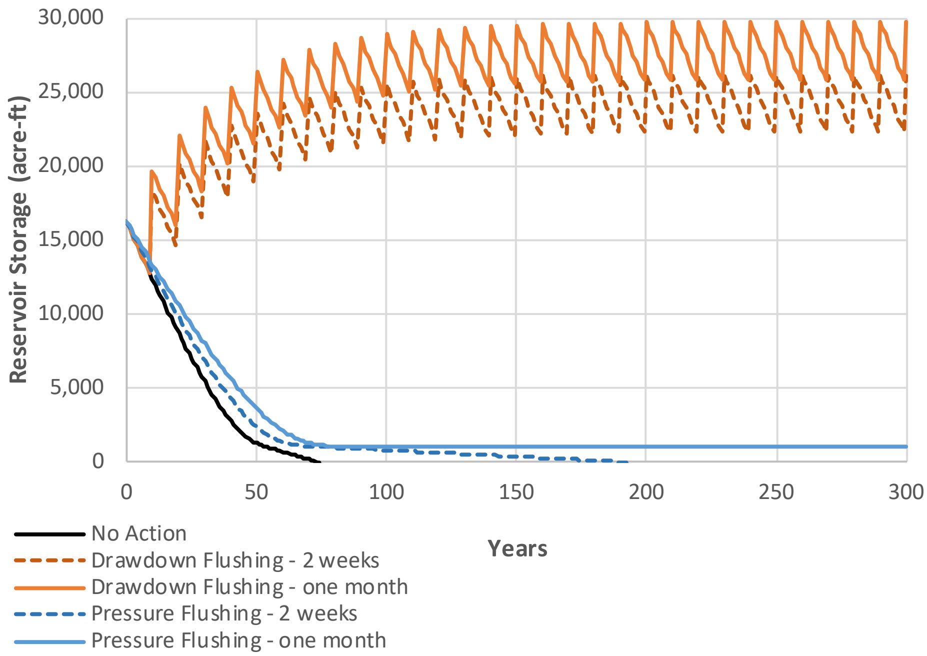

Figure 15. Estimated gross storage in Black Canyon under three operational schemes assuming two-week (dashed-lines) and one-month operations (solid line).

Implementation of the Sediment Management Plan

This study predicts that both pressure flushing and drawdown flushing could be used to extend the useful life of Black Canyon Dam. Pressure flushing of sediment with a full reservoir may allow continued hydropower production, but most of the reservoir will be lost and there will be practically no active storage available in the reservoir. Furthermore, the penstocks will need to be retrofit to avoid burial at 2472 ft in elevation. Pressure flushing will release less sediment downstream initially, but eventually, the reservoir will fill, and the annual sediment load will pass downstream.

Drawdown flushing at Black Canyon Reservoir is the best option to salvage reservoir capacity. If drawdown flushing is performed with the existing gates, then flushing would have to be conducted during the low flow winter months. This decreases the volume of sediment that can be removed during a single flush and results in a higher risk to negatively impacting the downstream biologic community. If larger gates were installed in the dam, higher flows could be used to flush the sediment, and the timing of the flush could be moved to the early spring. This timing of sediment release would correlate to a more natural timing of sediment release and have few negative downstream consequences.

Additional Analysis

Further investigation of both pressure and drawdown flushing can refine the timing, duration, and frequency of the operations. Studies could apply mobile-bed numerical modeling and physical modeling as well as a field test. Ideally, all three are completed before a sediment management plan can be implemented. The mobile-bed numerical and physical models will complement each other, while the field test is the best tool to predict results.

Mobile-bed numerical and physical model would forecast spatial depositional patterns and relative sediment volume removed for various flushing/sluicing scenarios. Erosion width may also be forecasted with a two-dimensional numerical model. While modeling cannot predict an exact volume of sediment displaced during a sediment removal event, it can predict patterns and be a powerful comparison tool. The model could predict where sediment may deposit in the river bed downstream of the dam. It could also inform where delta sediment may deposit in the reservoir as they move downstream. Furthermore, these tools could help predict how sediment removal volumes can increase with flushing or sluicing duration. For example, we can compare the results of a two-week flush verses a one-month flush to determine the relative increase in sediment displaced.

Both physical and numerical mobile-bed models have limitations. Numerical models apply sediment transport equations to predict erosion and depositional rates, which make simplifying assumptions. Numerical models fail to consider the three-dimensional effects, applying depth-averaged velocity and shear stress in a two-dimensional space and cross-sectional averages in a one-dimensional space. While physical modeling does account for all three dimensions, it has its own challenges. Physical modeling requires scaling to represent the natural reservoir in a laboratory space. Often the scaling is not proportional, requiring distortion. For example, the cross-sectional and longitude scale could be 1:100 (model: natural system), while the vertical scale may be much smaller, 1:20. As more parameters are distorted, there is a greater risk that the model may yield incorrect results. Mobile-bed modeling adds an additional component to scale. Scaling physical models to fine sediment, as is present in Black Canyon Reservoir, can be very challenging.

Field testing is the best tool to estimate the volume of sediment removed, erosion and deposition patterns, and downstream sediment concentration or turbidity levels. While field testing has occurred in the past, it has not been well documented and very little data were collected to support future flushing efforts. Recommended data collection efforts with each field test include:

- Bathymetric survey before flushing,
- Bathymetric survey after flushing,
- Reservoir stage data,
- Discharge measurements into and out of the reservoir,
- Gate opening height,

- Flush duration, and
- Turbidity measurements downstream of the dam.

Biologic studies of the impact of the fine sediment release should be conducted on the relevant fish species. The timing and duration of the sediment release could be optimized to limit the impact on the aquatic species downstream. The benefits to restoring a more natural sediment load should also be considered.

Plan for Future Monitoring and Possible Revisions

If dam management operations include pressure or drawdown flushing operations, additional monitoring will be required. Ideally, repeat reservoir surveys should be conducted before and after the flush to determine sediment volume removed. A smaller survey near the outlet works would give an estimate of sediment volume removed near the outlet works but will not inform the progression of the river delta. Additionally, basic operations data should be collected to include the flushing flow rate, gates opened during the operation, length of time of the operation, and rate of refill for drawdown if it is a drawdown flushing event.

Further, the downstream river health is a priority, and surveys of river health before and after the flush should be conducted to better estimate tolerances of the ecological community to elevated sediment loads. This information should be documented in a post sluicing/flushing report or memo.

Conclusions

Black Canyon Reservoir is filling with sediment and without effective sediment management, coarse sediment is predicted to start entering the penstocks between 2047 and 2063. If no change in dam operations occur, the reservoir capacity is predicted to be completely lost between 2056 and 2101. Once the reservoir capacity is lost, the sediment trapping capacity is also lost and the natural sediment loads will begin passing downstream.

To prevent the loss of reservoir storage and loss of hydropower generation, the current low-level outlet at Black Canyon dam can be used to move deposited sediments. If operated suitably, there is a potential to pass enough sediments to significantly extend the functional life of the reservoir. However, factors limiting the ability to erode reservoir sediments include the capacity of the low-level gates and the impacts to local fisheries. The low-level outlet gates can pass a maximum flow of 2,200 cfs, limiting the flushing/sluicing time to the low flow season. The 2013 flushing event temporarily decreased the downstream ecosystem productivity, which elicited strong public indignation. If additional gates were installed, the timing of a drawdown flush could be moved to March which would more closely mimic when sediment loads were naturally high. The higher flows would also limit the duration of the high turbidity impact.

Pressure flushing may also be used to extend the useful life of the hydropower facility but will not be very effective at maintaining the reservoir capacity, which impacts the dam’s ability to provide downstream flows. It has been reported that the sluice gates are already in use to at least some extent every year, and formally establishing a pressure flushing and monitoring plan with dam managers may be beneficial until a more sustainable flushing regime can be developed.

To develop a more specific and optimized plan and avoid unacceptable downstream ecosystem impacts, the system must be better understood. Future work should focus on defining the specific impacts to be avoided, cause of said impacts, and what operational conditions would allow the maximum sediments to be passed downstream while avoiding these impacts. Finally, better documentation is recommended for future sluicing or flushing activity to gain a better understanding of the system.

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