Interim Sediment Management Plan for First Dam, Logan River

Thirumurugan Bose

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Interim Sediment Management Plan for First Dam, 

Logan River.

by 

Thirumurugan Bose 

A project submitted in partial fulfillment 
of the requirements for the degree 
of 
MASTER OF SCIENCE 
in 
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Approved: 

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ABSTRACT

Interim Sediment Management Plan for First Dam, Logan River

by

Thirumurugan Bose, Master of Science
Utah State University, 2004.

Major Professor: Dr. Mac McKee
Department: Civil and Environmental Engineering

Sediment is a serious problem in the management of dams all over the world. In this project an interim sediment management plan for First Dam, on the Logan River in northern Utah, is discussed. The objective of the plan is to control the sediment budget of the reservoir in such a way that other reservoir maintenance activities (e.g., unusual drawdowns for structural repairs) will produce minimal downstream environmental impacts on water quality and aquatic resources.

This report presents a detailed literature review of the various sediment management practices used for reservoir sediment control. It also discusses the downstream effects of sediment flushing and sluicing events. In addition, several sediment management alternatives applicable for the case study reservoir are discussed, including their advantages and disadvantages. An interim recommendation for sediment management at First Dam is proposed, and sampling and monitoring procedures required during and between sediment flushing events are proposed.
The future work of the project of which this report is a part will be to obtain results from sediment flushing experiments that are described here, to analyze the data obtained from these experiments for better assessment of sediment management plans for First Dam, and utilize this information to prepare general sediment management guidelines for small reservoirs in Utah.
I am very much thankful to my major advisor, Dr. Mac McKee, whose encouragement, guidance, financial support and technical inputs were extremely vital in the successful completion of the project. He was always there for me at the time of need.

I would also like to thank my committee members, Dr. Ronald C. Sims and Dr. Blake Tullis for their invaluable suggestions during the course of the project. I appreciate the help rendered by Dr. John Neuhold for his guidance and the staff members of Utah State University Facilities for the data supplied as and when needed. I am grateful to all my friends, especially Ashwin Chandra Sullia and Prasanna Swaminathan for their support throughout the project.

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CHAPTER 1
INTRODUCTION

1.1 Background

The surface streams in Utah and the Rocky Mountain West are habitat for cold-water fisheries and provide the basis for a $750 million per year recreation fisheries industry in Utah, alone. These same streams are dammed for storage and power production, and their waters are diverted for irrigation and other uses. The dams utilized for these purposes are subject to sediment accumulation that creates an anaerobic environment in which the decay of organic material results in the production and storage of such toxic materials as hydrogen sulfide and methane.

The multi-year accumulation of these sediments and accompanying toxic materials generate a non-point pollution source as the sediments are occasionally flushed from the bottom of reservoirs as a requirement of dam maintenance activities or for increasing reservoir storage volume. The resulting releases of sediments can produce significant impacts on downstream water quality and deleteriously affect the fish and invertebrate populations in the tailraces and often in the stream channel miles downstream from the dams.

A recent occurrence of such impacts is exemplified by the flushing of an approximate ten-year accumulation of sediment from the reservoir at First Dam on the Logan River, Utah (see Figures 1.a and 1.b), on October 16, 2001. In this instance, an estimated 2,000 catchable size trout and whitefish were killed in a two-mile reach of the river downstream from the dam, spawning beds were damaged, and invertebrate populations were affected. Approximately ten years prior to this incident a similar flushing of First Dam on the Logan River caused the loss of some 8,000 trout and whitefish ranging in size from catchable to 20 pounds. In the period between these two events, no sediment management plan was in effect for the reservoir at First Dam.

Impacts to irrigation systems are also evident. Sediment flushing resulting from reservoir release, especially during low stream flow periods of the year, settles out in slow-velocity irrigation canals. These depositions require removal, adding to the maintenance cost of the canals. Also, when sediment is allowed to remain in the canals, aquatic vegetative growth is accelerated, often requiring the introduction of phytocides that in turn have additional toxic impacts to fish and invertebrate populations in streams receiving return flows.

1.2 Purpose

The purpose of this report is to propose an interim plan for sediment management for First Dam. The objective of the plan is to provide a design for sediment maintenance procedures to be followed at First Dam that will minimize downstream impacts on water quality and fish that might result from a periodic maintenance procedure on the dam itself.
that are necessary from time to time. This will be an "interim" sediment management plan because it is intended that as the design is implemented and its performance is monitored, it will be possible to discover ways of further improving sediment control procedures.

Figure 1.a: "First Dam" Location

The broader purpose of the project that supports the development of this interim plan for First Dam is to utilize First Dam as an experimental facility in order to develop more general management guidelines for use by the operators of small dams on recommended procedures to minimize the negative downstream impacts of sediment release.
1.3 Objectives

The objectives of this portion of the project are to:

- develop a comprehensive review of the literature pertinent to reservoir sediment flushing and sluicing, especially with regard to sediment management for maintenance of downstream water quality values

- develop a design framework for managing sediments in the reservoir at First Dam so that future maintenance procedures on the dam will not threaten downstream values

- design monitoring procedures for controlling flushing/sluicing events in order to protect water quality and fish during those events

- design monitoring procedures for assessing the effectiveness of sediment management measures applied at First Dam

Figure 1.b: Topography near First Dam on Logan River
1.4 Products

As discussed above, the main output of the project is this interim plan for sediment management in First Dam, which has as its main objective the specification of procedures to minimize the downstream impacts of sediment releases associated with periodic maintenance activities on the dam. By following the procedures recommended here, it should be possible for USU to operate the dam so as to safeguard downstream fisheries and water quality.
Approximately 40,000 large reservoirs and numerous small reservoirs around the world are used for water supply, power generation, flood control, recreation, etc. (White, 2001). Typically, between a half and one percent of the storage volume in a reservoir is lost annually due to sedimentation. The rate of loss of storage for a given reservoir is dependent on the rate of erosion of the catchments. In regions where erosion from the catchments has remained stable, the rate of storage loss is constant. In many areas of the world the designed lifespan of a dam is drastically reduced due to unpredictable sediment inflows, and it is this gradual loss of storage that has drawn the bulk of attention in the sediment management literature with respect to reservoirs. Sustaining the storage capacity of existing reservoirs has become an important issue. Substantial research has been conducted on the management of sediments in large reservoirs, but little attention has been given to small reservoirs.

The highest rates of storage loss are found in the smallest reservoirs. Even though many methods of sediment management have been examined, the uncertainty involved with respect to each reservoir is high. Each reservoir is unique with respect to local conditions, thereby making generalization of sediment management practices a very complex issue.

2.1 Physics of Sedimentation in Reservoirs

2.1.1 Sediment Transport Mechanisms in Reservoirs

Sediment particles are transported by flow in one or a combination of the following ways (Shen, 1971):

- rolling or sliding on the bed as surface creep
- leaping into the flow and then resting on the bed as saltation
- suspended and supported by the surrounding fluid during its entire motion

Sediments that move as surface creep or saltation are supported by the bed, and are called bed load. Sediments that are suspended or supported by the flow are called suspended load. Wash load is defined as the portion of sediment load governed by the upslope supply rate and is considerably less than the sediment transport capability of a river. In other word sediment that contains grain size lesser than bed load is termed as wash load. In general, suspended load provides the bulk of the total sediment load in an impoundment.
2.1.2 Reservoir Sediment Distribution

Two dynamic forces acting on individual sediment particles govern the movement of sediments into a reservoir. One is horizontal component acting in the direction of the flow owing to the force of the water movement. The other is the vertical force acting both upwards and downwards due to gravity and turbulence. As the flow enters the reservoir, the cross-sectional area increases and the velocity of flow, as well as the velocity of entrained sediment particles, decreases. Both the horizontal and vertical velocity components become small, resulting in the settlement of sediment particles. The pattern of how these particles deposit depends upon several factors such as the size of the sediments, reservoir inflow-outflow relations, size and shape of the reservoir, and the operation of the reservoir. Generally, deposition begins with the coarser sediments dropping in the reservoir headwater area, thereby gradually building a delta. Some of the finer particles will be transported by density currents down to the dam in a pattern as shown in Figure 2 (Shen, 1971).

Sediment management in reservoirs involves removing or transporting sediments from the reservoir which would otherwise reduce reservoir storage capacity, clog turbines, produce adverse effects on aquatic plants and animals, etc. Sediment management techniques for a large reservoir vary greatly from those employed for a small reservoir. For small reservoirs of the type to which this project is directed, the ratio of mean annual runoff to reservoir capacity is large. Selection of an optimal sediment control strategy will depend on factors including cost, potential for downstream flooding due to sediment release, impact to downstream infrastructure, water quality, and other environmental considerations.

Figure 2: Profile of a Typical Reservoir Delta
2.2 Sediment Management Options

While much research has been done on sediment management for the purposes of preserving storage in large reservoirs, little has been done with respect to sediment management in small reservoirs for purposes of minimizing the downstream impacts.

Several techniques are used for the removal of sediments. These include sediment sluicing, flushing, sediment evacuation, and dredging. The respective processes applied in using these techniques and their advantages and disadvantages will be discussed briefly. The applicability of each method depends on factors which include hydraulic limitations, hydrology of the stream, geology of the watershed, geomorphologic character of the river, and so on. For example, for sediment flushing to be effective the outlet gates should be built with sufficient capacity so that the flushing flows can be much higher than the flow in the stream, even during high flows.

2.2.1 Sediment Bypass

Sediment bypass is a type of sediment sluicing technique. During flood flows when the river is carrying a large quantity of sediments, the flow is bypassed directly downstream without allowing the sediments to pass into the impoundment. This management practice is more appropriate for rivers in which flash floods are common. This technique has expensive requirements, including construction of a bypass dyke between the upstream and downstream end of the reservoir (with enough hydraulic capacity), a control weir, energy dissipater, and so on. Generally, these additional construction requirements will not be economically feasible for small reservoirs.

2.2.2 Reservoir Conservation

In this method a sediment control dam upstream of a main dam is used to collect sediment before it enters the main reservoir. The sediment is later removed. Sometimes the recovered sediment can be used for other constructive purposes if the volume of sediment is large and the recovery cost is less than the revenue that might be obtained from sales of sediment plus the value of the preserved storage volume in the main reservoir. This method is mostly appropriate for large reservoirs where sediment removal would be a significant problem and where the economic value of storage capacity is significant. Use of this technique would be limited to those situations in which there would be high economic value of sustained reservoir capacity.

2.2.3 Sediment Flushing Using Outlet Gates

A common technique for managing sediment in small reservoirs is to install a washout gate in the body of the dam. The force of the current can then be used to flush sediment that has been deposited in the reservoir.

2.2.4 Excavation and Dredging
Dredging is a technique generally used in large reservoirs. In the long term it is often a costly solution to the problem of sediment accumulation. Dredging techniques are classified in terms of such things as the type of equipment used and the season of the year in which dredging takes place. Dry excavation is typically used for sediment removal in a reservoir that is normally empty for a portion of the year or that could be easily emptied. After dewatering the reservoir, sediment is excavated with an appropriate excavating device. This method is restricted to large reservoirs and tropical reservoirs that are annually emptied during a dry season.

Dredging systems are generally classified as either hydraulic or mechanical, depending on the type of machinery used. In hydraulic dredging, the sediments are thoroughly mixed with water to form a slurry. They are then transported to a point of placement as a sediment-water slurry, dried, and either disposed or used. A similar technique is used in mechanical dredging, except water entrainment is minimal. The main disadvantages of dredging are that it is a costly process and disposal of the sediment waste is required, which might involve environmental impacts.

2.2.5 Development of New Technologies

There are other newly emerging technologies that involve hybrids of such things as sediment flushing techniques and robots. For example, researchers at the Biwa Research Institute in Shiga, Japan, are using robots to monitor water quality and during reservoir sediment flushing procedures. The robots automatically manipulate its position and samples for water quality by itself during a flushing event or during other periods.

2.2.6 Sediment Routing within the Reservoir

Sediment routing is the process of manipulating hydraulics of the reservoir at times when the river discharge is advantageous to the pass sediment through or around the storage pool. The main objective of this is to reduce the deposition of sediment at that particular time. This may even require emptying the reservoir, as in flushing, but with the sole objective of minimizing the deposition or balancing deposition and scour during the flood season. A main advantage of reservoir routing is that it preserves riverine flows, and the natural water quality is maintained. This minimizes the downstream effects on aquatic life and irrigation canals. Major disadvantages in sediment routing are that a large amount of the flood or spring runoff water has to be released and the previously settled sediments are not removed. Sediment routing is most applicable at hydraulically small reservoirs where the water discharged by large sediment-transporting floods exceeds reservoir capacity, making sufficient water available for sediment release without infringing on beneficial uses. Some sediment routing techniques may even concentrate the on a particular region in the impoundment with the intent of reducing interference with beneficial uses.

Morris (1998) has classified sediment routing as follows:
Sediment Pass-Through

In sediment pass-through approach, sediments are passed through the impounded reach with minimum deposition. Most sediment pass-through techniques require reservoir drawdown to maximize flow velocity in order to pass sediment through the impounded reach without deposition. Pass-through techniques vary according to the hydraulic controls applied during routing.

Sediment Pass-Through with a Seasonal Drawdown

Under this technique the reservoir is partially or fully emptied at a predefined season of the year for weeks or even months, generally on a predefined schedule. Under partial drawdown the reservoir is maintained at a lower pool elevation for the predefined season so that the combination of a flow velocity increase and detention time decrease would pass mobilize sediment and pass it from the reservoir. The sediment release capacity is determined by the sediment transport capacity along the full length of the reservoir for the whole area in the impounded reach. If the reservoir is fully emptied during a particular season, then this approach resembles a flushing technique except that the outlets are open for the whole season. A routing channel will be formed, as in a flushing event, for the sediment to pass through. The detention time of the reservoir is reduced during the flood or spring runoff season which helps in sediment pass-through. Settled sediments could be flushed during a free-flow period between seasons. By this method the peak concentration of sediments could be kept under control, as opposed to a flushing event, thus reducing negative downstream effects.

Flood Drawdown Routing Technique

The flood drawdown routing technique involves the control of hydraulic gates and weirs during flood periods. In reservoirs which are hydraulically small, the gate operation may be controlled using a rule curve and discharge measurements at the dam or at an upstream gage station. Depending on the desired grain size to be removed from the reservoir, a set rule curve for the operation of the hydraulic structures can be developed along with other criteria. This technique was used at the Cowlitz Falls Dam with the following set of rules (Morris, 1998):
- The 100-year flood level in the upstream area of the reservoir cannot exceed the pre-dam flood level. This established a minimum flood control drawdown curve.

- Prevent the upstream deposition of sediment during the flood period, with maximum sediment pass-through.

- Allow continuous operation of the turbines so that the reservoir water level is kept above the intake structure.

- Open the lower level gates as early as possible so that debris from floods is passed.

In reservoirs with significant storage or limited discharge due to a limited capacity of the release structures, sediment sluicing can be done using a rule curve. In this method, the reservoir gates are opened during the rising arm of the flood hydrograph and closed as soon as there is enough water to only refill the reservoir. The reservoir can also be emptied and the gates opened just before the beginning of the flood season so that some of the sediments that are settled can also be removed. This requires accurate prediction of the flood hydrograph, a thorough knowledge of the volume of water in the reservoir, and an understanding of the sediment hydrograph that the flood is going to carry.

**Sediment Bypass for an Instream Reservoir**

If topographical conditions are favorable, a large capacity channel could be built cross the actual river channel just upstream of the reservoir with flood control weirs. This is more ideal when if the river course is such that the river upstream of the reservoir meanders so that a short feasible channel could be constructed that connects directly to the downstream end of the reservoir. The floodgates are normally closed during the non-flood season allowing the water passing over the weir to get stored in the reservoir. During flood seasons the gates are opened so that all the water is diverted to the bypass channel. This technique is advantageous only when the topographical condition is feasible enough to construct a bypass channel and flood weirs.

**2.3 Sediment Flushing**

Sediment flushing is a widely used technique in many part of the world. Sediment flushing is concerned with the removal of sediments that have settled in the reservoir at a previous time. The main difference between reservoir flushing and sluicing is that flushing is concerned with the removal of sediments that have settled in the reservoir at a previous time, whereas sediment sluicing is concerned with passing sediments straight through the reservoir during times of flood flow. In flushing, the time series of sediment release below the dam differs significantly from that of sediment inflow. A proper sediment outlet design helps in the efficiency of reservoir flushing. Negative impacts of sediment discharge on aquatic life can be minimized by installing refuges for fish and taking steps to keep sediment out of irrigation channels (The world Commission on dams,
With proper hydrologic and hydraulic design the downstream effects of flushing with this method can be minimized.

### 2.3.1 Physics and Efficiency of Flushing

The control of reservoir sedimentation through hydraulic flushing has been employed for several years, but no comprehensive analysis has been conducted to fully understand the sediment flushing process. Lai (1995) and Shein (1995) conducted laboratory experiments to investigate the flushing process during drawdown flushing, including outflow sediment discharge, characteristics of the flushing channel, and flushing effectiveness. From both laboratory and field data, it was found that the outflow sediment discharge can be related to a hydraulic parameter which is a function of outlet discharge, water-surface gradient, and flushing channel width. It was also found that efficiency of the flushing increases when retrogressive erosion increases during flushing.

Scheurlein (1990) tried to develop a straightforward approach to calculate the approximate amount of sediment that would be removed in a flushing event. These calculations included information on the necessary drawdown for a desired flushing and are based on the simple assumptions of mass balance in the reservoir, a prismatic shape of the reservoir, and one-dimensional flow, a threshold sediment size below which all the sediments will be flushed and uniform flow during flushing (Scheurlein, 1990). Factors such as lateral mixing of the incoming flow on the way through the reservoir were not considered. This model will give a rough estimate of required drawdown for flushing assuming that the drawdown discharge, width of the sediment channel, and the height of the reservoir are known.

Knowledge of the quantity of sediment flowing into and out of a reservoir over time will give an estimate of the total amount of sediment volume present in the reservoir. This can provide insight into the hydraulic and hydrologic control required on the reservoir in order to manage sediment. Jansson and Erlingsson (2002) tried to estimate the sediment inflow and outflow for the Cachi Reservoir between two flushing periods to test the efficiency of the flushing event. The main principle to estimate sediment loads by a rating-curve technique is to collect sediment data from a large number of runoff events at equal intervals during the rising and falling stages using turbidity meter recordings. The turbidity readings were converted to sediment concentrations using a regression equation and the relation developed between the turbidity and sediment concentration. Then sediment concentrations were plotted against discharge using a logarithmic regression plot and the sediment rating curve was developed assuming that the major part of the sediment inflow comes during flash floods. The sediment through-flow determined with Sundborg’s physically based sedimentation model amounted to 20 percent of the suspended inflow, which matched well with the empirical budget. The Sundborg model assumes that the trap efficiency is a function of sediment concentration, settling velocity, and water discharge. With the required inflow, outflow, and sediment through-flow during flushing, a mathematical model was developed to predict the current and future behavior and trap efficiency of the reservoir. It was also cross checked with the empirical values taken at various cross sections to get a reliable estimate of trap efficiency and
grain size distribution. It was found that the total accumulation of sediment was about 14 percent of the total sediment inflow (Jansson and Erlingsson, 2000), and the sediment outflow during reservoir flushing was 71 percent of the inflow. This proved that sediment flushing was highly effective, but this type of sediment budgeting requires careful analysis and reliable values from field data.

Milhous calculated flushing flows with two concepts in mind. One is determine the parameters required for calculating flushing flows and the second is the integration of a flushing flow requirement with a habitat requirement. However, the equations he developed are specific to gravel and cobble.

Anders and Joar (1999) tried to understand the sedimentological and geomorphologic effects of reservoir flushing in the Cachi Reservoir, Costa Rica. The sediment distribution and loading conditions were studied for both pre- and post-flushing periods to gain an understanding of the sediment erosion and deposition during sediment flushing. The erosion sequence is based on the theory that too coarse bed material will not be eroded, and coarse materials that are eroded will be re-deposited first. Monitoring stations were set up along an 80-km length of the reservoir downstream of the reservoir. Flow, suspended sediments, and grain size were measured at calculated times. The results implied that the flushing flow follows the old river channel where it deposits its load. Since the reservoir is flushed every year, the sediments along the river channel are loose enough so that they are flushed out first when the gates are opened. A basic lag between the peak sediment concentration and water discharge was observed which implies that the largest part of the flushed-out sediments are released towards the end of the main flushing event and the beginning of the free-flow phase. This might not be the case in all flushing events since it depends on the flushing flows and time duration of the total flushing event.

### 2.3.2 Types of Sediment Flushing Procedures

White and Ackers classified sediment flushing into:

- **Empty flushing**: This involves fully emptying the reservoir--or emptying it to a maximum limit close to the outlet level--and then flushing the sediments through the outlet gates.

- **Pressure flushing**: This requires less drawdown. In this approach, sediments are flushed by the pressure exerted due the remaining head in the impoundment. This technique is considered less effective since only the materials close to the reservoir outlet are flushed. Sediments from further upstream will move downstream but generally do not get flushed.

**Emptying and Flushing**

In this type of flushing, the reservoir pool level is lowered down to the outlet level and the sediments are flushed. This can be done either in the flood season or in the non-flood season. Flushing during flood seasons will have very high flows and greater sediment
release. Also, during these periods the sediment concentrations in the river will be naturally high and so the environmental downstream effect will be limited. A disadvantage is that the dam must have the hydraulic capacity to discharge enough flow to provide drawdown of the reservoir pool.

Emptying during non-flood seasons is an easier task if the hydraulic capacity of the outlets are limited, but the flushing efficiency is reduced since less flow is present to mobilize the sediment from the upstream end of the reservoir. As a result, only the sediment close to the outlet gates is flushed. A remedy would be to increase the flushing period for a longer time so that the desired amount of sediment is flushed. In some areas the reservoir is emptied during the early flood season and operated without much detention. It is then refilled during the later part of the flood season. By incorporating elements of both sediment flushing and sluicing, this technique is more effective rather than using only one of these approaches.

**Flushing with Partial Drawdown**

Due to the restriction in either allowable drawdown or the invert elevation of the flushing outlet, flushing might have to be undertaken with only partial reservoir drawdown. In partial drawdown flushing, the reservoir pool is partially drawn down and the outlet gates are opened under the remaining pressure. The controls are adjusted according to local conditions. In some cases the reservoir is lowered and the outlet is opened under pressure. Flow is allowed to continue for a time, and then the reservoir is refilled. This drawdown-refill process is repeated a number of times until the desired amount of sediment have been removed.

**Pressure Flushing**

Under pressure flushing the reservoir pool elevation is lowered to a minimum operating level and then outlet gates are opened allowing a conical scour hole to be formed near the gates. At the same time, a minimum operation level is maintained. A study of the Gebian Reservoir indicated that by using this technique, sediments at the scour hole could be evacuated in two or three hours, but 20 to 30 hours were required to fill the scour hole again with sediments. Repeated drawdowns were required for good results.

**2.4 Mathematical Modeling of Sediment Releases**

The efficiency and process dynamics of sediment flushing has been simulated with mathematical models. Various mathematical models have been developed that focus on different sedimentation mechanisms. Though the reliability of these models is often questioned, they can sometimes be used to obtain rough estimates of sediment mobilization and to predict the overall behavior of the system. As mentioned earlier sediment transport and sediment flushing are complex phenomena that are not well understood. Mathematical models reflect only case specific conditions and cannot be generalized since each reservoir has its own hydraulic and hydrologic conditions. In a survey conducted in 1987 the Interagency Sedimentation Working Group (ISWG) found
that 48 computer models were available for simulating sediment transport, but there was little guidance available to select and properly use these models to carry out sedimentation analyses (Fan and Springer, 1996).

Jansson and Erlingsson (2002) used a mathematical model based on Sundborg’s equation of trap efficiency. A sediment release on the North Fork Cache River in northern Colorado resulted in a massive fish kill and channel sedimentation that filled pools critical for fish winter habitat. Two mathematical models, HEC-6 and GSTARS 2.0, were used to understand the change in pool elevation and morphology after sediment flushing. Channel surveys were conducted after the sediment release, after experimental discharge, and again after the snow melt receded to obtain input data for the models. The models use sediment load, a sediment-rating curve, and gradation in bed material as input. HEC-6 was found to be more reliable than GSTARS 2.0, though HEC-6 was only a one-dimensional model. It was also found that the experimental discharge helped in establishing an improved pool volume for fish.

Olsen (1999) developed a two-dimensional numerical model to simulate flushing events. The model uses the Navier-Stokes equations on a two-dimensional grid. The resulting flow field is converted to three dimensions and the convention diffusion equation for sediment concentration is solved. The results of the model were compared with those of a physical model. The deviation between the measured and calculated bed level profiles was high (Olsen, 1999).

Chang et. al. (1996) developed a model for the North Fork of the Feather River for application of a sediment pass-through (SPT) technique. The main purpose of the SPT technique is to maintain a sediment balance through the reservoir so that there is no net erosion or deposition. This is similar to a sluicing technique. The model was developed using FLUVIAL-12. The model generated a rating curve that specifies the reservoir drawdown required and operation of the control gates to accomplish a sediment mass balance. The study concluded saying that the SPT technique is a good sediment management procedure provided a proper drawdown-discharge relation is available. Proper use of the rule curve would dramatically increase the performance of sediment management measures (Chang et. al., 1996).

Chang et. al. (2003) developed a combined reservoir simulation and sediment flushing model to determine how to meet water demands and at the same time perform efficient flushing. In the reservoir simulation model, a genetic algorithm is used to optimize and determine the flushing operation rule curve. First the reservoir simulation model is run based on the storage continuity equation, and when a decision is made to flush the reservoir, the sediment flushing volume is calculated and the output discharge-stage curve is updated. These procedures run in a loop until satisfactory rule curve parameters are obtained. This model was implemented on the Tapu Reservoir using 36 years of historical data. The performance of the model proved to be much better than using a conventional reservoir operation method (Chang et. al., 2003).

2.5 Downstream Effects of Sediment Releases from Reservoirs
The main purpose of this project is to determine how sediment flushing can be accomplished at First Dam with minimum downstream impact. Generally during sediment flushing, the concentration of total suspended sediments (TSS) and temperature increases while dissolved oxygen (DO) concentrations decline, depending on the sediment characteristics. This section provides information about the impacts of these changes during sediment flushing. Unfortunately, little work has been done on these problems.

The environmental impact of increased TSS concentrations in streams is not well understood. Research has been conducted to understand the impact on aquatic fauna and flora due to TSS increase. Despite this, there is little agreement on the environmental effects of suspended sediment as a function of concentration and duration of exposure. Newcombe and MacDonald (1991) compiled a summary of more than 70 papers on the effects of inorganic suspended sediments on freshwater and marine fish and other organisms in an effort to develop a database on such effects. They concluded that environmental pollutant severity is not only dependent on the concentration of the pollutant but also on the duration of exposure. In their study, Newcombe and MacDonald (1991) divided the effects of exposure to concentrations of suspended sediments on aquatic life into 14 categories and provided a database on these effects with respect to various aquatic organisms. The study provides information on various TSS concentrations, the time of exposure, stress index (log raised to the product of TSS concentration and time of exposure), and the level of effect on each stage of brown and rainbow trout species, which are the predominant species downstream of the First Dam case study. The data for brown and rainbow trout suggests that the exposure to TSS alone for a period of time does not kill the fish unless the concentration is abnormally high and the period of exposure is for a very long time. The paper concludes by recommending use of the stress index rather than just the TSS concentration to evaluate the impact of sediment concentrations on trout species.

Bergstedt and Bergersen (1991) conducted a study of the effects of sluicing operations on fish populations in the Wind River, Wyoming. The maximum sediment concentrations in the river were as high as 18,000 mg/L directly below the release point. In this study, fish were tagged to understand their behavior and movement. Although the effects of suspended solids on fish have been well studied, there is a lack of agreement on the concentration necessary to cause health effects (Bergstedt and Bergersen, 1991). Everest et al. (1987) reported that mortality of salmonioids only occurs when concentrations are greater than 20,000 mg/L. Newcombe and MacDonald (1991) suggested that mortality can occur at lower concentrations and that the severity of the effect is also related to the duration of the event. While Newcombe and MacDonald (1991) recommended use of both TSS concentrations and duration of exposure, others have suggested that threshold levels, temperature, fish size, and particle size also have to be taken into consideration (Servizi and Martens, 1992; Gregory et al., 1993).
CHAPTER 3

ALTERNATIVE PROCEDURES FOR FLUSHING/SLUICING AT FIRST DAM

3.1 Background

The case study reservoir First Dam on the Logan River, Logan, Utah, is a small concrete buttress dam built in 1914. It is located at the mouth of Logan Canyon at latitude 41°44'25" N., longitude 111°47'29" W. First Dam is owned and operated by Utah State University (USU). It is primarily used by the University for research purposes and power production, and the small lake that it forms provides recreation opportunities to the local community. The dam, which underwent renovation in 2001-2002, consists of three sections, namely: a slab buttress, spillway, and power station. The slab buttress section, which is 112.5 feet long and 25 feet high at its maximum, was designed as a counter for a retaining wall [5]. The Ambersen spillway section of the old dam sat in the center of the span with a height of 26 feet and length of 69 feet. The spills were controlled by seven stop-log structures across the top of the section. The original powerhouse, located next to the spillway, had a 1.5 MW capacity. A view of the dam before rehabilitation began in 2001 is shown in Figure 3.

Figure 3: First Dam before Renovation
In 1999 the Utah Department of Natural Resources, Division of Water Rights, examined the dam and declared it to be a high-risk structure. As a result, a decision was made in 2000 to rehabilitate the dam. Actual construction work associated with the rehabilitation effort began in the fall of 2001, and rehabilitation was completed in Dec 2002 (Fitch, 2002).

The primary objective of the rehabilitation project was to overlay a 4-foot reinforced concrete (RC) buttress over the slab buttress, and then to provide automatic pneumatic lead gate controls for the spillway. In addition, the generator and powerhouse were replaced, and a new axial flow turbine was fixed to one of two new penstocks. The turbine has automatic gate valves that adjust the discharge intake with respect to the flow. The new low-head turbine and generator can produce 350 kilowatts. The energy that is generated is fed directly into the USU campus power grid. The spillway is now controlled by twin Obermeyer gates, which can be operated either manually or automatically. At the bottom of the spillway, two low-level outlets are provided for drawdown and reservoir-flushing purposes, as shown in Figure 4. The reservoir volume is 140 acre-feet.

The Utah Water Research Laboratory (UWRL) is located a short distance below the dam. The UWRL diverts water from the reservoir at First Dam for purposes of conducting hydraulics research. Flows that are diverted from the reservoir through the UWRL research facilities are returned to the river approximately a half-mile below the dam.
Immediately downstream of the dam is a diversion that provides water for irrigation. A typical cross section of First dam is shown in Figure 5.

![Image of Cross Sectional View of First Dam](image)

Figure 5: Cross Sectional View of First Dam

3.2 Potential Procedures for Flushing/Sluicing at First Dam

A properly designed and implemented reservoir maintenance management plan could minimize the impacts of reservoir flushing on downstream water quality, fisheries, agriculture, and other water uses. As mentioned earlier, the ultimate purpose of this research project is to determine inexpensive and effective sediment control procedures for small reservoirs in Utah so that the negative downstream impacts of reservoir operations can be minimized. This chapter will deal with the various alternatives for flushing or sluicing that might be applied at First Dam, based on the hydraulic structures and hydrologic and other local conditions that prevail. The advantages and disadvantages of experimenting with each alternative will be discussed. Based on trade-offs among the sediment management alternatives, a decision tree is developed that illustrates the range of management decisions that might be followed, from most conservative and safe, to most risky from the point of view of maintenance of downstream water quality.

As anoxic sediments are released from a reservoir, naturally occurring chemical reactions can take place that can release ammonia, hydrogen sulfide, or methane gases. At high enough concentrations, these can be toxic to fish. The presence of these chemicals is influenced by water quality properties like dissolved oxygen (DO), temperature, and total suspended solids. In all cases of reservoir flushing/sludging to be conducted at First Dam, these parameters will be periodically monitored during the flushing/sludging event and, should their levels begin to fall outside pre-agreed ranges, flushing/sludging controls will be modified or terminated. The design of monitoring procedures and locations are discussed in the next chapter.
3.2.1 Estimation of Hydraulic Conditions Necessary to Mobilize Sediments

Modeling of the mechanics of sediment transport through a reservoir is a difficult and imperfect science. Available tools for this type of analysis only provide rough quantitative estimates of the amount of sediment that would be released in a sediment flushing event. This is especially the case for cohesive soils (Morris and Fan, 1998). In the case of First Dam, calculation of the fluid velocity necessary to impart motion to the sediments--called incipient velocity--would be a questionable exercise because flushing will involve the transport of sediment ranging from clay through gravel. Although several bed load and sediment transport equations are available in the literature, in practice these are largely empirical and exhibit extremely large ranges in the estimates they provide of incipient velocity and sediment transport. Choosing an appropriate equation to employ, therefore, depends entirely on the available data and geometry of the sediment profile of the reservoir.

3.2.2 Alternative Sediment Management Procedures during High Flows

The main problem to describe on the exact period of flushing is to decide on what exactly are high flows and low flows. As a definition used here, a high flow occurs when the inflow into the reservoir is greater than the maximum capacity of all release mechanisms exclusive of the spillways. Otherwise, a low flow prevails. Under high flows, the hydraulic structures at the dam are not capable of drawing down the pool elevation of the reservoir. The various sediment management alternatives possible for high flows are discussed below.

**Alternative 1**

In the first alternative, adjustments in total releases through the reservoir are controlled by throttling flows through the low-level outlets. This process requires high flows in the river for good results. This procedure assumes that the deposit of sediment that is located on the bottom near the lower level gates (see Figure 6) is the most dangerous to the downstream environment.

The control procedures for this alternative are as follows. First, all outlets from First Dam except the lower level outlets and the UWRL diversion will be fully opened (refer to Figure 7). Then the low-level outlets will be opened a small percentage, say 20 percent of full valve opening. During flushing, the diversions into downstream irrigation canals should be curtailed so that the canals do not incur sedimentation damage. This will also ensure that all the release is used for dilution and thorough mixing of the sediment coming from the lower level outlets. This alternative, and the next, will provide some aeration for the anaerobic sediment that is discharged, especially if substantial quantities of water can be passed over the spillway.

At this point it is recommended that upon initially opening the low-level outlet valves, flows through the outlets be maintained for a period of four to six hours. Anecdotal evidence and the data collected from the April 22, 2002 reservoir drawdown (see
Appendix 1) indicate that the plug of sediment that is released requires a few hours to mobilize. If the downstream monitoring activities indicate that water quality parameters are well within the tolerated limits, the opening of the low-level outlet valves might be increased to, say, 40 percent or even higher. Until more experience is gained, however, these adjustments will have to be done according to information collected from the water quality monitoring. If the DO or turbidity measurements begin to approach the agreed limits, then the percentage opening of the lower level outlets should be reduced or totally closed. In this way the safest procedure for sediment management will be ensured.

Figure 6: Trash Racks in Front of Intakes to the Turbine and Low-level Outlets

The advantage of following this procedure is that maximum mixing of the sediments can be accomplished since the flows from the spillway and turbine would have high discharges. The disadvantage is that since the process is done without any drawdown in the reservoir the amount of sediment released will probably be much less in comparison to flushing the reservoir with a drawdown.

**Alternative 2**

This process will require higher flows than Alternative 1. In this procedure, the spillway gates will be adjusted to create a hydraulic jump in the stilling basin downstream of the dam while the low-level outlets are opened, thereby aerating the sediments being discharged. This process might be combined with the discharges outlined in Alternative 1 (i.e., including flows through the penstock). The energy dissipaters that are present in blocks just downstream of the dam structure (Figure 8) will help in creating turbulence to
produce efficient mixing. This procedure, along with Alternative 1, is the most conservative for minimize downstream effects.

3.2.3 Alternative Sediment Management Procedures for Low Flows

As previously defined, low flows occur when capacity for releasing water from the reservoir is sufficient to cause a drawdown of the reservoir pool. The literature on reservoir flushing indicates that flushing events done during high flows with a maximum drawdown are more efficient in removing sediments that flushing during low flows.

**Alternative 3**

Alternative 3 is similar to Alternative 1 except that water does not spill over the spillway. This procedure is also possible during high flows when water is present for spills but sizable releases are also required for the UWRL. In this alternative, the reservoir pool elevation is drawn down, and then the low-level outlets are opened. As in Alternative 1,
the low-level valves would be used to throttle the releases in a manner consistent with
meeting pre-defined downstream water quality requirements during sediment flushing
(see Figure 9). By lowering the reservoir pool elevation below the spillway, this
alternative would generate higher shear velocities on the deep sediment deposits

immediately upstream of the dam. In turn, this would help to more efficiently flush the
sediments from the reservoir. In addition, this alternative would be more likely to
achieve some mobilization of sediments that are further upstream in the reservoir.

**Alternative 4**

This procedure is intended to provide thorough mixing of the sediments settled in the
bottom before the actual flushing event begins. In this procedure, the reservoir pool
elevation is pulsed; first, the reservoir is drawn down to a level near the intake to the
penstock; then it brought back to normal (see Figures 10 and 11). The lower level outlets
are then opened to induce sediment mobilization. As in other alternatives, the resulting
downstream water quality parameters are monitored. If the concentrations are within pre-
agreed limits then the actual flushing event is conducted. If the results are not
satisfactory then the reservoir is again drawn
down, perhaps to a few feet below the penstock intake level, and then brought back to normal. The greater the amplitude achieved in pulsating, the greater will be the effect in mixing of sediments. However, the effect of a higher drawdown risks a more negative impact on downstream water quality and fisheries. This risk might be minimized if Alternative 4 is used in combination with others that might have already reduced the size of the sediment plug located immediately upstream of the dam. The effective drawdown depth could be used for future flushing events. In addition, there is the possibility that the anaerobic bottom sediments could be aerated to some extent. The main advantage of this process is that by pulsating the reservoir level, some of the sediments in the upstream portions of the reservoir might become mobilized and pass released. By the time the actual flushing event begins, a portion of the sediments would have accumulated near the downstream end.

![Figure 11: Schematic of Reservoir Pulsing for Alternative 4](image)

**Alternative 5**

In this approach, sensor devices that measure the dissolved oxygen concentration and turbidity would be fit either into the upstream portion of the low-level outlets or on the downstream side of the outlets. With the low-level outlet valves open, the sensors could be monitored to detect unacceptable levels of turbidity. Should this occur, the valves could be closed immediately. The advantage of this process is that it is quite simple. A disadvantage is in the difficulty and cost of sensor installation. The principal disadvantage of this alternative is its lack of assurance that sampling done at the outlet works would be representative of actual water quality conditions that would result downstream.

**Alternative 6**

This process involves carefully controlling the valves of the lower-level outlets under low-flow conditions. Initially, a very conservative control, say, a 20 percent valve opening, is set and the downstream water quality is tested. If the downstream DO and turbidity standards are met, then the control valves are opened further, perhaps another 10
percent, for increase the release of sediment (see Figure 12). The main problem with this approach is the risk of mobilizing too great a plug of anoxic sediment. Uncertainties also involve the decision of the initial opening of the low-level outlet valves and the increment required for changes in the valve opening. This alternative could be undertaken in combination with other alternatives for better results.

Figure 12: Illustration of Low-level Outlet Control for Alternative 6

Table 1 shows the various advantages and disadvantages associated with each alternative (see Table 1).

3.3 Recommended Flushing/Sluicing Procedures for First Dam

In consideration of the uncertainty involved in managing reservoir flushing, and recognizing the lack of data and understanding of the relationships among sediment releases, water quality, and fisheries impact, it is recommended that initial flushing activities at First Dam be confined to high-flow conditions. Alternative 1 or 2 should be implemented first, and the results of these attempts should be studied before alternatives involving more risk to downstream water quality and fisheries be attempted.

This should be considered an interim recommendation pending the outcome of sediment flushing events and the analysis of the data they will produce.
Table 1: Advantages and Disadvantages of Various Alternatives

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Flow conditions</th>
<th>Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>High flows</td>
<td>Release of the sediment in proportion.</td>
<td>- Thorough mixing due to high flows.</td>
<td>- No drawdown</td>
<td>Better with a combination other process</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Dilution and re-aeration possible.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Re-aeration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative 3</td>
<td>Low flows</td>
<td>Release of the sediment in proportion with draw down</td>
<td>- Drawdown</td>
<td>- No spills</td>
<td>Better with combination of others. E.g., Alt 1 during high flows and alt 3 during low flows.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Reservoir capacity is sustained</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative 4</td>
<td>Low flows</td>
<td>Pulsating the reservoir</td>
<td>- Possibility of re-aeration.</td>
<td>- Could be fruitless.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Brings the sediment closer to the dam.</td>
<td>- Helps only in re-aeration</td>
<td></td>
</tr>
<tr>
<td>Alternative 5</td>
<td>Any flows</td>
<td>Automatic sensors</td>
<td>- Easy and simple to follow.</td>
<td>- Difficult in installation and cost. -doubt whether the measurement the whole system.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Any flows</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative 6</td>
<td>Any flows</td>
<td>Open the valve and check for water quality.</td>
<td>- Easy and simple to follow.</td>
<td>- Least conservative technique. - Initial amount to be opened. - Increment</td>
<td></td>
</tr>
</tbody>
</table>
4.1 Introduction

Monitoring is one of the most important factors influencing the success of a sediment management plan. Proper design of sampling and monitoring will help in decision-making during a sediment flushing event. A program of sampling will also help in measuring the success of a flushing event and in determining the need to conduct future flushing/sluicing activities.

This chapter summarizes the available resources for monitoring and presents information about the proposed installation of a monitoring station. Information about the frequency of sampling, monitoring of the components to be tested, the procedures for testing the components, and other details are also discussed.

The following sections provide information on proposed sampling activities involving stream flow, chemistry of sediments in the reservoir, reservoir bathymetry, background water quality parameters, and water quality conditions during sediment flushing activities.

4.2 Stream Flow

Stream flow is the most important property to be monitored during a flushing event. Quantitative knowledge of stream flow is required in order to estimate sediment loading and the effectiveness of sediment control measures. It plays a key role in deciding what types of sediment management procedures to apply.

4.2.1 Location of Stream Flow Gages

The available resources were assessed for obtaining adequate measurements of stream flow both in and out of the reservoir. A USGS gage station exists just upstream of the reservoir near the Logan River Old Power House (USGS 10109000, Logan River above the State Dam) that can be used to obtain inflow data to the reservoir. Both hourly and daily mean flow can be obtained online for this station.

To measure and evaluate the flows downstream of First Dam, a gauging station is proposed to be installed to provide continuous (15-minute interval) and daily average flow estimates. Three sites were considered for the location of this monitoring station, including one immediately downstream of First Dam, at the bridge crossing the river at the UWRL parking lot, and a site downstream from the UWRL return point to the river. These sites present different trade-offs in terms of construction costs, potential for vandalism, and difficulty of providing power and telemetry capabilities (refer to Table 2).
Upon consideration of these trade-offs, it is recommended that the stream flow gauging station be located at the UWRL Bridge.

### Table 2: Trade-offs Among Alternative Stream Gage Sites

<table>
<thead>
<tr>
<th>Location</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediately downstream of First Dam</td>
<td>Stable cross section; a USGS station gage station hut is already there and it might be possible to obtain access to this; would be located upstream of first canal diversion, so a better total release directly from the reservoir could be easily estimated.</td>
<td>Access cannot be controlled and damage/vandalism might be a problem; this might not be far downstream to assess the actual concentration of sediments since mixing cannot be assured; power supply and telemetry would be difficult; permission must be obtained from the USGS to use the old hut.</td>
</tr>
<tr>
<td>UWRL bridge</td>
<td>Stable cross-section; access/vandalism would be much less of a problem; power supply/telemetry would be simple to develop; full mixing would probably be assured.</td>
<td>The site is downstream of first diversion below the dam, so any releases into the irrigation canal would have to be obtained separately.</td>
</tr>
<tr>
<td>Downstream from the UWRL, near the UWRL hydraulic return point</td>
<td>Cross section should be stable, give or take vegetation. Thorough mixing could be ensured at this point.</td>
<td>High risks of vandalism/damage compared to the UWRL bridge option; greater difficulty for power/telemetry. Maintenance problem due to the greater distance from the UWRL.</td>
</tr>
</tbody>
</table>

### 4.2.2 Design of the Stream Gage at the UWRL

The various methods of discharge measurement have been evaluated in terms of compatibility with local conditions. The best method would be to install a gage instrument that will measure the stage in the stream so that a stage-discharge rating curve can be developed and used. It is proposed to construct a steel frame hanging from the UWRL bridge with an ultrasonic sensor attached to it. This installation should be relatively easy and cost-effective. The ultrasonic sensor will measure the water level in the river with reference to a selected datum. Care must be taken to select a sensor location that is minimally affected by turbulence and humidity. A data logger will be
fixed to the sensor so that the reading signal can be recorded and transmitted to a computer at the UWRL.

A stage-discharge rating curve will be developed at the UWRL site over the course of the spring runoff period in 2004. This will accomplished using velocity metering equipment available at the UWRL.

4.3 Sediment Chemistry

Toxic chemicals that might be produced in the process of releasing anoxic bottom sediments from First Dam include ammonia, hydrogen sulfide, and methane gases. The presence and concentrations of these chemicals are affected by water quality parameters including temperature, pH, and dissolved oxygen.

The objective of the sediment sampling activity is to characterize the potential toxicity to important aquatic species of the sediments at the bottom of the reservoir after they have been mobilized and fully mixed by a reservoir flushing event. Accordingly, sampling and analysis need not focus on the particular characteristics of sediment cores and/or the locations from which they were taken, but instead develop information about the potential toxic agents that will be produced as the sediments that are mobilized by a flushing event are mixed in the stream and move down the river channel below the dam. Parameters to be assessed will include NH₄, CH₄, H₂S, pH, EC, and ORP. The area immediately upstream of the dam in the reservoir where anoxic sediments accumulate is limited to the bottom of the narrow river channel that is submerged by the reservoir pool. This area is approximately 30 feet wide and 150 to 200 feet long. Twenty sediment cores will be obtained from this area at locations uniformly distributed along the longitudinal axis of the channel. This will be done one time only, before spring runoff when river flows and water velocities are relatively low. While it would be possible to obtain undisturbed samples by employment of a trained Scuba diver, this would involve greater sampling expense and would not likely yield data of any additional value for purposes of chemical analysis. Such samples, however, might be useful for hydraulic study of incipient motion velocities.

Laboratory analysis of all samples will be performed at the Utah Water Research Laboratory. The chemical and toxicity information developed from these tests will be used to determine the best control measures for preventing the formation of toxic anoxic bottom sediments and for minimizing their impacts during periods of reservoir flushing. In later stages of the project, the chemistry of these bottom sediments will be related to the geology of the Logan River watershed so that watershed characteristics can be utilized in a qualitative fashion in the general reservoir management guidelines to be developed by the project.

4.4 Bathymetry

4.4.1 Bathymetric Survey
Bathymetric surveys will be conducted twice during the project to determine the quantities of sediment upstream of the dam that are mobilized by the flushing activities. Flushing events will also be monitored to determine the quantity and timing of sediment release. This will be done through sampling of suspended sediments and stream flows upstream and downstream of the case study reservoir during the spring runoff period surrounding reservoir flushing events.

The equipment required to conduct a bathymetric survey ordinarily consists of standard land surveying instruments, sonic sounders, boats, and a variety of auxiliary equipment including GPS locator and radios for communication. Sonic sounders have transmitters and receivers that measure the depth of the channel bottom by exploiting information about the time required for sound waves to travel up and down the water column. The depth will be measured at regularly spaced grid points in the reservoir. During the survey the GPS location of each point of survey will be noted for reference. Doing the survey again after the actual event will provide information about the change in sediment profile and amount of sediment that has been mobilized.

4.4.2 Alternative to Bathymetric Survey

The costs associated with conducting a bathymetric survey are high. An alternative would be to utilize a trained Scuba diver to fix steel pins on the reservoir bottom. The pins would have a graduated scale that could be used periodically to measure the deposition/scour of sediment. By re-surveying the pins before and after a sediment flushing event is performed, a sediment budget could be calculated and the effectiveness of the flushing event could be evaluated. This could be an inexpensive survey technique provided that public recreational activities on the reservoir of First Dam (e.g., fishing) do not result in frequent removal and loss of the pins. In addition, photographic views of the sediment profile might be obtainable during the Scuba diving work if light conditions on the bottom of the reservoir permit.

4.5 Background Water Quality Conditions

Water quality measurements will be obtained during non-flushing periods in order to develop a profile of normal levels of DO, total suspended solids (TSS), turbidity, pH, conductivity, and temperature in Logan River upstream and downstream of First Dam. Monthly sampling will be done for these constituents. (Continuous monitoring of these parameters is beyond the budget of the project.)

Background concentrations of the above constituents will be monitored at the same locations each time. While various locations were evaluated, the USGS gage station above First Dam (where discharge data will also be available) and a station near the UWRL hydraulic return point to the river (were the stream gauging station is proposed) have been selected for background water quality monitoring.

TSS cannot be directly measured in the field, so laboratory analyses of grab samples will be needed to obtain estimates of sediment concentrations. It is hoped that by monitoring
turbidity and TSS every month at both upstream and downstream sampling locations, an estimate of the sediment that settles in the reservoir could be obtained. In addition, it might be possible to build a TSS-turbidity rating curve for these points on the Logan River. With the sediment inflow, outflow, deposition and the bathymetric survey conducted before and after flushing events, a sediment budget can be obtained for future sediment management practices. In this way the approximate time for flushing could be calculated. Monitoring procedures, laboratory analyses, and quality assurance criteria are described in the project proposal.

4.6 Water Quality Monitoring During Flushing/Sluicing Events

The little data that are available (see Appendix 1) indicate that temperature and conductivity do not show significant changes during flushing events, but turbidity, TSS, and DO demonstrate classic transport patterns as a result of sediment release from First Dam.

The objective of this sampling is to provide an estimate of sediment discharge during a flushing event and qualitatively evaluate the potential impacts to fisheries that might result. Initially, sampling will be conducted at 30-minute intervals following the commencement of flushing activities. Field experience with a previous flushing event at First Dam indicates that this sampling frequency is sufficient to capture the pulse that is discharged. Also, previous experience shows that ambient water quality levels for the parameters being measured are re-established within a 6- to 8-hour period. The results of field sampling will be evaluated during the flushing event and the sampling frequency will be decreased to hourly (or a lesser frequency), depending on the rate at which concentrations return to ambient levels. The duration of sampling during a flushing event will be dictated by the duration of the event itself and the rate at which ambient concentration levels are re-established after termination of flushing. Sampling will be done during a flushing event at a single location that is far enough downstream of the dam to allow for flows to be fully mixed. As indicated in the previous section, this location, selected on the basis of proximity to the stream flow gauge, ease of access, and likelihood of complete mixing, has been chosen to be near the UWRL hydraulic return point on the Logan River. The sampling procedures and related quality assurance mechanisms for these monitoring activities are described in the project proposal.
CHAPTER 5

PRODUCTS OF ANNUAL SEDIMENT MANAGEMENT ACTIVITIES AT FIRST DAM

5.1 Annual Sediment Management Report for First Dam

It is recommended that an annual sediment management report be prepared by USU Facilities, the operators of First Dam. This report should document the sediment management procedures employed during the year, present the data collected throughout the year on water quality and stream flow conditions, present water quality and stream flow data pertaining to any flushing/sluicing activities, and provide estimates of the quantity of sediment that entered and left the reservoir throughout the year. In general, a sediment budget should be provided in the report to guide future sediment management activities.

The annual sediment management report should also recommend any changes in sediment flushing/sluicing procedures and in water quality and stream flow monitoring. These recommendations should be based on analyses of the data collected from the on-going and event-specific monitoring that is recommended in this document. In this way the efficiency of sediment management could be improved each year.

5.2 Data

It is also recommended that the data collected under the auspices of the sediment management program be made readily available in published report form and via the web. The on-going water quality sampling results should be published in the EPA STORET system.
REFERENCES


APPENDICES
APPENDIX A

ANALYSIS OF THE APRIL 2002 FLUSHING EVENT

Some limited water quality data were collected during the flushing event that was held at First Dam on April 22, 2002. These data have been used, together with various assumptions about stream flow and the mechanics of sediment mobilization, to estimate the discharge required in Logan River in order to produce a flushing condition that would not violate Utah state water quality standards.

The flow in the Logan River on April 22, 2002, as measured at the USGS gage upstream of First Dam, was approximately 150 cfs. It is assumed that the volume of sediment flushed would be equal to the amount of sediment deposited after a flushing event that was conducted approximately 6 months earlier on October 16, 2001. Table 1 and Figure 1 show the observations of TSS made during the flushing event on April 22, 2002.

Table 3: Time-series of TSS Measurements Following the April 22, 2002 Flushing of First Dam

<table>
<thead>
<tr>
<th>Time of observation, hours following the opening of low-level outlets</th>
<th>TSS (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00:00</td>
<td>5</td>
</tr>
<tr>
<td>0:35:00</td>
<td>153</td>
</tr>
<tr>
<td>1:05:00</td>
<td>37</td>
</tr>
<tr>
<td>1:35:00</td>
<td>82</td>
</tr>
<tr>
<td>2:05:00</td>
<td>80</td>
</tr>
<tr>
<td>2:50:00</td>
<td>750</td>
</tr>
<tr>
<td>3:25:00</td>
<td>1030</td>
</tr>
<tr>
<td>4:25:00</td>
<td>578</td>
</tr>
<tr>
<td>8:15:00</td>
<td>195</td>
</tr>
<tr>
<td>25:45:00</td>
<td>40</td>
</tr>
</tbody>
</table>
Figure 13: Suspended Sediment Concentration Pulse Following First Dam Flushing

A rough estimate of the amount of sediment that was flushed during the event was calculated from these data. This calculation required the assumption that the discharge in the lower outlets started at 450 cfs and linearly decreased to 150 cfs over a period of 4.5 hrs, and then held constant at 150 cfs until the low-level outlet valves were closed approximately 8 hours after the flushing activities began. From this an estimate of the mass of total suspended sediment that was discharged was calculated, as shown in Table 4.

Table 4: Estimation of Sediment Mass Discharged in the April 2002 Flushing Event

<table>
<thead>
<tr>
<th>Time (hrs)</th>
<th>Discharge Q (cfs)</th>
<th>TSS (mg/L)</th>
<th>Discharge Q (lit/sec)</th>
<th>Loading rate = TSS * Q (mg/sec)</th>
<th>Time (sec)</th>
<th>Area of each trapezoid segment (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00:00</td>
<td>450</td>
<td>5</td>
<td>12742.56</td>
<td>63712.8</td>
<td>0</td>
<td>1860743098</td>
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<td>0:35:00</td>
<td>410.38</td>
<td>153</td>
<td>11620.566</td>
<td>1772136.283</td>
<td>2100</td>
<td>1954659061</td>
</tr>
<tr>
<td>1:05:00</td>
<td>376.41</td>
<td>37</td>
<td>10658.856</td>
<td>399707.1177</td>
<td>3900</td>
<td>1079749582</td>
</tr>
<tr>
<td>1:35:00</td>
<td>342.45</td>
<td>82</td>
<td>9697.1472</td>
<td>800014.6401</td>
<td>5700</td>
<td>1348964700</td>
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<tr>
<td>2:05:00</td>
<td>308.49</td>
<td>80</td>
<td>8735.4378</td>
<td>698835.0267</td>
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<td>8327462062</td>
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<tr>
<td>2:50:00</td>
<td>257.55</td>
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<td>7292.8739</td>
<td>5469655.39</td>
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<td>217.92</td>
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<td>6170.8796</td>
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<td>2452942.8</td>
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<td>4247.52</td>
<td>169900.8</td>
<td>90000</td>
<td></td>
</tr>
</tbody>
</table>

Sum= 65484974386 mg
     65484.97 kg
     144370 lbs
     72.2 tons

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Figure 14 provides a plot of sediment loading from First Dam versus time for the April 22, 2002 event. Note from Figures 13 and 14, mobilization of the sediment plug requires some time after the low-level outlet valves are opened. Also note that the sediment plug tends to mobilize quickly, with a peak TSS concentration occurring about four hours after initiation of flushing.

![Diagram of loading rate vs time](image)

**Figure 14: Sediment Loading Versus Time for the April 22, 2002 Flushing Event**

From these calculations, the approximate total weight of TSS released from First Dam during this short event was estimated to be 72.2 tons. The maximum TSS loading rate was approximately 6.5 kg/sec.

These data can be used to determine whether state water quality standards can be met with more frequent flushing of the reservoir. For example, if one assumes that a larger or smaller sediment plug will have the same time base as the one shown in Figure 14, and if one further assumes that in a normal year the sediment that would be released from First Dam by drawing the reservoir down and fully opening the low-level outlet valves would be double that of the April 2002 experience, than one can calculate the flow that would be required in Logan River to provide enough dilution in order to meet state water quality standards. Under normal sedimentation conditions, it might not be unusual for the quantity of sediment to accumulate in the downstream portion of First Dam to be double the quantity that was released in the April 2002 event. This means that for a "normal" flushing event, the maximum sediment loading rate produced by flushing would be twice that of the April 2002 event, or 13 kg/sec. The state standards for TSS are 90 mg/l. The flow needed to meet state TSS standards under these loading can be calculated as

\[
\frac{13 \text{ kg/sec}}{90 \text{ mg/l}} = 144,000 \text{ l/sec, or 5100 cfs}
\]
Therefore, to maintain state TDS standards under the assumed sediment discharge conditions, the flow in the river would have to be on the order of 5100 cfs. However, from Figure 15 it can be seen that the Logan river peak flows are only on the order of 1000 cfs to 1500 cfs.

For a peak spring runoff of 1000 cfs, a TSS concentration of approximately 450 mg/l would be produced from the above flushing assumptions.

**Figure 15: Peak Flows at the USGS Station above First Dam**
From the above analysis, a need for the involvement of Utah Department of Environmental Quality (UDEQ) and Division of Wildlife and Fisheries in assessment and evaluation especially for sediment release concentration standards and water quality standards is felt.