Managing Sediment In Utah's Reservoirs

March 2010

UTAH STATE WATER PLAN

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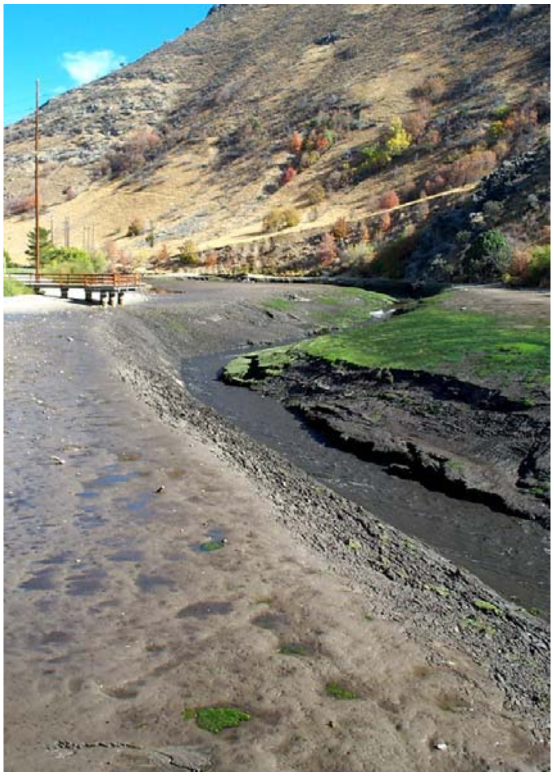

Utah Division of Water Resources

UTAH STATE WATER PLAN

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PREFACE

One of the responsibilities of the Utah Division of Water Resources is comprehensive water planning. Over the past 15 years, the Division has prepared a series of documents under the title "Utah State Water Plan." This includes two statewide water plans, an individual water plan for each of the State's eleven major hydrologic river basins and "special studies" (such as this document). Preparing these documents involves major data collection, as well as extensive inter-agency and public outreach efforts. Much is learned through this process. State, local, and federal water planners and managers obtain valuable information for use in their programs and activities, and the public receives the opportunity to provide meaningful input in improving the state's water resources.

This document is the latest in the "Utah State Water Plan" series and provides important information regarding a significant issue that is negatively impacting Utah's water supply: reservoir sedimentation. It examines the impacts of sedimentation in Utah's reservoirs and estimates current and future storage losses. It also discusses several sediment management strategies that can be implemented at reservoirs to ensure their future usefulness. Several Utah case studies are presented as well as the basic economics, potential environmental and other impacts of sediment management. Potential funding sources are also included. Finally, this document makes recommendations that can assist the water community to meet the sediment challenge.

An Adobe Acrobat (pdf) version of this document is available for free download at: www.water.utah.gov . Reader comments regarding this publication are welcome.

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EXECUTIVE SUMMARY

A reliable water supply is predicated on adequate storage capacity to keep water flowing despite normal fluctuations in the supply and the demand. Therefore it is important to do everything possible to protect and maintain storage capacity. Sediment is accumulating in every reservoir in Utah. Although slow, sedimentation steadily reduces reservoir capacity, and thus represents a noteworthy threat to the sustainability of water supplies. While water suppliers know this is happening, many believe little can be done about it. In addition, the usually slow and steady nature of sediment deposition makes it easy to overlook. So, other matters take priority and the problem is passed on to succeeding generations. However, as some dam owners have already discovered, the time eventually arrives when the situation requires action. At that point sediment management costs are greater, and some options may no longer be available. This report provides managers, water planners, and decision-makers with the tools needed to proactively address this situation. It presents a comprehensive review of the problem, describes numerous effective solutions and identifies potential funding sources. The following paragraphs summarize the main points of each chapter.

CHAPTER 1
INTRODUCTION

In the United States, the traditional approach to sediment management has been to dedicate a portion of the reservoir's original capacity to accommodate sediment accumulation. This was for a defined time period, usually 100 years. Dam builders apparently believed that, after the "design life" was reached, the reservoir would be taken out of service. However, dams are rarely retired, and consequently there is an implied assumption that future administrators, a future generation, will deal with the sediment accumulation problems.

Sediment accumulation occurs mostly in the active or live reservoir storage, the volume from which water can be released for intended uses. This loss of water storage capacity reduces water deliveries. This negatively impacts water users, electric power production, flood water storage, recreational use, and ecological regimes. It is estimated that to maintain a reservoir's original function, replacement storage is needed when 15 to 40 percent of a reservoir's storage is lost. It is also estimated this new storage will cost two to 10 times the original cost.

The 1930s dust bowl experiences brought the U. S. Soil Conservation Service into being. The highly successful efforts of this agency resulted in a reduction of the U. S. sedimentation rate to approximately 0.22 percent of total reservoir capacity per year. This is much better than the worldwide average of 1.0 percent, although it is still a problem. Kansas has partnered with the U.S. Geological Survey and other federal agencies to study sediment accumulation in reservoirs throughout the state. Texas has also studied sediment accumulation throughout the state. They estimate losing about 90,000 acre-feet per year and are losing more reservoir capacity than they are gaining.

Utah has a long and continuing tradition of watershed management, which, in addition to other benefits, reduces erosion. Today's efforts are sponsored by a cadre of federal, state and local agencies. Other than this, Utah does not have any coordinated efforts to assess or manage reservoir sedimentation. In addition to watershed management, there are methods to deal with sedimentation which are not being employed. Dam owners would benefit from implementing these methods in order to keep reservoirs sustainable.

CHAPTER 2
ESTIMATING AND MEASURING SEDIMENTATION IN RESERVOIRS

This chapter covers the three most commonly used ways to estimate sedimentation rates. While providing only rough approximations, they can provide insight, direct preliminary planning and help identify possible problem areas:

- <u>Regional Rate of Storage Loss.</u> This uses data from several reservoirs in a region to plot a graph of annual storage loss versus drainage area. The sedimentation rate of other reservoirs in the region can then be estimated from the graph.
- <u>Regional Regression Relationship.</u> This uses a complex formula incorporating eight

site-specific parameters to estimate the sedimentation rate.

- Reservoir Capacity Correlation of 1105 U.S. Reservoirs. This estimates the sedimentation rate of a given size reservoir anywhere in the United States.

A reservoir's sediment accumulation rate has to be determined in order to establish the magnitude of the problem. Calculating that rate requires comparison of the original reservoir volume to the present volume.

There are two ways to measure the present reservoir volume, a range survey and a contour survey. A range survey uses a sonar device to measure water depth along preset range lines that cross the reservoir at regular intervals. The contour survey (or bathymetric survey) also uses a sonar device to measure water depth, and incorporates a Global Positioning System (GPS) to determine the boat location. An approximate grid pattern is followed across the entire reservoir surface. The overall sedimentation rate is determined using the original reservoir volume, the present volume, and the number of years since the reservoir began storing water.

Several natural watershed factors affect sedimentation rates. These include rainfall intensity and duration, soil type, geology, topography, ground cover vegetation, and natural wildfires. Several human factors also affect sedimentation rates. These include grazing livestock, raising crops, logging, mining, construction, and human-caused fires. It is important to understand both natural and human factors affecting sedimentation to develop effective sediment management solutions.

CHAPTER 3
SEDIMENTATION IN UTAH RESERVOIRS

This chapter includes a brief history of reservoir construction in Utah. Since 1847, water users have built a total of 133 reservoirs larger than 1,000 acre-feet. Over 250 reservoirs smaller than 1,000 acre-feet have also been constructed.

Sedimentation data exist for only 18 Utah reservoirs larger than 1,000 acre-feet capacity. Using this data, plus an estimate of sedimentation for all Utah reservoirs larger than 1,000 acre-feet, yields an approximate statewide sedimentation rate of 0.2 percent per year. This compares favorably to the U.S. rate of 0.22 percent. Using the annual reservoir sedimentation rate of 0.2 percent per year, the total capacity loss statewide is about 12,340 acre-feet per year.

Total constructed reservoir storage is estimated to be 6,170,000 acre-feet. After accounting for sedimentation losses, present capacity is estimated to be 5,267,000 acre-feet, a decline of 903,000 acre-feet or 15 percent. Assuming no new dams are built, in 50 years, total reservoir storage capacity will be about 4,613,000 acre-feet. This is a decline of 1,557,000 acre-feet, or 25 percent. By the year 2100, Utah reservoirs will have lost about one-third their original capacity. The following graph shows these trends over time.

Utah is currently the fastest growing State in the nation. Water must be provided for an additional 26,000 people each year. Projections indicate the population will increase to nearly 6.8 million by 2060. This will *increase* municipal and industrial water demands. Coupled with the ongoing *decrease* in reservoir capacity, it is clear that addressing reservoir sedimentation should be a priority.

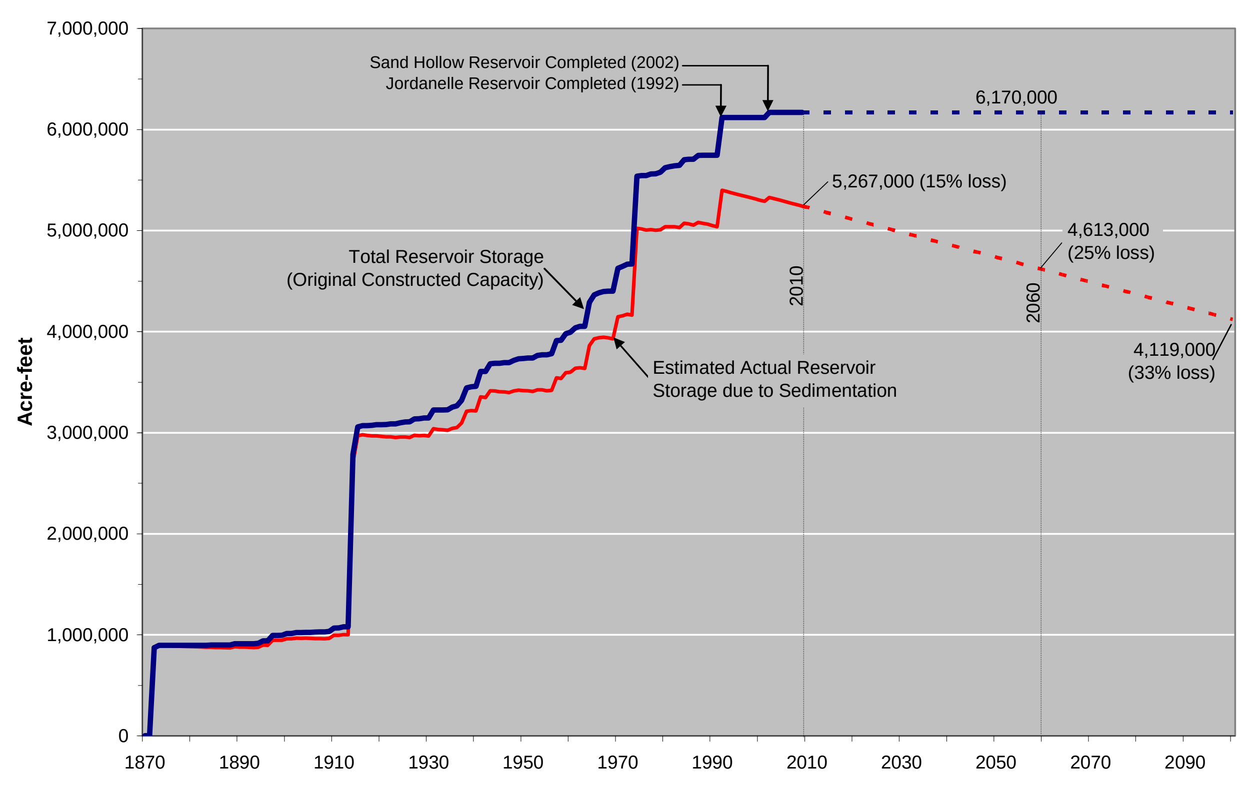
CHAPTER 4
RESERVOIR SEDIMENT MANAGEMENT METHODS

Several sediment management methods are described in this chapter. Optimal results will require some combination of methods. The chapter also discusses how to deal with sediment at diversion dams and other water infrastructure.

Watershed management can significantly reduce the amount of sediment that reaches a reservoir. Such management involves protecting the ground from erosion with vegetation, land terracing, and channel stabilization. It also includes the control and scheduling of activities such as construction, mining, logging, and grazing. Cooperation among state and federal agencies that manage public lands, such as with the Utah Partners for Conservation and Development, helps fund and implement projects that limit erosion.

Upstream trapping is another way to reduce the amount of sediment reaching the reservoir. This includes constructing hydraulic structures such as

Current and Projected Impact of Reservoir Sedimentation on Utah's Total Storage Capacity



natural vegetation filters, check dams, detention basins and upstream reservoirs that trap sediment. Another option is to build the reservoir off of the main stream channel and selectively divert the waters that fill it. This entails directing clear water into the reservoir, primarily during non-flood conditions, while sediment-laden waters are bypassed. Constructing wetlands upstream of the reservoir also helps remove sediment from the stream.

Once sediment reaches the reservoir inlet, a number of options are available for passing it downstream without being deposited in the reservoir. The reservoir can be drawn down before high runoff events to allow sediment-laden waters to pass through the reservoir; this is termed sediment pass-through. Being more dense than water already in the reservoir, sediment-laden “density currents” can form which follow the reservoir bottom to the dam where they can be discharged through low-level outlets; this is known as density current venting. Runoff flows can be monitored, and when heavy sediment loads are detected, the flow can be intercepted upstream and routed around the reservoir in a canal or pipeline; this is known as sediment bypass. A permanent pipeline can be located on the reservoir bottom running from the point of sediment deposition to, and through, the dam; this is known as hydrosuction bypass.

Once sediment has been deposited in the reservoir, there are options for removing it. Simply drawing down the water level and letting it flow out through low-level outlets in the dam re-mobilizes some of the previously deposited sediment and flushes it out. Another option is to excavate sediment from the reservoir after the water level has been drawn down and the sediments are allowed to dry. Yet another is to use a dredge, with a boom extending to the reservoir bottom, to suck sediment up and remove it from the reservoir. Finally, hydrosuction bypass uses the energy of a siphon to remove sediment and discharge it over the dam to the stream below; it requires a barge with a boom extending to the reservoir bottom.

If sediment accumulates to such an extent that the above methods are not practical, it may be necessary to deal with the loss of storage capacity. Raising a dam just a few feet can add considerable storage volume since it's at the top of the reservoir, where the basin is wider. However, this is a temporary fix as sediment will continue to flow into the reservoir. Sediment accumulation may ultimately reach the point where it is necessary to decommission or dismantle the dam. These are important to consider in the "life-cycle" of a reservoir.

CHAPTER 5
ECONOMICS OF SEDIMENT MANAGEMENT

Three basic economic analysis methods are described; they are cost effectiveness analysis, least-cost analysis and benefit-cost analysis. Estimating the present day cost of past sedimentation is reviewed using examples of reduced crop production, reduced yield of municipal and industrial water, reduced hydroelectric power production, reduced flood storage capacity and reduced recreation activity. Estimating the future costs if nothing is done is evaluated using examples in the agriculture, and the municipal and industrial sectors.

The ultimate goal of the water supply community is *– to create a sustainable water supply for future generations that includes adequate storage facilities.* Two methods of achieving that goal are presented. They are: (1) use a sinking fund and (2) use the Reservoir Conservation, or RESCON approach. RESCON entails performing an economic and engineering evaluation of alternative strategies for managing sedimentation over the entire reservoir life.

Potential sedimentation project funding sources are described. These include federal programs sponsored by the U.S. Department of Agriculture, the Army Corps of Engineers, the Bureau of Reclamation, and the Environmental Protection Agency. State of Utah programs include those sponsored by the Board of Water Resources, the Community Impact Board and the Drinking Water Board. A total of 12 potential funding programs are described, including contact information.

CHAPTER 6
ENVIRONMENTAL AND OTHER CONSIDERATIONS

The chapter begins with a discussion of the several parameters used to define water quality. These include total suspended solids, total dissolved solids, turbidity, biochemical oxygen demand, chemical oxygen demand and dissolved oxygen. Effects of sediment releases on aquatic life are discussed with attention to the numerous contaminants that can enter a reservoir, and potentially accumulate and concentrate in the sediments. Release of high sediment concentrations from a reservoir can have serious impacts to the downstream environment, infrastructure, river channel and recreation. It can also cause flooding.

Federal laws and the agencies that enforce them are outlined. These include the National Environmental Protection Act, Clean Water Act and Endangered Species Act; the Federal Energy Regulatory Commission, Federal Emergency Management Agency and the Natural Resources Conservation Service. A similar discussion is presented for the two Utah state agencies having a direct role in regulating sediment releases: the Division of Water Quality and Division of Wildlife Resources. While careful coordination is required, sediment releases can be made today under the provisions of both federal and state laws.

CHAPTER 7
DAM OWNER'S GUIDE
TO SEDIMENT MANAGEMENT

With effective action, economic losses caused by sediment accumulation can be minimized. That is the goal of sediment management. The following figure shows the positive impacts of sediment mitigation on reservoir life. The intersection of the "Reservoir Capacity" line and the "Required Storage Capacity" line shows when reservoir capacity no longer meets requirements. *This occurs long before the reservoir is completely filled with sediment.* The "**Case 1**" line shows reservoir capacity if no action is taken and sediment is allowed to accumulate. The "**Case 2**" line shows reservoir capacity if sediment mitigation strategies are implemented, resulting in slower sedimentation and longer reservoir life. The "**Case 3**" line shows reservoir capacity after removing a volume of sediment from the reservoir, and simultaneously implementing sediment mitigation strategies, to further extend reservoir life. The "**Case 4**" line shows reservoir capacity after enacting sediment mitigation strategies that prevent sediment accumulation completely. When this is possible, the result is *the "Reservoir Capacity" and "Required Storage Capacity" lines never intersect and the reservoir's useful life is extended indefinitely.*

Development and implementation of a sediment management program involves several steps. Not all are mandatory and some can occur simultaneously.

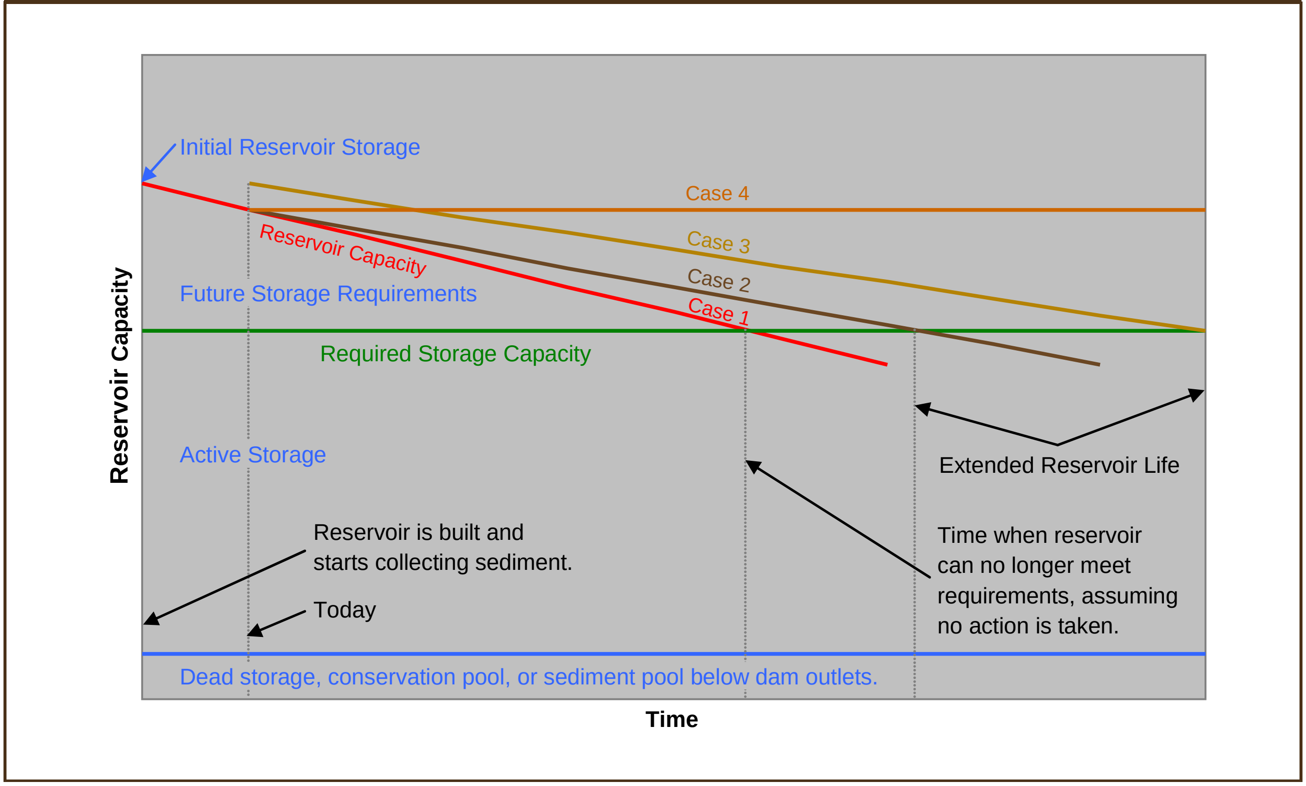
- Conduct a preliminary investigation to gather known information.
- Engage stakeholders to determine their unique and often conflicting requirements.
- Perform a reservoir survey to accurately establish the reservoir's present volume and determine the sedimentation rate.
- Perform an economic analysis to compare sedimentation losses to the cost of mitigation strategies.
- Set up a monitoring plan to establish baseline stream and infrastructure conditions before any sediment is released.
- Determine regulatory requirements in order to comply with the laws of the land.
- Conduct a public relations campaign to assure public involvement and continued good relationships.
- Identify potential sediment mitigation strategies and select the viable ones. Decide on those to be implemented.
- Establish a timeline to meet stakeholder requirements and prevent damage by sediment releases.
- Apply for project funding to eligible sources.
- Develop an operations and maintenance plan including implementation of actions identified earlier.

CHAPTER 8
RESERVOIR SEDIMENT MANAGEMENT CASE STUDIES

This chapter contains several sediment management case studies, with a focus on Utah reservoirs.

Wide Hollow Reservoir. Sedimentation rate 0.91 percent, capacity loss 48 percent. This off-stream site has had sediment problems since it was first

Impacts of Sedimentation and Sediment Management on Reservoir Life



built. Frequent diversion of the entire Escalante River into the reservoir has been part of the problem. Along with dam safety problems, the situation is being remedied by complete removal and replacement of the dam. Improved sediment basin operation at the diversion works is expected to minimize sedimentation issues, as has upstream improvements to the watershed.

Gunlock Reservoir. Sedimentation rate 0.86 percent, capacity loss 28 percent. A highly erodable watershed, with widely fluctuating Santa Clara River flows, has led to significant sedimentation. Trapping sediments upstream and excavating them are currently employed. Investigation of other methods may prove beneficial.

Millsite Reservoir. Sedimentation rate 0.44 percent, capacity loss 14 percent. Some sediment pass-through occurs incidental to dam operation. Erodable Mancos Shale, plus other sources in the upper drainage, contribute sediment. A recent study recommended hydrosuction dredging as the most cost-effective strategy.

Piute Reservoir. Sedimentation rate 0.21 percent, capacity loss 18 percent. Sediment has been a problem since the reservoir was built. A 2005 dam safety upgrade included raising the dam height, thus increasing capacity. Further investigation is needed to see if the new outlet structure can be used for sediment pass-through or flushing.

Otter Creek Reservoir. Sedimentation rate 0.21 percent, capacity loss 22 percent. Normal watershed erosion was compounded by fire denuding a large area. New spillway gates raised the reservoir level to recover lost storage capacity. Further investigations may benefit the situation.

First Dam. Sedimentation rate 0.74 percent, capacity loss 64 percent. Despite being below two other reservoirs, this very small and old dam has accumulated a great deal of sediment. Sediment pass-through and flushing helps preserve the limited remaining storage.

Quail Creek Diversion Dam. A small impoundment of 295 acre-feet diverting Virgin River water from an erodable drainage area of almost 1,000 square miles causes problems. Several federally listed and sensitive species compound sediment management. A detailed plan with timed releases using sediment pass-through and dredging keeps the facility operating.

CHAPTER 9
CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Information about sedimentation rates in Utah is limited.

2. Utah's estimated average sedimentation rate is 0.2 percent per year.

3. Although sedimentation may not be an urgent concern, it is still a very important issue.

4. Sedimentation is already a critical concern for a number of individual reservoirs.

5. Utah's net reservoir storage capacity has been declining since the mid-1990s.

6. Sediment management can effectively mitigate sedimentation in reservoirs.

7. Active watershed management has reduced Utah's sedimentation rate over time.

8. Annual drawdown has likely reduced sedimentation in many of Utah's smaller reservoirs.

9. Sediment management efforts can impact downstream environment and infrastructure.

Recommendations

1. Reservoir owners should be proactive in addressing sedimentation. They should collect data to assess their situation, determine when significant shortages may occur, and develop long-range sediment management plans.

2. The Utah Division of Water Resources should help reservoir owners collect, analyze and interpret the data to determine the extent of sedimentation and possible impacts to reservoir users. In addition, the division should help identify potentially applicable sediment management alternatives. The division

should also establish and maintain a long-term database of sedimentation data and reports.

3. The Utah Division of Water Resources should identify and exercise options that exist within the law to protect sites for additional and replacement storage capacity, both surface and subsurface.

4. Water users should support organizations that are already involved in watershed management, for example the Utah Partners for Watershed Development, so they can continue to improve watershed management programs and target problem areas.

5. The Utah Division of Water Resources should identify and make the most of opportunities to educate and inform the water community about sedimentation issues.

6. State agencies involved with sediment release from reservoirs should establish a point of contact to assist reservoir operators.

1

INTRODUCTION

Utah is a semi-arid state that receives an average of 13 inches of precipitation each year. Much of this falls in the mountains during the winter months as snow. As spring arrives and temperatures rise, the snow melts, filling streams and rivers with water. To capture water and store it for future use, hundreds of reservoirs have been constructed all across the state. Water stored in these reservoirs is used primarily by agriculture, but also provides a reliable water supply to numerous cities, towns and industries around the state. Without reservoirs, some communities in Utah simply would not exist, and economic activity and growth in other communities would be impaired.

The importance of reservoirs to Utah is clear. However, a commonly unnoticed but ongoing threat to the sustainability of these reservoirs is — sedimentation. Sediment is slowly displacing water stored in Utah's reservoirs, reducing storage capacity. While the sudden loss of Utah's reservoir capacity would be a catastrophe, its gradual and continual loss due to sedimentation receives little attention or corrective action.[1] While watershed management has been practiced for many years in Utah, many of the other available sediment management strategies have not.

PURPOSE AND GOALS OF THIS STUDY

The purpose of this document is to highlight the important issue of reservoir sedimentation. Relatively little is known about sedimentation in Utah's reservoirs and this document attempts to answer some basic, but important questions: How big a threat is sedimentation? How urgent is the problem? What are the costs of sedimentation? What can be done to manage sediments and preserve the useful life of Utah's reservoirs? How does sedimentation vary in the state and why? What actions, if any, should be taken to address the problem?

To answer these questions, this document gathers together as much data and information about sedimentation in Utah's reservoirs as possible. Data are presented from various sedimentation surveys, and case studies for several reservoirs in Utah are provided. While the amount of information may not be sufficient to fully assess the scope of the problem, the data that are available offers insights that are important to help define and shape future actions.

To better quantify the problem, this document presents a brief overview of the history of sediment management. It also provides a summary of the technology that exists to effectively manage sediment in reservoirs, and discusses options for those situations where no solutions are feasible. A goal of this document is to encourage consideration of available sediment management technologies when designing future dams, as well as when existing dams are to be modified, upgraded or enlarged. Improved reservoir operations will also reduce sedimentation.

THE SEDIMENT CHALLENGE

The erosion of soil from one location, and its subsequent transport to and deposition at another location, is a natural phenomenon. In many areas of the world, man-made disturbances to the landscape have greatly increased erosion rates. While careful watershed management can reduce the current rate of soil

Left: Sediment-laden water from the Colorado River entering Lake Powell near the Hite Bridge.
Right: Delta sediment deposits visible at the same location at a lower reservoir water level.
(Satellite images obtained from Utah Automated Geographic Resource Center and Google Earth, 2008.)

erosion, it is not possible to eliminate it altogether. Selected efforts in the USA and other countries have slowed erosion rates. Examples include activities of the Civilian Conservation Corps and the Natural Resources and Conservation Service.

On most stretches of a river, there is a balance between sediment inflow and sediment outflow. The construction of a dam dramatically alters this balance. A dam creates a pool of water that reduces the stream velocity to near zero. Energy that moved the sediment particles of many sizes is no longer available, and the reservoir traps the sediment. In the case of on-stream reservoirs, most incoming sediments are retained resulting in relatively clear water leaving. Thus, an impoundment created by a dam will continually lose active water storage capacity to sediment accumulation unless the sediment balance is restored.[2]

Throughout history, dam builders have understood the sediment challenge and struggled to design impoundments that adequately address it. As a result, dams built in antiquity, have succumbed to sediment accumulation and no longer fulfill their intended purposes. Since then there has been an ever-increasing knowledge of hydraulics and the mechanics of sediment transport and deposition. Still, even modern dam builders struggle to address the sediment challenge. Thus, many modern dams have already suffered the same fate and many more inevitably will. Fortunately, a number of sediment management and sediment mitigation strategies have been developed through time. These will be explored in this report with the anticipation that they will be more universally adopted.

Frequently, dam builders in the United States and other parts of the world have not considered sediment management as an important part of dam design, operation and maintenance. Although the U.S. Bureau of Reclamation's handbook, *Design of Small Dams*, acknowledges reservoir sedimentation as an issue to consider, the primary concern in the handbook with regard to sediment is to "prevent the premature loss of usable storage capacity."[3] The handbook states:

> At the time of design, provisions should be made for sufficient sediment storage in the

> reservoir so as not to impair the reservoir functions during the useful life of the project or during the period of economic analysis.[4]

While this approach to sedimentation is understandable, it falls short of the ultimate goal of the water supply community — *to create a sustainable water supply for future generations that includes adequate storage facilities*. Others have summarized the shortcomings of the traditional approach to dam building in much stronger terms:

> Reservoirs have traditionally been planned, designed and operated on the assumption that they have a finite 'life,' frequently as short as 100 years, and will eventually be terminated by sediment accumulation. Little thought has been given to reservoir replacement when today's impoundments are lost to sedimentation, or to procedures to maintain reservoir services despite continued sediment inflow. There has been the tacit assumption that somebody else, members of a future generation, will find a solution when today's reservoirs become seriously affected by sediment.[5]

Sediment management in reservoirs is no longer a problem to be put off until the future; it has become a contemporary problem.

—Rodney White in *Excavation of Sediment from Reservoirs.*

The applicability of the traditional approach to sediment for the future is made questionable by the fact that suitable sites for dams are dwindling in number, and the economic and environmental costs of new structures are often socially unacceptable. Reservoirs are typically located at sites with unique hydrologic, geologic, topographic and geographic characteristics, and existing reservoirs already occupy the best available locations. Therefore, "if future generations are to benefit from essential services provided by reservoirs it will be largely through the preservation and continued utilization of existing reservoir sites, not the continued exploitation of a shrinking inventory of potential new sites."[6]

Water supplies and other benefits derived from reservoirs cannot be considered renewable resources unless sedimentation is adequately addressed. Sediment management and sediment mitigation should be explored as methods of extending the serviceable life of existing dams. This is especially true since reservoirs are relied upon to provide vital services well beyond their so-called "economic life," and are only rarely taken out of service. In many cases, society expects reservoirs to continue providing water almost indefinitely.

CONSEQUENCES OF SEDIMENTATION

The most obvious and significant consequence of reservoir sedimentation is the loss of valuable water storage capacity. However, there are other impacts, some of which are positive, that occur upstream and downstream of a dam once the sediment balance is disrupted. The loss of storage capacity and other consequences are discussed in the following sections. It's well to view these impacts in the light of a constantly increasing population, keeping in mind Utah is the fastest growing state in the United States.[7]

Loss of Storage Capacity

Sediment typically accumulates in the active or "live" storage volume of a reservoir; That is, the volume from which stored water is drawn out for beneficial uses. Loss of storage capacity in a reservoir has multiple impacts. The nature and severity of these impacts depends largely on the water uses in the affected reservoir. While the water in some reservoirs in Utah is used exclusively for agricultural irrigation or municipal and industrial needs, in many reservoirs the storage capacity is also used for electric power production, flood protection and recreation. The American Society of Civil Engineers Sedimentation Engineering handbook indicates that to maintain its function, replacement storage is needed when 15 to 40 percent of a reservoir's storage is lost. It is also estimated that the cost of new storage will be 2 to 10 times the cost of the original storage.[8]

Agriculture

Agricultural irrigation is by far the largest use for water stored in Utah's reservoirs. Agriculture uses approximately 81 percent of the total developed water supply in Utah[9] and 91 percent of the total diverted surface water.[10] Consequently, the loss of storage capacity due to reservoir sedimentation will significantly impact agriculture. Insufficient water to irrigate cultivated lands reduces productivity. Reduced agricultural productivity reduces agricultural revenues and could eventually put local farmers out of business and require importing more products. Industries that support or benefit from agricultural activity would also be impacted. The general economic multiplier for agriculture is about 2.65 to 1.[11] That is, for every agricultural dollar lost, an additional $1.65 is lost from industries that support agriculture. Furthermore, agriculture-oriented businesses in Utah offer a greater stimulus than most other industries in the state.[12]

Because the loss of storage capacity due to reservoir sedimentation occurs gradually, the impacts on agriculture are not readily discernable. Natural fluctuations of the water supply mask the loss of storage capacity, especially in cases where sediment accumulation in a reservoir has not been measured. While in many areas the loss of capacity has been compensated for, to some extent, by increased water deliveries and irrigation efficiencies, this practice is not sustainable. If storage loss is not mitigated, farmers may experience chronic water shortages due to sedimentation and the consequences will become especially apparent during drought – when the water is most needed. There is the potential for permanent loss of productive lands. Such losses will make life in many struggling rural communities even more difficult.

Municipal and Industrial

Municipal and industrial water uses amount to only about nine percent of the total use of surface water in Utah;[13] however, lost storage capacity in reservoirs could impact these uses more severely. While the agricultural sector makes up less than one percent of Utah's gross domestic product, the other 99 percent is produced by sectors reliant upon municipal and industrial water supplies.[14] Therefore, water shortages caused by insufficient storage capacity in Utah's reservoirs could harm the state's economy.

Natural fluctuations in the water supply, and the gradual nature of sediment accumulation, can mask the loss of storage capacity. Moreover, increased water-use efficiency over time will likely temper many municipal and industrial impacts. The long time periods involved may also allow replacement supplies to be developed and secured before shortages are realized. However, even if replacement water sources can be found, their cost will be significant.

Electric Power Production

More than 85 percent of the electricity generated in Utah comes from coal-burning power plants.[15] There are seven coal-fired generating stations in Utah with a total capacity of approximately 5,080 megawatts.[16] With some minor exceptions, water stored in reservoirs is used for cooling at these generating stations. The loss of an adequate supply of cooling water for even one generating station has the potential for widespread effects. In the event of a power reduction, "brown-outs" and rotating "blackouts" could have severe economic and personal impacts for those served by the power plant.

In addition, there are 28 hydropower facilities in Utah with a total generating capacity of 261.8 megawatts.[17] They provide about two percent of Utah's total electric generation.[18] As a reservoir fills with sediment, water that would normally be stored and released through hydroelectric turbines may be less available. The ability to produce peaking hydropower may also be impacted.

In some unique circumstances, a sediment-filled hydropower reservoir can become a large and valuable wetland area and still be able to generate power from run-of-the-river flows released from another reservoir upstream. Power generating capacity is limited, but some capacity is still available. This is true of Cutler Reservoir located about 10 miles west of Logan, Utah.

Flooding

When storage capacity in a reservoir is lost, the ability of the reservoir to attenuate peak flows and protect downstream areas from flooding is reduced. In some cases, this may require the normal operation of a reservoir to be changed—possibly further reducing the usable water supply in the reservoir— to preserve the reservoir's flood protection capability.

Upstream Consequences[19]

Sediment deposits near Hite Marina, Lake Powell. (Associated Press photo by Trent Nelson.)

Delta Deposition

Coarse grained sediments are deposited where rivers and streams enter a reservoir, forming a delta. The delta not only diminishes active reservoir storage capacity, but can cause channel aggradation upstream of the reservoir. Channel aggradation occurs when the bed of the stream or river rises as sediment is deposited, often resulting in water-logging and flooding of adjacent land. Delta deposits are also prime locations for the growth of phreatophytes, deep-rooted plants that obtain water from the water table or the layer of soil just above it. These plants retard flood flows and trap sediments, leading to further aggradation and flood problems. They also deplete the water supply through evapotranspiration. On a more positive note, delta deposits often create wetlands that are desirable for recreation and wildlife habitat.

Earthquake Hazard

Sediment deposits have a greater density than water and thus any sediment deposited against a dam can increase the seismic forces on the structure during an earthquake. Also, sediments near the dam may liquefy during an earthquake causing the sediment to quickly flow toward, and bury, bottom outlet structures. This could impair water releases after the earthquake until repairs are made.

Recreation

Sediment can accumulate in popular shallow areas and side canyons, at boat ramps and other recreational facilities, impairing boater access and diminishing the user experience. Sediment deposits may also reduce the usable surface area of a reservoir at all water levels, reducing open water activities including recreation.

Air Pollution

As reservoirs are drawn down seasonally, fine sediment deposits can erode and be transported by wind, creating a nuisance and health hazard to nearby communities. This has been a significant problem at Buffalo Bill Reservoir near Cody, Wyoming. When the reservoir is drawn down, strong canyon winds pick up dust and sand and transport it to the town.[20]

Abrasion

Hydraulic turbines and outlet works can be eroded by sand-size sediments. In facilities operated at high hydraulic heads, even coarse silts can damage these facilities. This damage reduces the efficiency of power production and eventually requires removing generating units from service for repair or replacement.

Ecology

Reservoir ecology can be dramatically impacted by sedimentation. Open-water habitat transitions to wetlands and eventually upland as sediment is deposited and accumulates above the water surface. Furthermore, a large fraction of organics, nutrients and contaminants occur in particulate form and are taken up and held by clays. These accumulate in the reservoir bottom. These constituents can play a large role in the reservoir oxygen budget and species composition. Sediment accumulation in the reser-

River runners floating down the Colorado River below Havasu Creek in Grand Canyon National Park. Lack of sediment in the water, which historically replenished sand bars and created beaches all along the river, makes finding a good campsite challenging.
(Photo by Mark Lellouch, courtesy of National Park Service.)

voir can potentially affect aquatic habitat, dissolved oxygen, water temperature, and other related parameters.

Downstream Consequences[21]

Stream Morphology

When sediment is trapped in a reservoir, stream morphology downstream is dramatically impacted. Clear water in the channel downstream of the dam tends to scour the streambed causing it to become incised, coarsen, degrade, and become armored. Coarsening can make the streambed less desirable for certain wildlife and unsuitable as habitat for native and introduced aquatic species. "Channel degradation can increase both bank height and bank erosion rates, increase scour at downstream bridges, lower water levels at intakes, reduce navigational depth in critical locations, and lower groundwater tables in riparian areas, adversely affecting both wetlands and agricultural areas. Recreational use can be affected, as in the Grand Canyon where the sandbars used as campsites by river-rafters have been significantly eroded."[22] In many areas the stream is no longer connected to the adjoining floodplain. This results in a loss of spawning and rearing habitat, and loss of food for the fish. Finally, the clear water results in increased temperatures and increased algae growth from increased light penetration.

Positive Consequences

Sedimentation in reservoirs can also have positive impacts downstream of a dam. Reservoirs greatly reduce the quantity of suspended solids, especially in watersheds disturbed by deforestation and development. This reduces the cost of water treatment and can be beneficial to aquatic ecosystems sensitive to elevated suspended solids levels. Many recreational uses, such as fishing, also benefit from reduced suspended sediment and enhanced water clarity. Cold clear water below large dams such as Flaming Gorge and Lake Powell have created trophy fisheries for non-native species such as trout. But often this is at the expense of the native species, which are adapted to the cooler and more sediment laden streams

Ecology

Sediments transported by rivers carry important nutrients and organic material such as algal cells and finely divided organic detritus. "Modification of the production and transport of this organic material by the dam-reservoir system can have important ecological consequences downstream. Reservoirs can greatly reduce the downstream transport of detrital organic material used as a food source in the downstream ecosystems. Conversely, reservoirs with a prolonged detention period can discharge water enriched with limnoplankton (tiny freshwater plant and animal life)."[23]

MANAGING SEDIMENT[24]

There are many different ways to manage sediment in reservoirs that have proved successful at various locations throughout the world. These methods fall into the following four categories (each is discussed in greater detail in Chapter 4):

- ➢ Minimize Sediment Entering the Reservoir – carefully manage land use in the watershed to conserve soil and water, increase vegetation cover, construct upstream catchments, or locate reservoirs off-stream.

- Minimize Deposition of Sediment in the Reservoir – vent sediments through the reservoir, or bypass sediments via a conduit through or around the reservoir.
- Remove Sediment Accumulated in the Reservoir – flush, excavate, or dredge sediment out of reservoir.
- Compensate for Sediment Accumulated in the Reservoir – enlarge, decommission or relocate the dam, or find an alternate water source.

The sediment management method that is best suited for any given reservoir depends on the unique situation and circumstances at each site. Sediment grain size, reservoir capacity, ratio of annual stream flow volume to reservoir volume, and other physical characteristics of a reservoir often dictate which methods are feasible and which are not. The uses and associated economics of a reservoir also play a key role in determining the appropriate sediment management scheme. For instance, uses such as cooling coal-fired power generators, hydropower, drinking water, or industrial manufacturing are more likely to implement an aggressive sediment management solution than irrigating feed crops for livestock.

SEDIMENT MANAGEMENT AROUND THE WORLD

Dam construction goes back thousands of years. However, the vast majority of dams older than 200 years are no longer in operation today. While the demise of these structures can often be traced to simple neglect due to changing economic and political conditions, many succumbed to the steady accumulation of sediment.[25] Only a few of the world's ancient dams remain in operation today and a main reason for their longevity is they were fortunate to not have a significant problem with sediment or they employed some form of sediment management.

The Almansa Dam in Spain is the oldest known dam to incorporate sediment management technology.[26] Constructed in 1394, the dam has a large outlet at its base which allows the reservoir to be entirely emptied and accumulated sediment flushed downstream. Historically, this was accomplished by laying large wooden planks in specially designed grooves in the outlet structure, thus allowing water to accumulate behind the dam. Periodically, these planks were cut away from inside the outlet and then a long rod inserted through the sediment from the upstream side to initiate flushing.[27] Because of the hazardous nature of this work, it was often performed by people condemned to death and who were subsequently granted a pardon if they survived.[28] The Almansa Dam was enlarged in 1586 and is still in operation today.

In several regions of the world, sediment management is now an important part of dam design, operation and maintenance. This section highlights some of the more noteworthy efforts to manage sediment and ensure the sustainability of dams and reservoirs around the world.

India

The annual average reservoir sedimentation rate in India is estimated to be about 0.46 percent, that is, the average reservoir loses 0.46 percent of its original capacity each year.[29] In the Himalayan regions, sedimentation rates are much higher. To reduce the sediment problem, officials in India have primarily employed traditional watershed management, upstream catchments, sediment pass-through and flushing methods. Several other newer techniques, such as siphoning, have also been implemented at certain sites.[30]

Baira Reservoir

Baira Reservoir is part of the Baira Siul Hydroelectric Project on the Ravi River in northwest India. During the first year and a half of operation, about 20 percent of the reservoir's original capacity was displaced by sediment. This prompted careful study of the problem, including physical and mathematical modeling, to devise an effective solution. As a result of these studies, the diversion tunnel which diverts water from the Baira River to the reservoir was equipped with a service gate and an emergency gate to facilitate flushing of sediments. The first flushing operation was resoundingly successful, removing an estimated 80 percent of accumulated sediments from the reservoir.[31]

Uri Dam

Uri Dam is a diversion dam that directs water from the Jhelum River into an intake pipeline for a hydropower plant in the state of Jammu and Kasmir, India. It was designed and constructed with several sediment management facilities that allow fine-, medium- and coarse-grained sediments to be removed from the water before it enters the intake pipeline. The unique facility includes nine spillway bays, four steel-lined sediment excluder culverts, two secondary sediment culverts, two de-silting basins, and a sediment removal system for each basin. The combined operation of all these facilities allows sediment to be removed from the inflowing water under a variety of flow conditions and also allows peak flood waters with extreme sediment loads to entirely bypass the intake.[32]

China

By the turn of the 21st century, China had approximately 86,000 reservoirs with a combined capacity of over 405 million acre-feet.[33] In the mid-1990s, the annual average reservoir sedimentation rate in China was estimated to be about 1.19 percent, [34] much higher than most locations in the world. This sedimentation rate, when applied to the China's total reservoir capacity, corresponds to an approximate loss of nearly 5 million acre-feet of capacity per year.

China has long recognized the nature of its sediment challenge. As a result, Chinese officials treat sediment management with the same importance as water management. To combat the impacts of sedimentation in China's reservoirs, engineers there have implemented aggressive sediment management strategies at critical hydropower and water storage dams. The primary sediment management techniques employed in China, like India, include: watershed management, installation of upstream catchments or check dams, and utilization of sediment pass-through and flushing facilities at dams. Density current venting, siphoning, and dredging are also employed at various reservoirs where conditions for each method are favorable.[35]

Gezhouba Project[36]

The Gezhouba Project on the Yangtze River is a good example of China's success with the sediment pass-through method, which is primarily used in reservoirs with a large inflow volume in relation to storage volume. The original capacity of the reservoir formed by the Gezhouba Dam in the early 1980s was 1.3 million acre-feet; however, in just a few years this capacity had shrunk by 8 percent. To halt the accumulation of sediment in the reservoir, engineers installed sediment pass-through facilities in conjunction with the navigation locks that were being built at the dam in 1987 and a sediment balance was successfully achieved soon thereafter.

Most major rivers in China have multiple dams and transporting sediment downstream often just transplants the sediment problem to the next reservoir in line. As a result, sediment management in some river systems has necessitated a coordinated approach. One instance where coordinated sediment management has experienced some success is on parts of the Yellow River. The Sanmenxia Dam stores water when inflow is relatively clean and passes water through the reservoir downstream when it is silt- and mud-laden. These actions cause a density current at the downstream Xiaolangdi reservoir, which passes it through its flushing outlets.

Three Gorges Project (TGP)[37]

The Three Gorges Project on the Yangtze River is China's most ambitious dam construction project to date. Estimated to cost $21.69 billion, construction began in 1993 and hydropower was first produced by the dam's many turbines in 2007. Sediment research for TGP was conducted over a period spanning more than 30 years. This research included prototype observation, mathematical model simulation, and 14 physical model tests and analogue analysis on existing projects performed by four research institutes in China. Sediment management methods employed successfully at Gezhouba and Sanmenxia dams will be employed at TGP.

The water level in Three Gorges Reservoir is designed to be lowered 30-40 m (100-130 ft) during the flood season, to allow sediment-laden floodwater to pass through the reservoir. This low water level would be maintained for a total of about five months

Three Gorges Dam under construction near Sandouping, China, 2004. Sediment management techniques employed at the dam will be among the most sophisticated anywhere in the world. (Photo permission by Wikipedia Commons License: http://commons.wikimedia.org/wiki/Commons:GNU_Free_Documentation_License)

each year and produce flow velocities sufficient to transport incoming sediments through the reservoir and flush some of the sediment deposited in the reservoir. After 100 years of operation, the models predict that a sediment balance will be achieved and 86 to 92 percent of the reservoir's original storage capacity will remain available thereafter. Sediment accumulation at this level is not expected to impact important navigation and power generation components of the project.

SEDIMENT MANAGEMENT IN THE UNITED STATES

The primary approach to managing reservoir sedimentation in the United States has been to provide storage in the reservoir to accommodate sediment over the design life. Additionally, best management practices have been promoted and implemented on public and private lands in order to restore and maintain watershed health and reduce erosion. During the Dust-bowl era of the 1930s, many millions of acres of poorly managed lands were ravaged by drought; wind and water erosion became a serious problem. The federal government responded by creating the Soil Conservation Service which, in conjunction with locally formed Soil Conservation Districts, worked to protect watersheds from erosion. These efforts have proved largely successful, as the annual reservoir sedimentation rates in the United States (approximately 0.22 percent of total reservoir capacity per year) are well below the world average (approximately 1.0 percent).[38]

Although U. S. sedimentation rates are relatively low, sedimentation is still an issue that affects every reservoir. Water supply, flood protection, hydropower, navigable waterways, recreation and important ecosystem functions are all negatively impacted by sedimentation. In the Mississippi River drainage, sedimentation impacts each of these important areas and it drains approximately 40 percent of the continental United States. Massive volumes of sediment are trapped behind the approximately 8,000 dams located in the drainage.[39] While this sediment certainly reduces water storage, it has a much larger impact on navigable waterways and important ecosystem functions. Billions of dollars have been spent to dredge sediment and keep waterways navigable and the flow of commerce unencumbered. Reduced amounts of sediment reaching the Mississippi River Delta has also resulted in the loss of many hundreds of square miles of coastal wetlands that once buffered the coastal population, including New Orleans, from the full force of tropical storms

Box 1 - Federal Agencies Concerned With Sedimentation Issues

- United States Army
  - Army Corps of Engineers
- Department of Agriculture
  - Forest Service
  - Natural Resources Conservation Service
- Department of the Interior
  - Bureau of Land Management
  - Bureau of Reclamation
  - Fish and Wildlife Service
  - National Park Service
  - United States Geological Survey
- Environmental Protection Agency
- Federal Emergency Regulatory Commission

and hurricanes. Plans to restore the flow of sediment to the Mississippi River Delta and restore these wetlands will require billions of dollars more of future investment.

In the Southwest, sedimentation is mainly a threat to the region's water supplies. Sedimentation reduces the amount of snowmelt and other runoff from the mountains that can be captured and subsequently delivered to farms and communities during low-flow periods. Sedimentation also threatens the ability of these reservoirs to attenuate flash floods and other peak flows that are fairly common in parts of this semi-arid region. Ironically, these high flows are also responsible for most of the sediment transport to the reservoir.

While awareness of the sedimentation issue is fairly universal throughout the United States, only a few states have active programs to better understand and manage the problem. Kansas and Texas are two such states.

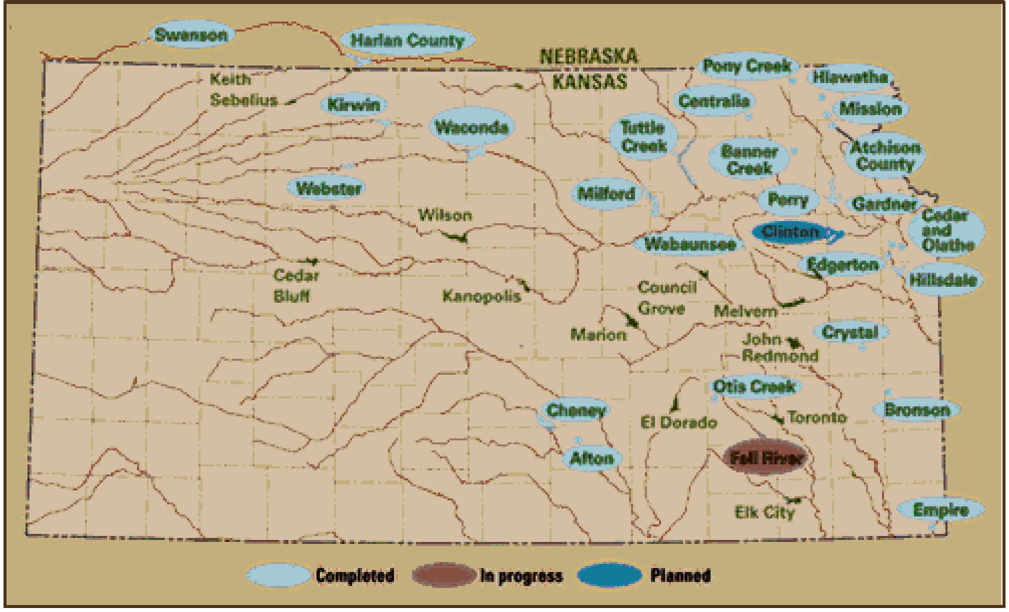
Kansas

The State of Kansas, in cooperation with local authorities, the U.S. Geological Survey (USGS), and other federal agencies, has implemented an aggressive program to study sediment accumulation in the state's reservoirs. To date, USGS has produced detailed studies of sediment in 28 significant reservoirs throughout the state, see Figure 1. The objectives of these studies are to: (1) estimate total sediment volume and mass, (2) estimate annual sediment deposition and yield from each reservoir drainage basin, (3) analyze the chemical and geological makeup of the sediment, (4) estimate annual loads and yields of these constituents, and (5) provide a baseline for future assessments.[40]

Information from the USGS sediment studies in Kansas can be used to: (1) reconstruct a portion of the historical sediment- and water-quality records in the reservoir, (2) identify any trends in sediment and water quality that can be traced to natural processes or human activity in the basin, (3) provide an early warning of potential water-quality problems, (4) provide a baseline for assessing the effectiveness of best-management practices (BMPs) implemented in the drainage basin, and (5) help develop and evaluate total maximum daily loads (TMDLs).[41]

Kansas has 24 large federal reservoirs that provide flood protection, water supply and recreation benefits. In addition, hundreds of smaller reservoirs provide an important part of the state's municipal water supply. Most of these reservoirs are 30 to 60 years old. The sediment studies conducted by the USGS have revealed unexpectedly high sedimentation rates, in some cases more than twice the original projected rates. This represents a total loss of water storage capacity from 20 to 50 percent in surveyed reservoirs. These findings have prompted the Kansas water community to conduct numerous workshops and discussions about what can be done to

FIGURE 1
USGS Reservoir Sediment Studies in Kansas



Source: U.S. Geological Survey, "Reservoir Sediment Studies in Kansas." Retrieved from the USGS's Internet web page: http://ks.water.usgs.gov/Kansas/studies/ressed/, January 2008.

address the problem.[42]

To date, the primary action that has been taken to address the sediment problem in Kansas has been to implement BMPs in watersheds with particularly significant erosion problems. These BMPs are typically implemented in response to TMDLs that identify sediment as a significant pollutant. Some water users have also investigated dredging sediments. A cost estimate prepared for a dredging operation at one reservoir revealed that an annual expenditure of $20-25 million would be necessary just to keep pace with the existing sediment loads entering the reservoir.[43] Support for such a large and ongoing expenditure is unlikely.

Although Kansas has not developed a comprehensive plan to manage sediment, the knowledge gained from the investigations has shed important light on the scope and urgency of the problem. Many in the state now realize that sediment in reservoirs poses a serious threat to the state's water supply and eventually significant measures to curtail or halt sediment accumulation, or replace lost storage, will be required.

Texas

Texas has 196 major reservoirs that store more than 5,000 acre-feet; 175 of these provide water for municipal, agricultural or industrial uses.[44] Sedimentation has long been a concern for many of the water users relying on these reservoirs. The Natural Resources Conservation Service (NRCS), formerly known as the Soil Conservation Service (SCS), has built nearly 2,000 flood and sediment retention structures in Texas, including some in watersheds above these reservoirs. Most were constructed between 1950 and the early 1970s and were designed to capture 50-years worth of sediment. Those constructed after the early 1970s were designed for a 100-year period.[45]

In the early 1990s, many of the NRCS structures were nearing their design life and thus no longer able to retain sediment, raising serious questions and concerns for water supply reservoirs downstream. As a result, in 1991 the Texas Legislature authorized the Texas Water Development Board (TWDB) to create the Lake Hydrographic Survey Program to help determine how quickly reservoirs were filling with sediment. Since the inception of this program, TWDB has collected sediment data for 95 of the state's major reservoirs (approximately 6 per year). These reservoirs represent over 70 percent of the state's total surface water supplies. Some reservoirs have been surveyed twice to gather sufficient information to estimate sedimentation rates.[46]

By extrapolating the completed reservoir sediment survey data to the rest of the state, TWDB has been able to estimate the total annual loss in storage capacity in Texas, and in some cases, project future losses for planning purposes:

> TWDB estimates that Texas' major reservoirs are losing approximately 90,000 acre-feet of storage per year due to sedimentation. This equates to a loss of roughly 0.27 percent of the total major reservoir capacity per year, or approximately 13 percent [of total capacity] over the 50-year planning horizon. Thirteen percent of the total current storage capacity of the state's major water supply reservoirs is approximately 4.5 million acre-feet, which is more than the 3.4 million acre-feet expected to be gained through the construction of 14 new major and two minor reservoirs…In other words, the state is losing more reservoir capacity than it is gaining.[47]

TWDB has studied dredging as a potential solution to the state's sedimentation problem.[48] One study compared the cost of dredging to the average cost of new reservoir construction and found that in general dredging cost about $2 per cubic yard, or approximately double the cost of new reservoir construction. However, the study also found that the economics of dredging was more favorable in instances where aesthetics, boater navigation, safety and other public interests were considered. Such was the case with at least three lakes in Texas that have been successfully dredged.[49]

A general conclusion of the Texas 2007 State Water Plan is that new reservoirs will need to be constructed to meet growing future demands and replace water storage losses due to sedimentation. As noted above, the plan recommends the construction of 16 new reservoirs over the next 50 years as part of an overall plan to meet Texas' future water needs. The plan also recommends that the sites where these reservoirs are to be built, as well as other sites that may be needed beyond the 50-year planning horizon, be given special protected status.[50] The TWDB estimates the total cost to implement the plan, including the new reservoirs, at around $30.7 billion.[51]

SEDIMENT MANAGEMENT IN UTAH

There is no coordinated effort to manage reservoir sedimentation throughout Utah. However, there are many ongoing programs to reduce erosion in troublesome watersheds as well as numerous instances where dam owners have directly or indirectly addressed sediment problems.

Watershed Management

Like many states throughout the country, Utah has a long history of managing watersheds to conserve and protect valuable soil and water resources. Not long after pioneers settled the Salt Lake Valley, human uses in valuable watersheds surrounding Salt Lake City were closely monitored and controlled in order to prevent unwanted erosion and water quality degradation.[52] For many years other watersheds throughout the state generally lacked this kind of control and oversight. However, many of these non-urban areas also received important protection when the National Forests were created in the early 1900s, and when the SCS (now the NRCS), and the Bureau of Land Management were established in the 1930s and 1940s.

Today the efforts of these agencies are complimented by a cadre of state and local programs and initiatives aimed at improving watershed health on both public and private lands. These include:

- Utah Watershed Restoration Initiative[53]
- Utah Partners for Conservation and Development[54]
- Utah Watershed Coordination Council[55]
- Other non-governmental organizations

Under authority of the Clean Water Act, the Utah Division of Water Quality helps identify and improve sediment problems through the Total Maximum Daily Load (TMDL) program. One successful example of this program reducing erosion is on Rees Creek, a tributary of Echo Creek in the Weber River drainage. Watershed improvements on Rees Creek have reduced sediment loads entering Echo Creek by approximately 95 percent.[56]

Sediment entering Weber River from Echo Creek. (Photo courtesy of Doug Garfield, Summit County Conservation District.)

Specific examples of watershed management include the terracing of steep slopes (especially in the upper drainage) that had been over-grazed, and the construction of many small debris basins and or catchments upstream of reservoirs and communities. The NRCS has constructed several dozen debris basins and other catchments to capture sediment during high flow events. An example of an upstream catchment constructed above a reservoir for the primary purpose of keeping sediment out of the reservoir is a sediment pond built just upstream of Blue Creek Reservoir near Howell in Box Elder County.[57]

Other Instances of Sediment Management

In addition to the state's watershed improvement efforts, a few dam owners and water managers in Utah have taken specific actions to address sedimentation in their reservoirs. This is often done in response to problems that sediments have caused to normal dam operation, and not necessarily to preserve reservoir storage capacity. Twenty-five Utah reservoirs have been surveyed to estimate the amount of storage capacity that has been lost to sedimentation. Only a few reservoirs with no apparent sediment impairment problem have been identified. The extent of the sediment problem for most Utah reservoirs is unknown. Challenges created by sediment, and mitigation efforts at several Utah reservoirs, are discussed briefly below and in more detail in the case studies of Chapter 8.

Many Utah dams are operated in a manner that enables sediment to flow out of the reservoir outlets. These dams are used exclusively for agricultural irrigation and are drawn down, often completely drained, late in the irrigation season. The regular draining of these structures allows some sediment to be flushed downstream through the dam's bottom outlets. Although sediment removal from these reservoirs could be considered simply an "incidental" benefit of draining the reservoir, it helps to reduce the net accumulation of sediment and preserve active storage capacity.

At some small hydroelectric dams, sediment is passed through the reservoir on a regular basis to prevent it from impairing water flow into and through hydropower intakes. Two such facilities include Yellowstone Dam on the Yellowstone River (60 acre-feet) and First Dam on the Logan River (70 acre-feet). While the relatively small size of these structures make them more susceptible to sediment impacts, their size also makes it relatively easy to remove sediment.

Some dam owners have excavated sediment from the bottom of their reservoirs to keep outlets and diversion structures clear, and also recover a small amount of storage capacity. The owners of Gunnison Reservoir (12,800 acre-feet) near Manti estimate that about 20 percent of its original capacity has been lost to sediment. They have restored some capacity over the years by periodically excavating sediment from the reservoir.[58] The owners of Gunlock Reservoir (10,900 acre-feet) near Santa Clara drained the reservoir in the fall of 2008 to modify the outlet structure and removed sediment that was deposited near the outlet during the 2005 and 2007 flood events. The details of excavation efforts at these and other reservoirs have not been documented, so it is difficult to know how widespread or effective they have been. Typically, these instances of excavation are viewed by the dam owner as necessary maintenance, not sediment management.

Box 2 - State Agencies Concerned With Sedimentation Issues

- Department of Agriculture and Food
- Department of Environmental Quality
  - Division of Water Quality
  - Division of Drinking Water
- Department of Natural Resources
  - Division of State Parks and Recreation
  - Division of Water Resources
  - Division of Water Rights
  - Division of Wildlife Resources

Several dams that have been upgraded to meet dam safety requirements have also been raised to recover storage capacity that has been lost due to sediment accumulation in the reservoir. These include two of the state's older reservoirs: Otter Creek Reservoir (52,700 acre-feet), which was built in 1897 and Piute Dam (71,800 acre-feet), which was built in 1908. Over the years, both of these reservoirs had lost a significant amount of storage to sediment accumulation. Most or all of the lost storage was recovered as part of the dam rehabilitation by simply raising the level of the dam or spillway a few feet.

NOTES

[1] Morris, Gregory L. and Jiahua Fan, *Reservoir Sedimentation Handbook,* San Francisco: McGraw-Hill, 1997, 1.3. The wording used here is similar to that used by this source to describe the loss of the world's reservoir capacity.

[2] Ibid, 1.1.

[3] U.S. Bureau of Reclamation, *Design of Small Dams,* A Water Resources Technical Publication Washington, DC: U.S. Government Printing Office, Reprint, 2004, page 540. The original version of the document was published in 1960

and included just one page on the topic of sedimentation. A 32-page appendix on sedimentation was added to the 1987 revision, which is the version quoted in the text.

[4] Ibid, page 529.

[5] Morris and Fan, 1997, 1.3.

[6] Ibid, 1.4.

[7] Retrieved from the Internet website: http://www.census.gov/Press-Release/www/releases/archives/population/013049.html, March 7, 2010.

[8] American Society of Civil Engineers, *Sedimentation Engineering*, 1975, 615.

[9] Utah Division of Water Resources, *Conjunctive Management of Surface and Ground Water in Utah*, July 2005, page 4.

[10] Hutson, Susan S. et al, *Estimated Use of Water in the United States in 2000,* U.S. Geological Survey Circular 1268, Reston, VA: USGS, 2004, 7-8. Percentages cited include only freshwater sources, not saline sources.

[11] Retrieved from Utah Dept. of Agriculture and Food Internet web site: http://ag.utah.gov/pressrel/GeneralAgComments.html, October 6, 2008. Confirmed by Larry Lewis, Public Information Officer, Utah Department of Agriculture and Food. The Utah State University study was done by Dr. Bruce Godfrey. October 8, 2008.

[12] Retrieved from Utah Dept. of Agriculture and Food Internet web site: http://ag.utah.gov/pressrel/cup_water.html, October 6, 2008. Confirmed by Larry Lewis, Public Information Officer, Utah Department of Agriculture and Food, October 8, 2008. Also, confirmed by the Governor's Office of Planning and Budget, October 8, 2008.

[13] Hutson et al, 2004, page 8. Percentages cited include only freshwater sources, not saline sources.

[14] Governor's Office of Planning and Budget, *2008 Economic Report to the Governor,* Salt Lake City: 2008, page 79.

[15] Governor's Office of Planning and Budget, *2008 Economic Report to the Governor,* Salt Lake City: 2008, page 190.

[16] Retrieved from Utah Geological Survey, Utah Energy and Mineral Statistics which is a web-based repository for energy and mineral data for the State of Utah: http://ugs.utah.gov/emp/energydata/statistics/electricity5.0/pdf/T5.2.pdf, October 6, 2008.

[17] Retrieved from Utah Geological Survey, Utah Energy and Mineral Statistics which is a web-based repository for energy and mineral data for the State of Utah: http://ugs.utah.gov/emp/energydata/statistics/electricity5.0/pdf/T5.6.pdf October 6, 2008.

[18] Governor's Office of Planning and Budget, *2008 Economic Report to the Governor,* Salt Lake City: 2008, page 190.

[19] Morris and Fan, 1997, 2.8-2.10.

[20] American Society of Civil Engineers, *Sedimentation Engineering,* Vito A. Vanoni, Ed., New York City: 1975, page 602.

[21] Morris and Fan, 1997 2.10-2.13. The text in this section is derived entirely from this source.

[22] Ibid., 2.10.

[23] Ibid., 2.12.

[24] White, Rodney, *Evacuation of Sediments from Reservoirs*, London: Thomas Telford, 2001, iii-iv. Many of the methods and descriptions found in this section are derived from this source.

[25] Morris and Fan, 1997, 3.2.

[26] Ibid.

[27] Smith, Norman, *A History of Dams*, London: Peter Davies, 1971, page 109.

[28] Schnitter, Nicholas J., *A History of Dams: The Useful Pyramids*, Rotterdam: A.A. Balkema, 1994, page 126.

[29] White, Rodney, 2001, page 156.

[30] Liu, Jian, Bingyi Liu and Kazuo Ashida, *Reservoir Sediment Management in Asia*, presented at the 5th International Conference on Hydro-Science and -Engineering, September 18-21, 2002, Warsaw, Poland.

[31] Ibid.

[32] Ibid.

[33] Ibid.

[34] White, Rodney, 2001, page 157.

[35] Liu, Liu and Asida, 2002.

[36] Ibid.

[37] Ibid.

[38] Ibid.

[39] *Dams Are Thwarting Louisiana Marsh Restoration*, New York Times Article, June 29, 2009.

[40] U.S. Geological Survey, *Reservoir Sediment Studies in Kansas*. Retrieved from the USGS's Internet web page: http://ks.water.usgs.gov/Kansas/studies/ressed/, January 2008.

[41] Ibid.

[42] Personal communication with Kyle Juraceck, Ph.D. and Research Hydrologist, U.S. Geological Survey, January 29, 2008.

[43] Ibid.

[44] Texas Water Development Board, *Water for Texas 2007*, vol. II, *2007 State Water Plan*, Doc. No. GP-8-1, (Austin: Texas Water Development Board, 2007), 138.

[45] Ibid, 158.

[46] Ibid, 159.

[47] Ibid.

[48] Allen Plummer Associates, Inc., *Dredging vs. New Reservoirs*, 2005. Submitted to the Texas Water Development Board per TWDB Contract #2004-483-534, in association with Peter M. Allen, Ph.D., P.G. and John A. Dunbar, Ph.D., P.G.

[49] Texas Water Development Board, 2007, 159.

[50] Texas Water Development Board, *Water for Texas 2007*, vol. I, *Highlights of the State Water Plan*, Doc. No. GP-8-1, Austin: Texas Water Development Board, 2007, 11.

[51] Ibid, 2.

[52] Hooten, LeRoy W., *Salt Lake City Watershed Management Programs: 1847-1997*, Salt Lake City Public Utilities, 1997. Retrieved from Salt Lake County's online Water Resources Library: http://www.waterresources.slco.org/html/Water_Library.html, June 20, 2008.

[53] See http://wildlife.utah.gov/watersheds/ for details of Utah Watershed Restoration Initiative.

[54] See https://fs.ogm.utah.gov/PUB/Oil&Gas/Outreach/WatershedInitiative_042007_files/frame.htm for details of the Utah Partners for Conservation and Development.

[55] See www.waterquality.utah.gov/watersheds/coord.htm for details of the Utah Watershed Coordination Council.

[56] Garfield, Doug, "Rees Creek Water Quality Demonstration Project-Fact Sheet." Presented to participants at a Rees Creek restoration project tour, June 2008.

[57] Personal communication with Ray Sorensen, Blue Creek Irrigation Company, June 5, 2008.

[58] Personal communication with Roland Beck, Gunnison Irrigation Company, May 2008.

2

ESTIMATING AND MEASURING SEDIMENTATION IN RESERVOIRS

To determine if there is a sediment problem, and the magnitude of that problem, the rate at which sediment is accumulating in the reservoir must be determined. Finding that rate requires the original reservoir volume, the volume of accumulated sediment, the date the reservoir was first built, and the current date. The sediment accumulation rate (S), in percent per year, can be calculated as follows:

$$S = \frac{\text{(acc. sediment volume)}}{\text{(orig. reservoir volume)} \times \text{(yrs. to acc. sediment)}} \times 100 = \%\ \textit{per yr.}$$

Usually, reservoir volume is determined at the spillway crest. The original reservoir volume is generally available from the engineering drawings for the dam. Land surveys or topographic maps may provide the original land surface before the reservoir began filling. Then, with another future survey, the accumulated sediment volume can be estimated.

The estimated annual sedimentation rate is valuable as a general description of sedimentation but should not be construed to mean that sedimentation is the same each year. Large floods such as those experienced in northern Utah in 1983 and southern Utah in 2005 can produce a decade's worth of sediment in just a few months. How to perform these analysis and the factors influencing sedimentation rates, are the subjects of this chapter.

ESTIMATING SEDIMENTATION RATES IN RESERVOIRS

There are several approaches to estimating reservoir sedimentation rates. Different inputs are needed and different outputs are produced by each. Selection of method should use specific criteria (outlined below) and methods must be used only in situations for which they are appropriate. This section presents some reservoir sedimentation estimating methods, along with examples. The examples use actual situations found at selected Utah reservoirs. The following methods are discussed:

- Regional Rate of Storage Loss
- Regional Regression Relationship
- Reservoir Capacity Correlation of 1105 U.S. Reservoirs

It should be noted that these methods generate only rough approximations. As such, management decisions and basin sediment yield estimates should not be based solely on these methods. However, the information obtained may provide insight and be used to direct preliminary watershed planning and to identify potential problem areas. Multiple methods could be employed and the results compared to formulate a better understanding of sedimentation for a given reservoir and drainage. These methods are technical, and are best employed by professional engineers familiar with them. Using engineers to assist in sediment management will be discussed in detail later in this report.

Regional Rate of Storage Loss[1]

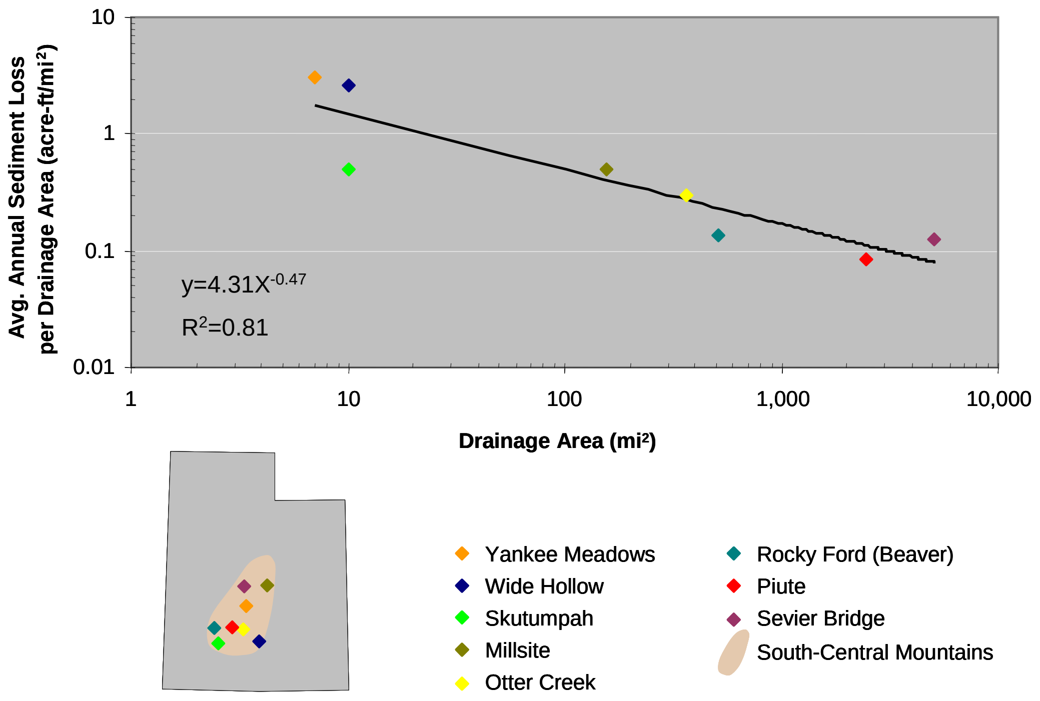
This method uses available data from reservoir sedimentation surveys within a specific region to develop a relationship between annual storage loss and watershed size. This relationship can then be used to estimate the sedimentation rate for other reservoirs within the region. This method works best when the reservoirs used to develop the correlation have similar watershed characteristics (geology, vegetative cover, land use) and dams are operated in a similar manner. While this approach works well in some areas, it can be difficult to apply to others — especially when there is limited sediment survey data available. It is also necessary to take into consideration sediment trapping by upstream reservoirs.

The mountainous area of south-central Utah is one region where the correlation between storage loss and drainage area appears promising. Sediment survey data is available for eight reservoirs within this relatively small area. Figure 2 shows a scatter plot of this data as well as the regression equation and other statistical data. The relatively high R^2 value (a statistical parameter indicating analysis quality) indicates a good correlation and suggests that sedimentation rates for other reservoirs within the region could be estimated with some degree of confidence.

Regional Regression Relationship[2]

Similar to the Regional Rate of Storage Loss method, the Regional Regression Relationship method uses available sedimentation data to generate a relationship between sediment yield and watershed characteristics. This method requires many data points to derive regression equations. In 1976, Dendy and Bolton developed regression equations based on resurvey data for over 500 reservoirs.[3] The drainage areas varied from roughly 1 to 30,116 square miles. The derived regression equations yield an estimate that can provide insight regarding sedimentation of the reservoir in question. However, the results are rough approximations. The equations convey a basic relationship based upon averages and therefore actual sedimentation may be higher (in arid or erosive areas) or lower (in mountainous or undisturbed areas) than the estimated value. The derived equations and definition of terms are shown below:

FIGURE 2
Example of Regional Rate of Storage Loss Method
Utah South-Central Mountains



This is an example. Additional data points would be desirable before this relationship is broadly applied to other reservoirs within the region.

Equation 1: (where Q < 2 in/yr)

$$\frac{S}{S_R} = C_1 \left(\frac{Q}{Q_R} \right)^{0.46} \left[1.43 - 0.26 \log \left(\frac{A}{A_R} \right) \right]$$

Equation 2: (where Q > 2 in/yr)

$$\frac{S}{S_R} = C_2 e^{\left(-0.11 \frac{Q}{Q_R} \right)} \left[1.43 - 0.26 \log \left(\frac{A}{A_R} \right) \right]$$

A = Watershed area, mi^2 (km^2)
A_R = Reference watershed area value, 1.0 (2.50)
C_1 = Equation 1 coefficient, 1.07 (0.375)
C_2 = Equation 2 coefficient, 1.19 (0.417)
Q = Mean annual runoff depth, in/yr (mm/yr)
Q_R = Reference runoff depth value, 2 in/yr (50.8 mm/yr)
S = Specific sediment yield, $\text{ton/mi}^2\text{/yr}$ ($\text{ton/km}^2\text{/yr}$)
S_R = Reference specific sediment yield value, 1645 $\text{ton/mi}^2\text{/yr}$ (635 $\text{ton/km}^2\text{/yr}$)

Figure 3 contains an example calculation using the Regional Regression Relationship for Millsite Reservoir. Comparison to the Millsite Reservoir case study in Chapter 8 shows an actual sedimentation rate of 0.44 percent per year.

Reservoir Capacity Correlation of 1105 U.S. Reservoirs[4]

Using sedimentation data from 1,105 U.S. reservoirs, researchers have developed an inverse correlation between reservoir capacity and the annual sedimentation rate. This relationship is shown in Figure 4; note the logarithmic horizontal scale. The main point of this graph is that smaller reservoirs accumulate sediment at much faster rates than do larger reservoirs. Using the graph provides a quick and easy way to estimate the sedimentation rate for a reservoir of nearly any size (approximately 5 acre-feet to 2.5 million acre-feet). However, most of the reservoirs used to derive this relationship are located in watersheds that are not like those found in Utah. They are located in the Great Plains and the Eastern U.S., which have a considerably different climate, geology and topography. Moreover, data was collected from the entire country and may, or may not, be accurate for an individual Utah reservoir. None-the-less, using the graph can provide a rough estimate, or first approximation, of the sediment accumulation rate based on reservoir size only. Moreover, using the curve to quickly estimate sedimentation rates for numerous reservoirs throughout a broad region might provide useful insight.

MEASURING SEDIMENT ACCUMULATION IN RESERVOIRS

The estimating methods previously discussed are helpful in identifying potential sediment problems. However, effective sediment management in reservoirs also requires specific information about the rate and pattern of sediment deposition.[5] Once a potential problem is identified, reservoir owners need to quantify the actual volume of sediment deposits. There are many different ways to measure deposition in a reservoir. Included are mass balance, spud survey (steel rod with sediment-catching grooves, penetrating full sediment depth), sedimentation plates and horizon tracing using nuclear isotopes. However, two methods that measure both the rate and pattern of deposition are usually preferred. These are the Range Survey and the Contour Survey. Regardless of the method used, the longer the time between surveys, the more accurate will be the estimated average sediment accumulation rate.

It is best to perform surveys on full reservoirs having clear water. A full reservoir makes the survey easier and more complete. Turbid waters can cause inaccuracies. Another important consideration is to have correct elevation control for the survey. Otherwise, accuracy is compromised. This includes using the same elevation benchmarks as previous surveys, where possible.

Range Survey

A range survey is typically performed from the water surface using a sonar device to measure the depth of water along preset range lines that cross the reservoir at regular intervals. It is best accomplished when the reservoir is full, thus facilitating the fastest and easiest survey from a boat. A typical ground survey is performed for any portion of the range that is not submerged. This method requires survey data of the original reservoir bottom along each range

FIGURE 3

Example of Regional Regression Relationship Method

Millsite Reservoir

$A_R = 1.0$
$Q_R = 2$ *in/yr*
$S_R = 1645$ *ton/mi²/yr*

First, using GIS or other tools estimate the drainage area above Millsite Reservoir (A) and the mean annual runoff depth for this area (Q).

$A = 157\ mi^2$
$Q = 5.40$ *in/yr*

Next, since Q is greater than 2 inches per year, use equation 2 and solve for specific sediment yield (S), where $C_2 = 1.19$.

$$\frac{S}{S_R} = C_2 e^{\left(-0.11\frac{Q}{Q_R}\right)}\left[1.43 - 0.26\log\left(\frac{A}{A_R}\right)\right]$$

$$\frac{S}{1{,}645 ton/mi^2/yr} = 1.19e^{\left(-0.11\frac{5.40 in/yr}{2 in/yr}\right)}\left[1.43 - 0.26\log\left(\frac{157 mi^2}{1.0 mi^2}\right)\right]$$

$S = 1{,}250\ ton/mi^2/yr$

Then, multiply the specific sediment yield (S) by the drainage area (A) to obtain tons of sediment entering the reservoir per year.

$S = 1{,}250\ ton/mi^2/yr \times 157\ mi^2 = 196{,}000\ ton/yr$

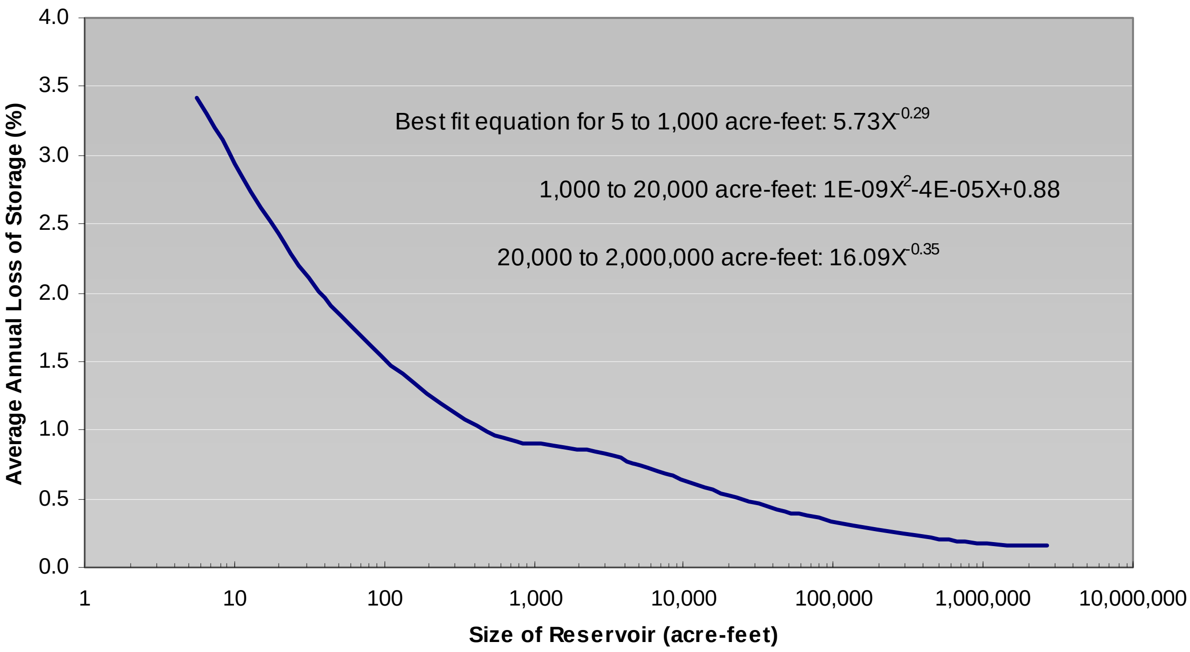
Next, convert this to acre-feet per year by using the measured (or estimated) specific weight of the sediment deposits (81 lb/ft³).

$$S = \frac{196{,}000 ton}{yr}\cdot\frac{2000 lb}{ton}\cdot\frac{ft^3}{81 lb}\cdot\frac{ac-ft}{43{,}560 ft^3} = 111 ac-ft/yr$$

Finally, divide the annual sediment load by the original reservoir capacity (at spillway) and multiply this by 100 to determine the annual percent loss of storage capacity in the reservoir.

Sedimentation Rate = 111 *ac-ft/yr* ÷ 18,000 *ac-ft* × 100 = 0.62 *%/yr*

FIGURE 4
Reservoir Capacity Correlation of 1105 U.S. Reservoirs



Source: Curve digitized and re-plotted from Rodney White, *Evacuation of Sediments from Reservoirs,* London: Thomas Telford, 2001, Figure 2.5.

line, see Figure 5, prior to the reservoir filling with water. It yields multiple profiles of the reservoir bottom and sediment deposits from which a total sediment volume can be interpolated.

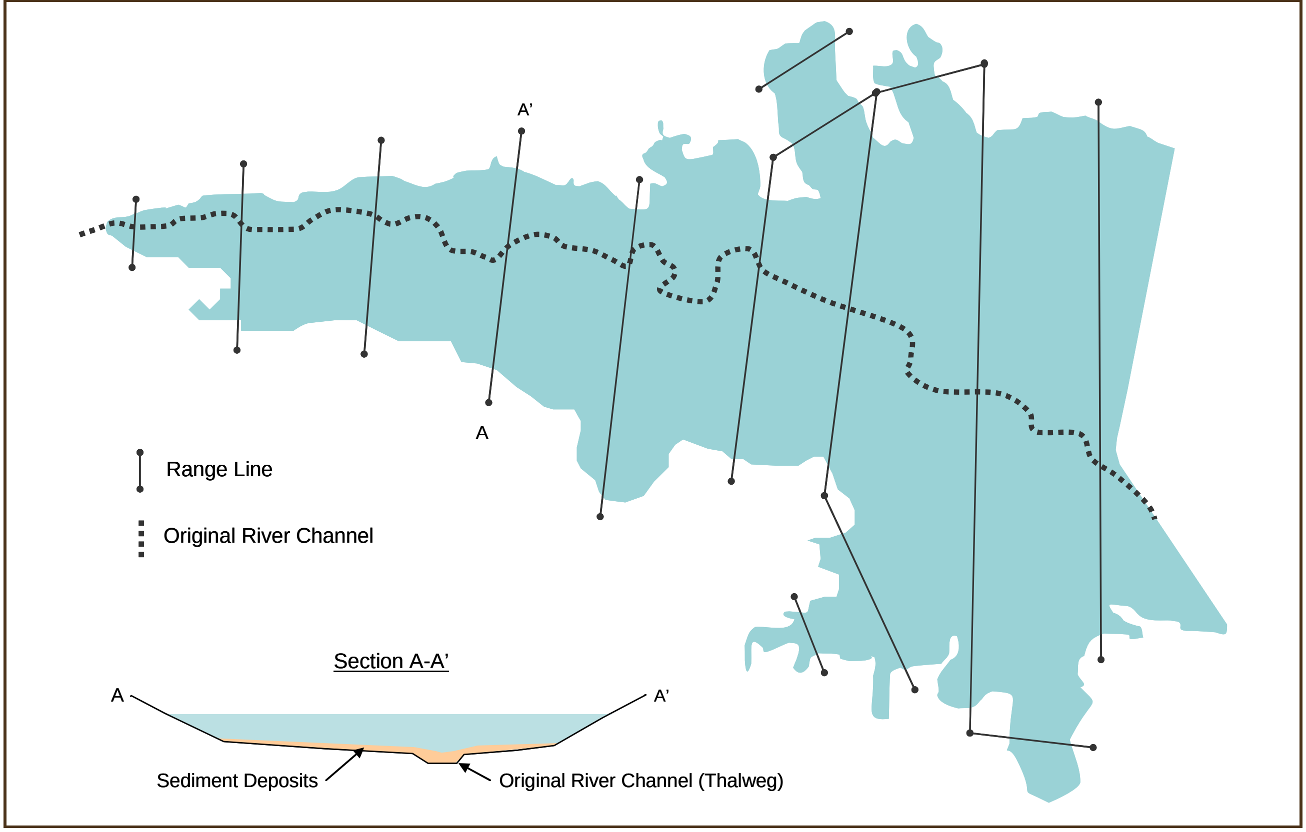
Range surveys are typically faster and more economical than contour surveys because much less data is required. In the past, these surveys were the most commonly used method to measure sedimentation. Assuming previous surveys exist, range surveys are valuable in accurately reflecting changes in sediment volume over time. Despite these advantages, range surveys are increasingly being supplanted by automated contour survey methods.[6]

Contour Survey

A contour survey for a reservoir (also known as a bathymetric survey) is typically performed from the water surface using a sonar device to measure the depth of water and a Global Positioning System (GPS) device to measure geographic location. A contour survey can also be performed from the ground using traditional survey equipment or from the air using aerial photogrammetry when the reservoir is empty, or for any portion of the reservoir that is not submerged. To accurately estimate the rate and pattern of sedimentation, this method requires fairly detailed survey data of the entire reservoir bottom prior to the reservoir filling with water. Because most dams were built many decades ago when survey technology was not as advanced as it is today, comparing a modern contour survey to a pre-reservoir survey can be problematic. Thus, more than one contour survey, spaced several years apart, may be required to accurately estimate the present sedimentation rate.

In addition to the traditional contour survey, scientists have developed a special kind of survey that does not rely on pre-reservoir contour data of the original bottom surface of the reservoir. This type of survey uses sub-bottom profiling technology. Sub-bottom profiling combines a sonar device in the 200-

FIGURE 5
Schematic Example of a Range Survey



kHz range with a lower-frequency signal in the 5- to 24-kHz range. This lower frequency can penetrate sediment deposits and reflect a signal from a denser horizon consisting of soil or rock. If conditions are right, sediment deposits of up to 30 feet can be measured using this method.[7] However, the usefulness of this method is site-specific. If the sediment has entrained gas, for instance, this method is unable to determine sediment thickness. If gas is present, ground-penetrating radar would likely be the best method to define sub-bottom characteristics.[8] Some reservoir surveyors believe highly turbid conditions during a sonar survey negatively impacts accuracy.[9]

The U.S. Bureau of Reclamation (USBR) has developed a reconnaissance technique to help estimate sedimentation in very large reservoirs.[10] This technique is basically a variant of the contour method which only requires conducting a detailed survey at critical inlets to the reservoir. In a 2001 a Lake Mead survey and a 2004 partial survey of Lake Powell, the USBR used this method to map the sediment delta of major side streams. This method allows USBR to estimate the rate of sedimentation at large reservoirs without having to conduct an expensive full-scale contour survey of the entire reservoir.

The U.S. Geological Survey (USGS) and USBR both have the equipment necessary to conduct contour surveys. While the USBR is equipped with traditional contour survey technology, USGS can also perform sub-bottom profiling. Some Utah universities are also developing contour surveying capacity.

Another option to perform a contour survey is using a Light Detection and Ranging (LIDAR) system. This is a remote sensing method that employs an airplane flying at low altitude while laser beams are directed into the reservoir and onto the ground around it. The distance to the surfaces is precisely measured using laser pulses that are reflected back to the airplane.[11] While providing the needed information, LIDAR is costly, complex and requires trained specialists.[12] It may also be limited by water that is not sufficiently clear.[13]

NATURAL WATERSHED FACTORS AFFECTING SEDIMENTATION RATES

The rate at which a watershed contributes sediment to its streams is affected by both natural and human factors. The primary natural factors include rainfall amounts and intensity, soil type, bedrock outcrops, topography, ground cover and vegetation. Human activity can alter most of these natural factors and consequently can have a strong impact upon the resulting erosion and sedimentation rates.

Rainfall Intensity and Duration

One of the biggest factors affecting erosion and sedimentation rates is the amount of rainfall and the intensity with which the rain strikes the ground. Throughout the winter, much of Utah's upper watersheds receive precipitation in the form of snow. The snowpack then melts in the spring, and some of it infiltrates into the ground. The spring runoff causes considerable erosion as evidenced by muddy waters which can persist for several weeks. Approximately 50 percent of annual streamflow volumes occur during only 25 percent of the year during April, May and June.[14] Typically, the water from melting snowpack finds its way to Utah's streams in a much more calm and controlled fashion compared to intense thunderstorms. Although runoff from melting snow may have a lower sediment concentration than thunderstorm runoff, it runs for a much longer time and derives sediment from a larger area. Thus, it produces a larger percentage of the annual sediment volume. None-the-less, on a local basis, and for short durations, an intense thunderstorm may generate large quantities of sediment.

Although thunderstorms can occur at any time of the year, in Utah such storms are most prevalent in late summer or early fall and in early springtime. These locally intense storms can, and often do, produce large sediment yields from a watershed into the stream. Thunderstorms that follow closely on the heels of a previous storm, or while snowmelt is still occurring, can produce very high sediment yields because the ground is saturated and highly susceptible to erosion. These conditions can trigger landslides and mudflows, further increasing the sediment delivered to the stream and reservoir.

Streambed erosion is directly related to the stream flow volumes. While low flows may have high suspended sediment loads and look very muddy, high flows have the energy necessary to aggressively erode streambanks and mobilize the entire streambed. Consequently, the majority of sediment moved by a stream takes place during high flow events, whether they are a result of rapid snowmelt or intense thunder shower.

Soil Type, Geology and Topography

Soil type, geologic features, and topography also play key roles in determining the amount of sediment that reaches the streams and flows into the reservoirs. Generally, cohesive soils (clays and clayey silts) are less susceptible to erosion than the more granular soils (sandy soils and loams). Bedrock outcrops, faults or other geologic features can serve to concentrate flows and increase water velocities, thereby increasing erosion. Steeper terrain greatly enhances soil erosion because it not only increases the flow velocities but it also decreases the resistance soil particle impose upon one another, particularly as the slope approaches the angle of repose for the soil type. Steeper terrain also means straighter and steeper stream channels, greatly increasing the channels capacity to transport large sediment loads. Where the terrain is less steep, stream channels tend to meander more. This in turn reduces the velocities and allows the heavier suspended sediments to redeposit.

Ground Cover

The amount of vegetative cover in a watershed is among the most important factors determining the amount of sediment washed into a stream. This includes plants of all sizes from tall trees to short shrubs and grasses. Vegetative root systems tend to hold soils together. The leaf cover of deciduous trees and needles of conifers, those that are on the plants and the litter on the ground, will shield the soil from the direct impact of falling rain. Where rain is allowed to land directly upon bare soil, the high velocity of the droplets tends to break up the soil and facilitate erosion. Planting vegetation is among the most effective ways to prevent erosion in a watershed.

In January 2005, heavy snowpack coupled with intense rainfall led to significant erosion and flood damage all along the Santa Clara River in Washington County.

Natural Wildfires

Another very important natural factor affecting erosion is wildfires. Many people think of wildfires as being human caused. While some are, wildfires ignited by dry-lightning strikes have always been a part of the natural process. Much, if not all, of the vegetative cover is removed by the fire and the burned area becomes much more susceptible to erosion.

In addition to the obvious problems caused by the lack of vegetation after a fire, it has been shown that in the summertime vast areas blackened by fire can generate much more heat than the adjacent green landscape. This heat can produce convective air currents that can draw passing thundershowers directly over the blackened landscape.[15] Thus Utah, with its thunderstorm season following directly upon the heels of wildfire season has experienced many intense rainfall events on recently burned watersheds. These often result in landslides and/or significant mudflow events and increased erosion.

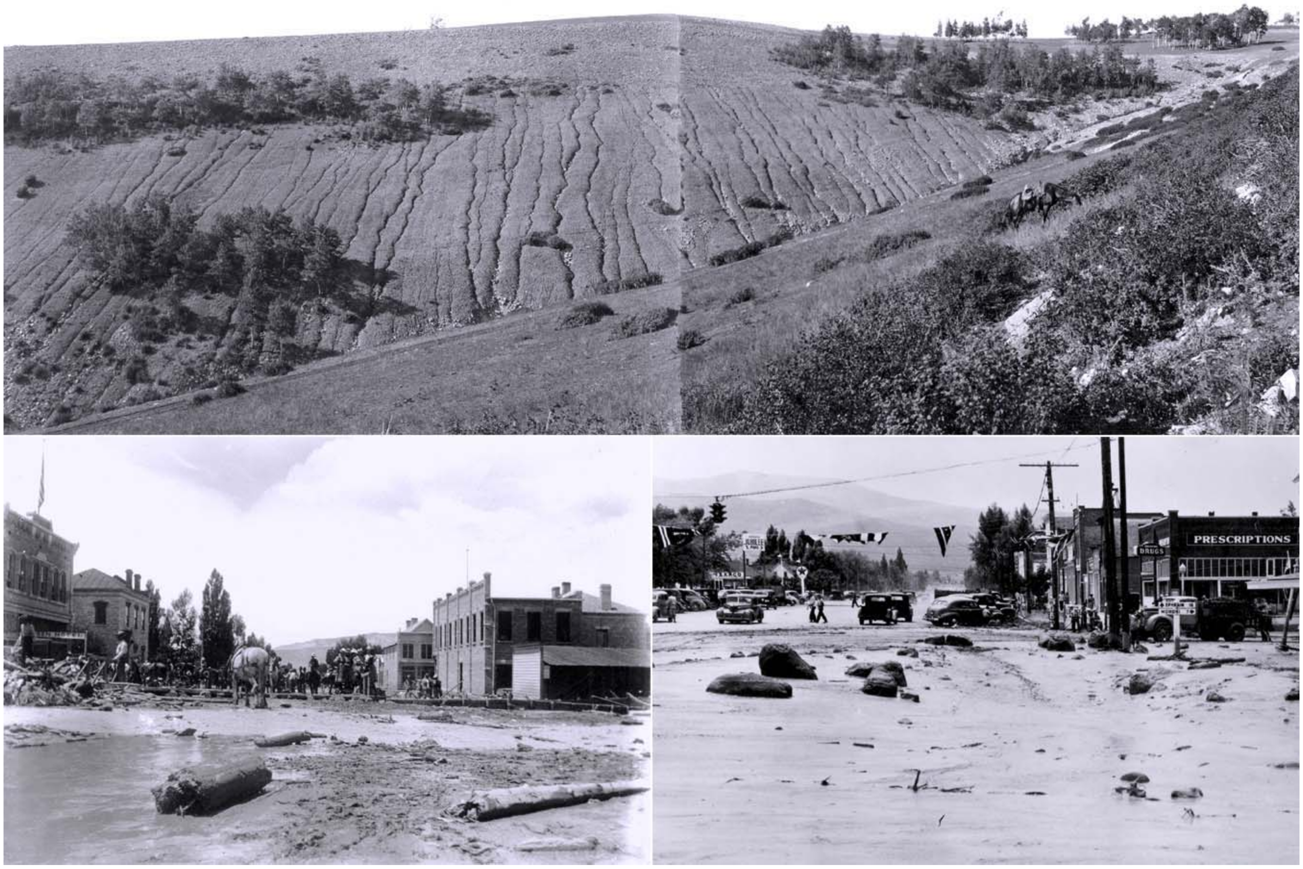
HUMAN FACTORS AFFECTING SEDIMENTATION RATES

Many human activities can negatively alter the natural characteristics of the watershed and thereby change the erosion rates and sedimentation loads. This section provides background into the watershed sediment problem and the need for management.

Livestock Grazing and Agriculture

Livestock grazing was probably the first human activity to have widespread impacts upon the state's watersheds and significantly increase erosion. Cattle and sheep grazing not only reduces vegetation and ground cover, it also breaks up the ground with the animal's hooves. Both of these actions accelerate erosion and sediment yield. In the past, over-grazing has been a significant problem, not only in Utah, but throughout the West. In recent decades, much has been learned about this problem and management techniques have been developed in an effort to minimize grazing impacts. Today's grazing allotment managers are usually careful to monitor and manage grazing in an effort to maintain a healthy watershed. However, there have been occasions when federal agencies administering public lands sought to maximize revenues, resulting in overgrazing. This, in turn, led to increased erosion due to lack of vegetative cover. When this occurs, reservoir owners downstream of overgrazed lands receive more sediment. It may be beneficial to evaluate conditions in the reservoir drainage above the dam and, if appropriate, ask the federal land administrators to reduce grazing.

It is worth noting that the Manti La-Sal National Forest (Carbon, Emery and Sanpete Counties) was established in reaction to sediment problems created by over-grazing of sheep and cattle. It has been estimated that, prior to 1904, there were 500,000 sheep and between 15,000 and 18,000 cattle grazing on



Top: Effects of over-grazing at the head of the left fork of Ephriam Canyon, August 1910.
Bottom: Mud and debris washed into towns at the base of the Wasatch Plateau before livestock management.
(Photos courtesy of Manti La-Sal National Forest, Price, Utah)

what is now that National Forest. The result was literal denuding of vegetation across the entire range. Summer storms produced “devastating floods that brought tons of mud and rock into villages at the foot of the mountains.”[16] See the above pictures. In 1903, alarmed citizens on both sides of the mountains requested that the Wasatch Plateau be designated a National Forest Reserve and be regulated by the federal government. By 1907 the Forest Service was established and management of the mountain range became its responsibility.[17]

Studies to evaluate livestock impacts and alternative range management strategies were initiated as part of normal operations on the national forest. As a result, grazing reductions have continued for many years. Total grazing allotments were reduced to 172,200 acres in 1912. This was reduced another 20 percent by 1920. Further reductions occurred between 1930 and 1950. Eventually, in the 1960s an additional 50 percent reduction in grazing allotments was required.[18] Today, the multi-use concept adopted by the Forest Service accommodates multiple uses of the forest. In 2009 the grazing allotment in the Manti La-Sal National Forest was 66,095 head of sheep and 10,772 head of cattle.[19]

Other agricultural activities also impact sediment erosion. Any time a field is plowed, it will sit for a time without vegetation and be susceptible to maximum erosion. Flood irrigation often results in over-application of water which can cause increased erosion as well. Even sprinkler irrigated fields that are well managed and meticulously cared for will have more erosion than a field not covered by crops.

Logging, Mining and Construction

Logging and mining activities also greatly increase the potential for erosion and increased sedimentation

Grazing, mining, logging and farming are among the many human activities that increase erosion and subsequently increase reservoir sedimentation rates.

rates. Beyond the obvious reduction in the number of trees as a part of the logging process, often there is considerable ground disturbance associated with road construction and the operation of machinery. In addition to the construction of access roads, mining operations often include the placement of erodible material which can be washed to local streams.

Almost any type of construction or development in the upper watershed will result in increased runoff, as permeable ground is covered over by impervious structures and pavement. When this happens not only is the amount of runoff water increased, but usually there is an accompanying increase in velocity, and a corresponding decrease in the "time of concentration" (the time it takes for water from the entire contributing area to collect in one location). All of these factors tend to increase erosion and the amount of sediment delivered to streams.

Fires

Fires were mentioned earlier in the discussion of natural factors, but many fires result from human activities. Also, since people have fought both human-caused and natural wildfires for many decades, some areas have become choked with fuels (thick underbrush, dead and dried logs, and tree branches). Since these areas have not been subjected to periodic natural burns, considerable fuel loads have accumulated. Fires in such areas burn much more intensely, resulting in more vegetation loss and long recovery periods. This in turn leads to longer exposure periods and higher erosion rates.

NOTES

[1] Morris, Gregory L. and Jiahua Fan, *Reservoir Sedimentation Handbook,* San Francisco: McGraw-Hill, 1997, 7.30-7.31. The wording used here is similar to that used by this source.

[2] Ibid. 7.31-7.32.

[3] Dendy, F. E. and G. C. Bolton, *Sediment yield-runoff-drainage area relationships in the United States*, Journal of Soil and Water Conservation, 1976, page 264.

[4] This correlation was derived from sedimentation data found in Dendy, F.E. and W.A. Champion, *Sediment Deposition in U.S. Reservoirs: Summary of data reported through 1975.* Miscellaneous Publication No. 1362. Compiled by USDA Sedimentation Laboratory, Oxford Miss.: Agricultural Research Service, 1978.

[5] Morris and Fan, 1997, 10.1.

[6] Ibid, 10.16.

[7] Ibid, 10.14.

[8] Personal communication, Robert L. Baskin, Supervisory Hydrologist, U.S. Geological Survey, Salt Lake City, UT, August 14, 2009.

[9] Personal communication, Cory Cram, Watershed and Environmental Coordinator, Washington County Water Conservancy District, August 7, 2009.

[10] For a description of this technique, see: Ferrari, Ronald L., *Reconnaissance Techniques for Reservoir Surveys,* Denver: Dept. of Interior, 2006.

[11] Retrieved from the Internet website: http://en.wikipedia.org/wiki/Lidar, January 29, 2010.

[12] *CLICK: The USGS Center for LIDAR Information Coordination & Knowledge*, monograph, February 2007, page 1.

[13] Retrieved from the Internet website: http://sofia.usgs.gov/projects/index.php?project_url=bathysed, January 29, 2010.

[14] Utah Division of Water Resources, *Conjunctive Management of Surface and Ground Water in Utah*, July 2005, page 40.

[15] Elizabeth Mulvihill Page, *Post-wildfire impacts on microclimate—a numerical investigation*, 18th Conference on Applied Climatology, Tuesday, 19 January 2010. Retrieved from the internet website: http://ams.confex.com/ams/90annual/techprogram/paper_159347.htm, February 25, 2010.

[16] U.S. Forest Service, Manti La-Sal National Forest, *Layne on Grazing*, April 6, 2009, page 1.
Document provided by Ann King, April 7, 2009.

[17] Ibid.

[18] Ibid. page 2.

[19] Personal communication with John Healey, Manti La-Sal National Forest, April 14, 2009

3

SEDIMENTATION IN UTAH RESERVOIRS

To put the potential impact of sedimentation in Utah's reservoirs in perspective, a basic understanding of the history, capacity and uses of these reservoirs is important. This chapter provides this information, presents a compilation of sedimentation data currently available for Utah reservoirs, and estimates the total rate of storage capacity loss due to sedimentation for the state as a whole.

SUMMARY OF UTAH RESERVOIRS

Reservoirs Not Included in the Summary

The following discussion of Utah's reservoir development does not include Flaming Gorge and Lake Powell reservoirs. Lake Powell, with its 27 million acre-feet of storage capacity, began filling in 1963 with the completion of Glen Canyon Dam. Flaming Gorge Dam was completed in 1964 and the reservoir has 3.7 million acre-feet of storage capacity. Although Flaming Gorge Dam is located in Utah, and much of both reservoirs are located within the boundaries of the state, these two reservoirs provide water for all seven states of the Colorado River Basin, including Utah. These reservoirs have their own administration and management. Also, due to their size they present some unique sediment challenges that go beyond the scope of this report. Consequently, although both Flaming Gorge and Lake Powell are included in Figure 6, and listed in Table 1, these reservoirs are not included in the following analysis and discussion of Utah's statewide reservoir storage.

History of Utah Reservoir Construction

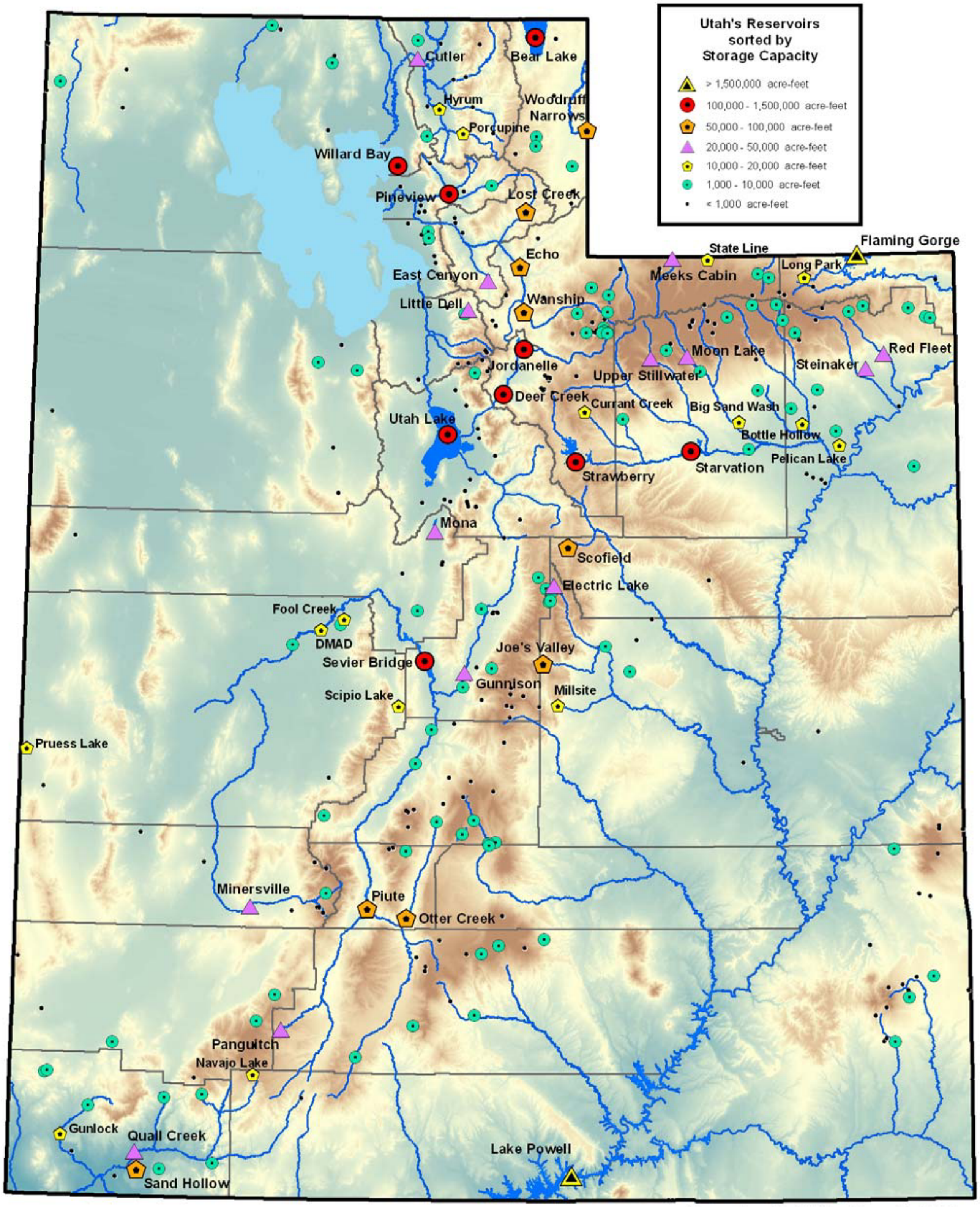
From 1847 to 1950

The early establishment of permanent communities throughout Utah during the years of 1847-1877 was primarily the result of Mormon colonization. These communities were most often established at the mouth of canyons where perennial streams could be diverted for irrigation. This early period was largely a time of canal building, with very few reservoirs constructed.

By 1870, Utah's immigrants had built 277 canals having a total length of 1,043 miles and watering 115,000 acres.[1] The last quarter of the 19th century was a relatively dry period ending with 10 consecutive drought years between 1896 and 1907. "During the three decades following 1875 the need for reservoirs was keenly felt, but their construction was retarded by several factors, especially lack of funds."[2]

In the first half of the 20th century, new agricultural development relied heavily on the construction of dams and water storage reservoirs. Utah's streams typically experience peak runoff in late May and early June, while the maximum water requirement of crops occurs in July and August. This coupled with the development of even more agricultural land, made the need for reservoir development readily apparent.

FIGURE 6
Utah's Reservoirs



*Reservoirs under 10,000 acft are not labeled

The year 1910 marks a rough transition from canal building to reservoir construction. It should not be inferred, however, that there were no reservoirs built prior to that time nor, that canals were no longer built subsequent to that date. There are still about 30 reservoirs in use today that were built before 1900. Most of the reservoirs constructed during that early period were small, with limited impacts. There were, however, several exceptions. A small dam was constructed at Utah Lake's outlet to the Jordan River in 1872. The huge surface area of Utah Lake made it possible to achieve a vast amount of storage (870,000 acre-feet) with a very small impounding structure and very little cost. See Table 1 for a list of Utah's reservoirs larger than 4,000 acre-feet.

This technique of enhancing a natural lake with a small dam at its outlet to generate larger amounts of storage space, at relatively little expense, was a very effective and often-used method employed by the state's early water developers. In 1872, Utah residents in the upper Sevier River Basin enhanced Panguitch Lake with a small dam, thus generating a large volume of storage (23,730 acre-feet). With the construction of a very small dam at the outlet of Bear Lake in 1914, 1.4 million acre-feet of storage space was created. The storage capacity of many lakes high in the Uinta Mountains and most of the naturally occurring lakes along the Wasatch Front were enhanced in this way during the first couple of decades of the 20th Century.

Utah's early water developers were also adept at identifying many of the state's most efficient sites for storing water. In 1897 Otter Creek Reservoir was put into operation. Modified in 1983 and 2000, this reservoir now stores 52,700 acre-feet of water behind a 1,220 foot long dam that is only 43 feet high. First put into operation in 1915, Strawberry Reservoir initially stored 270,000 acre-feet of water. Subsequent modifications in the 1970s have enlarged Strawberry Reservoir to 1,100,000 acre-feet. Sevier Bridge Reservoir was completed in 1914 and stores 236,000 acre-feet of irrigation water for use in the lower Sevier River Basin.

Figure 7 shows the construction of Utah's reservoirs by decade. The greatest decade of reservoir construction, in terms of storage volume created, occurred between 1910 and 1920. The enhancement of Bear Lake and the completion of Sevier Bridge Reservoir in 1914, along with the construction of Strawberry Reservoir in 1915, made this decade the most productive decade for the development of Utah's reservoir storage capacity. The 2 million acre-feet of storage developed in that decade more than tripled Utah's statewide storage capacity at the time. Each of these structures will soon celebrate its 100th anniversary.

About forty reservoirs were built in the 1920s, but most of these were smaller than 4,000 acre-feet. The one exception was Cutler Reservoir in the Bear River Basin, which was built primarily to generate hydropower.

The thirties and forties was a period of much dam building and reservoir construction. The Bureau of Reclamation (USBR) was active, building many of its projects statewide. In the Weber Basin, Echo Reservoir was completed in 1931 and Pineview Reservoir in 1937. Moon Lake, in the Uintah Basin, began storing water in 1938. Deer Creek Reservoir, built to provide a reliable drinking water supply for Salt Lake City, was completed in 1941. Scofield Reservoir, in the West Colorado River Basin, was completed in 1943. Originally begun in 1908, Piute Reservoir was enlarged to its current capacity in 1938.

From 1950 to 2009

In the 1950s the Bureau of Reclamation enlarged Pineview Reservoir and built Wanship Dam (Rockport Reservoir). Irrigators in Rich County constructed Woodruff Narrows Reservoir in 1959. Woodruff Narrows is actually located in Wyoming but the irrigation company that owns it, and the actual ground irrigated, is located in Rich County, Utah.

The Bureau of Reclamation continued to build several large dams in the 1960s. Steinaker Reservoir, in the Uintah Basin, was completed in 1961. In 1964, Willard Bay Reservoir was completed adjacent to the Great Salt Lake at the lower end of the Weber Basin. Joe's Valley Reservoir, in the West Colorado Basin, began storing water in 1965.

Many reservoirs were built in the 1970s. It was second only to the 1910 to 1920 decade in creation

TABLE 1

Utah’s Major Reservoirs – Larger Than 4,000 acre-feet

Reservoir	Date Built	Storage Capacity* (acre-feet)	Basin	Reservoir	Date Built	Storage Capacity (acre-feet)	Basin
Lake Powell[†]	1964	27,083,092	Colorado	Stateline	1979	14,000	Uintah
Flaming Gorge	1968	3,789,000	Colorado	Long Park	1980	13,700	Uintah
Bear Lake	1914	1,452,000	Bear	Porcupine	1962	13,000	Bear Lake
Strawberry	1915	1,106,500	Uintah	Gunnison	1889	12,800	Sevier
Utah Lake	1872	870,000	Utah Lake	Big Sand Wash	1965	12,100	Uintah
Jordanelle	1992	372,000	Utah Lake	Pelican	1967	11,900	Uintah
Sevier Bridge	1914	236,200	Sevier	Pruess	1900	11,800	West Desert
Willard Bay	1964	215,000	Weber	Bottle Hollow	1970	11,100	Uintah
Starvation	1970	167,500	Uintah	Gunlock	1970	10,900	Cedar/Beaver
Deer Creek	1941	147,000	Utah Lake	Scipio	1936	10,400	Sevier
Pineview	1937	110,000	Weber	Johnson	1910	10,300	West Colorado
Echo	1931	73,900	Weber	Upper Enterprise	1912	9,900	Cedar/Beaver
Scofield	1943	73,600	West Colorado	Recapture	1984	9,300	SE Colorado
Piute	1908	71,800	Sevier	Smith & Moorehouse	1987	8,400	Weber
Rockport	1957	62,100	Weber	Grass Valley	1917	8,400	Cedar/Beaver
Joe’s Valley	1965	61,500	West Colorado	Causey	1966	7,900	Weber
Woodruff Narrows	1959	57,300	Bear	Mantua	1961	7,600	Bear
Otter Creek	1897	52,700	Sevier	DMAD	1959	7,500	Sevier
Sand Hollow	2002	51,400	Washington	Ash Creek	1960	6,300	Kanab/Virgin
East Canyon	1964	51,200	Weber	Fish Lake	1935	6,300	West Colorado
Moon Lake	1938	49,500	Uintah	Oaks Park	1939	6,200	Uintah
Quail Creek	1984	40,300	Virgin	Cottonwood	1982	6,100	Uintah
Steinaker	1961	38,200	Uintah	Neoponset	1924	6,000	Bear
Meeks Cabin	1970	32,500	Uintah	Browns Draw	1981	5,900	Uintah
Electric Lake	1974	31,500	West Colorado	Lake Boreham	1937	5,800	Uintah
Upper Stillwater	1987	29,500	Uintah	Red Creek	1960	5,700	Uintah
Cutler	1927	26,500	Bear	Huntington	1949	5,600	West Colorado
Red Fleet	1980	26,170	Uintah	Newton	1871	5,600	Bear
Panguich Lake	1872	23,730	Sevier	Kolob	1956	5,600	Washington
Lost Creek	1972	22,500	Weber	Miller Flat	1949	5,600	West Colorado
Little Dell	1953	20,500	Jordan	Huntington North	1966	5,400	West Colorado
Mona	1895	19,200	Utah Lake	Cleveland	1909	5,300	West Colorado
Hyrum	1935	18,800	Bear River	Newcastle	1956	5,200	Cedar/Beaver
Millsite	1971	18,000	West Colorado	Mill Meadow	1954	5,200	West Colorado
Fool Creek #1	1948	17,781	Sevier	Gunnison Bend	1895	5,000	Sevier
Currant Creek	1977	15,670	Uintah	Whitney	1966	4,700	Bear
Navajo Lake	1910	14,200	Sevier	Fool Creek #2	1948	4,400	Sevier
Minersville	1914	14,100	Cedar/Beaver	Woodruff Creek	1970	4,400	Bear River

*The storage capacities shown here reflect current (2009) reservoir size, including enlargements and improvements subsequent to the initial dam construction. Consequently, for some reservoirs the storage capacity shown here may differ from the initial reservoir storage capacity shown in Figure 7.

FIGURE 7

Construction of Utah Reservoirs by Decade

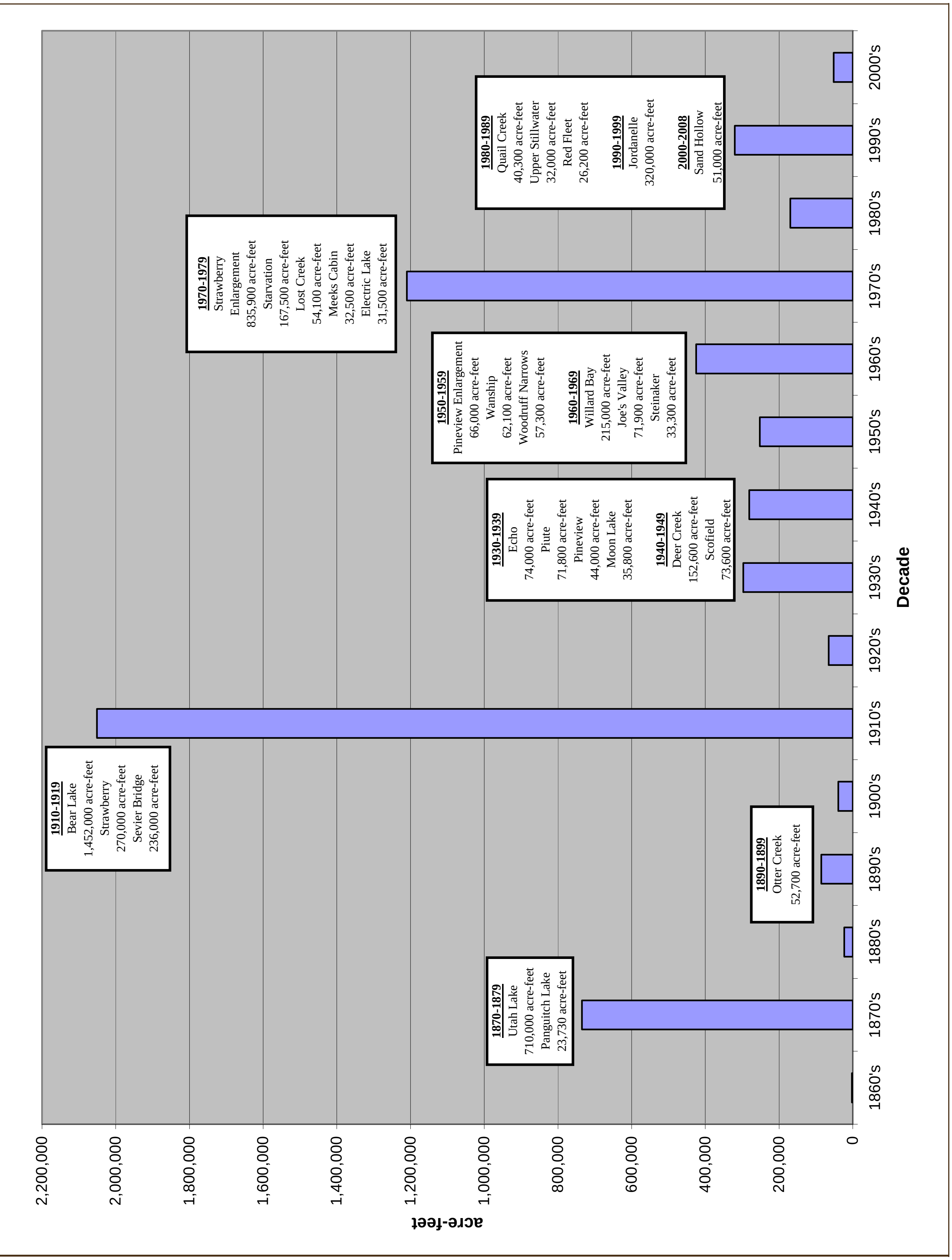
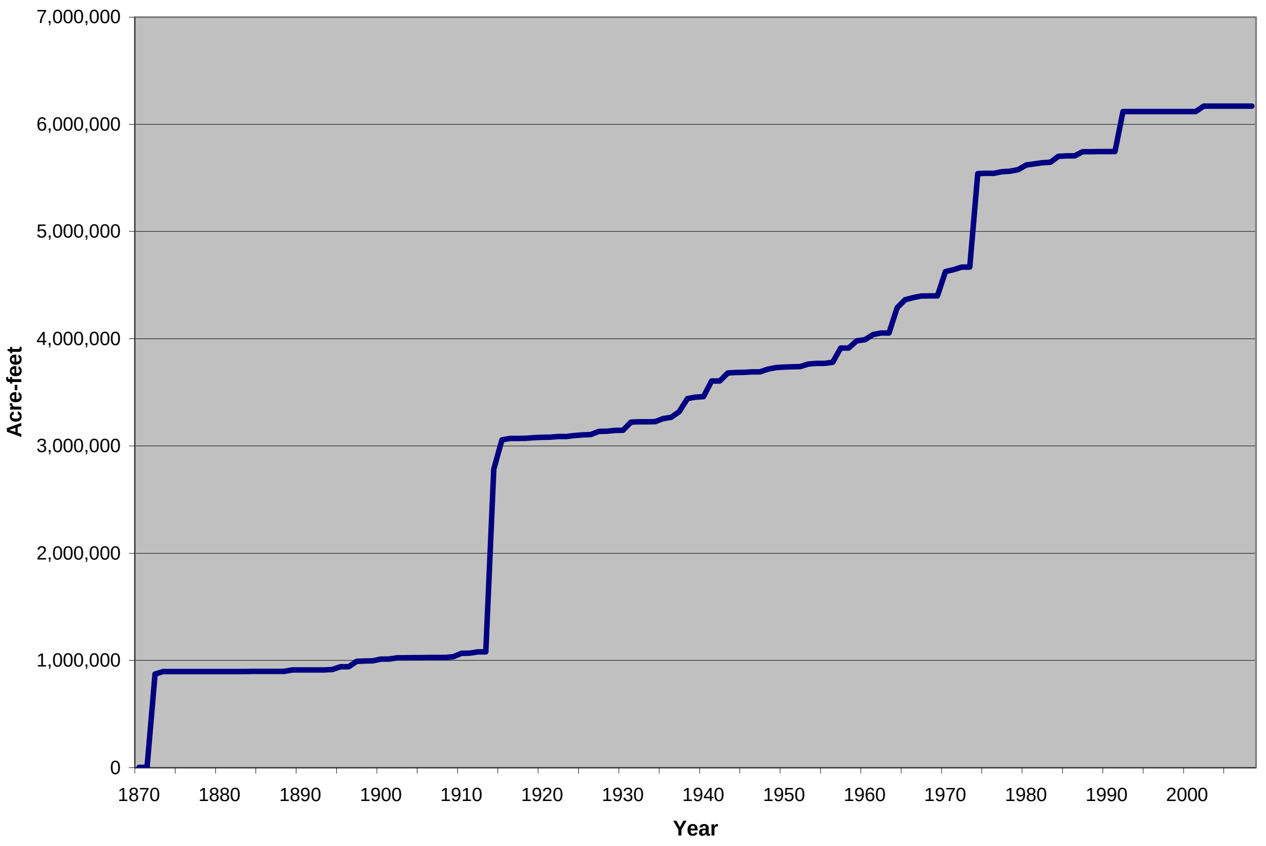


FIGURE 8
Utah's Statewide Reservoir Storage vs Time



of new reservoir storage capacity. In the Uintah Basin, the Bureau of Reclamation completed both Meeks Cabin Reservoir and Starvation Reservoir in 1970. In 1973, the new Soldier Creek Dam was completed which enlarged Strawberry Reservoir by 835,900 acre-feet. A dam forming Electric Lake was constructed in 1974 by Utah Power and Light. In 1972, Lost Creek Reservoir was constructed by the Lost Creek Irrigation Company.

In the Uintah Basin, the Bureau of Reclamation built Red Fleet Reservoir in 1980 and Upper Stillwater in 1987. Washington County Water Conservancy District built Quail Creek Reservoir in 1984. Jordanelle Reservoir was completed by the Bureau in 1992 and in 2002 Washington County Water Conservancy District completed Sand Hollow Reservoir.

Figure 8 shows the accumulation of statewide reservoir capacity over the years. New reservoir construction has produced on average approximately 44,000 acre-feet of new reservoir storage per year. The graph also shows that there has been relatively little new reservoir construction since the mid 1970s.

Reservoir Storage Capacity Size Breakdown

Figure 9 shows a breakdown of Utah's reservoir storage capacity by reservoir size. Utah currently has a total reservoir storage capacity of approximately 6.2 million acre-feet. A little over 4.6 million acre-feet (about 75 percent) of that total storage is in nine reservoirs larger than 100,000 acre-feet in storage capacity. These are: Bear Lake, Strawberry, Utah Lake, Jordanelle, Sevier Bridge, Willard Bay, Starvation, Deer Creek and Pineview.

Nine more reservoirs between 50,000 acre-feet and 100,000 acre-feet account for just over half a million acre-feet of storage or 9 percent of the state's total. They are Echo, Scofield, Piute, Rockport, Joe's Valley, Woodruff Narrows, Otter Creek, Sand Hollow and East Canyon. The state has eleven reservoirs between 20,000 and 50,000 acre-feet accounting for just over 340,000 acre-feet or 6 percent of the state's storage capacity. They are: Moon Lake, Quail Creek, Steinaker, Meeks Cabin, Electric Lake, Upper Stillwater, Cutler, Red Fleet, Panguitch, Lost Creek and Little Dell. Eighteen Utah Reservoirs are between 10,000 acre-feet and 20,000 acre-feet providing nearly 250,000 acre-feet (4 percent) of the state's storage. The state has 86 reservoirs between 1,000 acre-feet and 10,000 acre-feet of storage capacity. These make up five percent of the states total reservoir storage. There are a total of 133 Utah reservoirs larger than 1,000 acre-feet. The state's many small reservoirs, less than 1,000 acre-feet account for only 1 percent of the state's total storage.

Except for the federal reservoirs previously discussed, all of the state's reservoirs that are larger than 1,000 acre-feet are regulated by the Utah Division of Water Rights (The State Engineer's office). There are about 255 reservoirs in the state that are smaller than 1,000 acre-feet. Some of these are regulated and some are not. The State Engineer's office actually has a list of about 700 water impounding structures that it regulates. Many of these, however, are debris basins, retention basins, water treatment ponds, or some other type of small impoundment that serves a localized need. This discussion of reservoirs and the lists included here are not intended to be a comprehensive list of all the state's water impoundments, but a list of the state's important water storage facilities, and the ones for which sedimentation represents a threat to the state's water supply.

Reservoir Water Uses

As stated earlier, the state's first reservoirs were constructed to provide late season irrigation water. Today reservoirs are created for many reasons including: drinking water, cooling coal-fired generating plants, hydropower, industrial uses, recreation, flood control, environmental and other uses. Many of the state's largest reservoirs, particularly those constructed during the last fifty years, have been designated as multi-purpose facilities. This means that when constructed, the intent was to provide water for many, if not all, of the aforementioned uses. Quite a few of the Bureau

FIGURE 9
Utah's Reservoir Storage by Reservoir Size

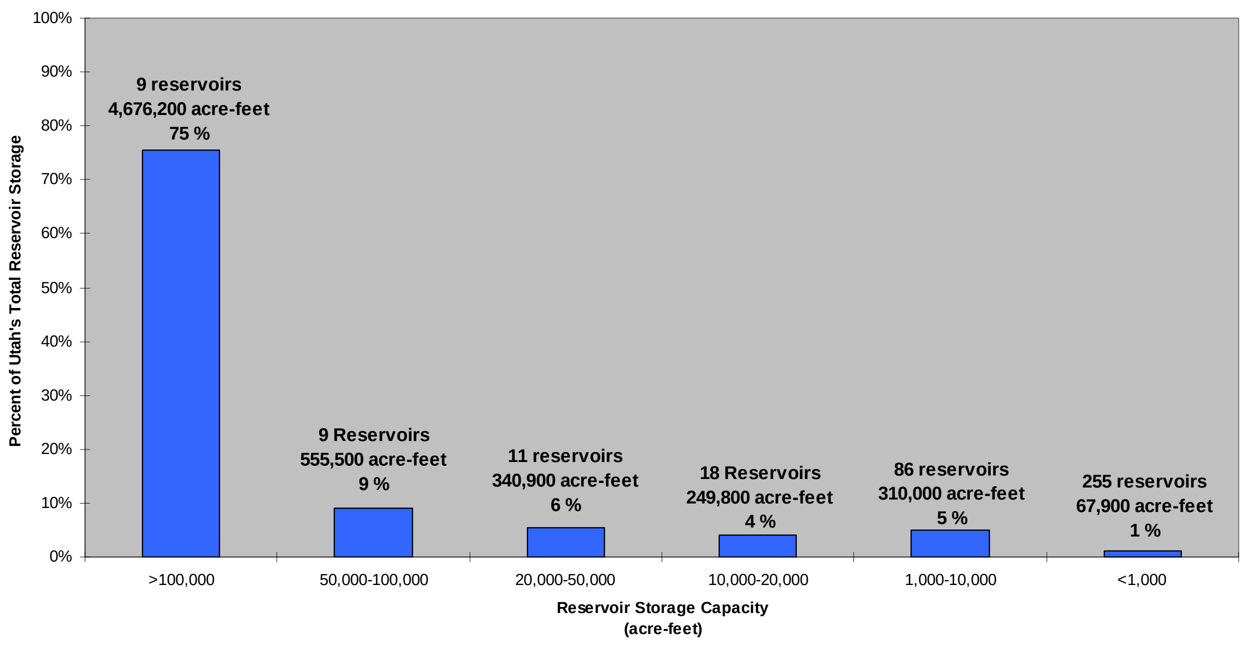
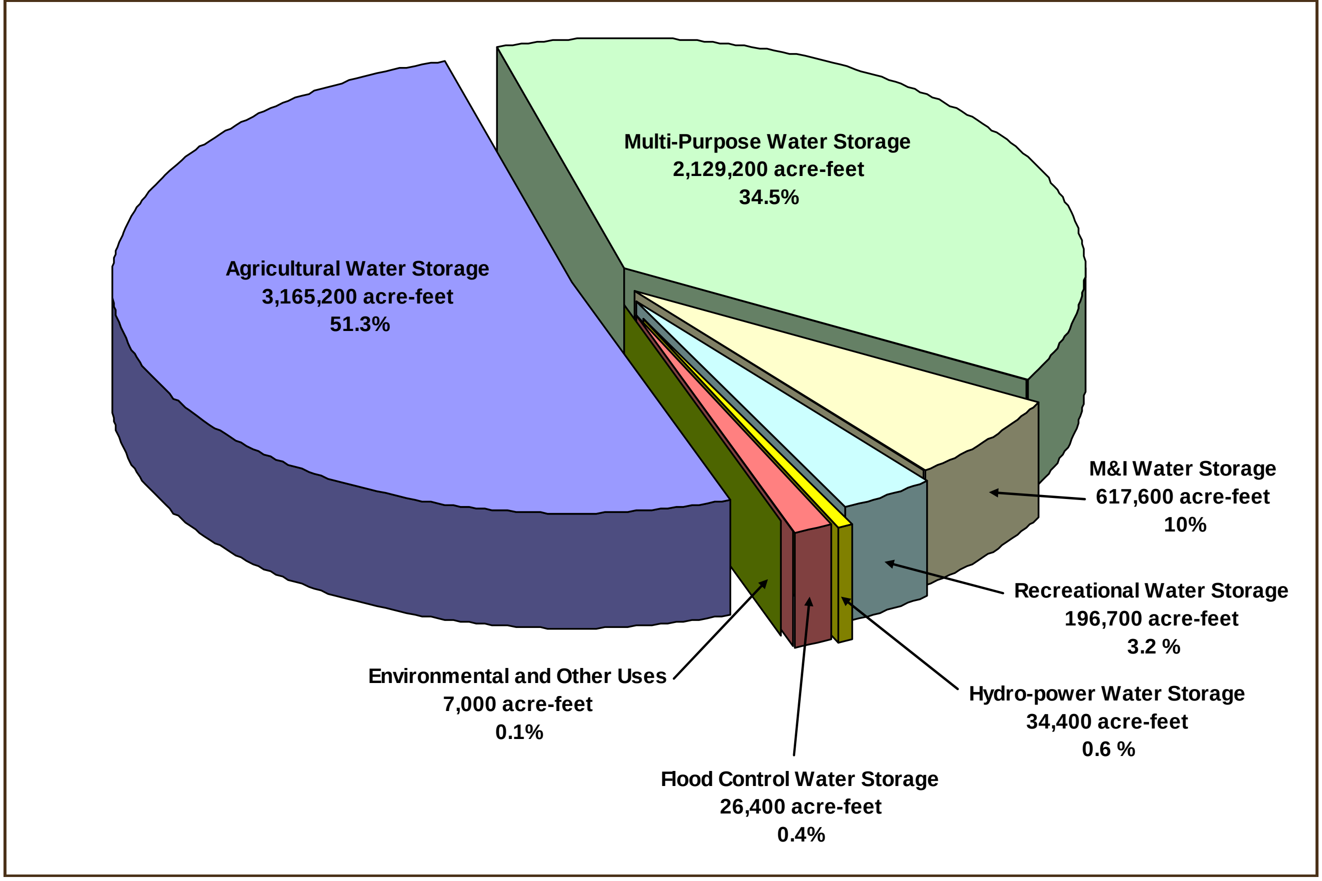


FIGURE 10
Reservoir Storage Use in Utah



of Reclamation projects fall into the multi-purpose category, including some of the largest reservoirs in the state: Strawberry, Starvation, Pineview, Joe's Valley and Wanship. The state's multi-purpose reservoirs make up about 2.1 million acre-feet, about 34 percent, of Utah's total reservoir storage capacity.

Nearly 3.2 million acre-feet, 51 percent of the state's total reservoir storage, is designated specifically for irrigation use. Assuming that a similar percentage of the multi-purpose reservoirs are also being used for irrigation, the state's total irrigation storage would be roughly 70 percent of the state's total storage or about 4,200,000 acre-feet. Ten percent (about 618,000 acre-feet) of the state's total of reservoir storage is designated specifically for municipal and industrial uses. With a similar percentage of multi-purpose storage also providing M&I water, the total statewide M&I storage is about 680,000 acre-feet or about 13 percent of the state's 6.2 million acre-feet storage. Notably, M&I accounted for about 13.4 percent of freshwater withdrawals in Utah in 2000.[3]

Figure 10 shows Utah's reservoir storage capacity designated for agriculture, M&I, recreation, hydropower, flood control, environmental and other uses. In each case, however, it should be pointed out that the numbers only reflect the storage space designated specifically for the purpose indicated. In Deer Creek Reservoir, people recreate on water that is stored primarily for M&I use. In Piute Reservoir people recreate on water that is stored primarily for irrigation. This is true on the vast majority of Utah's reservoirs. The same thing holds true for hydropower, flood control and environmental uses. In many locations around the state, power is generated from irrigation releases and reservoirs that were first built for irrigation and are now managed to assist in flood control. So although only about 34 percent of the state's reservoir storage is designated as multi-purpose, the vast majority of Utah's

Left: Visible sediment deposits at Millsite Reservoir near Ferron.
Middle: Wide Hollow Reservoir near Escalante.
Right: Echo Reservoir near Coalville.
(Satellite images from Utah Automated Geographic Reference Center, http://mapserv.utah.gov/SGID/, 2008)

reservoir storage is now managed with multiple purposes in mind.

AVAILABLE SEDIMENTATION DATA

Sedimentation data exist for only 18 of Utah’s major reservoirs; that is, those larger than 1,000 acre-feet. Much of these data come from reservoir surveys conducted between 1930 and 1975 by the U.S. Soil Conservation Service (now the Natural Resources Conservation Service, NRCS) and the U.S. Bureau of Reclamation. The data were collected and published in a national summary of reservoir sediment deposition surveys.[4] This nationwide database was revised in 2009 and is now the Reservoir Sedimentation Database (RESSED). It can be accessed at http://ida.water.usgs.gov/ressed/ and http://pubs.usgs.gov/ds/ds434/ “The database is a cumulative historical archive that includes data from 1755 to 1993. The 1,823 reservoirs included in the database range in size from farm ponds to the largest U.S. reservoirs. Results from 6,617 bathymetric surveys are available in the database.”[5]

The national summary of sediment deposition contains sedimentation data for only 14 water storage reservoirs in Utah. Also included in this report are sedimentation data from 11 other water storage reservoirs in Utah that were collected by the U.S. Bureau of Reclamation and individual dam owners. Data for a total of 25 Utah reservoirs are included in this report.

Sedimentation data exist for only 18 reservoirs larger than 1,000 acre-feet, and another 7 reservoirs between 20 and 1,000 acre-feet. These data are presented in Table 2. Most of the data originate from a Range Survey or a Contour Survey conducted to determine the volume of deposited sediment. Both of these survey types are described in Chapter 2. Some of the data points in the table are approximations, the accuracy of which is unknown because the method used to calculate them cannot be confirmed. These estimates and the weighted averages associated with them are marked with an asterisk (*) in Table 2.

Fortunately, the available sedimentation data in Utah is from reservoirs that are widely separated geographically, and represent a broad range of reservoir sizes. Although breaking down the data by geographic region, reservoir elevation, and vegetative type within the contributing watershed might be useful, there are simply not enough data available to make these categorizations meaningful. However, a review of the data suggests that several reservoirs located in the more arid central and southern regions of the state (Iliff Anrus, Black Knolls, Lake Powell, Millsite, Skutumpah, Yankee Meadows and Wide Hollow reservoirs) experience a significantly higher sedimentation rate than other areas of the state. The rates in that more arid regions are greater than 0.5 acre-feet of sediment per square mile of drainage area. Reservoirs located at higher elevations in the

TABLE 2

Sedimentation Data for Utah Reservoirs

Reservoir	Date Built	Storage Capacity Initial Survey (acre-feet)	Drainage Area (mi^2)	Period Assessed	Sedimentation Rate (% annual capacity loss)	Estimated Annual Sediment Volume (acre-ft)	Avg. Ann. Sediment Vol. per mi^2 of Drainage Area (acre-feet /mi^2/yr)	Estimated Capacity Loss as of 2009 (%)
Lake Powell[†]	1964	27,083,092	26,000	1964-1989	0.14	36,946	1.42	6
Sevier Bridge	1908	250,000	5,120	1908-1932	0.26	647	0.126	26
Starvation[††]	1969	167,310	950	1969-1979	0.07	117	0.15	3
Piute	1908	81,200	2,440	1908-1936	0.32	257	0.106	-
				1961-2004	0.21*	171*	0.070*	-
				Weighted Average	*0.25**	*204**	*0.084**	*25*
Echo	1930	75,718	732	1930-1954	0.10	76	0.104	8
Scofield[††]	1946	73,600	154	1946-1979	0.17	127	0.50	11
Wanship[‡]	1957	62,116	320	1957-2007	0.20	124	0.388	10
Otter Creek	1897	52,660	364	1961-2004	0.21*	110*	0.302*	10
East Canyon	1915	31,200	144	1915-1954	0.10	32	0.124	7
Steinaker[‡]	1961	40,355	19	1961-2006	0.02	7	0.368	1
Rocky Ford (Bea.)	1914	23,260	510	1915-1940	0.30	70	0.134	28
Hyrum[‡]	1935	18,925	220	1935-2005	0.09	17	0.077	7
Millsite[§]	1971	18,000	157	1971-2004	0.44	79	0.503	17
Gunlock[~]	1970	10,884	306	1971-2004	0.86	94	0.307	33
Upper Enterprise	1909	9,000	25	1909-1940	0.16	15	0.62	16
Yankee Meadows	1926	2,500	7	1926-1940	0.86	21	3.1	71
Wide Hollow[^]	1954	2,324	10	1954-1968	1.58	37	3.7	-
**				1968-1992	0.74	17	1.7	-
				1992-2007	0.57*	13*	1.3*	-
				Weighted Average	*0.91**	*21**	*2.1**	*50*
Rocky Ford (Sev.)	1890	2,115	900	1890-1940	1.25	27	0.029	100
Duck Fork	1942	718	3.4	1942-1962	0.07	0.50	0.14	5
Skutumpah	1893	667	10	1893-1940	0.76	5	0.506	88
Booby Hole	1895	607	5	1895-1940	0.03	0.20	0.024	3
Indian Creek #1	1898	318	12	1898-1940	0.14	0.45	0.038	16
First Dam	1914	70	226	1914-2001	0.74*	0.52*	0.002*	70
Iliff Anrus	1949	20	1.1	1949-1966	4.10	0.82	0.76	100
Black Knolls	1922	20	0.6	1922-1965	0.99	0.20	0.34	86

Note: Unless otherwise indicated, data derived from *Sediment Deposition in U.S. Reservoirs: Summary of data reported through 1975.* Miscellaneous Publication No. 1362. Compiled by F.E. Dendy and W.A. Champion, USDA Sedimentation Laboratory, Agricultural Research Service, Oxford Miss., 1978.

*Calculated from a measured reservoir capacity provided by dam owner, the accuracy of which cannot be confirmed.

[†] Lake Powell sedimentation rate derived from data provided by Chris Cutler, U.S. Bureau of Reclamation, February, 2005.

[‡] Total loss of storage capacity provided by U.S. Bureau of Reclamation, Provo Office, November 2007.

[§] Millsite sedimentation rate derived from data reported by Rollin Hotchkiss, Brigham Young University, July 2008.

[~] Per Corey Cram, Washington County Water Conservancy District, February 2008.

[^] Utah Division of Water Resources, *Escalante River Resource Study Task Force I Report,* 1973.

**Franson-Noble & Associates, Inc., *Raising and Rehabilitating Wide Hollow Dam Feasibility Study and Other Water Management Studies,* 1992.

[††] Ron Ferrari, U.S. Bureau of Reclamation's Sedimentation Group, Denver Office, 2008.

mountainous regions of central and northern Utah (i.e. Echo, Piute, East Canyon, and Hyrum) experience far lower sedimentation rates.

According to the available data, Utah reservoirs are losing capacity at anywhere from 4.1 percent per year to about 0.02 percent per year. The highest rate is 205 times greater than the lowest rate, which indicates a wide a range of sediment accumulation rates across the state. Sixteen of the 24 data points (excluding Lake Powell), or 68 percent of the data, fall between 0.1 and 1.0 percent per year. Even this large percentage of available data represents a variation greater than a factor of 10 in sedimentation rates. The median sedimentation rate is 0.23 percent and the weighted average of all the data is 0.2 percent. The weighted average is based on reservoir capacity and the total capacity of the reservoirs with sediment data. The reservoirs for which data are available account for approximately 16 percent of the total capacity of all Utah reservoirs, which shows how few reservoir sedimentation data are available.

For reference, Table 3 lists the number of years it would take for a reservoir to fill completely with sediment at various sedimentation rates. The table assumes a linear sediment accumulation rate over time. This is not accurate due to numerous variables unique to each reservoir. Since most reservoirs lose functionality long before becoming completely filled with sediment, a "half life" is also presented. As mentioned previously, the weighted average capacity loss for Utah reservoirs is 0.2 percent per year.

TABLE 3
Annual Sedimentation Rates and Reservoir Life

Capacity Loss per Year* (%)	Filled Reservoir Life (years)	Half-Filled Life (years)
1.00	100	50
0.75	133	67
0.50	200	100
0.25	400	200
0.20	500	250
0.15	667	333
0.10	1000	500

*The percentage shown is based solely on the original capacity of the reservoir, no compounding.

STATEWIDE ESTIMATES OF SEDIMENTATION

As noted in the previous section, there are only limited reservoir sedimentation data available for Utah's reservoirs, making it difficult to fully assess the impacts of sedimentation on the state's water supplies. However, using the data that do exist, and estimating the rates of sedimentation for other significant reservoirs, provides a range of values that are reasonable for making some rough approximations and assumptions.

There are several methods of estimating reservoir sedimentation presented in Chapter 2. The only method that can be appropriately applied to the significant reservoirs in Utah is the Capacity and Sedimentation Correlation of 1,105 U.S. Reservoirs. For purposes of this report, only those reservoirs larger than 1,000 acre-feet are considered significant. Using this method to estimate sedimentation rates for all reservoirs for which no sedimentation data is available reveals a weighted average sedimentation rate of 0.2 percent per year for all significant reservoirs in Utah.[6] This compares very favorably with the 0.2 weighted average rate for the reservoirs in Utah where sedimentation has been measured. Although both of these rates are approximations and based on averages, the figures seem reasonable considering several researchers have estimated the average annual rate of reservoir sedimentation in the entire U.S. to be between 0.20 and 0.22 percent.[7,8]

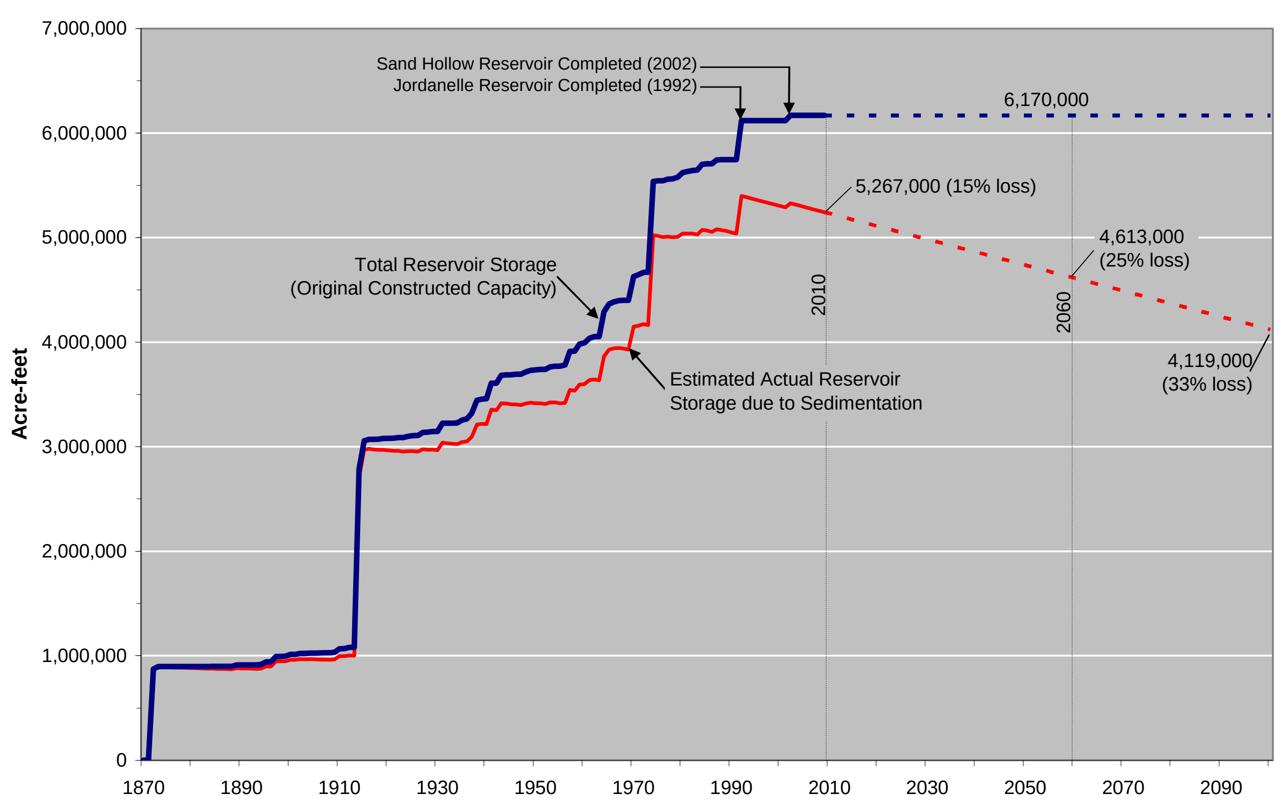
Estimated Current and Future Reservoir Storage Capacity Loss Due to Sedimentation

Assuming the annual reservoir sedimentation rate in Utah is 0.2 percent per year, the total capacity loss would be about 12,340 acre-feet per year. This is roughly equivalent to losing the total storage of Big Sand Wash or Gunnison Reservoir every year. To estimate past, present, and future storage capacity losses, the 0.2 percent sedimentation rate was applied to the state's reservoirs from the date constructed to the year 2100. The results of this analysis are shown in Figure 11 and discussed below.

Total Utah reservoir storage in 2010 is estimated to be 6,170,000 acre-feet. This includes the original constructed capacity, plus subsequent enlargements.

FIGURE 11

Current and Projected Impact of Reservoir Sedimentation on Utah's Total Storage Capacity



After accounting for sedimentation losses, the revised estimate is about 5,267,000 acre-feet, a decline of 903,000 acre-feet or 15 percent. Assuming no new storage is built in the future, by 2060 (50 years away, and the Utah Division of Water Resources' planning horizon) total reservoir storage capacity will be about 4,613,000 acre-feet. This is a decline of 1,557,000 acre-feet, or 25 percent. This is roughly equivalent to the *combined* storage of Utah Lake, Jordanelle and Sevier Bridge Reservoirs. By 2100, 90 years away, Utah will have lost about one-third of the original reservoir capacity.

With the exception of 2002, when Sand Hollow Reservoir was built, Utah's total reservoir capacity has declined steadily since 1992. Moreover, if no new reservoirs are built, total reservoir capacity will continue declining into the foreseeable future.

These significant insights clearly demonstrate the impact of reservoir sedimentation, and make it obvious why there is a serious concern for water users throughout the state.

Conclusion

Utah is the fastest growing State in the nation.[9] The projection is that Utah's population will more than double from about 2.7 million in 2008 to nearly 6.8 million[10] by 2060, only 50 years away. Without new dams, it's estimated total reservoir capacity will have *decreased* 25 percent by that time. The *increase* in municipal and industrial water demands, along with the ongoing *decrease* in reservoir capacity, clearly indicate the need to do something about sedimentation.

This study is the first attempt to quantify sedimentation statewide. Estimates in this chapter present one possible scenario based on limited data; additional studies and reservoir capacity surveys are needed to gain a better understanding of the problem. However, it's clear from what is known that reservoir sedimentation is a significant and inevitable threat to the long-term sustainability of Utah's water supplies. The following chapters present some useful strategies to help Utah water providers address the problem.

NOTES

[1] Israelsen, O. W., *"The History of Irrigation in Utah,"* 1954, page 2. An interesting comparison is Utah had about 4,600 miles of canals in 2007.

[2] Ibid, page 3.

[3] Utah Division of Water Resources, *Conjunctive Management of Surface and Ground Water in Utah*, July 2005, page 4.

[4] See Dendy, F.E. and W.A. Champion, *Sediment Deposition in U.S. Reservoirs: Summary of data reported through 1975*. Miscellaneous Publication No. 1362. Compiled by USDA Sedimentation Laboratory, Oxford Miss.: Agricultural Research Service, 1978.

[5] Retrieved from the Internet website: http://pubs.usgs.gov/ds/ds434/, January 28, 2010.

[6] This is a weighted average based on total reservoir capacity, excluding Lake Powell. Lake Powell is excluded because it greatly skews the weighted average downward due to its enormous capacity of over 28 million acre-feet.

[7] White, Rodney, *Evacuation of Sediments from Reservoirs*, London: Thomas Telford, 2001, page 234.

[8] Crowder, B.M., 1987. *"Economic Costs of Reservoir Sedimentation: A Regional Approach to Estimating Cropland Erosion Damages," Journal of Soil and Water Conservation*, 42 (3), pages 194-197.

[9] Retrieved from the following Internet website: http://www.census.gov/Press-Release/www/releases/archives/population/013049.html, February 25, 2010.

[10] Utah Governor's Office of Planning and Budget, *"2008 Baseline City Population Projections,"* Salt Lake City: May 2008.

4

RESERVOIR SEDIMENT MANAGEMENT METHODS

Managing sediment in reservoirs can take many forms. It can be as complex as carefully administering the land in the watersheds above a reservoir to minimize erosion, or as simple as constructing facilities to bypass or channel sediment around or through a reservoir. While watershed management has been practiced for many years in Utah, many other available sediment management strategies have not. This chapter explores additional methods employed throughout the world to manage reservoir sedimentation. It also briefly discusses how to deal with sediment at diversion dams and other water infrastructure.

SEDIMENT CHARACTERISTICS

Before discussing sediment management, it is useful to define the terms used to describe sediment. Sediment is analyzed similar to soil, that is, by drying a sample and shaking the material through a series of nested sieves. The top sieve has the largest opening, with sieve opening sizes getting progressively smaller, until a pan at the bottom catches the very tiny particles. The following terms are used to describe sediment:[1]

- Boulders - rocks over 12 inches in size
- Cobbles - rocks from three to 12 inches in size
- Gravel - particles from 0.2 inch to three inches in size (0.25 = ¼ inch)
- Sand - particles from 0.0029 inch to 0.2 inch in size (0.02 = 1/64 inch)
- Silt and clay - particles smaller than 0.0029 inch (0.002 inch = diameter human hair)[2]

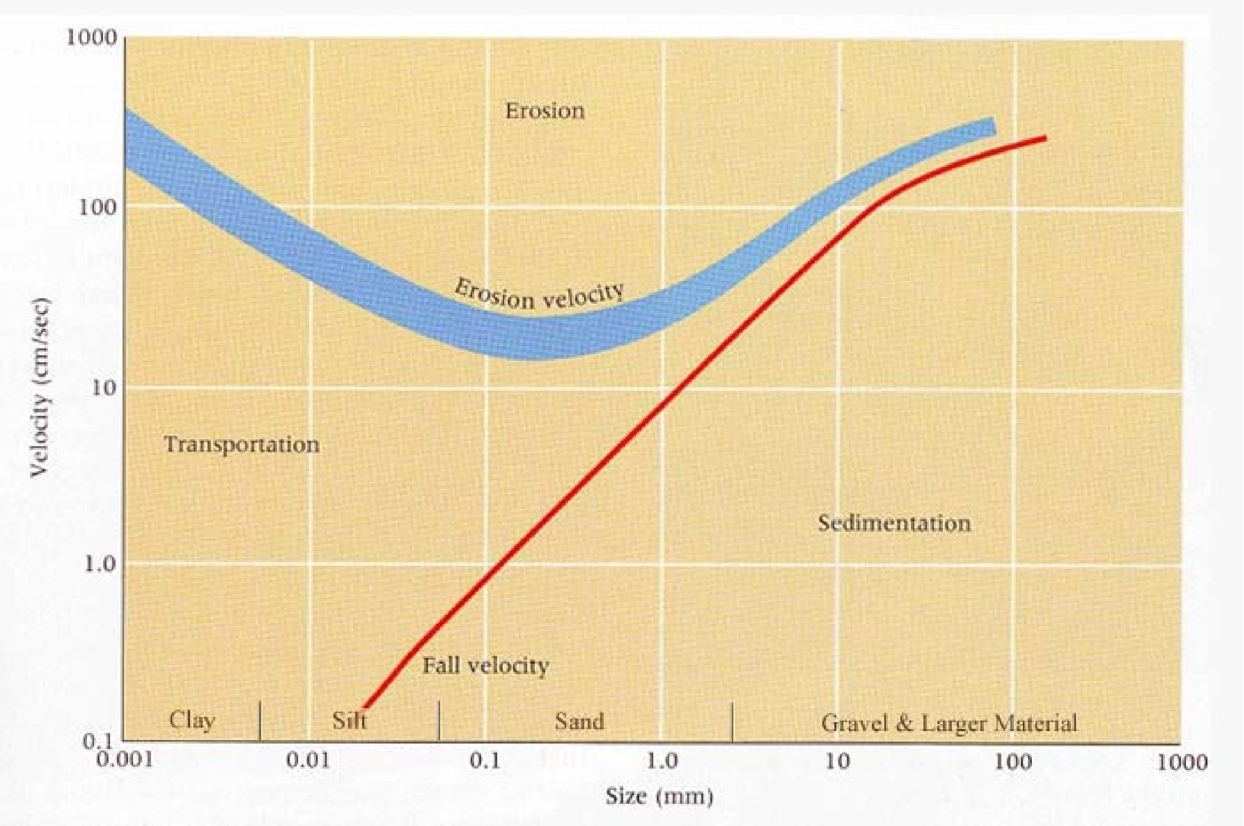
Another term used in this discussion is “bed load” which is defined as, “The material which is moved along a river bed by rolling and pushing, usually at a velocity much less than that of the river. Bed load is usually composed of sands and gravels but when the water level is high and the current strong, boulders may be moved.”[3]

> **Whereas the twentieth century focused on the construction of new dams, the twenty-first century will necessarily focus on combating sedimentation to extend the life of existing infrastructure. This task will be greatly facilitated if we start today.**
>
> —Gregory Morris in *Reservoir Sedimentation Handbook, p 1.5.*

When considering the several management methods which move sediment, it is useful to understand, and visually appreciate, the relationship between water velocity and ability to transport material of various sizes. Figure 12 shows this association. Observe when erosion, transportation and sedimentation occur. When streamflow drops below the ”erosion velocity”, particles will be transported or deposited, instead of eroded. When streamflow drops below the “fall velocity”, particles are deposited as sediment.[4] Notice that clay particles and fine silts (smaller than 0.06 mm) require higher velocities to move since they stick together. Sands (between 0.06 mm and 2.0 mm) are relatively easy to move as indicated by the lower velocities in this size range. Par-

FIGURE 12

Erosion, Transportation and Sedimentation Properties of Various Sediments



Source: Modified from http://clward.files.wordpress.com/2008/09/geog-hjulstrom-curve1.jpg

ticles in this size range are the most easily eroded and most easily moved. Gravels (larger than 4 mm) require higher velocities to be moved due to larger size and weight.[5] Clay particles are difficult to remove and complete reservoir drawdown, with high velocities for long periods, may be necessary.

OVERVIEW OF SEDIMENT MANAGEMENT METHODS

The methods available for managing sediment in reservoirs can be grouped into the following four basic categories.[6] Further detail for these methods is provided in subsequent sections.

Minimize Sediment Entering Reservoir

- Watershed management – implement land use practices, agricultural best management practices and engineering methods to increase vegetative cover, improve plant health and reduce erosion.
- Upstream trapping – construct debris basins, check dams and vegetation screens to reduce flow velocities and trap sediments.
- Locate reservoir off-stream – build dam at an off-stream location to minimize trapping sediment produced by the drainage basin.
- Preserve, enhance, restore and construct wetlands – in addition to reducing sediment in streams, wetlands provide numerous other benefits.

Minimize Deposition of Sediment in Reservoir

- Sediment pass-through – pass sediment-laden flows and flood waters through the reservoir.
- Density current venting – pass sediment-induced density currents through the reservoir and out the bottom outlet of the dam.

Left: Visible clouds of sediment-laden water in Starvation Reservoir.
Middle: Bear Lake.
Right: Woodruff Narrows Reservoir.
(Satellite images from Utah Automated Geographic Reference Center, http://mapserv.utah.gov/SGID/, 2008)

- Sediment bypass – route or bypass only the sediment-laden flows around the reservoir via pipeline or open channel.
- Hydrosuction bypass – construct a sediment collection structure at the reservoir inlet and use the hydraulic head of the reservoir to bypass the sediment downstream through a pipeline.

Remove Sediment from Reservoir

- Flushing – re-suspend deposited sediments in the water column and pass them through low-level outlets of the dam.
- Excavation – mechanically remove dry accumulated sediment from the reservoir bottom.
- Dredging – mechanically remove accumulated sediment.
- Hydrosuction dredging – use the hydraulic head of the reservoir to remove sediment from the bottom of the reservoir, this method is often called siphoning.

Compensate for Sediment Accumulated in Reservoir

- Enlarge dam – raise height of dam to recover lost storage capacity.
- Decommission dam – terminate operation of dam and remove if necessary.
- Construct a new dam – build a new dam at an alternate location to recover lost storage capacity.
- Other Mitigation Measures and Alternatives – conjunctive management, aquifer storage and recovery, and other measures.

Most of the sediment management methods described above can be used to extend the useful life of reservoirs. However, a sediment management program that attempts to restore the sediment balance and achieve sustainability may require a combination of methods. The technical, economical and environmental feasibility of each method depends on a number of factors, including:[7]

- The availability of suitable engineering facilities at the dam to control water levels and outflows.
- The availability of water and its value if diverted from other uses.
- The predictability of river flows, including seasonal variations.
- The physical and chemical characteristics of the sediments entering and within the reservoir.
- The availability of disposal sites for dredged or excavated sediments.
- The effects of evacuating sediments from the reservoir on the downstream environment.

- The effects of sediment management on other reservoirs and infrastructure downstream.
- The institutional and political problems among affected stakeholders.
- The value of the reservoir uses.
- The value of the storage capacity.

While sediment management can help sustain the vital benefits provided by reservoirs, it will not always be possible to restore the sediment balance and some dams will inevitably need to be enlarged, decommissioned or possibly replaced.[8] The ultimate fate of any given reservoir will be determined by its unique:

- Physical and hydrological characteristics.
- Water use and facility operation.
- Social, economic, environmental and political factors.

Most Utah reservoirs are designed and operated to capture as much water as possible. This means they also capture as much sediment as possible. Several sediment management methods require that some water be expended to reduce the amount of sediment captured. This means that, at least in the short term (perhaps one season), a portion of the water intended to be stored for specific purposes will not be available. Varying amounts of water are either lost or used. Small amounts of water are lost due to evaporation when using check dams. Larger amounts of water are used by sediment pass-through, flushing, density current venting, sediment bypass, and hydrosuction bypass. In each case, the amount of water expended should be considered before implementing the method. Ideally, the cost of the short-term water loss is less than the long-term water storage gain. However, other economic factors besides the value of water need to be considered for a complete evaluation of the utility of the methods discussed below.

MINIMIZE SEDIMENT ENTERING RESERVOIR

One of the most effective, and least-expensive, ways to deal with the problem of sedimentation is to minimize the amount of sediment that reaches the reservoir. There are two general strategies to accomplish this goal for existing reservoirs: (1) reduce the amount of erosion that occurs by carefully managing the land and stream channels within the watershed (watershed management) and, (2) trap the sediment before it reaches the reservoir. A third strategy exists for future reservoirs, namely locate them off-stream. Depending on what percentage of a stream is diverted, this may allow reduction of many sediment problems typically associated with on-stream reservoirs.

Watershed Management

Watershed management is the single most important sediment management practice. Minimizing the amount of sediment reaching the reservoir is much preferred to dealing with it after it causes problems. Watershed management is often the best place to expend resources and can be the most cost effective.

All natural flowing waters contain some sediment and it will not be practical, or even possible, to completely eliminate it from a reservoir's tributary streams. Some environments experience high erosion rates as a simple consequence of soil type, climate, topography, geology and other natural factors. This is the case for many arid and dry basins within Utah. Thus, even well-implemented erosion control practices will not entirely eliminate the transport of sediment. Another key point is that erosion rates often vary widely across a river's drainage. Frequently a disproportionately large amount of the sediment will be contributed from a relatively small area or watershed within the total drainage area. Consequently, it is worth the effort to identify areas that contribute most of the sediment and concentrate erosion control efforts there. See Appendix B for a thorough discussion of how to identify sediment sources in the watershed.

There are a number of techniques that can be employed to significantly reduce erosion in a watershed. These basically fall into three categories: vegetative treatment, structural intervention and operational measures.

Vegetative Treatment

The use of vegetation to armor the ground against erosion is the most natural and economical of the three categories. Good vegetative cover provides the best long-term protection against erosion by keeping rain from dislodging soil particles and washing them away. Typically, the better the plant health, the more resistant the drainage will be to erosion. Watersheds that have been damaged by fire, overgrazing, excessive or unregulated logging and mining, or other types of degradation, will experience increased erosion rates. Restoring vegetative cover can require significant time and effort, especially when the watershed has been severely degraded or the climate is semiarid. Ongoing monitoring of plant health in the watershed is required since numerous activities over time can cause problems. Examples include fire, landslides and human activities.

Because Utah is the second driest state in the country, vegetative treatment may be challenging to implement. It's simply difficult to grow plants with little water. This is especially true in areas with soil and geologic formations that are not conducive to plant growth. For example, Mancos Shale is so salty that no vegetation grows in it. That formation is a major contributor to sediment in Millsite Reservoir so mitigation in the watershed is only minimally effective.

Structural Intervention

Structural intervention uses constructed structures to reduce the runoff volume and velocity or to protect soils from contact with flowing water. Included in this category are: land terracing, diversion channels and channel stabilization structures such as rip-rap, gabions and debris basins. Structural measures generally have a higher cost than vegetative measures and both can have maintenance costs. But structures are often the most effective at quickly and dramatically reducing erosion. The extensive land terracing in the high elevations of the Wasatch Front Range during the 1930s is an example of structural intervention in Utah. The success of many of these measures depends upon regular maintenance to remove locally deposited sediments to a location where they will remain in the watershed. Without such maintenance, the effectiveness of these measures will decrease over time. Whenever structural intervention is contemplated, it is imperative that the Utah Division of Wildlife Resources be consulted to determine if such structures will impede fish passage.

Operational Measures

This is the control and scheduling of activities to minimize erosion. It includes scheduling such things as construction, lumber harvesting, grazing and other human activities within the drainage area. For many of Utah's watersheds, grazing is one of the largest impacts on erosion. Over-grazing and uncontrolled livestock access to stream banks can produce huge sediment loads. Consequently, for very little cost, careful adherence to sound grazing schedules and limiting stream access can have a dramatic impact upon the health of the watershed. In recent years more attention has been paid to scheduling livestock movements and grazing practices throughout the state. Nevertheless, there may still be opportunities to improve grazing practices and better manage the scheduling of other human activities that impact the erosion of watersheds. Scheduling details are unique to the watershed and to the planned activities. The services of a range management specialist would be beneficial in this regard. The NRCS can provide such specialists.

Institutional Efforts to Protect and Restore Utah Watersheds

Reservoir sedimentation is only one of the impacts erosion imposes upon a watershed. Erosion also strips the countryside of its topsoil layer, posing a threat to wildlife, farmers, neighboring communities, and other public and private land owners. Consequently, there are many public agencies and private interest groups whose efforts to manage watersheds are completely compatible with reservoir owners who seek to minimize sedimentation.

Over a decade ago the state and federal agencies that have key roles in managing public lands in Utah formalized their coordination efforts with the creation of Utah Partners for Conservation and Development (UPCD). This organization consists of the following agencies:

- Bureau of Land Management
- Utah State University Extension Service
- USDA Natural Resources Conservation Service
- Utah Association of Conservation Districts
- U.S. Fish and Wildlife Service
- U.S. Farm Services Agency

- U.S. Forest Service
- Utah Department of Environmental Quality
- Utah Department of Natural Resources
- Utah Association of Resource Conservation and Development (RC&D) Councils
- U.S. Bureau of Reclamation
- National Park Service
- Utah School and Institutional Trust Lands
- Utah Division of Wildlife Resources
- Utah Division of Forestry, Fire and State Lands
- Utah Division of Parks and Recreation
- Utah Department of Agriculture and Food

UPCD serves as a clearinghouse to coordinate and share participants' conservation concerns and priorities, discuss and implement solutions, and promote an atmosphere of collaboration among landowners, private organizations, and state and federal agencies. The UPCD lists as its primary concern the following:[9]

- Native wildlife and biological diversity
- Water quality and yield for municipal, agricultural and wildlife uses
- Sustainable agriculture on farms and ranches
- Quality of life through outdoor recreation activities

Although controlling erosion and reducing reservoir sedimentation is not listed as a primary concern of the UPCD, the efforts and programs aimed at accomplishing the listed goals will ultimately improve the health of the watershed and reduce erosion and sediment transport. One of the best places to get expertise, as well as engineering design and financial assistance, for watershed management is the Natural Resources Conservation Service (NRCS). They have several programs designed for just this purpose. These programs are described in Chapter 5.

In 2003, UPCD began to implement the Utah's Watershed Restoration Initiative. This initiative is a partnership-driven effort to conserve, restore and manage ecosystems in priority areas across the state to enhance the health of Utah's watersheds. The initiative began as a response to the invasion of cheatgrass and other invasive species that are damaging Utah's watersheds. Cheatgrass is of particular concern because it crowds out native grass species, and when there is a fire it burns very intensely. Most native species are more fire resistant. Consequently, the presence of cheatgrass results in a greater wildfire threat and, after a fire, increased erosion potential.

Since its creation, Utah's Watershed Restoration Initiative has treated 750,000 acres across the state as part of about 1,000 projects. The initiative leverages state funds with federal funds and matching contributions from industry and the private sector. In 2007, $2.5 million dollars of state funding was combined with an additional $7.5 million of federal, private and industry money. Through the Utah Department of Natural Resources, the Utah Division of Water Resources encourages reservoir managers to work with UPCD to improve watersheds above their reservoirs. More information can be found at www.utahpcd.info/. In addition, the Uintah Basin Watershed Council was formed in February 2010 with support from the U. S. Department of Agriculture Service Center in Vernal.

Utah's Watershed Restoration Initiative has been very successful. However, other erosion control programs around the country and worldwide have not always worked, despite large expenditures. Improper planning and execution, or lack of long-term support for maintenance and commitment by land owners, are among reasons for this. As a result, reservoirs built under the assumption that sediment yields can be controlled solely by upstream watershed practices have not always had that promise fulfilled.[10] It can also be costly and difficult to implement widespread watershed improvement practices over a large area. Consequently, although there are long-term benefits associated with wise watershed management practices and watershed rehabilitation efforts, it may be necessary for reservoir owners to consider other methods, in addition to erosion control.

Upstream Trapping

Another watershed management method that can be employed to reduce the amount of sediment reaching a reservoir is upstream sediment trapping. Hydraulic structures that trap sediment may be classified in the following categories:

- Natural vegetation filters – under some circumstances, riparian vegetation reduces water velocity, thus trapping sediment before it enters the reservoir.

- Check dam – a small grade control structure, usually only a few feet high, designed to trap bed load material and reduce erosion.
- Debris basin – a larger structure used to trap coarse sediment and other debris before it enters the downstream channel.
- Sediment detention basin – a basin designed to trap suspended sediment (silt and clay) to control and improve water quality.
- Reservoir – although reservoirs are usually not designed or built to trap sediment, this function is filled very well. Consequently, wherever there are two or more reservoirs constructed in tandem, the downstream reservoir(s) benefit from the sediment removal accomplished by the upstream reservoir(s).

Depending on individual circumstances, engineered sediment trapping structures may be expensive. However, the structures may be quite cost effective when compared to the cost of managing sediment after it reaches a reservoir. Sediment trapping structures also require maintenance such as periodic sediment removal or reconstruction, which further increases the cost of these types of projects. Absent maintenance, structures such as check dams and terraces will tend to fail, eventually releasing the previously-trapped sediment. On the other hand, structures that trap sediment tend to be very effective and can produce rapid and sometimes dramatic results, reducing sediment loads immediately after being put in place. This is a distinct advantage over many other erosion control strategies that may take years to produce the desired affects. It is important for reservoir owners to consider the differences in cost, time to take effect, and effectiveness of these two methods. In some instances, and at some locations, it may be prudent to implement traditional watershed management strategies while in other instances sediment trapping may be more effective. Occasionally, a combination of the two strategies will be the most effective.

Natural Vegetation Filters

When the natural drainage of a small reservoir is distributed over a wide area, and no distinct channel brings water into the reservoir, riparian vegetation can limit sediment input to the reservoir. Riparian vegetation consists of plants that grow naturally on the banks of streams and the shores of lakes and reservoirs. This condition can develop even though there was originally one stream into the reservoir. For example, the natural drainage upstream of Wide Hollow reservoir has developed a broad growth of willows and cottonwoods that naturally slow water velocity and promote sediment deposition before it enters the reservoir. This has resulted in establishment of a natural berm that spreads out flood flows and traps sediment. After several years the berm elevation is estimated to be at least nine feet above the original ground level. This is based on three consecutive fences being buried under sediment.[11] Construction of the new dam will include promoting willow growth at several places around the reservoir.[12]

Check Dam Example

For many years the Weber Basin Water Conservancy District has struggled with suspended sediment in Weber River water diverted for treatment for drinking water. The Utah Division of Water Quality identified Echo Creek (which flows into the Weber River) as, “the largest contributor of sediment in the upper Weber watershed,”[13] with its sediment load qualifying it to be classified as a 303d impaired water body under the Clean Water Act. Echo Creek contributed approximately 12,800 tons of sediment to the Weber River each year. [14] In turn, Rees Creek was identified as being the largest single sediment contributor to Echo Creek,[15] providing about 16 percent of the Echo Creek load.[16] An active landslide in the upper drainage is one sediment source. In addition, years of mis-management by a local cattle company had left the lower drainage range and riparian areas denuded of vegetation resulting in continual overland and stream-bank erosion. Cattle also trampled the streambanks, further aggravating the situation.

A joint effort of the following organizations resulted in the design and construction of seven check dams along lower Rees Creek, from 2002 to 2008.

- Kamas Valley Soil Conservation District
- Coalville Natural Resources Conservation Service
- Utah Division of Water Quality
- Utah Valley University

- Weber Basin Water Conservancy District
- Summit Soil Conservation District
- USDA, Natural Resources Conservation Service

In addition, new owners of the cattle ranch adopted improved grazing practices, such as piping water to watering troughs away from the stream, and rotating herds onto different fields. This reduced cattle trampling plants near the stream and pushing sediment into the stream, and also allowed vegetation to increase in the valley. See photos at the right.

Top-left: Eroding stream banks along Rees Creek above the sediment ponds.
Top-right: Muddy water from Echo Creek entering the Weber River.
Bottom-left: Simple check dam construction.
Bottom-right: Rees Creek check dams holding water and sediment.
(Photos courtesy of Weber Basin Water Conservancy District.)

Measurements of Total Suspended Solids (TSS) in the stream above and below the project showed the following results, "The overall average of suspended sediments carried by Rees Creek during the monitoring periods combining the 2005 and 2007 data above the project site is 275 ppm. After Rees Creek flows through the seven basins, the amount of suspended sediment drops to 14 ppm, this equates to a sediment reduction below the project site of 19 times."[17] Stated another way, sediment was reduced by 95 percent below the check dams as compared to above them. This project had an immediate and significant positive impact on controlling sediment loads in Rees Creek and Echo Creek.

Total project cost over six years was in the range or $240,000, with that cost being shared by Weber Basin WCD ($118,000), two grants from the Utah Division of Water Quality, and in-kind work done by the other stakeholders. NRCS provided engineering design services at no cost. This project is an excellent example of a collaborative effort by interested and committed stakeholders, combining several methods to control sediment, resulting in measurable and substantial success.

Apart from the above-mentioned project, stream rehabilitation was employed on Echo Creek below the mouth of Rees Creek. See photos below. In 1989, low dams were created in the stream channel, resulting in sediment accumulation and greatly increased vegetation in the stream channel. In 2007, the naturally steep banks were cut back and vegetated, resulting in greatly reduced sediment loads into the stream.

<u>*Sediment Detention Basin Example*</u>

In the early 1990s, Blue Creek Irrigation Company, in Box Elder County, built a sediment detention basin immediately upstream of Blue Creek Reservoir. This facility was built specifically to intercept sediment that was making its way into the reservoir. Blue Creek Irrigation Company also reports that the Soil Conservation Service did some land terracing and re-vegetation work in the upper watershed around the same time. These two strategies have greatly reduced the amount of sediment that now reaches the reservoir.

<u>*Upstream Reservoir Example*</u>

An upstream reservoir is the most important single factor controlling sedimentation in many reservoirs.[18] Many of Utah's reservoirs are located below one or more reservoirs that are higher in the watershed. Consequently, many of Utah's reservoirs benefit from sediment trapping provided by an upstream reservoir. However, this benefit will diminish as the sediment retention capacity of the upstream reservoir is reached or if the owner of the upstream reservoir alters the reservoir's operational

Left: Steep eroding stream banks on Echo Creek in foreground and rehabilitated sloping banks in background. Right: Low dam on Echo Creek filled in and vegetated.

procedures to pass more sediment downstream. Jordanelle Reservoir above Deer Creek Reservoir is one example of this situation.

Locate Reservoir Off-Stream

Another option is to build the reservoir off of the main stream channel and fill it by selective diversion of the water. This allows diverting clear water into the reservoir, primarily during non-flood conditions, while sediment-laden waters bypass the reservoir. This reduces the sedimentation problem and avoids many of the other environmental problems associated with an on-stream reservoir. When conditions permit, relatively clear water can be diverted high up in the watershed and conveyed by pipeline to an off-channel storage site lower in the drainage. While off-stream is not an option for an existing reservoir, it might be a viable option for a new reservoir. Strict operation and maintenance procedures are essential, especially when the entire stream is diverted to the off-stream site. Otherwise, it becomes another on-stream reservoir capturing most of the sediment load. The geology and vegetation of the natural drainage to the off-stream site need to be considered as they will impact sediment loading.

Several Utah reservoirs are located off-stream and are believed to experience reduced sedimentation rates as a result. These include Willard Bay, Quail Creek and Sand Hollow reservoirs. The measured sedimentation rate in Steinaker Reservoir (and off-stream site) is only 0.02 percent per year. This is one-tenth the estimated statewide rate of 0.2 percent per year.

However, locating a reservoir off-stream does not always result in a reduced sediment load to the reservoir. For example, Wide Hollow Reservoir is located off-stream, yet it has experienced an average sedimentation rate of 0.91 percent of its original capacity per year, 4.6 times greater than the state average. There are several reasons for this including, diverting the entire Escalante River (and all the sediment) at times, a high contribution of sediment from the reservoir's natural drainage area that has very little vegetation, and possibly less-than-ideal sediment management at the diversion structure.

Preserve, Enhance, Restore and Construct Wetlands

Wetlands upstream of the reservoir remove sediment from the stream, thus preventing it from entering the reservoir. In addition, by dissipating wave energy and stabilizing stream shorelines, wetland vegetation buffers the adjacent upland from wave action and erosion.[19] Hence, it behooves reservoir owners to preserve, enhance, restore and construct wetlands. This will be challenging for several reasons. These include:

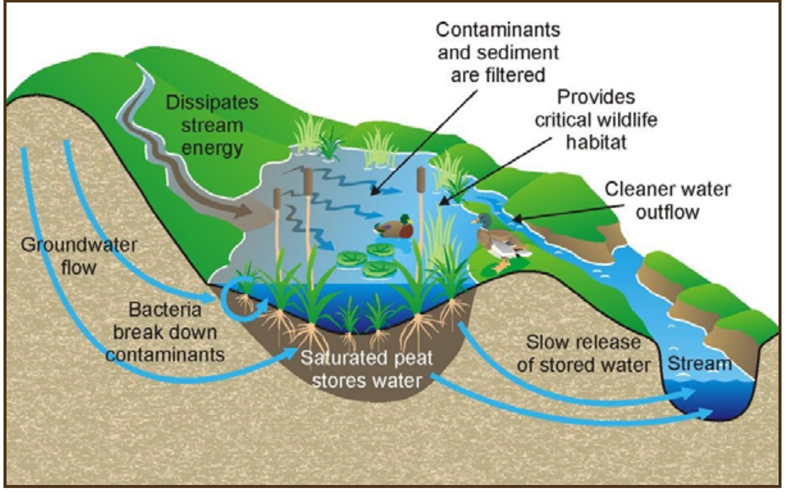
- "Over the past 200 years, more than 50 percent of the wetlands in the coterminous U.S.

(and presumably Utah) have been lost and many of the remaining wetlands are degraded."[20]

- Most wetlands are located on private property. Land owners typically do not have the money or interest to improve such wetlands. Land owners can enroll in federal or state programs in which the public agency puts together a team of specialists who help with the restoration work.[21]
- Wetland preservation, enhancement, restoration and construction is a technical field using many disciplines.[22]

These factors make it all the more important and convincing to do everything possible to improve wetlands. Wetlands above reservoirs keep sediment out of reservoirs while those below reservoirs help mitigate the effect of sediment releases. In addition to controlling sediment, wetlands enhance fish habitat, provide support for birds and other wildlife, protect biodiversity, enhance biological productivity, offer flood protection, improve water quality, and improve aesthetics and recreation (see Figure 13).[23] Wetlands improve water quality by removing nutrients (like fertilizers), remove Biological Oxygen Demand (BOD), remove metals and other pollutants, and remove pathogens that threaten human health.[24] In addition to the references cited here, many resources are available to assist in wetland work. The referenced software simulates wetlands when working with them.[25]

FIGURE 13
How Wetlands Work



Source: http://geoscape.nrcan.gc.ca/h2o/bowen/images/wetlands_e.jpg

MINIMIZE DEPOSITION OF SEDIMENT IN THE RESERVOIR

One problem common to virtually all sediment control methods is plugging of water intakes. Whether the inlet to a suction pipe or the trashrack at the entrance to a reservoir outlet, considerable debris accumulates during operation. Water flow is greatly restricted, making it difficult to remove sediment. Various method have been used to deal with this situation. They include:

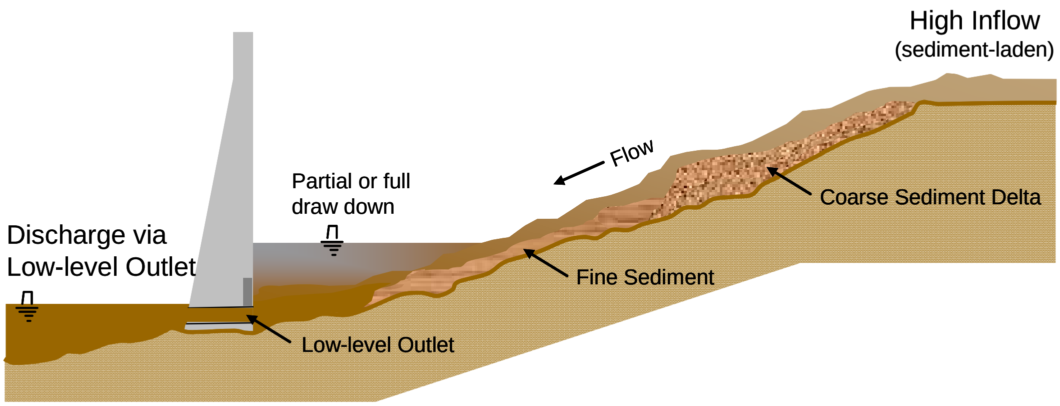
- Raking trashracks from above the water by hand from shore or boat. Where conditions permit, a backhoe or excavator can be used to clear trashracks. Using scuba divers is not very productive, and can be dangerous.
- Blowing air into the plugged structure to eject the debris, followed by collecting and disposing of the debris. On suction pipes this is done as needed, which can be a several times a day. On outlet works under a dam, this can be a major undertaking costing tens of thousands of dollars.

Sediment Pass-through

Method Description

Sediment pass-through (sometimes referred to as sluicing) is the practice of allowing high runoff events, which typically carry large sediment loads, to flow unimpeded through the reservoir basin after the reservoir has been partially or fully drawn down. "The objective with sluicing (sediment pass-through) is to provide sufficient sediment carrying capacity within the reservoir during flood conditions to minimize sediment deposition and maximize sediment through-flow."[26] The heavily sediment-laden water is passed through low-level outlets in the dam to the river below. Fine sediments remain in suspension as the flow moves through the reservoir. If adequate velocity is maintained throughout the reservoir basin, larger-size sediments may also pass through the reservoir or be transported closer to the dam where subsequent sediment pass-through may be effective. Although sediment pass-through

FIGURE 14
Sediment Pass-Through



can also remobilize sediments already deposited in the reservoir, this is not the intent. See Figure 14 for a simple illustration of sediment pass-through.

The vertical scale on figures in this chapter is greatly exaggerated. The slope of a reservoir bottom is very gradual. In order to show the various methods, it was necessary to fit the figures on a page that is especially narrow when compared to the length of a reservoir. Thus, the vertical exaggeration was necessary.

If the reservoir is empty or near empty, high sediment loads can be passed through with minimal water loss and a very high sediment routing efficiency. If the reservoir is full, it may not be economical to drain the reservoir due to the value of the stored water. In this case, a previously worked out cost/benefit ratio, comparing the impact of sediment pass-through to the loss of stored water, may help provide the trigger point to begin pass-through. Early spring runoff is the most predictable event likely to have high sediment content and is usually the most applicable for scheduled pass-through. Other flood events that develop from thunderstorms and an early or quick snowmelt are less predictable, but may also carry high sediment loads that would be desirable to pass through the reservoir if possible. In particular, thunderstorms that occur at the end of the irrigation season when reservoir levels are already low could provide ideal opportunities for sediment pass-through.

Considerations

On river reaches that have several reservoirs in series, pass-through will carry the sediment downstream to the next reservoir. Clogging of downstream canals and intakes, as well as a changing flow pattern within the reservoir, may occur. High sediment concentrations may also periodically exceed the limits where fish and other aquatic species can survive. This is especially true if sediments already deposited in the reservoir are remobilized during pass-through. This has happened at some very small Utah reservoirs.

Pass-through generally requires low-level outlets that can accommodate the high flows that generate large sediment loads. For scheduled pass-through events, such as springtime runoff, sluice gates should be designed to minimize backwater during the highest flows expected. Some Utah reservoirs may not have low-level outlets of sufficient size, and this would limit the effectiveness of this method. Even if they are large enough, if the low-level outlets have not been operated regularly, there is concern that once opened, the outlets may not shut properly.

In Utah's semiarid climate, many reservoirs have been placed on streams with limited flows. Pass-through is most applicable to reservoirs where flows are not only large enough to be effective but also sufficient to refill the reservoir after pass-through ends. In some cases, all or most of a river's annual flow may be stored in a reservoir, limiting the water available for pass-through. In such cases, other sediment management methods may be more practical.

Summary – Sediment pass-through

- Objective: route sediments through reservoir during high inflow events to prevent deposition and maintain storage capacity.
- Structural and mechanical requirements: low-level outlets of sufficient size to pass high sediment flows. The existence of a dead pool below the outlets will hamper flushing effectiveness.
- Reservoir operation: partial or full draw down of water level required. This may limit pass-through to the end of the irrigation season, and to thunderstorm events or early spring runoff in order to allow the reservoir to fill to a level that will not inhibit water allocations.
- Target sediments: most grain sizes, including some bed loads. Regular pass-through will allow the river to establish a natural channel through the reservoir, thus facilitating sediment transport.
- Disposition of sediment: discharged to the downstream environment, restoring a more natural sediment balance.

For an example of sediment pass-through, see the case study on First Dam in Chapter 8.

Density Current Venting

Method Description

Density currents can form when sediment-laden water from a stream enters the relatively clearer water of a reservoir. As the turbid, more dense, water enters the reservoir, it will “plunge” to the bottom with minimal mixing through the main body of water in the reservoir. The density current then follows down the path of the pre-impoundment river channel to the face of the dam. If the density current is strong enough, and lasts long enough, for it to reach the dam, the sediment-laden water can be discharged through low-level outlets (vented). If the density current is not vented, a “muddy lake” forms near the dam, and over time the sediments will settle out and eventually consolidate. See Figure 15 for a simple depiction of density current venting.

While density currents form easiest when cool, turbid water enters the warmer reservoir, they can form with any inflow that has high sediment concentration. Once the flow of turbid water entering the reservoir ceases, the whole length of the density current stalls and the sediment settles within the reservoir. Outlets need to be low enough to coincide with the bottom of the muddy lake. Venting operations are most efficient when the gates are opened to match the flow rate of the density currents. If the outlet can be adjusted to match the flow rate of incoming density currents, then wasting water or settling sediment can be minimized.

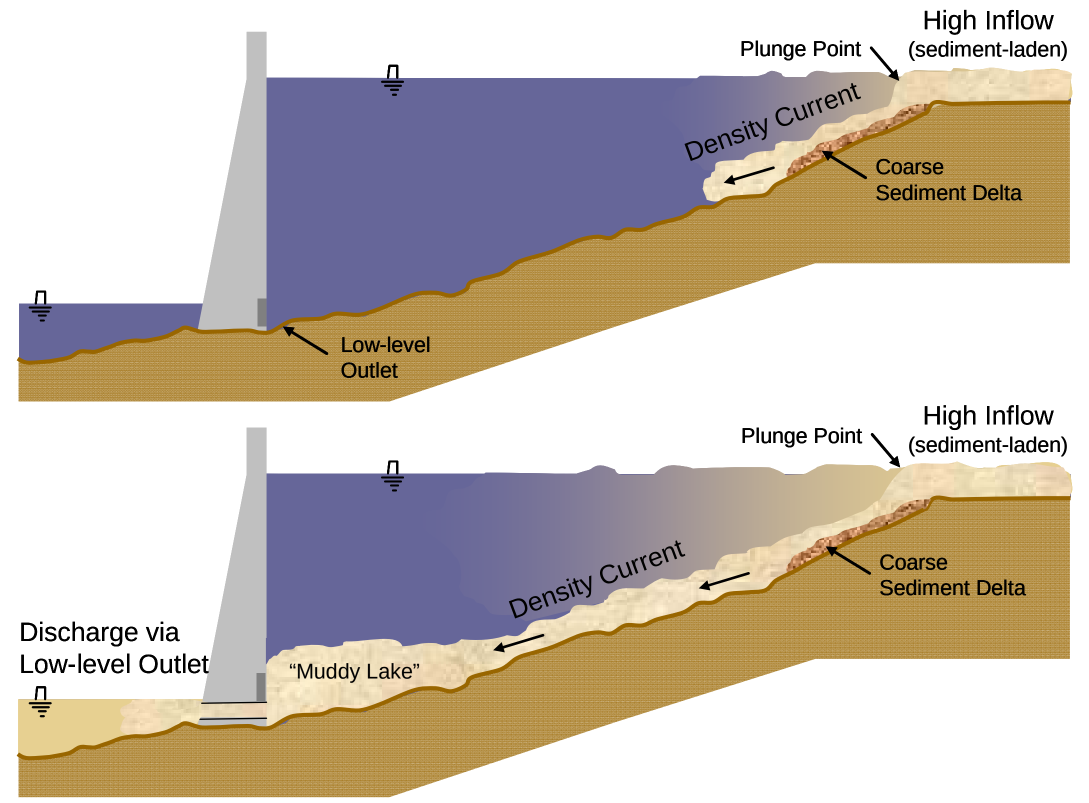
Considerations

Density currents form under only certain conditions that have not been described by any predictive relationship. Thus employing density currents to vent sediment cannot be built into the design of a dam or reservoir. Rather, if density currents are thought or known to occur, this management alternative may be considered.

The efficiency of venting operations depends greatly on the timing of the opening and closing of the reservoir outlets; therefore, it is important to know when turbidity currents begin and end. Remote turbidimeters can be placed where water flows into the reservoir and near the low-level outlets to determine when density currents reach each location. In addition, density currents can be detected by using deep water samplers lowered from the reservoir surface to the deepest levels of the former river channel. Continuous sampling at low-level outlets can indicate when a density current has arrived but not when it has ended. Turbid water remaining in the muddy lake after the density current has stalled can be drained from the base of the dam at a lower release rate.

Although density currents can be easily vented from reservoirs once detected, even with ideal conditions, most operations can only vent no more than about half of the total sediment reaching the reservoir. Typical venting efficiencies are about 20 percent since many density currents do not last long enough or are not detected early enough for effective vent-

FIGURE 15
Venting Density Currents



ing. However, removal of over 100 percent of the fine-grained sediments has been recorded for specific events. These high efficiencies are attributable to the remobilization of unconsolidated fine sediments within the reservoir by the density currents.

As the reservoir accumulates sediment over time, the deepest levels of the former river channel will gradually fill in and flatten, spreading any density currents that form across a flattening reservoir floor, resulting in increased resistance to flow. This causes more and more fine sediment to drop out along the path of flow. If too much material drops out of suspension in any one density current, the current may slow or stall, causing all sediments to settle within the body of the reservoir. Periodic flushing or sediment pass-through can help maintain the channel through the reservoir, along which density currents can flow.

One way to determine whether or not a given reservoir is a candidate for venting is if a thick layer of fine-grained sediment is found extending horizontally upstream from the dam. This may indicate the frequent formation of a "muddy lake" and subsequent deposition of sediment at this location. Another indicator is the formation of a plunge point near the reservoir's inlet. A plunge point is where dense turbid water drops quickly to the bottom of the reservoir, causing a counter-current on the surface which brings floating debris back to the plunge point.

In general, shorter, straighter reservoirs are more efficiently vented. The configuration of Joe's Valley or Scofield reservoirs, for example, may make them good candidates for venting. However, density current venting can be performed at any reservoir where they form. Currents reaching 80 miles in length have been documented in Lake Mead. Density currents may reach the dam more readily in some reservoirs when they are drawn down, which also reduces the amount of water used. With the reservoir drawn down, inflow may re-suspend sediment from the exposed reservoir bottom, increasing the sediment concentration in the density current.


Clear water spilling out of Millsite Reservoir.

Summary – Density Current Venting

- Objective: route suspended sediments through the reservoir to prevent deposition and prolong reservoir life.
- Structural and mechanical requirements: low-level outlets that can be adjusted to match the rate of incoming density currents and turbidimeters that can detect when density currents begin and end.
- Reservoir operation: no draw down of water level required. However, discharge from the reservoir should match inflow for the duration of the density current, possibly diminishing water storage. Venting can occur only when appropriate conditions are detected.
- Target sediments: fine-grained sediments, mainly silts and clays. Under ideal conditions, fine-grained sediments already deposited in the reservoir may also be vented. Periodic sediment pass-through or flushing will allow the river channel in the reservoir to remain, and will increase the venting efficiency .
- Disposition of sediment: discharged to the downstream environment, restoring some of the natural sediment balance.

There are no known examples of density current venting in Utah. However, incidental venting of density currents may be taking place at Millsite Reservoir because of the way the reservoir is operated. See the Millsite Reservoir case study in Chapter 8 for more information.

Sediment Bypass

Most of Utah's reservoirs are built directly on the stream. After a reservoir is filled, excess water is passed through outlets or over a spillway downstream. The disadvantage of this operation is that nearly all but very fine sediment entering the reservoir is trapped. The water that is sent downstream is, for the most part, free of sediment. See the above photo of clean water spilling at Millsite Reservoir for an example.

Utah's reservoirs receive the majority of sediment during the relatively short spring runoff. Millsite Reservoir, for example, receives 90 percent of its annual sediment during the six week period between May 1 and June 15.[27] Millsite Reservoir completely fills in seven out of ten years, which means clear water flows over the spillway downstream on a regular basis. In addition to the spring runoff, late summer thunderstorms often produce high flows along with correspondingly high sediment loads. Thunderstorms are more prevalent in southern Utah because of its close proximity to tropical moisture coming from the Gulf of Mexico. These storms can produce high sediment loads. Routing these high sediment flows around reservoirs during such events is called sediment bypass and is an effective method of reducing sediment deposition in the reservoir.

Method Description

Runoff flows are monitored and when heavy sediment loads are detected, they are intercepted by a diversion structure upstream of the reservoir and are transported around the reservoir using a canal or pipeline. Bypassing can be automatically activated with electronic controls or it can be done by a human operator. The sediment-laden water is then discharged into the stream below the dam. This can be done whenever sediment loads entering the reservoir are undesirable. If there is carryover water from the previous season still in the reservoir, and the snowpack is good, early sediment-laden runoff can be bypassed and later cleaner runoff can be sent to the reservoir. Whether a canal or pipeline is used depends on the physical layout conditions at each reservoir. Depending on the unique characteristics of each reservoir and contributing river, bypass diversions can be built to allow most, or part, of incoming flows to bypass the reservoir. In effect, bypassing takes the reservoir "off stream" during periods of high sediment inputs.

Considerations

Bed loads allowed into the bypass canal or pipeline can settle out in the by-pass system, thus reducing flows and requiring regular maintenance. The canal or pipeline must be sized for anticipated flow rates and sloped appropriately to keep sediment loads in suspension. The diversion needs to be designed to keep out sediment sizes larger than the design limits for the pipeline or canal. This can be accomplished using vertical vanes that deflect bed material placed in the river bottom near the diversion. See the end of this chapter for construction details. In addition, the diversion can incorporate a high level intake that excludes bed loads during high flows. Depending on conditions, cleanout access devices may be advisable along the conduit.

Local topography may limit the ability to construct a bypass canal or pipeline that diverts flow around the reservoir. Furthermore, if one of the reservoir's purposes is flood control, a portion of high sediment flows may have to be trapped in the reservoir to prevent flooding.

Bypass for an off-stream reservoir is readily accomplished by closing the diversion structure during periods of heavy sediment load. Quail Creek Diversion Dam in Washington County is operated in this manner. Bypass structures may accumulate sediments themselves. Bed loads typically drop out behind the diversion dams requiring the structure to be mechanically cleaned. Some diversion structures are designed for sediment pass-through and or flushing during high flows. Including a gate structure that allows flushing an on-stream diversion eliminates or reduces the frequency of mechanical sediment removal. The gate also increases the flow capacity of the diversion structure during high flow events.

Bypassing sediment has the added benefit of more closely approximating the normal regime of sediment flow to downstream river reaches. This maintains both sediment concentration and timing. Fast flowing streams carry larger bed load particles such as sand and gravel that are important for fish spawning habitat. If it is possible to bypass some of the bed load around the reservoir, this would be desirable, since these sediments are the most difficult to remove from a reservoir once deposited. Bypassing fine sediments will restore turbidity downstream to more natural levels, which is advantageous for Utah fishes.

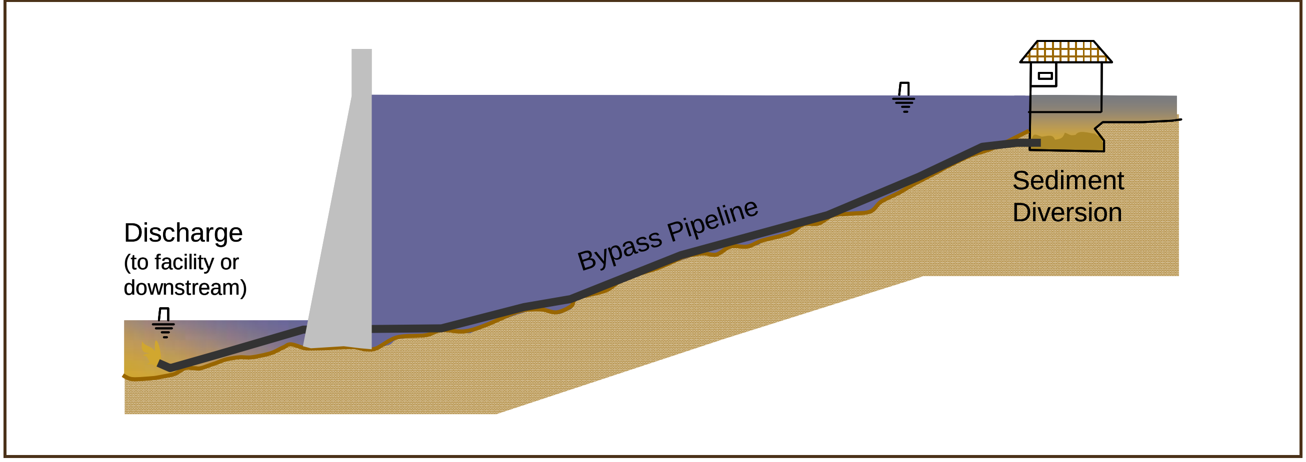
Summary – Sediment Bypass

- Objective: route sediment-laden flows around reservoir to prevent deposition and prolong reservoir life.
- Structural and mechanical requirements: diversion structure above reservoir and canal or pipeline to route flow around or through the reservoir.
- Reservoir operation: no draw down of water level required. However, any flow that is bypassed may reduce the ability of the reservoir to fill. Bypass can take place whenever sediment loads are undesirable.
- Target sediments: mainly fine-grained sediments and possibly some bed load. The amount of bed load transported depends on the flow velocity that can be maintained in the bypass conduit.
- Disposition of sediment: discharged to the downstream environment, restoring a part of the natural sediment balance.

Hydrosuction Bypass[28]

The hydrosuction bypass method is an innovative way to minimize sediment deposited in a reservoir. Like sediment bypass, hydrosuction bypass intercepts all or a portion of the sediment-load (depending on the grain size) before it enters the reservoir and transports it downstream of the dam.

FIGURE 16
Hydrosuction Bypass



Modified from, "Hydrosuction Sediment-Removal Systems (HSRS): Principles and Field Test," R.H. Hotchkiss and Xi Huang, Journal of Hydraulic Engineering, June 1995.

Method Description

Hydrosuction bypass removes sediment by harnessing the energy created by the elevation difference between the water levels above and below the dam. This "hydraulic head" is the driving force (or suction), which transports water and sediment through a pipeline. Depending on circumstances, little or no external energy is required. "The method uses a pipeline at or near the bottom of the reservoir that extends from a point of sediment deposition, to the dam. The pipe continues through the dam to a discharge point downstream."[29]

Hydrosuction bypass requires a permanent structure upstream of the reservoir to intercept sediment before it enters the reservoir. The "sediment excluder" structure collects sediment and water via natural flow and the suction created by the siphon system, discharging it downstream as depicted in Figure 16. With this system, most of the sand that comes into the reservoir and some fines (clay and silt) leave the reservoir, ultimately maintaining the reservoir capacity by bypassing the natural sediment load. If sufficient hydraulic head is available, larger bed load material (small gravel) can also be transported. A permanent rigid pipeline system from the sediment excluder to the discharge point is required. To better control sediment releases downstream, a second pipe that introduces clear water into the system may be required to prevent blockage and to regulate sediment concentration downstream.[30]

Considerations

Hydrosuction bypass provides a finer control than other sediment management methods. It can be operated to control water-sediment mixture releases, to mimic the natural sediment load as if the dam were not there, and to regulate the sediment-transport capacity of the stream. This is accomplished through the use of instrumentation and technologies for monitoring and a simple valve system to control intake and outflow.[31] Hydrosuction bypass techniques provide these benefits and operational flexibility while requiring less water than either sediment pass-through or flushing. No information could be found regarding whether hydrosuction poses a risk for entraining fish in the pipeline.

If the reservoir is long, the required pipeline would experience significant friction loss and need to be designed accordingly. The design of a hydrosuction bypass system may be complex, depending upon reservoir, hydrology and sediment characteristics. In addition to capital costs to install, there are operational and maintenance costs associated with hydrosuction systems.[32] Hydrosuction is very operational and maintenance intensive compared to some other methods.

Hydrosuction bypass is better suited for small to medium reservoirs. There are several factors that determine feasibility as a sediment management option. For example, sufficient hydraulic head is needed to transport sediment. The farther sediment is transported and the larger its grain size, the greater the hydraulic head required.

Summary – Hydrosuction Bypass

- Objective: using the hydraulic head of the reservoir, route sediment through a pipeline to prevent deposition thus maintaining reservoir storage capacity and prolonging its life.
- Structural and mechanical requirements: diversion structure above reservoir to collect sediment and a pipeline to route a portion of the flow and sediment to the reservoir outlet.
- Reservoir operation: minimal or no draw down of water level required. Can be done any time sufficient water and hydraulic head is available.
- Target sediments: mainly fine-grained sediments and sand. Sediments larger than sand may also be transported, depending upon the hydraulic head available and the flow velocity that can be maintained in the pipeline.
- Disposition of sediment: discharged to the downstream environment, restoring a more natural sediment balance.

Refer to the Valentine Mill Pond, Nebraska case study in Chapter 8 for an example of hydrosuction bypass.

REMOVE SEDIMENT FROM RESERVOIR

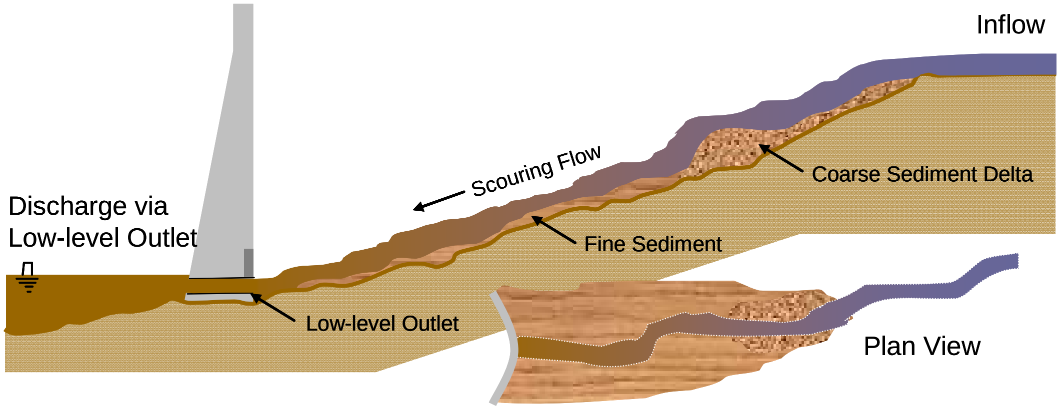
All methods involving removing sediment from the reservoir entail the issue of possible contaminants contained in the sediment. Once mobilized, some of these contaminants can cause considerable harm. Depending on the contaminant, this issue has the potential to completely halt a project that disturbs them. Of course, this depends on potential contaminant sources, both natural and human-made, upstream of the reservoir. Sediments that are to be removed need to be thoroughly sampled and subjected to detailed examination well in advance of actual sediment removal. Depending on the results, a plan to deal with the contaminants may be required.

Flushing

Method Description

Sediment flushing re-mobilizes sediments previously deposited in a reservoir by drawing down the water level and letting the water flow out through low-level outlets in the dam. The main difference between flushing and sediment pass-through, is that pass-through allows high sediment flows to move *through* the reservoir without impoundment, minimizing deposition. Flushing targets sediments *already deposited in* the reservoir. Pass-through requires timing of releases to periods of high volume, high sediment concentration inflows to the reservoir, while flushing may take place when conditions are more convenient to reservoir operations. Water flowing through the reservoir scours sediment de-

FIGURE 17
Sediment Flushing



posits and carries them to the dam and to the river below, see Figure 17.

As flushing begins, sediments near the outlet slough off first and are carried through the dam. As the reservoir water level drops, the flow coming into the reservoir will typically follow the path of the pre-impoundment stream channel, eroding sediments and eventually scouring down to the original stream bed. As scouring progresses further, the channel may meander, forcing additional material to slough into the channel, which gradually flattens the reservoir basin. Spreading out the incoming flow across the sediment delta will increase flushing efficiency. If flushing is done regularly and for a long enough time, eventually a sustainable reservoir capacity will be reached.

Considerations

Water availability is a key consideration in determining if flushing is practical. Generally, flushing can successfully achieve a sediment balance if the reservoir's capacity to inflow ratio is 0.3 or less (e.g. for a reservoir capacity of 3,000 acre-feet, the annual inflow volume should be 10,000 acre-feet or more). While there are not many water storage reservoirs in Utah that have capacity to inflow ratios of this magnitude, there are several reservoirs and diversion dams on large streams for which flows will be more than adequate for high-efficiency flushing. Gunnison Bend Reservoir, for instance, has an average annual inflow that is 35 times larger than its capacity, for a capacity to inflow ratio of about 0.03.

An alternate guideline for flushing is to devote at least 10 percent of the mean annual inflow into the reservoir to flushing. This will be a much easier target to reach for most reservoirs, as long as the reservoir is already drawn down or drained normally. Although flushing at this rate may not be able to restore the sediment balance and maintain reservoir capacity, regular flushing will still remove local deposits near the dam and outlet facilities.

Because flushing is most effective when the reservoir is empty, flushing typically takes place in early spring before reservoir filling begins, just as stream flows begin to rise. However, in many irrigation reservoirs in Utah, flushing is more likely to take place at the end of the irrigation season when reservoirs are drawn down or completely emptied. Although flows will be much lower at this time, some flushing of finer-grained sediments will still occur. Flushing can also take place when a reservoir is drawn down in anticipation of high spring runoff or other flood flows. Generally, the more closely flushing conditions mimic pre-impoundment conditions, the more successful flushing operations will be.[33] High flushing discharges for shorter time periods will be more efficient than low flushing discharges spread out over longer period of time.

Sediment characteristics will vary significantly with the topography surrounding the reservoir. Sediments deposited in high mountain reservoirs will generally consist of larger particles such as sand, gravels and small cobbles. In the valleys where slopes are more moderate and reservoirs are larger, fine-grained sediment will make up the largest portion of the sediment load.

Long and narrow reservoirs with steep sides can be flushed more effectively and thus retain a greater portion of their original capacity than wide and shallow reservoirs. The sediments most effectively flushed are coarse silts to fine gravels, since these tend to deposit in the deepest levels of the former river channel where river-like conditions are reproduced during flushing. Finer sediments may have settled outside the reach of flushing waters. Larger gravels and cobbles deposited at the entrance to the reservoir will likely require flood level flows to be flushed.

For effective flushing, the dam's outlets should be sized to pass at least twice the average annual inflow rate (e.g. if the average annual inflow rate is 20 cfs, the outlets should be sized to pass at least 40 cfs).[34] In some cases heavy equipment may be used to push sediments into the scour channel, further increasing the effectiveness of flushing. This is done at Yellowstone Dam, a small hydroelectric facility on Yellowstone Creek in the Uintah Basin. Such sediment loads can easily overload the downstream sediment transport capacity of the river and likely result in temporary deposition in the channel.

Flushing operations can produce high and uncontrolled sediment loads below the reservoir and care must be taken to protect the downstream environment and infrastructure. Although flushing allows sediment to pass below the dam similar to natural events, the high concentration of sediment can negatively impact stream habitats and aquatic wildlife. The initial “slug” released from the reservoir during flushing usually contains the highest sediment concentration and is therefore the most problematic. Reservoir sediments can also contain concentrated pollutants such as organic debris, and anaerobic deposits that can cause problems. Since flushing operations typically generate suspended sediment concentrations greater than 100,000 mg/L, water quality will be degraded. Careful monitoring of turbidity is advisable to make sure water quality is not degraded beyond established limits. Temporarily removing fish from downstream reaches by stunning and trapping prior to flushing may be an effective way to minimize impacts. Because of issues with sediment releases and carry-over storage, flushing operations are not practical for larger reservoirs. The environmental impacts associated with flushing are typically more manageable at smaller reservoirs and diversion structures.

Summary – Flushing

- Objective: remove sediments already deposited in reservoir to maintain storage capacity.
- Structural and mechanical requirements: low-level outlets of sufficient size to pass flushing flows. The existence of a dead pool below the outlets will hamper flushing effectiveness.
- Reservoir operation: full draw down of water level required. This may limit flushing to the end of the irrigation season or whenever the dam is emptied to perform maintenance.
- Target sediments: all sediments, including bed loads. Regular flushing will allow the river to establish a natural flow bed through the reservoir, thus facilitating sediment transport.
- Disposition of sediment: discharged to the downstream environment, restoring a more natural sediment balance.

For an example project, see the case study on Quail Creek Diversion Dam in Chapter 8.

Flushing in Utah

Based on a survey of small dam owners, performed by the Utah Division of Water Resources in the summer of 2008, there is some evidence that end-of-season reservoir flushing has effectively helped maintain reservoir storage capacity. The survey was designed to collect information about 21 small dams that have been in place a long time, and were suspected to have been significantly impacted by sediment. However, only one-third of surveyed dam owners expressed concern that sedimentation has become a critical issue with the potential of impacting future operations. The fact that most of the surveyed dam owners had not noticed significant sedimentation problems was surprising and begged the question, “Why?” The final six dam owners contacted as part of the survey were asked whether or not they believed that the reservoir’s drawdown condition in the late irrigation season facilitated the flushing of sediments. While no quantitative data was provided, each owner answered the question affirmatively. Several owners provided anecdotal information about observed heavy sediment loads in downstream canals and/or streams below the reservoir as a result of the annual draining of the reservoir. See Appendix A for details. From the survey, it appears that incidental sediment flushing is routinely occurring for many of Utah’s small reservoirs that are emptied annually.

Excavation

Excavation of sediment from a reservoir using heavy equipment is energy intensive. In addition, high labor costs and road and equipment repair can make excavation more expensive than dredging (discussed later). In order to excavate sediments from a reservoir basin, the reservoir must be at least partially drawn down for extended periods, resulting in a temporary reduction in storage capacity and associated impacts to water users. Excavation and dredging require a place to temporarily store or permanently dispose of sediments.

As mentioned above, excavation requires at least partial draw down of the reservoir to drain and access sediments. With partial draw down, the coarser, quick-draining sediments that accumulate near the entrance in the reservoir delta can be exposed. Shortly after the sediment dries, heavy equipment can usually be supported by the coarse sediment. Fine sediments located further down in the reservoir may be broadly distributed and drain much more slowly after exposure to the air, thus taking substantially longer to dry adequately enough to support heavy equipment. When a reservoir is fully drawn down to prepare for excavation, finer-grained sediment can be flushed out, provided the dam has low-level outlets with adequate capacity.

To cut costs as much as possible, a disposal site should be located close to the reservoir. Depending on the sediment composition, uses could include leveling of farm fields, re-covering of eroded areas, land fills, surface mine reclamation. Fuel costs to excavate and transport spoils can be the determining economic factor for project feasibility.

Excavated sediment is loaded into trucks, trains or onto conveyer belts for transport to the disposal site. The method of transport is usually determined by the least expensive option available, but may be influenced by other factors. Truck transportation may incur costs associated with road repair and weight limitations. Train transport is very expensive unless the project volume is great enough to provide economics of scale to recoup equipment and track laying expenses. The Milltown Reservoir Project[35] near the Anaconda Mine in Colorado, is a superfund site currently using rail transport to remove 1,400 acre-feet (out of 4,200 acre-feet of reservoir sediment) of contaminated mine sediments from the reservoir basin to the Anaconda Smelter Superfund site 100 miles away. Conveyor systems are an option for sediment transport although these are limited to shorter distances and may require power transmission lines. Since most excavation projects are less than 800 acre-feet,[36] truck transportation is generally used.

Dredging

Similar to excavation, dredging can be energy intensive and requires a location to temporarily store or permanently dispose of sediments. Dredging apparatus typically include a barge with pumps and generators and piping that extends to the disposal site. A boom extends from the barge to the reservoir floor and will typically have a horizontal auger or cutter head on the end. Sediment slurry is heavier than clear water and limits suction depths. To dredge sediments at greater depths, a separate pump located at the end of the suction pipe or cutter head can be installed.

The location of the dredging barge is typically controlled by adjusting lines attached to the shore or anchors placed on the reservoir bottom. Some dredging barges use poles (or spuds) sunk into the sediment as feet to "walk." As the sediment is dredged the resulting slurry is transported to the shore through flexible piping suspended at the reservoir's surface by floats. The piping and floats can be a hazard for boating activities, especially in the summer. In some cases, the sediment slurry may be placed in a barge for transport to another location for offloading. Pumping and disposal costs account for the bulk of dredging expenses.

Many of Utah's rivers are too small to receive large releases of dredged sediment slurry, necessitating the dewatering of slurries before returning the water to the reservoir or waterway. If sediments are to be deposited on land, a disposal site as near to the reservoir as possible will need to be located to minimize transportation costs. The sediment slurry could be piped to an area to be leveled, used to fill and reclaim an abandoned surface or underground mine, or for other similar disposal or uses. Besides being potentially contaminated, most fine-grained sediments suitable for suction dredging have a low compressive strength – limiting their desirability and use. In any case, the sediments have to be stabilized once in place to prevent sediment and disturbed contaminants from re-entering the waterway. In some river reaches, returning a small portion of the sediments to the stream will benefit aquatic habitats by providing nutrients for plant and animal life and spawning material and concealment for fish. In this case a controlled, continuous release of the sediment may be desirable.

For the most part, large dredging projects in the U.S. have been limited to navigable waterways. The largest reservoir dredging project in the continental U.S. was in Illinois' Lake Springfield Reservoir, which removed about 1,865 acre-feet of sediment.[37] Dredging can entail the loss of the water used to transport the sediments with associated impacts to water users. "Dry" dredging uses closed clamshell buckets that limit the amount of water removed as well as the amount of turbidity created by dredging.

Closed and open buckets can remove sediments at near in-situ moisture levels, limiting the amount of water leaching from excavated materials. Closed buckets are frequently used in areas that have contaminated silts or where turbidity needs to be controlled. Slurry dredging entails using large amounts of water mixed with sediments for long distance transport. Once the slurry reaches the deposition site it is ponded to allow settling. The remaining water is evaporated or filtered through straw bales or by other methods and the water returned to the river or reservoir. If sediments are contaminated the slurry may be placed in a lined containment area, the water evaporated and the solids eventually capped to limit infiltration. Slurry systems have the advantage of economically moving large amounts of sediment long distances without the hazards of road traffic or road damage. Slurry pipes can be temporarily laid on open ground or buried for aesthetics.

Hydrosuction Dredging

Dredging water bodies as a method to restore or maintain capacity and navigation has been employed for centuries. In hydrosuction dredging, analogous to siphon dredging, deposited sediment is dredged and transported downstream or to an offsite location with minimal power requirements.

Method Description[38]

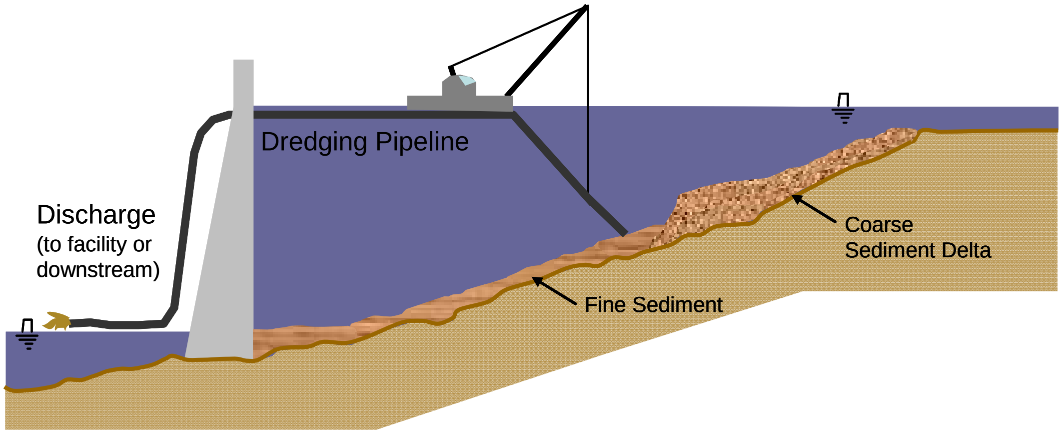
Dredging traditionally requires a mechanical pump to provide the energy or driving power to remove and transport deposited sediment. Hydrosuction dredging or siphoning, on the other hand, works with the same principles as hydrosuction bypass, which requires no external energy with the hydraulic head providing the driving force. However, hydrosuction dredging differs from hydrosuction bypass in design and implementation.

There are two variations of hydrosuction dredging: (1) siphoning, where the water-sediment mixture is passed through a pipe over the top of the dam, and (2) bottom discharge, where the mixture is piped through low-level outlets of the dam.[39] The hydrosuction dredging pipeline inlet is not meant to be stationary and may involve the use of a floating barge to allow adequate coverage of the reservoir bottom, see Figure 18. The piping system would likely consist of a combination of rigid and flexible pipes in order to facilitate movement along the reservoir floor.

Considerations

As with any sediment management methodology, there are both positive and negative points to consider. A benefit of hydrosuction dredging is that it can be used to collect and transport sediment of cer-

FIGURE 18
Hydrosuction Dredging



Modified from, "Hydrosuction Sediment-Removal Systems (HSRS): Principles and Field Test," R.H. Hotchkiss and Xi Huang, Journal of Hydraulic Engineering, June 1995.

tain grain sizes to improve aquatic habitat downstream.[40] Operations can be timed so that sediment-laden water is discharged into relatively clear spillway or hydropower releases so as to match the sediment transport capacity of the receiving river. Also, if the sediment is contaminated, it can be diverted to an offsite facility for additional management rather than being discharged downstream. Hydrosuction dredging is a more controlled operation than flushing and sediment pass-through. The concentration of sediment in the effluent is controlled by the pipeline diameter and distance to the outlet; factors considered in the design of the system.

Depending on how much the sediment has consolidated and compressed, a mechanical device may be needed to break it up. Water jets, cutter heads, horizontal augers or rotating tines can break up consolidated sediments; however, a power source would be needed. The intake shapes for hydrosuction dredging (which can be thought of as the adaptors of a vacuum machine) are the same as those used in conventional dredging activities.[41] In order to remove sediments at greater depths, a separate pump located at the end of the suction pipe or cutter head can be installed. With hydrosuction dredging, the use of a floating barge and pipeline may interfere with recreational and operational activities to some degree, requiring conscientious management and scheduling.

Summary – Hydrosuction Dredging

- Objective: using the hydraulic head of the reservoir, dredge deposited sediments from the reservoir.
- Structural and mechanical requirements: floating barge and pipeline of sufficient size to remove targeted sediments. A mechanical device to break up sediments may also be required to dislodge consolidated sediments.
- Reservoir operation: minimal or no draw down of water level required. Can be done any time sufficient water and hydraulic head is available.
- Target sediments: mainly fine-grained sediments and sand. Sediments larger than sand may also be transported, depending upon the hydraulic head available and the flow velocity that can be maintained in the pipeline.
- Disposition of sediment: discharged to the downstream environment, restoring a more natural sediment balance. Sediments can also be discharged to settlement basins and removed separately.

An example of hydrosuction dredging is the Rioumajon Dam in France. A hydrosuction siphon or “hydroaspirator” was developed, installed and now straddles this gravity arch dam to remove sediment from around the intake structures and sluice gate. This system operates automatically when water spills, creating suction and thereby removing any deposited sediment in the vicinity. This is a small scale maintenance operation with an installation cost of roughly $166,000 (2007 dollars).[42]

COMPENSATE FOR SEDIMENT ACCUMULATED IN RESERVOIR

There are several options to compensate for lost reservoir storage. A new reservoir may be built nearby either on- or off-stream if a suitable location exists. Conveyances may be improved and the water from the original reservoir stored at a new reservoir or used for ground water recharge. In some cases, a dam may be raised to provide more storage. Irrigation efficiencies may be improved to make limited storage go further.

Enlarge the Dam

Enlarging an existing dam to compensate for lost storage may be a good option to **temporarily** replace storage lost to sedimentation. Raising a dam by just a few feet can add considerable storage volume as the storage added is at the top of the reservoir basin, where the basin is typically wider, and the most storage volume can be gained for each foot of rise in the dam. The feasibility of raising a dam, however, is dependent upon the many variables unique to each location. One of the most important is available property that can be inundated.

Many of Utah’s earthen dams were built long ago when dam building was more of an art than a science. Dams were frequently built of a single soil material with no drain in them to relieve the hydraulic pressures that could build up from seepage. In addition, few dams were “keyed” into underlying bedrock or had the cracks in their bedrock foundations grouted to reduce the chance of channeling. Today's dam safety standards, refined by soil science (especially since the Teton Dam failure in Idaho on June 5, 1976), have been established and compliance is mandatory for all new and high hazard dams in Utah. As funding becomes available, those dams rated as the highest hazard are gradually being upgraded to the new standards. Raising any dam would also require conformance to the new safety standards.

To raise the height of an earthen dam built with a homogeneous embankment, the downstream face (typically built at a 2:1 slope) would have to be removed and a chimney drain (a water-pervious vertical column with a collecting pipe or channel at the bottom) installed before replacing and enlarging the embankment. For smaller earthen dams, it may be possible to install drain wells to relieve hydraulic pressures if the enlargement is also relatively small.

Raising the more modern earthen dams with multiple zones of different fill types would be more difficult. The dam would have to be excavated down to expose the impermeable and drain layers and then brought up with additional material to the new height. Additional material would have to be placed on the downstream face to add mass and keep the slope at a 2:1 pitch.

The history of each dam also helps determine if it can be raised. If there have been issues with seepage or piping, the dam may require more modification or complete rebuilding. In raising the dam, the spillway would also have to be raised or modified. Control structures such as intakes and gates might also need to be modified.

Many concrete dams may be candidates for enlargement depending upon their original construction and the factor of safety built into them. Most earthen dams are gravity dams, meaning that their mass provides the resistance force to hold back the water. Concrete dams can be either gravity or concrete arch dams. Concrete arch dams can be made thinner and less massive because the arch of the dam allows them to distribute large resistive forces into rock walls at the side of the dam. As with earthen dams, many structures such as intakes, spillways, control structures and various piping would have to be modified with an enlargement. Any lakeside facilities such as parks, roadways, campgrounds, or canal intakes would also have to be considered when raising a dam.

Decommission or Dismantle Dam

Eventually a reservoir may fill with sediment to the point it is no longer able to fulfill the purposes for which it was built. Numerous options to manage the sediment can be explored, and some may be implemented over time. However, eventually, sediment accumulation may reach the point that it becomes necessary to decommission or dismantle the dam creating the reservoir. Although neither of these steps will by itself compensate for the capacity lost to sedimentation, they are important steps to consider in the entire "life-cycle" of a dam. The im-

Demolition of Marmot Dam and subsequent erosion of sediment deposits behind the dam. Cherryville, Oregon (Photos courtesy of Portland General Electric.)

pacts and costs of either option will need to be considered, and in some cases may lead to other unanticipated outcomes.

Decommissioning usually means leaving the dam in place or removing part of the dam. The dam is most often left in place to stabilize reservoir sediments; it can also continue to serve as a point of diversion. Where a hydro generating station is present, retaining the dam preserves the hydraulic head and flows can be managed from upstream reservoirs. Partial removal of a dam is attractive in cases where stream flows are to be restored without incurring the cost of complete demolition and removal of the dam. Also, leaving sediments in place behind the dam may be preferred if deposits are contaminated with harmful substances. Some small dams in Utah have been decommissioned. Second Dam and Third Dam on the Logan River in Logan Canyon are two examples.

Dismantling removes the entire dam from the river. This is the most environmentally challenging because of the potential for very large releases of sediment. Staged dismantling of a dam, where it is lowered incrementally by notching, can allow a gradual removal of upstream sediments, thus avoiding catastrophic releases downstream. For any proposed removal, the environmental issues will have to be studied, as well as affects to river operations. This may entail involvement of the Federal Energy Regulatory Commission (FERC), compliance with the National Environmental Policy Act (NEPA) as well as the Endangered Species Act (ESA). Achieving compliance would likely mean studying environmental impacts and involving the cooperation of state and local government agencies and citizen groups. There are no known cases in Utah of a dam having been dismantled.

Utah has 173 dams classified as “inactive” by the Utah Division of Water Rights.[43] The dams range in size from three acre-feet to over 10,000 acre-feet. Uses vary from irrigation to mine evaporation ponds. Reasons for becoming inactive vary from them being breached, having failed and not been repaired, to having the outlet works removed.[44] A complete list and details for an individual dam can be obtained from the division’s internet web page.

Construct a New Dam

There are several issues that limit construction of new dams to replace sedimentation losses. Because of environmental protections and the costs of mitigating the affects of dams on the environment it has become more complex and difficult to build new dams either on- or off-stream. Riverine environments can be altered by the reduced flows to the point where natural changes in temperature, acidity, turbidity and nutrient loading can produce conditions that are detrimental to aquatic wildlife. Replacement dam projects (with an already established water supply from the old dam) will be required to mitigate environmental affects which may include the demolition of the old dam and downstream sedimentation issues. However, leaving a decommissioned dam in place could provide new wetland areas to offset habitat losses at the new site.

Many suitable reservoir sites with appropriate topography and geologic integrity have been lost to development. Housing, roads, farms, and factories have been located in close proximity to the river and existing reservoirs. Relocation or retirement of these facilities adds to the expense of new reservoir projects. Even off-stream locations can have features that limit their suitability. Some areas once thought suitable for water storage may have undergone other uses that have left them unsuitable, such as oil, natural gas and coal mining activities. These land use changes may be difficult or expensive to mitigate. For these and other reasons it may be more economical to recover lost storage through sediment management. For example, it is estimated that, “The rejuvenation of existing reservoirs by the introduction of flushing facilities, particularly those which have lost between 40% and 60% of their original storage, is attractive in that costs are likely to be between 10% and 30% of the cost of new dams of a similar capacity.”[45]

The American Society of Civil Engineers Sedimentation Engineering handbook indicates that in order to maintain its function, replacement storage is needed when 15 to 40 percent of a reservoir’s storage is lost. It is also estimated that the cost of new storage will be two to 10 times the cost of the original storage.[46]

Other Mitigation Measures and Alternatives

In Utah most reservoirs are built, not because there is inadequate water supply, but because the timing of the natural supply of surface water does not coincide with the demand pattern. A reservoir stores high spring flows for use in the late summer when the demand exceeds the stream's natural flow. Another purpose is to store excess water during wet years for use in dry years. As the reservoir fills with sediment, the owner does not lose a water source. Instead, the owner loses the ability to store water, and the ability to alter the natural delivery pattern to meet the demand pattern. If, as this happens, the owner is unable to adequately address the sedimentation problem, enlarge the dam, or construct a new reservoir, it will become necessary for the owner, to otherwise mitigate the continuing loss of storage capacity. Even in the extreme case when a reservoir is completely filled with sediment and abandoned, the owner might still retain the right to stream flow. It may be possible for the owner to replace the loss of stored water with an alternative, new or otherwise supplemental water source.

One option available to the reservoir owner is to combine the use of surface water with ground water withdrawals. This method, called conjunctive management, can be a useful tool to offset the impacts of sedimentation. Along the same lines, the owner may be able to replace lost surface storage capacity with subsurface storage. This method is called aquifer storage and recovery (ASR). In many instances ASR may prove to be more cost effective than building a new reservoir, particularly when environmental issues come into play. These methods can be used to mitigate the losses in storage and effectively extend the functional life of a reservoir. In some instances, even when a reservoir has completely been filled with sediment and abandoned, the use of conjunctive management and ASR may be able to offset at least some of the loss of storage. In July of 2005, the Division of Water Resources published a report entitled, *Conjunctive Management of Surface and Ground Water in Utah*, which explains this topic in detail. This publication is available on line at http://www.water.utah.gov/.

To a limited extent it may be possible offset some storage loss by altering the demand pattern. It was the demand pattern that dictated the need for the reservoir in the first place. One example of altering the demand pattern is the conversion of irrigation water to municipal and industrial (M&I) uses. Water that is stored for agricultural use is typically delivered to farmers in mid- to late-summer. Demand patterns that more closely match the flow pattern of the river could reduce the need for storage. Converting irrigation water to municipal and industrial (M&I) uses may, or may not, prove beneficial since M&I storage requirements may be less than, the same as, or greater, than the agricultural demand. Other changes, such as conservation efforts, can also produce a change in the demand pattern. In extreme instances, when sedimentation becomes an insurmountable problem and no other mitigation strategy can economically be applied, the last demand pattern change would be to abandon the use of the water, along with the reservoir.

MANAGING SEDIMENT AT DIVERSIONS AND OTHER STRUCTURES

For the most part, the sediment management methods discussed to this point apply primarily to sediment in reservoirs. However, some of these methods can also be employed to manage sediment at other water-related infrastructure such as diversion dams and canals. Additional management techniques specifically designed for these types of facilities are also available. This section provides a brief overview of some of these other methods as well as a few example projects.

Managing Sediment at Diversion Dams and Diversion Structures

Diversion dams, and the small impoundments they create, share many similarities with larger dams and water storage reservoirs. In many ways, diversion dams are simply miniature storage dams. However, a major difference between diversion dams and larger structures is the relative ease with which sediment can be managed at a diversion dam.

Diversion dams block the free-flow of the river and slow the velocity of the passing water, thus trapping larger sediment grain sizes behind the dam. Sediment control at these structures is often necessary to prevent sedimentation and improper function. A common solution to this problem is to install a sluice gate in the structure, which allows sediment trapped behind the dam to be periodically or continuously channeled downstream. Nearly all diversion dams are equipped with a spillway or bypass channel that also allows peak flows (often heavily laden with sediment), to flow over or completely bypass the dam. The key to managing sediment at a diversion dam is to provide sufficient flow to pass through the structure, allowing the bed load of a stream (any sediment that drops out of the water column when flow velocities decrease) to continue its path downstream while letting the cleaner water enter the conveyance channel unimpeded. The success of this strategy depends upon what percentage of the total water is diverted from the stream.

Occasionally, it is possible to divert water directly from a river without a diversion dam. In these instances, keeping sediment from entering the diversion structure poses some different challenges. Such structures are usually placed on slow-moving, meandering rivers that only contain fine-grained sediments such as silt and clay. Removing these finer sediments from the water can be difficult; however, by using submerged vanes (discussed later) or carefully designed intake structures, undercurrents can be created that keep much of the sand and heavy silt out of the diversion.

Managing Sediment in Canals and Other Conduits

There will always be instances where it is not economical to build a diversion structure (or rebuild an old structure) to handle sediment. Even if a structure can manage most sediments effectively, fine-grained sediments can still make their way into the conveyance facilities. As a result, it may be necessary to manage sediment after it has entered the canal or other conduit. In these instances the construction of sediment basins or vortex tubes may be appropriate. Submerged vanes (discussed later) may also work in canals.

Sediment basins are probably the most common way to remove sediment from a conveyance such as a canal. The concept of a sediment basin is quite simple: slow the velocity of the water down significantly and allow enough "resident" time for the sediments to settle to the bottom, thus enabling removal. The velocity and time required can be determined by a mathematical equation based upon the grain size of the sediments to be removed. Sediment basins can be large, relatively shallow structures constructed adjacent to the canal or deep narrow structures built into a portion of the canal.

Example of a vortex installed in a conduit to remove sediment. (Photo courtesy of Sepp Hasslberger.)

Vortex tubes are small diameter conduits installed in the bottom of the canal with a slit in the top to allow bottom sediments to be trapped and removed in a continuous stream of high-velocity, rotating water. Another type of vortex forces the entire flow of the conduit into a circular flow pattern. See photo above. The centrifugal force created by this flow pattern forces the sediments down the center of the vortex while the cleaner water flows up and over the top. Vortexes are most effective at removing heavier sediments from the water and are not able to remove fine grained silts and clays.

Another option is to simply allow sediment to flow through the entire length of the canal or conduit and be deposited on the land. This is called warping and is used in certain locations in China and elsewhere to build up low-lying land for future agricultural production or other uses. In order to be effective, flow velocities in the conveyances must be maintained to prevent sediment deposition.

Selected Examples of Sediment Management at Diversion Dams and Other Structures in Utah

Quail Creek Diversion Dam

Quail Creek Reservoir is an off-stream reservoir and removing sediment at the diversion structure before it enters the reservoir is a top priority. The Quail

Hydraulic dredging device in operation at Quail Creek Diversion Dam, near Hurricane. (Photos courtesy of Washington County Water Conservancy District.)

Creek Diversion Dam, located north-east of Hurricane in Washington County, is a good example of such a structure. See photos above. It diverts water from the Virgin River for Quail Creek and Sand Hollow Reservoirs through a nine mile aqueduct. The Virgin River is often heavily laden with sediment, which quickly builds up behind the diversion dam. Diverting water into the aqueduct under these conditions would not only deposit unwanted sediment in the reservoir but impair operation of the aqueduct. To avoid this, the diversion dam is equipped with a sluice gate as well as a dredging device that removes sediment near the aqueduct intake, allowing only cleaner water (void of heavy sediment) to enter the reservoir. The dredge works very well for silt, sand and even gravel. However, sticks, dead fish and other debris constantly clog the intake during operation. Constant clearing of this debris is necessary and the barge includes a means of blowing compressed air out the nozzle to get rid of these materials without removing the barge from the water for cleaning. For more information regarding sediment challenges at Quail Creek Diversion Dam, see the case study in Chapter 8.

Stoddard Diversion Dam

The Stoddard Diversion Dam is located on the Weber River northwest of the town of Morgan. It is a major feature of the Weber Basin Project and diverts water into the Stoddard Canal for delivery to the Wasatch Front where it is used for drinking water and secondary irrigation throughout Davis County. A portion of the water diverted by this dam is also used to generate power at the Gateway Power Plant near Mountain Green.

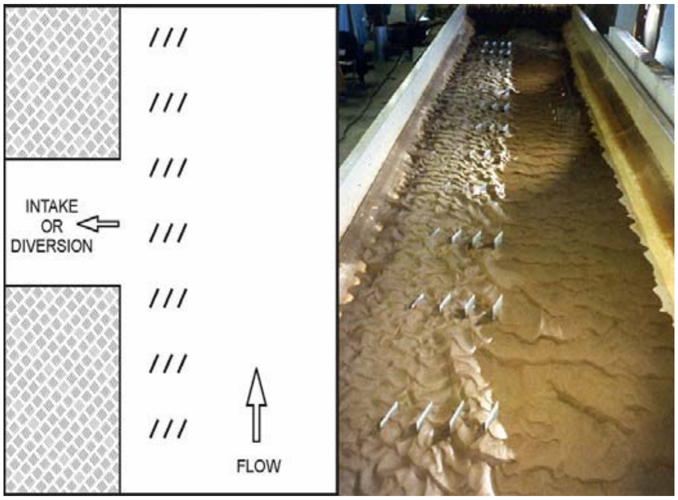
When the diversion dam was first built, sediment deposition in the canal was higher than anticipated, creating a maintenance challenge. Some sediment

Aerial view of Stoddard Diversion Dam and the "meandering forebay" that serves as a sedimentation basin before water enters the canal. (Photo courtesy of Weber Basin Water Conservancy District.)

also reached the hydropower plant and the water treatment plant in Layton, threatening damage to the turbines and increasing the cost of water treatment. To combat these problems, the U.S. Bureau of Reclamation constructed a unique sediment basin (which can essentially be described as a “meandering forebay”), between the diversion dam and the canal, to remove most of the sediment. This forebay is essentially a deep, excavated channel that forces the water to slow down and travel a long distance—thus dropping most of the sediment out of suspension—before it spills over into the canal. The channel is periodically dredged to remove deposited sediment.

Wide Hollow Reservoir, Feeder Canal

Wide Hollow Reservoir is another off-stream reservoir that receives water from a diversion dam several miles away. The major source of water for the reservoir is the Escalante River, which is heavily laden with sediment during spring runoff and other peak flow events. The diversion dam on the Escalante River is a simple diversion structure with a broad spillway that only passes high flows. The diversion dam itself is not equipped with any special features to manage sediment other than a trash rack that keeps out large rocks and cobbles. As a result, the diversion dam can completely fill with sediment, much of which goes into the canal.

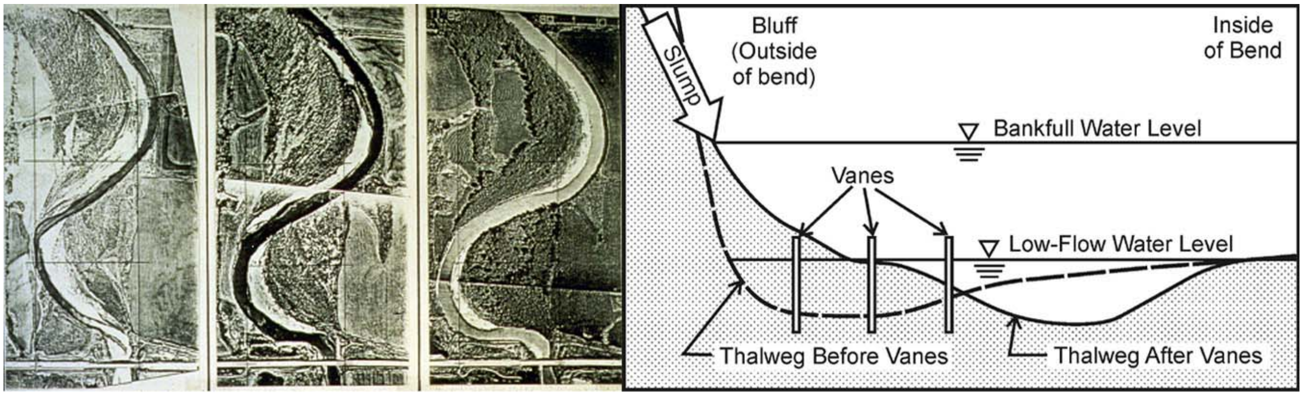


Vane arrangement to direct sediment away from diversion entry and laboratory model showing vanes effectiveness. (Illustration and photo from A. Jacob Odgaard, Sediment Management with Submerged Vanes)

Wide Hollow sedimentation basin with accumulated sediment. (Photo courtesy Franson Engineering)

To reduce the amount of sediment entering the reservoir, a sedimentation basin with a small sluice gate at each end was installed immediately after the diversion dam. See photo above. The sedimentation basin is a concrete-lined section of canal that is much deeper than the rest of the canal. This allows it to collect heavier sediments entering the canal. This includes the portion of the river’s bed load which makes its way past the trash rack at the entrance of the canal. When sediment deposits in the canal reach a pre-determined level, both sluice gates are manually opened and sediment is flushed from the canal back to the river. During high flow events, it is necessary to flush sediment from the basin several times a day to prevent it from flowing into the reservoir. When operated properly, the sediment basin greatly reduces the amount of sediment entering Wide Hollow Reservoir.

For more information regarding sediment challenges at Wide Hollow Reservoir, see the Wide Hollow Reservoir Case Study in Chapter 8.



Left: Aerial photos of (left) river encroaching on highway bridge, (middle) shortly after installing vanes, and (right) river channel stabilized by vanes thus protecting the bridge.
Right: Cross-section of stream with vanes installed showing moving the river bed to the preferred position over time. (Photos and cross-section from A. Jacob Odgaard, Sediment Management with Submerged Vanes)

Sediment Control at Diversion Intakes: Iowa Vanes

A "structure" has been developed with the specific intent of minimizing the amount of sediment taken in at a diversion structure. A book describing the design and use was written by A. Jacob Odgaard at the University of Iowa, thus the structures are called Iowa Vanes. "Several papers have been published over the years describing the technique, and field installations have proved its feasibility." [47] A series of slanted vanes is installed in the stream above, at, and below, the diversion. The vanes cause the sediment to be moved to one side of the river while the water is moved to the other side of the river. The effectiveness of these vanes has been shown in laboratory models, and in actual practice on rivers. See the two pictures above.[48]

There are no known installations in Utah, and thus there are probably no engineering firms experienced in the design and installation of Iowa Vanes in the state. However, given their apparent effectiveness, it appears worth trying to implement them at diversions that take water from a stream. They might also be considered for use in a canal from which turnouts take water into agricultural fields. These can accumulate sediment which impairs use.

NOTES

[1] U.S. Department of Agriculture, Unified Soil System: http://74.125.155.132/search?q=cache:V5p-jE2b_c0J:www.wsi.nrcs.usda.gov/products/w2q/H%26H/docs/training_series_modules/Unified-Training-Part-A.ppt+soil+grain+size+classification&cd=17&hl=en&ct=clnk&gl=us, July 6, 2009.

[2] Retrieved from the following website: http://hypertextbook.com/facts/1999/BrianLey.shtml, July 6, 2009.

[3] Retrieved from the following website: http://www.answers.com/topic/bed-load, July 6, 2009.

[4] Retrieved from the following website: http://en.wikipedia.org/wiki/Hjulstr%C3%B6m_curve, October 27, 2009.

[5] Retrieved from the following website: http://clward.files.wordpress.com/2008/09/geog-hjulstrom-curve1.jpg, October 14, 2009.

[6] White, Rodney, *Evacuation of Sediment from Reservoirs*, (London: Thomas Telford, 2001), iii-iv. Many of the methods and descriptions found in this section are listed in a similar fashion by this source.

[7] Ibid, iv.

[8] Ibid.

[9] Utah Partners for Conservation and Development, *"Utah's Watershed Restoration Initiative."* Retrieved from the Utah Division of Wildlife Resources' Internet web page: http://wildlife.utah.gov/watersheds/, November 2008.

[10] Morris, Gregory L. and Jiahua Fan, *Reservoir Sedimentation Handbook,* San Francisco: McGraw-Hill, 1998, 12.1.

[11] Personal communication with Pat Coughlin, New Escalante Irrigation Company, February 22, 2008.

[12] Personal communication with Eric Dixon, PE, Franson Civil Engineers, Inc. American Fork, UT, consultants on the new Wide Hollow Dam, December 10, 2009.

[13] Echo Creek Steering Committee, *Water Quality in the Upper Weber River Watershed,* (pamphlet).

[14] Utah Department of Environmental Quality, Division of Water Quality, *TMDL Water Quality Study of Echo Creek Watershed*, Utah, August 4, 2006, page 2.

[15] Weber Basin WCD, *Rees Creek Water Quality Demonstration Project Fact Sheet*, July 2007, page 1.

[16] Utah Department of Environmental Quality, Division of Water Quality, *TMDL Water Quality Study of Echo Creek Watershed*, Utah, August 4, 2006, page 23.

[17] Weber Basin WCD, *Rees Creek Water Quality Demonstration Project Fact Sheet*, July 2007, page 3.

[18] Ibid, 12.8.

[19] Interagency Workgroup on Wetland Restoration: National Oceanic and Atmospheric Administration, Environmental Protection Agency, Army Corps of Engineers, Fish and Wildlife Service, and Natural Resources Conservation Service, *An Introduction and User's Guide to Wetland Restoration, Creation, and Enhancement*, 2003, page 5.

[20] Ibid. page ii.

[21] Ibid. pages ii and vi.

[22] Ibid. page ii.

[23] Ibid. pages 4 and 5.

[24] Retrieved from the North Carolina State University website: www.water.ncsu.edu/watershedss/info/wetlands/values.html#ec, October 25, 2009.

[25] Retrieved from the Wiley Interscience website: www3.interscience.wiley.com/journal/118930759/abstract?CRETRY=1&SRETRY=0, *A Model To Enhance Wetland Design and Optimize Nonpoint Source Pollution Control*, by Erik R. Lee, Saied Mostaghimi, Theresa M. Wynn, October 25, 2009.

[26] Annandale, George W., PE, personal communication to the Utah Division of Water Resources, September 7, 2009
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[27] Hotchkiss, Rollin H., *Millsite Dam and Reservoir Sediment Management Feasibility Study*, Brigham Young University, Provo: 2008, page 6. This study was prepared for the Ferron Canal Company and made possible through the financial support of PacifiCorp and the Utah Division of Water Resources.

[28] Hotchkiss, Rollin H. and Xi Huang, *Hydrosuction Sediment-removal Systems (HSRS): Principles and Field Test*, Journal of Hydraulic Engineering, June 1995, Vol. 121, No. 6. The following discussion on hydrosuction bypass is a summary of the information presented in the referenced paper, pages 479-480.

[29] Ibid, page 479.

[30] Ibid.

[31] Ibid, page 480.

[32] Ibid.

[33] White, Rodney, *Evacuation of Sediments from Reservoirs*, London: Thomas Telford, 2001, page 58.

[34] Ibid, page 27.

[35] U.S. Environmental Protection Agency- Region 8 Mountains & Plaines, *Milltown Reservoir Sediments*, Retrieved from the EPA's Internet web page: http://www.epa.gov/region8/superfund/mt/milltown/, December 9, 2008.

[36] Morris and Fan 1997, 16.1.

[37] Morris and Fan 1997, 16.5.1.

[38] Hotchkiss, Rollin H. and Xi Huang, *"Hydrosuction Sediment-removal Systems (HSRS): Principles and Field Test,"* Journal of Hydraulic Engineering, June 1995, Vol. 121, No. 6. The following discussion on hydrosuction dredging is a summary of the information presented in the referenced paper.

[39] Ibid, 479.

[40] Ibid, 480.

[41] Ibid.

[42] Durgunoglu and Singh, 1993, pages 12-13.

[43] Retrieved from the Utah Division of Water Rights Internet web page: www.waterrights.utah.gov/cgi-bin/damview.exe, July 18, 2009.

[44] Ibid. looking at various individual dams.

[45] White, W.R., “Flushing of Sediments from Reservoirs,” World Commission on Dams Contributing Paper, HR Wallingford, U.K., 1999, ix.

[46] American Society of Civil Engineers, *Sedimentation Engineering*, 1975, 615.

[47] A.. Jacob Odgaard, *Sediment Management with Submerged Vanes*, 2009, pages 2 & 3. Available from the American Society of Civil Engineers publications.

> The book is written because design guidelines are not readily available to the profession. Several papers have been published over the years describing the technique, and field installations have proved its feasibility. However, there is no single source outlining the steps necessary for design. Written for both students of hydraulics and water re-

sources engineering and practicing engineers, in particular river engineers, the book offers a simple, step by step approach to the development of a submerged vane design for a given application. The book presents the most up to date design guidelines....

The book concludes with a summary of the design guidelines, in Chapter 6. The summary includes a list of typical dimensions. These typical dimensions are listed only to provide readers with a ‘benchmark’. Many variables affect the dimensions, some of which are summarized in this chapter. The chapter also summarizes the primary design steps for the four design objectives or scenarios. The summary may serve as a checklist in preliminary design. The chapter concludes with a list of the different vane materials that have been used so far in applications, ranging from simple wooden planks to sheet piling to double-curved reinforced concrete panels.

[48] Ibid. Pictures from pages 13, 42, 77, and 89.

5

ECONOMICS OF SEDIMENT MANAGEMENT

Like any other business decision, whether or not to pay for implementing a sediment management project is largely determined by finances or economics. This chapter explains how the costs and benefits associated with sediment management are determined. Also included is a list of potential sources for funding sediment mitigation projects.

BASIC ECONOMIC ANALYSIS METHODS

Cost Effectiveness Analysis

Cost effectiveness analysis is a technique used primarily in projects where benefits cannot be reasonably measured in monetary terms. This method is often used to calculate the cost per unit of benefit, and requires that means exist for quantifying benefits, but not necessarily attaching a monetary value to that benefit.

Least-Cost Analysis

Least-cost analysis is a form of cost-effectiveness analysis that is used to determine the lowest cost method of achieving a specified level of tangible or intangible outcomes. This method is often employed when pursuing environmental outcomes, such as controlling the quagga mussel or meeting a mandate to restore habitat for an endangered species. The outcome is defined first, and then the various means for achieving the outcome are analyzed to find the one having the lowest cost.[1]

Benefit-Cost Analysis

Benefit-cost analysis works well when both the outcomes (benefits) of a project and the costs associated with it can be stated in monetary terms. The Utah Division of Water Resources uses this method to evaluate larger projects, such as dams and reservoirs, pipelines, and similar projects when benefits can be adequately defined and measured. Some dams and reservoir projects in the state serve only agricultural uses. However, most reservoirs have a multipurpose designation serving agriculture, municipal and industrial, and recreation purposes. Each of these can be expressed in monetary terms.

All three methods of economic analysis must include the discounting of benefits and costs to present worth using a discount rate (percent) that reflects the state's, and/or the sponsoring agency's, cost of obtaining capital.[2] Decisions regarding sediment mitigation projects can be made using any one, or all three, of the above methods. Whenever possible, it's advantageous to value the benefits of such projects in monetary terms. This should be relatively easy when such measures provide more water for crop irrigation, hydroelectric power generation, recreation, flood storage, or municipal and industrial purposes.

ESTIMATING CURRENT COST OF PAST SEDIMENTATION

Reduced Crop Production

The Wide Hollow Reservoir provides a useful example. In 1968, sedimentation at Wide Hollow Reservoir had resulted in the loss of storage capacity of 515 acre-feet and a reduction in irrigated acreage of 1,045 acres.[3] If this land had stayed in production and produced four tons of alfalfa per acre, the annual loss in production would have been 4,180 tons of alfalfa (4 tons x 1,045 acres = 4,180 tons). Using a 2006 alfalfa crop budget for the Escalante area of Garfield County, taken from the Utah State University Extension Service web site,[4] a farmer's net return above operating costs was $111.19 per acre. Since the lost capacity is still lost today, it's appropriate to apply 2006 (latest available figures) crop costs and prices to the lost acreage estimate for 1968. The direct annual loss of net farm income in the Wide Hollow Reservoir service area would be ($111.19 x 1045 acres = $116,194) and ($116,194/515acre-feet = $226), or $226 per year, per acre-foot of reduced storage capacity.

In 2008 Wide Hollow is estimated to have lost 1,200 acre-feet of storage due to sedimentation. This means that sedimentation is costing at least ($226/yr/acre-feet x 1,200 acre-feet = $271,200), $271,200 per year in direct annual loss of net farm income. Industries that support or benefit from agricultural activity will also be impacted. The general economic multiplier for agriculture is about 2.65 to 1.[5] Thus, the total impact to Garfield County is about $718,680 per year due to sedimentation at Wide Hollow Reservoir.

Reduced Yield of Municipal and Industrial Water

Evaluating the direct cost of sediment encroachment on reservoir yield where the primary use is for municipal and industrial (M&I) purposes will require the identification and appraisal of alternative sources of water supply. The alternative cost approach to analyzing M&I losses from sedimentation then looks at the cost of obtaining the same quantity of water that can serve the same purpose from the best alternative source. For example, if sediment has reduced the storage capacity in a city's reservoir to the extent that its yield has been reduced by 2,000 acre-feet, the cost associated with that loss is equal to the cost of obtaining that amount of water from the next best source. If the next best source is to construct a pipeline from a large regional reservoir at an annual cost of $700 per acre-foot, then the annual cost of lost capacity to the city is $1.4 million (2,000 acre-feet x $700 = $1,400,000).

Reduced Hydroelectric Power Production

Evaluating the direct cost of sediment encroachment on reservoir yield of water used primarily for hydroelectric power generation would require an analysis similar to that used for M&I. The direct cost can be measured as the cost paid to replace the lost energy generating capacity, from the best alternative source. For example, assume there are three, 15-megawatt hydroelectric generators in a dam. Sediment accumulation has resulted in a 10 percent reduction in water available for generating power. The loss of generating capacity is (45,000 kw) X (365days/yr) X (24hr/day) X (0.1 reduction) = 39,420,000 kwh/yr. This means replacement energy will need to be purchased from the power grid at a wholesale cost of $0.0508 per kwh.[6] The direct cost of sediment encroachment on hydroelectric power production would be (39,420,000 kwh/yr) X ($0.0508 per kwh) = $2,002,536 per year. This assumes that lost capacity would not effect the kw marginal cost of energy from the power grid in the absence of sedimentation. The elevation head to generate hydro-power would still be available.

Reduced Flood Storage Capacity

Calculating the cost of sediment encroachment on the flood water storage function of specific reservoirs can be more difficult because floods can disrupt all types of economic activity – agricultural, municipal and industrial. The flood storage function of a reservoir is often only part of a multifaceted flood hazard protection plan. In theory, the analyst will attempt to identify flood damages expected to occur as a result of a certain magnitude of flood: 10-year, 25-year, 50-year, or 100-year flood, both with and without the storage capacity lost to sedimentation. For example, if the flood damage from a 50-year flood is $10 million without the lost flood storage capacity and only $5 million if the sediment encroachment was eliminated, the benefit would be $5 million. This amount could then be amortized to arrive at an annual cost to be consistent with other estimates of sedimentation annual costs. Alternatively, the other sedimentation costs shown above can be discounted to present worth to be consistent with the flood storage cost amount.

Reduced Recreation Activity

Sediment encroachment may impact recreation activities on and in a reservoir by filling the conservation or fish pool, which is often designed into the reservoir plan, or by rendering part of the reservoir too shallow for fishing, water skiing and other flat water recreation activities. This impact may be calculated by determining the number of visitor-days the reservoir would support without any sediment encroachment, then subtracting the number of recreation visitor-days remaining with the present level of sedimentation. This analysis depends on the availability of data showing recreation usage of the reservoir and an estimate of the dollar value of each visitor-day. Recreation is a major industry in Utah and these costs may be substantial.

ESTIMATING FUTURE COSTS IF NOTHING IS DONE

While the cost of lost storage capacity has not been tracked over the years, it is possible to estimate the present cost of the storage loss in specific reservoirs. A brief explanation of terms is necessary for this discussion.

- Reservoir Storage Capacity is the volume or space available in the reservoir to store water.
- Reservoir Yield is the volume of water released from the reservoir for productive uses. A reservoir may be drawn down and refilled several times in a normal year. Therefore reservoir yield would exceed storage capacity in wet years and be less in dry years, depending on the demand for the water.

A major element of the cost analysis is calculating the reduction in reservoir yield caused by sediment accumulation. The change in amount of water available from a reservoir (reservoir yield) is likely different than the amount of storage capacity lost to sedimentation. In determining the impact of sedimentation, it is the change in yield that determines the change in productive uses of reservoir water. Although minor, additional water will be lost since accumulated sediment results in shallower water, which is warmer. This enhances evaporation losses.

Agriculture Example

Assume the deposition of 100 acre-feet of sediment in an irrigation reservoir causes a reduction in yield of 80 acre-feet of water used for growing crops. Also assume that the reduction in reservoir yield causes farmers in the service area to suffer a reduced alfalfa yield of one ton per acre on 50 acres of land. If the value of alfalfa is $100 per ton, the reduction in farm income, would be $5,000 per year. This is the cost of sediment accumulation in the reservoir. Assuming that same amount of annual loss has been occurring over the last ten years, the present value of this loss is $60,400 [($5,000 per year) x (12.0843) compound interest at 4.14 percent for 10 years].[7]

Municipal and Industrial Example

Sediment mitigation can reduce the future costs of water supply development. As future sediment accumulation reduces the storage capacity of existing reservoirs, alternative water sources and or additional storage spaces may need to be constructed. Stopping or slowing the sedimentation process through mitigation projects can push scheduled new storage construction further into the future, thus reducing the present value of new construction or new supply costs. For example, if sediment mitigation can push construction of a new reservoir from 10 years to 20 years into the future, the savings would

TABLE 4

Sediment Mitigation Project Economic Savings

Cost in Present Dollars	Present Worth Cost if Built in	
Today	10 Years	20 Years
$1,000,000	1,000,000 X $1/(1+i)^{10}$ = $666,537	1,000,000 X $1/(1+i)^{20}$ = $444,272

Savings from mitigation for every $1,000,000 = $222,098 (assuming i = 4.14%).

be as shown in Table 4. The calculations assume compound interest at 4.14 percent as used above.

Sustainability

"Reservoirs have traditionally been planned, designed and operated on the assumption that they have a finite 'life,' frequently as short as 100 years, and will eventually be terminated by sediment accumulation. Little thought has been given to reservoir replacement when today's impoundments are lost to sedimentation, or to procedures to maintain reservoir services despite continued sediment inflow. *There has been the tacit assumption that somebody else, members of a future generation, will find a solution when today's reservoirs become seriously affected by sediment."*[8] (Italics added.)

This approach falls short of the ultimate goal of the water supply community — *to create a sustainable water supply for future generations that includes adequate storage facilities*. Reservoir owners are free to choose whether or not to consider future sedimentation costs in the present worth economic analysis of a project. Such costs would include constructing sediment management facilities, operation and maintenance and possible decommissioning of the dam. Past generations not considering these costs are negatively impacting those dealing with present day sediment problems.

Should the dam owner prefer, there are two ways to incorporate sustainability into dam construction. First, assume one decides not to manage sediment in the reservoir and intends to allow it to fill with sediment. That can be dealt with by creating a sinking fund that will pay for dam decommissioning at the end of reservoir life. "A sinking fund is a method by which an organization sets aside money over time to retire its indebtedness. It is a fund into which money can be deposited, so that over time its debentures or stocks can be retired. The amount invested in sinking fund can also be used for purchasing various assets for the company."[9] Sinking funds have been used since the early 1700s and are commonly used today by utilities and governments to pay off bonds and to save for future purchases.[10]

Another approach is directly related to reservoir sedimentation, project specific and economically comprehensive. It is the Reservoir Conservation, or RESCON approach. This entails performing an, "economic and engineering evaluation of alternative strategies for managing sedimentation in storage reservoirs."[11] This is a life cycle management approach that anticipates conducting operations and maintenance in ways that encourage sustainable use and continuously evaluates for that purpose. When the system ages, components are replaced and refurbished as is usual in conventional systems. When suitably implemented, and local conditions permit, reservoir capacity is preserved and the facility can be used perpetually. In those instances where decommissioning is necessary, that is included in the project management objectives.[12] Documents explaining RESCON are available at no cost as an Internet download.

PROJECT FUNDING

Funding sources are available to help finance sediment mitigation projects. Those sources are summarized in Table 5 below. Detailed information is provided following the table.

Federal programs have firm application deadlines and, if missed, applicants will have to wait a full year to re-apply. Further, while a project may qualify for financial assistance, the availability of funds depends on year-to-year Congressional appropriation. Also, there is considerable competition for limited funds among many water users in the western states.

Department of Agriculture

For eligibility requirements of the U.S. Department of Agriculture (USDA), Resource Conservation and Development Program (RC&D) see: www.ut.nrcs.usda.gov/programs/rcd.html. This program offers the use of federal funds on private lands. It also includes free engineering design services for such projects as check dams within the reservoir's drainage area. For specific local information, there are seven authorized RC&D areas in Utah, administered by council offices located at Logan, Murray, Heber City, Huntington, Roosevelt, Richfield, and Cedar City.

TABLE 5

Potential Federal and State Funding Sources for Sediment Mitigation Projects

Agency or Board	Fund or Program	Purpose	Assistance Types
Federal Government			
Department of Agriculture	Resource Conservation and Development Program, (RC&D) & other programs	Accelerate conservation, development, and utilization of natural resources	Cost Share
	Environmental Quality Incentives Program (EQIP)	Address soil, water, and related natural resource concerns on agricultural lands	Cost-share
Army Corps of Engineers	Civil Works	Flood control, water supply and recreation projects	Cost Share
Bureau of Reclamation	Water 2025	Collaborative water conservation, efficiency, and banking projects	Grants Cost Share
	WaterSMART Program	Conservation & more efficient water use	Grants Cost Share
	Technical Assistance To States, TATS	Environmental, economic, engineering, land use, and social analysis	Grants
	Rural Water Supply Program	Serve a community of no more than 50,000 people with domestic, industrial, municipal, and residential water	Grants Cost Share
Environmental Protection Agency	Clean Water Act, Section 319	Address nonpoint source pollution from human-made construction entering streams.	Grants Loans
State of Utah			
Board of Water Resources	Construction Programs Funding	Irrigation projects, wells and development projects	Loans
Community Impact Board	Permanent Community Impact Fund Board, PCIFB	Planning, construction and maintenance of public facilities for communities impacted by resource development on federal lands	Grants Loans
Drinking Water Board	State Revolving Fund	Drinking water projects for cities, towns and districts	Grants Loans
	Federal State Revolving Fund	Privately and publicly owned drinking water systems	Grants Loans

There are about 30 other USDA programs, some of which apply to sediment mitigation. These include:

- Emergency Watershed Protection (EWP): This program funds emergency measures such as purchasing flood plain easements, and minimizing runoff and soil erosion – to safeguard lives and property from floods, drought, and erosion on any watershed – where fire, flood or any other natural occurrence is causing, or has caused, sudden watershed impairment.[13]
- Small Watershed Program (PL-566): This program provides technical and financial (project implementation) assistance to help urban and rural communities protect, improve, and develop water and land resources, in watersheds of up to 250,000 acres (approximately 390 square miles).

Projects are undertaken at the request of local sponsors who seek assistance in addressing resource issues.[14]

- Rapid Watershed Assessments: This program defines a set of alternatives and estimates of conservation investments that best address local resource concerns. The information is used along with other relevant information to assist individuals, communities, non-profit organizations, local, state and federal entities, and others, to evaluate future conservation activities on a watershed basis. Rapid Watershed Assessments are already available on the Upper Weber, Lower Sevier, Middle Sevier, Upper Green River, Lower Green River, Montezuma Creek, Escalante Desert, and Upper Virgin watersheds. [15]

The Environmental Quality Incentives Program (EQIP) is a voluntary conservation program that provides assistance to landowners and agricultural producers in a manner that promotes agricultural production and environmental quality as compatible goals. Through EQIP, farmers and ranchers receive financial and technical assistance to implement structural and management conservation practices that optimize environmental benefits on working agricultural land.[16] See the following Internet website for details: www.ut.nrcs.usda.gov/programs/EQIP/#How_Works. What's good for the environment is also good for sediment reduction.

The Wildlife Habitat Incentive Program (WHIP) is a voluntary program for conservation-minded landowners who want to develop and improve wildlife habitat on agricultural land, nonindustrial private forest land, and Indian land. The Natural Resources Conservation Service administers WHIP to provide both technical assistance and up to 75 percent cost-share assistance to establish and improve fish and wildlife habitat. See the following Internet website for details: www.nrcs.usda.gov/programs/whip/ What's good for wildlife may also good for sediment reduction.

Army Corp of Engineers

The Army Corps of Engineers (Corps) carries out projects in the following seven mission areas. Whenever possible, combine purposes on a single project.[17]

- Flood Damage Reduction
- Ecosystem Restoration
- Recreation
- Navigation
- Hurricane and Storm Damage Reduction
- Hydroelectric Power Generation
- Water Supply

National policy regarding water supply relegates the primary responsibility for water supply to the states and local entities. The Corps may participate and cooperate in developing water supplies in connection with construction, operation, and modification of Federal navigation, flood damage reduction, or multipurpose projects.[18]

Bureau of Reclamation

Water 2025 Initiative

In 2003, the Department of Interior began the *Water 2025 Initiative: Preventing Crises and Conflict in the West* to help western states meet growing water needs. This initiative, overseen by the Bureau of Reclamation (Reclamation), identified 12 areas in the west where the potential for water conflicts in the future are "highly likely." Two of the twelve areas are in Utah—the Wasatch Front and the St. George area. Water projects proposed in these areas are more likely to qualify for funding.[19]

Part of the Water 2025 Initiative, the *Water for America* program, focuses on 21st century water challenges and securing water resources for future generations. Similarly, *Challenge Grants* is another Bureau funding program.[20] Since 2004, 137 Challenge Grant projects have been funded. $30 million in Federal funding, combined with local partnerships, created almost $130 million worth of water management improvements in 16 western states for these projects. Those 137 projects created new water banks, promoted the use of advanced technology to improve water management, and increased collaboration among Federal, State, tribal, and local entities.[21]

The last Water 2025 Initiative program is *System Optimization Reviews*, which was begun in early

2008. This program received 33 applications and awarded $1.9 million in grants to water districts for twelve projects to improve delivery systems in California, New Mexico, Oregon and Utah. Including matching contributions of non-federal partners, the selected projects represent a combined investment of more than $3.8 million.[22]

During the fiscal year 2004, $4 million was made available to the Water 2025 Initiative and three projects in Utah received funding (limited to $250,000 per project). During fiscal year 2005, over $20 million was made available and 11 projects in Utah received funding (limited to $300,000 per project).

WaterSMART Program

This newly-instituted program seeks to leverage grants with a 50/50 share between Reclamation and the project sponsor. In 2009, grants for System Optimization Reviews in three states totaled just over $1 million and leveraged an additional $2.4 million.[23] Seventeen Water Marketing and Efficiency grants in six states contributed to $19 million in projects that propose to save 75,000 acre-feet of water each year.[24] Several criteria are used to award points used to decide to whom grants are awarded. The criteria include:[25]

- How well the project will improve sustainable water supplies for the 21st century and the extent of collaborative effort.
- Projects that will conserve water and improve efficiency.
- Projects that will improve water management through… other approaches where water savings are not quantifiable.
- Reasonableness of the cost for the benefits gained.
- The proposal demonstrates stakeholder involvement.
- The proposal is in a basin with connections to Reclamation project activities.

Technical Assistance To States (TATS)

This program enables Reclamation to assist states, statutory or state-chartered entities, legislatively authorized political subdivisions of the state, and Indian tribes to address water and related resource issues. Technical assistance is provided by Reclamation personnel when requested by the applying entity.[26]

Technical assistance activities include providing data, technical knowledge, and expertise to aid in conservation and allocation of natural resources. Assistance may also be provided in the technical, evaluation, and management phases of water resource programs and projects. Areas of technical assistance typically include, but are not limited to, environmental, economics, engineering, *sedimentation*, planning, recreation public land use, and social analysis.[27]

Rural Water Supply Program

This program is authorized by the Rural Water Supply Act of 2006. The program is designed to serve a community or group of communities, including Indian tribes and tribal organizations, each of which has a population of no more than 50,000 people, with domestic, industrial, municipal and residential water.[28] The program focuses on planning rural water supply projects that incorporate a regional or watershed approach to water management. This means focusing on projects that provide water to localities distributed across a region or watershed. Depending on qualifications, Reclamation will pay for 100 percent of appraisal investigations (up to $200,000) and 50 percent of any additional costs. For further information see: www.usbr.gov/ruralwater/.

Environmental Protection Agency

In 1987 Congress added Section 319 to the Clean Water Act to address pollution of the nation's waters from polluted runoff, including sediment.[29] From 1990 to 1999, these "319 funds" have funded over fifty projects in Utah. The monies are grants and loans administered through the Utah Department of Environmental Quality and the Utah Department of Agriculture and Food.[30] Annual conferences are held in Utah, and participation has been good for over a decade. The money is intended to be used to improve watershed and streams. See the *Utah Nonpoint Source Management Plan*, available at the following website for details of this program: www.waterquality.utah.gov/documents/NPS_Mgmt_Plan_2001.pdf.

Utah Board of Water Resources

Funding is available from the Board of Water Resources for projects that conserve, protect, or more efficiently use present water supplies, develop new water supplies, or provide flood control. There are three revolving loan funds from which finances might be obtained:

- The Revolving Construction Fund is for incorporated groups and water companies. Funding is available for irrigation and culinary water projects up to $500,000, and dam safety upgrades.
- The Cities Water Loan Fund is for municipal projects for political subdivisions.
- The Conservation and Development Fund is for projects for incorporated groups, political subdivisions, and Indian tribes.

See www.water.utah.gov for details and application forms.

Community Impact Fund Board

The Permanent Community Impact Fund Board (PCIFB) is a program of the Utah Division of Community Development. It helps state and local agencies and entities that are, or may be, directly or indirectly impacted by mineral resource development on nearby federal lands. The board provides assistance through grants and low interest loans for the planning, construction, and maintenance of public facilities. The funds also help community agencies provide public services. This is primarily a rural program and Salt Lake and Utah Counties are not eligible. For additional information, see: www.rules.utah.gov/publicat/code/r199/r199-008.htm.

Utah Drinking Water Board

Low interest loans and limited grants are available to all qualified public drinking water systems from the Utah Drinking Water Board. The Utah Division of Drinking Water administers two financial assistance programs: the State Revolving Fund and the Federal State Revolving Fund.

The State Revolving Fund program was created by the Utah State Legislature in 1984 and is governed by the Water Development Coordinating Council. It is a state funded program. Only political subdivisions (cities, towns, districts) are eligible for these funds.

The Federal State Revolving Fund program was created under the 1996 amendments to the Federal Safe Drinking Water Act. Most of the funds in this program originate from the federal government. These funds are available for privately and publicly owned community water systems and nonprofit non-community water systems. For additional information on all Utah Division of Drinking Water funding programs, see: www.drinkingwater.utah.gov/loan_program_intro.htm.

NOTES

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6

ENVIRONMENTAL AND OTHER CONSIDERATIONS

Whenever sediment management actions and sediment mitigation projects are contemplated, it is necessary to consider the potential environmental consequences, and to minimize those that are potentially negative. It's also important to comply with applicable environmental laws. This chapter discusses these issues, along with the state and federal laws that apply.

POTENTIAL ENVIRONMENTAL CONSEQUENCES OF SEDIMENT MANAGEMENT

This section introduces issues related to sediment management and the possible downstream consequences of actions to remove sediment from reservoirs, or to limit sediment from entering reservoirs.

Water Quality

There are several measurable physical, chemical and biological factors that can be used to define water quality. These factors are strongly linked to both plants and animals in aquatic ecosystems and used as indicators to describe the system's health. Many of these factors are directly or indirectly affected by sediment.

Water Quality Parameters

Total Suspended Solids (TSS) are all suspended particles in water that do not pass through a filter with a pore size of 2 micrometers (0.00008 inch). It is listed as a conventional pollutant in the U.S. Clean Water Act.[1]

Total Dissolved Solids (TDS) is an expression for the combined content of all inorganic and organic substances contained in a liquid which are present in a molecular, ionized or micro-granular suspended form.[2] These are dissolved or dispersed throughout the water. The micro-granular solids are small enough to pass through a 2 micrometer (0.00008 inch) pore size filter and are generally comprised of ions or charged particles. They may also include colloidal particles.

Turbidity is the cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are similar to smoke in air.[3] Conversely, it can also be regarded as the measure of the transparency of a liquid. The cloudier the water, the greater the turbidity. Turbidity is measured in Nephelometric Turbidity Units (NTU). The amount of sediment removed from a reservoir and put downstream is regulated through the NTU standard, which varies depending on the river's water quality classification.[4] Utah state law limits the maximum turbidity difference between water entering and leaving the reservoir to 10 NTU or less for waters classed 2A, 2B, 3A, 3B – and 15 NTU for class 3C & 3D.[5] Typically these low turbidity limits cannot be met during flushing operations which are intended to remove previously-deposited sediments.

Biochemical Oxygen Demand (BOD) is a measure of the oxygen consumed by organisms during the process of decomposing the organic material in the water sample. Aerobic (oxygen requiring) microorganisms use oxygen in the process of breaking down organic matter and, as it is consumed, the dissolved oxygen level decreases. BOD is considered an indicator of water quality.[6]

Chemical Oxygen Demand (COD) is a measure of all chemicals in a water sample that can be oxidized. Reservoir sediments often contain chemicals that may change their oxidation state under anaerobic (in the absence of free oxygen) conditions of the reservoir bottom. When these compounds are released during sediment removal they consume oxygen. This can reduce oxygen levels sufficiently to kill aquatic life in the stream below the dam.

Dissolved Oxygen is the amount of oxygen that is present in a liquid. It can be measured with a dissolved oxygen probe such as an oxygen sensor in the water.[7] There are three main sources of oxygen in the aquatic environment: 1) direct diffusion from the atmosphere; 2) wind and wave action; and 3) photosynthesis. Of these, photosynthesis by aquatic plants and phytoplankton is the most important.[8]

pH is a measure of the acid or base of a solution. It is the logarithmic measure of hydrogen ion concentration. Pure water is said to be neutral. The pH for pure water at 77 °F is close to 7.0. Solutions with a pH less than 7.0 are said to be acidic, and solutions with a pH greater than 7.0 are said to be basic or alkaline.[9] Utah reservoirs are generally slightly basic due to the geology of the region.

Effects of Sediment on Aquatic Life

When sediment is introduced into a stream in large or uncontrolled quantities, the impacts can be damaging to the aquatic ecosystem. This was the case in the Logan River during a flushing event to remove sediment from First Dam (see the First Dam case study in Chapter 8). Fish and other aquatic species are stressed by excessive sediment loads (especially silts) which can clog gills, and bury stream beds and plants. Biochemical Oxygen Demand (BOD)[10] can escalate during flushing due to organic material contained in reservoir sediments. Phosphates in the sediment can produce algal blooms that can deplete oxygen in the water when they die and decompose. Limits to BOD changes are also specified in the law. Gravel fish spawning areas can be covered by fine silts making them unsuitable for anchoring fish eggs and prevent those eggs from receiving oxygen. Organics and insect species that provide food for fish can be killed or covered by sediment.

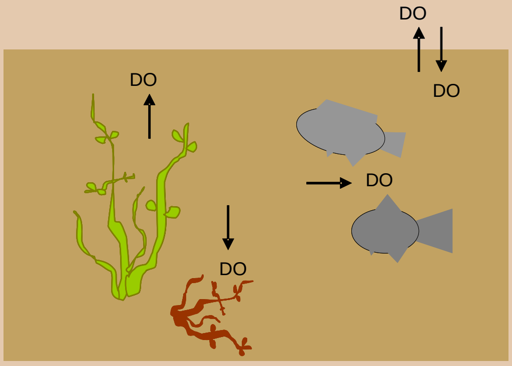
Pollutants deposited within reservoir sediments are also a concern. Past and present industrial and mining activities may have put toxic heavy metals into streams that later migrated to the reservoir. This accumulation increases their concentration. Airborne contaminants (such as mercury) can be generated hundreds of miles from the reservoir and still accumulate in the sediments.[11] In agricultural areas, pesticides, fertilizers and animal waste may be present in a reservoir, and many of these attach selectively to fine sediment particles. Regardless of what activities are believed to have, or have not, occurred upstream, testing reservoir sediments before they are discharged downstream is required.[12] On the other hand, if a stream has been deprived of sediment, the controlled re-introduction of sediment can help re-

BOX 3 - The Sediment and Dissolved Oxygen Scenario

Oxygen is the critical lifeline for aquatic life. Water absorbs heat directly from the sun. Higher temperature reduces the saturation concentration so that the water can hold less oxygen and oxygen levels tend to be lower in warmer water.

Turbidity from sediment causes photosynthesis to decline. Less sunlight reaches plants resulting in less plant growth. This decreases dissolved oxygen, a byproduct of photosynthesis. As plants die, bacteria utilize dissolved oxygen in the decomposition process, thus lowering the dissolved oxygen concentration available for aquatic life.

A decrease in photosynthesis decreases plant growth. This can lead to a reduction in the organisms that feed on plant life (invertebrates) and subsequently negatively impact larger organisms, such as fish, which feed on them. Lower dissolved oxygen content results in a less robust environment for fish and other organisms to inhabit.



store the natural sediment balance, while also improving habitat and aquatic life.

Sediment is inherent and essential to healthy aquatic systems. The amount or concentration of sediment that occurs naturally, and fluctuates during different seasons, is called background level. TSS and turbidity measure these levels. Issues can arise when background levels are surpassed for a given period of time.[13] Sediment can impair aquatic systems as well as enhance them. Purposefully introducing sediment into an aquatic system requires implementation of conscientious management strategies. Indirect impacts of sediment on fish and relatively large aquatic organisms are briefly discussed in Box 3.[14]

Each link in the food-chain is intricately influenced by, and dependent on, the links before and after it. As sediment impacts one link (for example, primary plant growth), the other links are also affected. For example, secondary plant growth and organisms that feed on plants. Sediment, therefore, can influence the health of an aquatic ecosystem in many direct and indirect ways. Some of the potential impacts of sediment are listed in Box 4, and Box 5.

When considering a sediment management strategy, it is important to be aware of the water quality issues that could arise. One important potential issue is the bio-accumulation of contaminants, or the increased buildup of harmful substances in an organism, especially an organism that forms part of the food chain. Not all chemicals bio-accumulate; whether or not bio-accumulation is an issue depends on what contaminants are contained in the reservoir. These contaminants are mixed with the sediment. Activities that remove sediment from the reservoir can also re-suspended the contaminants, which can bio-accumulate in fish and invertebrates.[15]

BOX 4 - Negative Sediment Impacts on Fish

TSS

-Particles may clog gills
-Lower growth rate and proper development causing them to be more susceptible to disease
-May be lethal at sufficient concentrations (hundreds to thousands of mg/l)
-Reduce the abundance of food
-Alter fish habits and movements, increasing risk of predation
-Inhibit ability to see and catch food
-Smother eggs and prevent proper development
-Introduce contaminants that have adhered to the sediment particles—contaminants may bio-accumulate
-Increased temperature
-Decrease dissolved oxygen

TDS

-Salinity toxicity
-Increased sensitivity to TDS during fertilization, may result in poor development

The degree to which fish and invertebrates are impacted by sediment depends upon two relatively controllable factors, the duration of the exposure and the amount of sediment introduced. These two factors also strongly influence the effect sediment has on aquatic habitat.

Stream Morphology and Aquatic Habitat

Stream Morphology is the physical structure of the stream made up of interconnected and interdependent systems. Physical changes to aquatic habitat depend upon several variables and may be either beneficial or harmful. Dams are highly efficient sediment traps that eliminate or severely limit the amount of sediment reaching the stream below the dam. The naturally-occurring sediment concentration background level downstream of a dam is likely to be far less than that upstream of the dam. In many cases, the stream below the dam is considered sediment-deficient. Streambank and streambed erosion are common results below a dam. This presents a challenge and an opportunity to manage sediment

BOX 5 - Negative Sediment Impacts on Invertebrates

TSS

-Particles may clog feeding apparatus (filter feeders)
-Destruction of habitat
-Clogging of larger substrate spaces
-May smother benthic communities
-Decreased biological diversity
-Causes decreased primary production (food source for several invertebrate species)

TDS

-Salinity toxicity (osmotic tolerances exceeded)
-Decrease biological diversity

in a controlled manner, and potentially restore the stream below the dam to more natural conditions.

Moving water is able to transport a natural amount of sediment. That amount depends on the sediment size, the flow volume and velocity of flow. Assuming appropriate sized sediment is available in the stream, greater volume and higher velocity translates to larger amounts of sediment being transported. A sediment-deficient or clean flow, like that found below a dam, has an increased ability to transport sediment. The clear flow naturally picks up sediments through erosion and scour of the downstream bed and banks. This results in destruction of aquatic habitat through substrate coarsening and changes in channel shape.[16] See the introduction to Chapter 4 for a more complete discussion of the relationship between water velocity and ability to transport material of various sizes.

Sediment management operations that convey sediments below the reservoir will likely cause stream habitat changes below the dam. These changes depend upon the "magnitude, duration, frequency and grain-size distribution of the sediment releases, and on the downstream channel characteristics."[17] A sediment release alters the aquatic landscape largely through deposition since sediment releases often exceed the transport capacity of the stream. This results in smaller streambed particle size, possible aggradation, filling in pools and riffles, and increased deposition on lateral and in-channel bars.[18] Increased sediment in the stream may reduce water quality by itself, transport and deposit contaminants previously contained in the reservoir, and alter riparian habitat downstream of the dam.[19]

OTHER POSSIBLE CONSEQUENCES

Downstream Water-Related Infrastructure

In many instances there is more than one dam on the same river. The upstream dam collects sediment and prevents it from being passed to the downstream dam. This effectively isolates the downstream dam from the adverse effects of that sediment. In such cases, sediment management at the upstream reservoir that passes sediment into the water below the dam will cause new sediment challenges for the downstream reservoir.

Dealing with these issues could be as simple as coordinating sediment discharges with the operation of a downstream reservoir or as complex as installing new sensors, structures and devices to remove sediment from the water before it enters the downstream reservoir.

In most cases, there are numerous other water-related water structures below dams. Diversion dams, canals, aqueducts, secondary irrigation ponds and drinking water treatment plants can be negatively impacted by increased sediment. In some cases, new measures to protect these facilities from upstream sediment management activities may be needed. The impacts of sediment releases on downstream facilities need to be carefully considered and mitigated as necessary.

Flooding

Releasing significant and uncontrolled amounts of sediment downstream of a reservoir can have flooding implications. Sediment deposited in a stream (aggradation) over a long period of time will significantly change the stream's elevation along its length (profile). This could lead to increased flooding if high-flow events are not able to scour away the deposited sediment and transport it further downstream. Low-lying areas where flow velocities are lower, and sediment is more readily deposited, are especially at risk. Significant problems could be created at such locations over time. Stream aggradation can cause water to overflow its previously established banks, expand flood plains, damage bridge abutments, and damage other structures near the stream.

Recreation

Sediment management activities are likely to impact recreation. Drawing down or draining a reservoir to dredge or excavate sediment will greatly diminish recreation opportunities during these activities. Other methods, such as hydrosuction dredging, that require floating equipment and pipelines could temporarily interfere with recreation activities. Sediment management impacts to recreation can be minimized by scheduling as many activities as possible during the off-season.

Sediment releases can also impact the quality of fishing, kayaking, rafting and swimming downstream. Although temporary, in most cases these impacts will be negative. However, in the case of kayaking, increased flows during normally minimal flow times could be beneficial.

FEDERAL REGULATIONS AND RESPONSIBLE AGENCIES

There are many environmental laws that protect the nation's land and wildlife. Some of these laws directly apply to riverine environments. The following is a description of the federal regulations and agencies impacting sediment management in Utah.

National Environmental Policy Act (NEPA)

The National Environmental Policy Act was created in 1969 to ensure that environmental impacts are considered when projects under federal agency jurisdiction are implemented. The Environmental Protection Agency (EPA) was organized in late 1970 from a collection of several government regulatory agencies to administer NEPA. Under NEPA, federal agencies are obligated to consider environmental consequences that are identified through studies called Environmental Assessments (EAs) or Environmental Impact Statements (EISs). These studies review the effects of proposed projects on the environment and compare alternative configurations that may reduce environmental impacts. The reports are also presented to other agencies and to the public, which then have a period of time to review and comment on them. NEPA provides the opportunity for interested parties to participate in the decision making process, aiming to balance environmental costs against the anticipated benefits. The EPA has administrative and review responsibilities for federal projects under NEPA, which responsibilities include receiving and filing completed EISs, publishing notices of filing and overseeing the procedures for public commenting. Because many dams have been built with federal money or have been built on public lands, they fall under NEPA requirements. Similarly, any actions to facilitate sediment management could require consideration of environmental impacts.

Federal Energy Regulatory Commission (FERC)

Building or modifying a power generating facility at a dam falls under the jurisdiction of the Federal Energy Regulatory Commission. FERC is an independent regulatory agency within the U.S. Department of Energy (DOE). FERC licenses hydropower projects. Because FERC projects involve federal money, an EA or EIS is produced and interested parties are allowed to comment. In addition, the process of licensing and re-licensing hydropower projects includes a review and approval of operating procedures. Operating procedures must comply with requirements for river flows for downstream users and the environment. Modifications to the operating procedures to accommodate sediment management have to be approved and incorporated into the existing plan. Hydropower facilities must be re-licensed every five years, yet the operating procedures can be modified in the interim by FERC, if changes are needed. FERC decisions are reviewed by the federal courts.

Clean Water Act

The Clean Water Act of 1977, Section 404 regulates discharges of dredged and fill materials into waters of the United States, including wetlands. The Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (Corps) share ultimate administration of Section 404. Because of EPA and Corps budget limitations, the state of Utah administers the Section 404 permit program for Utah's rivers through the Utah Division of Water Rights. The Corps retains permitting jurisdiction over Utah's wetlands. Typically called a Stream Alteration Permit, Section 404 permits in Utah cover all dredging, sediment pass-through, flushing and excavation activities up to the average high water mark of the stream or reservoir bank. All of these proposed activities require consultation with the Utah Division of Water Rights to ensure compliance with Section 404 before implementation. An important part of the Corps administration is Regulatory Guidance Letter No. 05-04, "Guidance on the Discharge of Sediments From or Through a Dam and the Breaching of Dams, for Purposes of Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act of 1899." A complete copy can be found in Appendix D.

Also included in the Clean Water Act are water quality standards that are administered by the Utah Division of Water Quality. Under the Clean Water Act, each state is required to identify the beneficial uses of each water body. The Utah Water Quality Board, working with the Utah Division of Water Quality, classified the quality of state waters and identified the beneficial uses. A determination was then made as to whether the water quality supports or does not support the listed beneficial uses. Beneficial uses not supported by current water conditions are then examined to determine if they are human caused or naturally occurring. Waters determined to not support beneficial uses due to human caused conditions are considered 'impaired' and placed on the EPA's 303d list of impaired waters. With the goal of returning water quality to supporting conditions, water impairments and contributing sources are identified as well as the limits for each contaminant at which the beneficial uses are fully supported.

State water quality designations can be found in *Utah Administrative Code, Rule R317-2-6*, and a list of water body classifications in *Rule R317-2-13*. Waters that are designated as High Quality Water Category 1 cannot receive new discharges of wastewater. High Quality Water Category 2 waters cannot be degraded below Category 2 water quality. In addition, "Waters whose existing quality is better than the established standards for the designated uses will be maintained at high quality unless it is determined by the Board, after appropriate intergovernmental coordination and public participation in concert with the Utah continuing planning process, that allowing lower water quality is necessary to accommodate important economic or social development in the area in which the waters are located."[20] All other waters of the state (Category 3 and below) allow point source discharges and degradation depending upon completion of an Anti-degradation Review (ADR). An ADR is conducted to determine compliance with state and federal regulating activities such as Clean Water Act *Sections 401* (FERC and other federal actions), *402* (UPDES permits), and *404* (Army Corps of Engineers permits). Utah's anti-degradation policy is meant to maintain current water quality and uses. In cases where pollutants exceed the allowable limits for historical uses, the Total Maximum Daily Load (TMDL) program goes a step further towards restoration of water quality. For each water body and contaminant, a TMDL is calculated and individual contributors to the impairment are assessed a Waste Load Allocation (WLA) for the respective operation. Once a TMDL is completed, it is submitted to the EPA for approval. After the plan has been approved, sediment management methods, such as sediment pass-through and flushing, might require modifications to the TMDL. Sediments deposited in some reservoirs can contain organic materials, pesticides, fertilizers and herbicides. Flushing and sediment pass-through can release these into the river reaches below the dam, consuming oxygen, clogging fish gills and causing other problems.

Utah waters not covered by a TMDL are still subject to Utah's anti-degradation policy for surface waters. Utah's anti-degradation policy requires that individual entities cannot divert water for use and then discharge it at a lower quality. Several water quality parameters that the Division of Water Quality enforces on releases from reservoirs are turbidity, dissolved oxygen, acidity, ammonia and temperature. Sediment releases have the greatest affect on turbidity and can lower the level of dissolved oxygen. For most of Utah's streams (class 3b or better), sediment releases are not allowed to increase turbidity by more than 10 NTU over the turbidity of the water entering the reservoir.[21] Waters quality of 3c through 3e can have a degradation of 15 NTU. Proposed releases of sediment from reservoirs are a concern to both the Division of Wildlife Resources (DWR) and the Division of Water Quality (DWQ). As discussed below, reservoir operators need to consult both in order to identify the water quality standards that may apply to their operations. Such releases may require monitoring.

Endangered Species Act (ESA)

The federal Endangered Species Act, passed in 1973, was created out of concern over the decline of wildlife species around the world. Under this act the viability of species worldwide were studied and those species that were identified as declining were "listed" according to the threat of extinction. Of the 1,818 worldwide species listed by the act as of August 2002, 1,260 are U.S. species.[22]

The ESA is administered by both the National Oceanic and Atmospheric Administration (NOAA), which includes the National Marine Fisheries Service for marine species and environments, and by the United States Fish and Wildlife Service (FWS) for freshwater species and environments. The Utah DWR has partnered with FWS to manage endangered species in Utah. Utah riverine species and environments are administered by the Utah Division of Wildlife Resources' Aquatic Habitat Section.

While anyone can petition to have a species listed, FWS and the National Marine Fisheries Service rely largely upon surveys they conduct. In Utah, DWR also identifies species within the state that have the potential to be listed by the ESA. This allows the DWR to address the recovery of sensitive species before more restrictive policies are mandated by the ESA. Listing of a species by the ESA has the potential to tie-up state lands and mineral and water resources, making them difficult to develop.

Since recovery is more manageable if a species is not Federally listed, the DWR developed the Utah Species of Concern list in order to encourage proactive management policies that may prevent listing by the Federal ESA. The Virgin Spinedace and Flannel Mouth Sucker are fish species on this list that receive pre-emptive treatment through management of Virgin River water flows in order to maintain critical habitat for this fish species. Since two Virgin River species are already listed, withdrawals from the river probably would not be further reduced if the Virgin Spinedace and Flannel Mouth Sucker become listed. However, other waters where these species live could require restrictive management.

While there is no current permitting process in Utah that protects aquatic environments from reservoir sediment releases, "taking" **[23]** of a species listed by the ESA, or as a Utah Species of Concern, is subject to penalties under the ESA, and the Utah State Agriculture and Wildlife Damage Protection Act (Utah Code Title 23, Chapter 15-Aquatic Wildlife).

DWR has partnered with the 'National Fish Habitat Action Plan.' The plan employs strategies to protect, restore and enhance watersheds and waterways across the country, including Utah. Enhancements include stream and watershed restoration, installation of migration barriers, road reconstruction and realignment, riparian fencing and land management alterations. DWR can make recommendations that will limit fish kills and that may possibly restore downstream sediments vital to fish habitat.

Federal Emergency Management Agency (FEMA)

The Federal Emergency Management Agency is responsible for emergency planning and response. Part of the agency's responsibility lies with mitigating flood damage. Large deposits of sediment in a river channel below a reservoir can increase flood potential for bank side properties. Activities in the upper watershed that may create erosion are also a concern when watershed protection plans are in place. Reservoir owners should contact FEMA's local authorities when considering large sediment discharges as that agency usually has local responsibility for flood control mitigation.

Natural Resources Conservation Service (NRCS)

The Natural Resources Conservation Service, originally known as the Soil Conservation Service, was created in 1935. It "has provided leadership in a partnership effort to help America's private land owners and managers conserve their soil, water, and other natural resources."[24] NRCS manages natural resource conservation programs that provide environmental, societal, financial and technical benefits. There are a variety of programs provided by the NRCS that help reduce soil erosion by managing farmland, watersheds, and water resources, as well as other programs. NRCS has engaged in activities that stabilize soil high in Utah's watersheds (such as high mountain terracing) as well as in valleys (farm and rangeland management practices). NRCS has watershed management programs that help restore abandoned farmland, rehabilitate fire scorched lands and control flooding. NRCS is also involved in monitoring snowfall and forecasting runoff. Many of the programs help assess and solve soil problems, with an emphasis on controlling wind and water erosion. See Chapter 5 for details of NRCS programs.

STATE REGULATIONS AND RESPONSIBLE AGENCIES

The need to pass sediment downstream of dams was not recognized when Utah's regulatory limits on turbidity were established. While the long-term intent is to revise those regulations,[25] they do allow for res-

<u>ervoir sediment releases on a case-by-case basis.</u> This section discusses those matters.

Some benefit can be gained from a brief review of decommissioning Cove Dam on the Bear River in Idaho. This project, August to November 2006, led to sediment releases which briefly exceeded the Idaho Department of Environmental Quality regulations regarding NTU limits.[26] A coalition of three state agencies, four federal agencies, four private environmental groups, the Shoshone-Bannock Tribes, and PacifiCorp (the dam owner), realized before the project was begun that exceedances were likely to happen. They agreed to look at the situation in light of the long-term environmental benefits to the stream and aquatic life, namely benefits to Bonneville cutthroat trout, as compared to the potential short-term negative impacts.

Estimates were developed, and it was found that the annual natural sediment load was substantially greater than the predicted worst-case sediment releases.[27] Also, it was determined that the stream and associated aquatic life community could tolerate limited exceedances, as long as they were not prolonged, even during low flows late in the year.[28] Stream turbidity was monitored throughout the project providing a near immediate feedback loop to adjust decommissioning operations in the event of turbidity increases.[29] Dam decommissioning was carefully completed with minimum short-term impacts to the stream, while providing numerous long-term benefits to fish habitat and river function.[30] This serves as an example of many different stakeholders cooperating to achieve their individual goals, along with doing the greatest good, within a regulatory framework.

Utah Division of Water Quality (DWQ)

DWQ’s mission is to, “Protect, maintain and enhance the quality of Utah's surface and underground waters for appropriate beneficial uses; and to protect the public health through eliminating and preventing water related health hazards which can occur as a result of improper disposal of human, animal or industrial wastes while giving reasonable consideration to the economic impact.”[31] This agency has regulatory authority to limit sediment releases from dams. That authority extends to issuing citations and the levy of substantial fines for violating regulations. Current regulations limit turbidity increases to no more than 10 NTU (Nephelometric Turbidity Units).[32] Obviously that standard is impossible to meet for typical reservoir sediment releases. Therefore, DWQ recommends the following:[33]

- <u>In all instances, contact DWQ</u> and coordinate with them to plan and implement reservoir sediment releases. DWQ is willing to work out a revised turbidity standard on a case-by-case basis that allows temporary exceptions, on a transient basis, for those situations where the 10 NTU limit will be exceeded. The plan will take into consideration factors unique to that reservoir and unique to the stream below the reservoir. The plan will need to involve the Utah Division of Wildlife Resources for their input to establishing the revised turbidity standard for the specific case. The turbidity increase limit will typically be referenced to background levels above the reservoir being compared to those below the reservoir.
- Remove sediment from a reservoir during the spring season runoff, whenever possible. More water is available for sediment transport downstream and reservoir sediment will accompany naturally-occurring sediment already in the stream. Aquatic habitats are accustomed to this annual occurrence with water temperatures being colder than other seasons, and naturally-occurring nutrients and organic materials are also present.
- When sediment releases are planned for later in the year, contact DWQ and the Utah Division of Wildlife Resources at least six months beforehand. This may occur at the end of the irrigation season when reservoir levels are drawn down for other maintenance and sediment releases can be done concurrently. The season of the year is critical to whether sediment will cause problems. Higher water temperatures later in the year, combined with sediment releases, can have adverse impacts that would not occur during the colder spring runoff.
- Make multiple, annual sediment releases of smaller quantities rather than allowing

sediment to build up for years, possibly necessitating larger releases less frequently.

- DWQ will give special attention to impaired streams having a Total Maximum Daily Load (TMDL) study. There are over 50 such streams in Utah. DWQ is required by law to reduce pollutants and restore water quality.[34] Dam owners are advised to determine if the stream below the dam has TMDL sensitivities that could limit sediment releases. TMDL listed streams are referenced by the previous endnote.
- Real-time NTU monitoring may be required. This will call for equipment above the reservoir and below the dam, combined with the ability to immediately regulate and reduce sediment release volumes in response to sediment levels below the dam approaching the revised turbidity standard. It is anticipated that the dam owner would purchase the equipment and permanently install it at locations mutually agreeable to DWQ and the dam owner. Dam owners will need to develop their own skills for such monitoring, or perhaps employ a knowledgeable consultant. When personnel resources permit, DWQ may assist in observing the NTU-monitoring equipment and participate in regulating reservoir sediment releases.

Utah Division of Wildlife Resources (DWR)

The Utah DWR has jurisdiction over public and private land and waters.[35] With regard to waters, their fundamental concern is to protect and preserve aquatic habitat for fish and other aquatic species. They have enforcement powers over sediment releases which pollute the waters[36] and kill fish.[37] They also have fisheries biologists in regional offices who are willing to work with reservoir owners regarding sediment releases. The main concern is not to release sediment during the spawning seasons of the several fish species below a specific dam. Meeting with DWR to plan and implement sediment releases is clearly in a dam owner's best interest to prevent problems and possible citations with substantial fines. Regional DWR offices are located in Salt Lake City, Price, Cedar City, Springville, Vernal and Ogden. Office contact information can be found in the annual Utah Fishing Guidebook which can be downloaded from http://wildlife.utah.gov/guidebooks/. When planning the timing of sediment releases, an excellent reference for determining when fish species spawn, and other information relevant to the timing, is contained in the endnotes.[38]

NOTES

[1] Retrieved from the Wikipedia Internet web page: http://en.wikipedia.org/wiki/Total_suspended_solids, February 22, 2009.

[2] Retrieved from the Wikipedia Internet web page: http://en.wikipedia.org/wiki/Total_dissolved_solids, February 22, 2009.

[3] Retrieved from the Wikipedia Internet web page: http://en.wikipedia.org/wiki/Turbidity, February 22, 2009.

[4] Water classifications allowing turbidity increases: 1C; domestic purposes, 2A; primary contact recreation, swimming, 2B; secondary contact recreation, boating, wading, 3A; cold water game fish and other aquatic life, 3B; warm water game fish and other aquatic life, 3C; non game fish and other aquatic life, 3D; protected for waterfowl, shore birds and other water-oriented wildlife.

[5] Utah Administrative Code R317-2, Table 2.14.2, Numeric Criteria for Aquatic Wildlife.

[6] Retrieved from the Wikipedia Internet web page: http://en.wikipedia.org/wiki/Biochemical_oxygen_demand, February 22, 2009.

[7] Retrieved from the Wikipedia Internet web page: http://en.wikipedia.org/wiki/Dissolved_oxygen, February 22, 2009.

[8] Retrieved from the University of Florida, IFAS Extension Internet web page: http://edis.ifas.ufl.edu/fa002, February 22, 2009.

[9] Retrieved from the Wikipedia Internet web page: http://en.wikipedia.org/wiki/PH, February 22, 2009.

[10] Biochemical Oxygen Demand or Biological Oxygen Demand (BOD) is a chemical measurement for determining how fast biological organisms use up oxygen in a body of water. It is used in water quality management and assessment, ecology and environmental sciences. Most pristine rivers will have a 5-day BOD below 1 mg/L. Moderately polluted rivers may have a BOD value in the range of 2 to 8 mg/L. Municipal sewage that is efficiently treated may have a value of about 20 mg/L or less. Untreated sewage varies, but averages around 600 mg/L in Europe and as low as 200 mg/L in the U.S. This note retrieved from the Wikipedia Internet web page: http://en.wikipedia.org/wiki/Biochemical_oxygen_demand, February 23, 2009.

[11] Personal communication with David Soballe, Research Biologist, U.S. Army Corps of Engineers, August 31, 2009.

[12] Ibid.

[13] DFO, *Effects of sediment on fish and their habitat,* Canada: DFO Pacific Region, Habitat Status report 2000/01, 2000, page 2.

[14] Personal communication with David Soballe, Research Biologist, U.S. Army Corps of Engineers, August 31, 2009.

[15] Willford, Wayne A., Michael J. Mac and Robert J. Hesselberg, "*Assessing the bioaccumulation of contaminants from sediments by fish and other aquatic organisms,*" Dordrecht: Dr W. Junk Publishers Netherlands, Hydrobiologia 149: 107-111, 1987, page 107.

[16] Stanley, Emily H. and Martin W. Doyle, *"Trading off: the ecological effects of dam removal,"* The Ecological Society of America, Front Ecol Environ; 1(1): 15-22, 2003, page 15.

[17] Wohl, Ellen and Sara Rathburn, "Mitigation of Sedimentation Hazards Downstream from Reservoirs," Internation Journal of Sediment Research, 18 (2): 97-106, 2003, page 98.

[18] Stanley, Emily H. and Martin W. Doyle, 2003.

[19] Wohl, Ellen and Sara Rathburn, 2003.

[20] Utah Administrative Code R317-2-3

[21] NTU—Nephelometric Turbidity Units—A measure of water clarity. An instrument called a nephelometer can be used to measure the amount of light scattered by suspended matter in the water. Turbidity is visually detectable at 5 NTU and above. Drinking water requires 0.5 NTU or below.

[22] U.S. Fish and Wildlife Service, *"ESA Basics, Over 25 years of protecting endangered species."* Retrieved from the U.S. Fish and Wildlife Service's Internet web page: http://endangered.fws.gov/pubs/esa%20basics.pdf, May 2004.

[23] "Take" is broadly defined and includes killing or harassment of a species.

[24] Retrieved from the NRCS's Internet web page: http://www.nrcs.usda.gov/about/, January 27, 2009.

[25] Personal communication with DWQ personnel, Michael Allred (Scientist), Carl Adams (Environmental Program Manager, TMDL), and Amy Dickey (Scientist), November 30, 2009.

[26] *Cove Dam Removal Project, Water Quality Monitoring Report*, November 2006, Cirrus Ecological Solutions, LC, pages 2 and 3. Also, personal communication with Idaho Department of Environmental Quality, Lynn VanEvery, Pocatello, ID, January 19, 2010.

[27] Personal communication with Idaho Department of Environmental Quality, Lynn VanEvery, Pocatello, ID, January 19, 2010.

[28] Ibid.

[29] *Cove Dam Removal Project, Water Quality Monitoring Report*, November 2006, Cirrus Ecological Solutions, LC, pages 2 and 3.

[30] Personal communication with Idaho Department of Environmental Quality, Lynn VanEvery, Pocatello, ID, January 19, 2010.

[31] Retrieved from the DWQ’s Internet web page: http://www.waterquality.utah.gov/, November 30, 2009.

[32] Utah Code, Rule R317-2, Standards of Quality for Waters of Utah, Table 2.14.2, Numeric Criteria for Aquatic Wildlife.

[33] Personal communication with DWQ personnel, Michael Allred (Scientist), Carl Adams (Environmental Program Manager, TMDL), and Amy Dickey (Scientist), November 30, 2009.

[34] Retrieved from the DWQ’s Internet web page: http://www.waterquality.utah.gov/TMDL/index.htm, November 30, 2009.

[35] Utah Code, Title 23, Wildlife Resources Code of Utah, paragraph 23-15-2.

[36] Utah Code, Title 23, Wildlife Resources Code of Utah, paragraph 23-15-6.

[37] Utah Code, Title 23, Wildlife Resources Code of Utah, paragraph 23-15-7.

[38] *Fishes of Utah, A Natural History*, by William F. Sigler and John W. Sigler, University of Utah Press, 1996.

7

DAM OWNER'S GUIDE TO SEDIMENT MANAGEMENT

Having explored the several elements of sediment accumulation and mitigation in reservoirs, it is now appropriate to bring these elements together in a logical sequence to guide dam owners and operators. This chapter presents specific actions starting with assessment of the current situation, and ending with a definition of how to mitigate conditions at a given reservoir. It's based on the experiences of dam owners, engineering consultants, federal agencies, academics, and others experienced in sediment management. While researching this report, many sediment management problems were encountered that could have been prevented. Measures to avoid these problems are included in this chapter. When the recommended actions are implemented, the useful reservoir life can be greatly extended.

SEDIMENT MANAGEMENT GOALS

From a sediment transport standpoint, it would be ideal to make a reservoir "transparent" to the stream. That is, on an annual basis, whatever volume of sediment enters the reservoir also leaves the reservoir. As far as sediment goes, it appears to the stream as if the reservoir were not present. This would allow the reservoir to function indefinitely at its present capacity. Realization of this goal will depend upon local conditions, and may not always be possible. However, some degree of sediment mitigation generally will be possible. Figure 19 is a conceptual or abstract diagram depicting sediment accumulation effects on reservoir storage and the results of various mitigation actions.

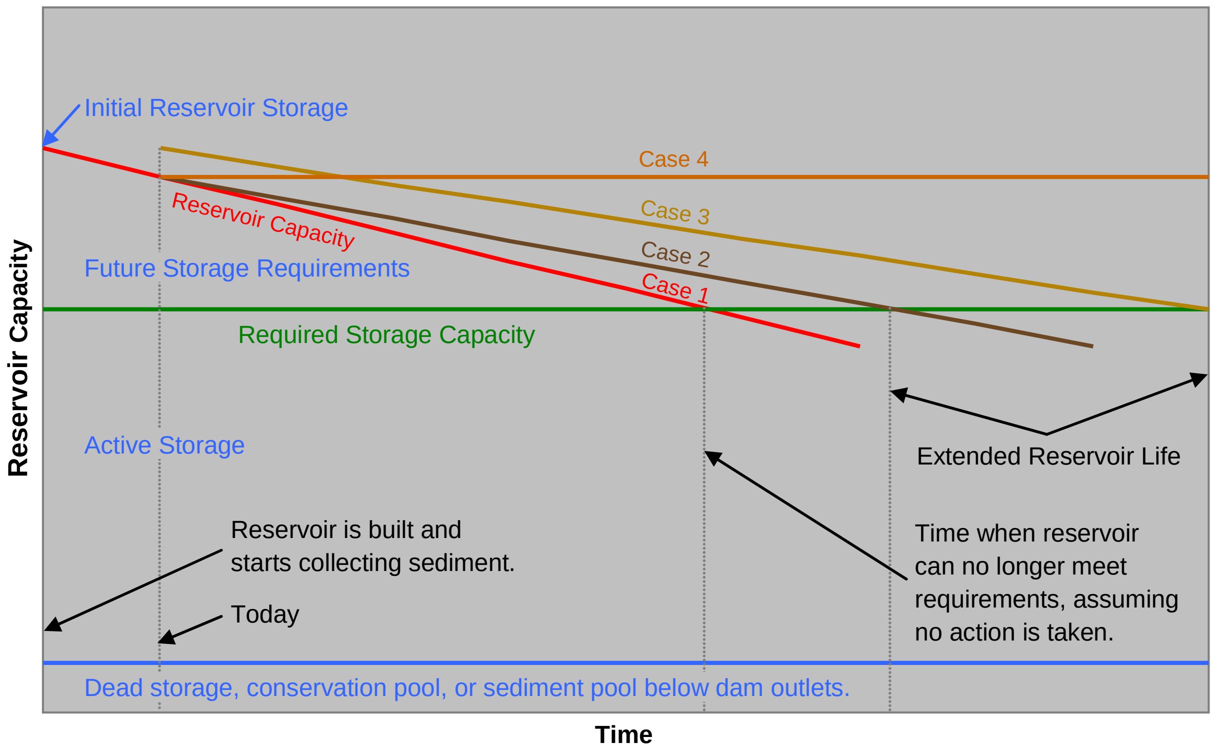
A reservoir is built to be cost effective by constructing it with capacity to meet future needs. As shown in Figure 19, the Initial Reservoir Storage is the sum of Future Storage Requirements, Active Storage, and Dead Storage. The line designated as Today is the point at which sediment mitigation is implemented.

Colored text in the following narrative designates reservoir capacity lines over time in Figure 19. The Reservoir Capacity line indicates the steady decline of the reservoir's storage capacity as sediment accumulates over time. This storage loss begins the moment water is stored. The rate of capacity decline (slope of the line) depends on local conditions. In reality, the decline of reservoir capacity is an irregular process with the greatest sediment accumulation taking place during annual spring runoff and during rainfall events. Both of these change over the years too. The rate of capacity decline is estimated as a straight line from the time the reservoir is built until today, and projected into the future.

The Required Storage Capacity line indicates the minimum storage necessary for the water system, of which the reservoir is a part, to function. Required Storage Capacity is often comprised of storage volumes for agriculture (irrigation), municipal and industrial (M&I), stock water, hydropower, fish culture, wildlife and conservation pool. While this line is shown as flat, it may increase or decrease with time, depending on circumstances.

Notice the intersection of the Reservoir Capacity line and the Required Storage Capacity line. This is the time when the reservoir capacity can no longer meet the requirements for which the reservoir was built. This occurs long before the reservoir is completely filled with sediment. As time passes beyond

FIGURE 19
Impacts of Sedimentation and Sediment Management on Reservoir Life



this point, reservoir uses can become more and more restricted. The restrictions can pass unnoticed due to the normal variations in the water supply and reservoir usage. With sufficient data, this point can be estimated to plan for the future and help determine the urgency for sediment mitigation actions. As mentioned in Chapter 4, this typically varies from when 15 to 40 percent of the reservoir storage is lost.

Case 1 – shows the reservoir capacity over time if no action is taken and sediment is allowed to accumulate with no mitigation.

Case 2 – shows the reservoir capacity if one, or more, sediment mitigation strategies are implemented, resulting in a slower rate of sediment accumulation in the reservoir. Notice the resulting extension of the reservoir's useful life.

Case 3 – shows the reservoir capacity after removing a certain volume of sediment from the reservoir and simultaneously enacting one, or more, sediment mitigation strategies that results in slowing the rate of sediment accumulation. Notice the greater extension of the reservoir's useful life than Case 2.

Case 4 – shows the reservoir capacity after enacting one, or more, sediment mitigation strategies that result in stopping sediment accumulation in the reservoir completely. Depending on local conditions, this may or may not be possible. When it is possible, the Reservoir Capacity and Required Storage Capacity lines never intersect and the reservoir's useful life is potentially extended indefinitely. One scenario to achieve this is a combination of bypassing sediment during spring runoff and hydrosuction removal of previously accumulated sediment. Hydrosuction or another single method alone could also accomplish this.

As with any conceptual or abstract model, the above diagram and explanation is greatly simplified. Reservoir operation typically involves storage of water that is available from the beginning of the year, through the irrigation season, and on to the end of the year. There may also be direct flows that pass through the reservoir, bringing associated sediment. Thus, the amount of water actually stored varies from year to year.

Even so, all sediment entering the reservoir displaces water that would otherwise be stored when the reservoir is full. During years when sufficient water is available to meet demand, sedimentation issues are not noticed. However, during drought years, when the water is needed most, the lack of storage due to sediment accumulation is keenly felt. Fewer crops can be grown, other requirements go unmet, and there are economic losses. With effective action, those losses can be kept to a minimum, and ideally, eliminated altogether. That is the goal of sediment management.

DEVELOP AND IMPLEMENT A SEDIMENT MANAGEMENT PROGRAM

To be effective, sediment management requires objectively looking at the issue, understanding how it can benefit reservoir operations and provide long-term benefits, and then taking appropriate action. Often people do not act until a problem is detectable. With regard to sediment, however, that is much too late. Sediment accumulation is quiet, relentless, and ongoing, and is not noticed for many years.

The following recommendations provide a comprehensive and detailed approach to dealing with sediment. Much work is involved and it is up to the reservoir owner to determine which of the recommendations will be implemented. Often financial and political realities influence such decisions. But things must change in order for improvement to be realized. The old adage, “Pay now or pay later” applies to reservoir sedimentation. Those irrigation companies that have struggled with sediment will see the wisdom in these recommendations.

While every project will have unique properties, the overall process to establish a sediment management program is similar for most reservoirs. The specific steps follow, roughly in order, but several actions could progress simultaneously.

1. Preliminary Investigation

Evaluate the overall situation to determine if there are problems caused by sediment accumulating in the reservoir. Contact knowledgeable stakeholders to ask what’s known; write down the information and ask the location of existing data. Gather existing data in one place. Visit the reservoir when the water level is low to estimate how thick and extensive the sediment delta and other sediment deposits are. Free satellite images from Google Earth may also be available to help in this regard. Take pictures and write down a description of conditions. Create a document summarizing what is known. This groundwork sets the stage and guides future steps.

2. Engage Stakeholders

Discuss the situation and proposed actions with stakeholders. This step is crucial to the success of reservoir sediment removal. Conflicting requirements are almost inevitable. They can be resolved before actions are taken that could potentially cost more money, as well as damage relationships and the environment. Stakeholders include those involved with the stored water such as agricultural interests, multi-purpose users, municipal and industrial (M&I) users, recreational interests, electrical power generating stations (coal-fired and hydro-power), flood control agencies, and environmental interests. Additional stakeholders include land owners above and below the reservoir, private individuals and corporate entities. Also include state and federal wildlife agencies interested in the conditions within and adjacent to the stream above and below the reservoir, as well as within the reservoir itself. Because of the many stakeholders, this step can be complex and time-consuming. However, past experience has shown that when it is not done thoroughly, serious problems typically result.

While a series of stakeholder meetings will be needed, inviting them to a regular meeting of the agency or entity controlling flows through the reservoir could save time. Allow sufficient meeting time for discussion and provide an agenda beforehand so attendees can prepare. Include specific discussion questions such as:

- To what extent is sediment a problem? What specific data justifies regarding the situation as a problem? Impact costs and damages, including pictures, are especially useful.

- How much sediment has accumulated in the reservoir? What is this estimate based on? What is the confidence of the estimate accuracy: high, medium or low?
- Have any engineering surveys been performed resulting in high confidence estimates of sediment accumulation? If so, where are the records of the survey?

3. Gather and Organize Information

Establish and maintain a comprehensive sediment management program file. Compile all known sediment-related information for the reservoir itself, the watershed above the reservoir, and the stream leading to and from the reservoir. In particular, look for information on the source and timing of sediment influx into the reservoir. Contact the various state and federal agencies who may have such information. Include information gathered from all stakeholders. This file should be updated regularly and kept for the life of the reservoir.

4. Conduct A Reservoir Survey

If the estimate of accumulated sediment estimate is not highly reliable or has not been updated in the past 15 to 20 years, decide how a higher quality estimate can be obtained. <u>This estimate underlies all future decisions and actions.</u> It will be a judgement call on whether decision makers are comfortable committing substantial funds based on the quality of the available information. If the accumulated sediment estimate is questionable, it is advisable to spend the necessary funds to get more current and reliable survey information before committing to future actions.

The most common method to determine reservoir capacity is to conduct a contour survey as explained in Chapter 2. Organizations able to provide high quality accumulated sediment estimates include the U. S. Bureau of Reclamation (Provo office), the U.S. Geological Survey (Salt Lake City office), Brigham Young University (Civil and Environmental Engineering Department), and engineering firms. Working with universities may be less expensive and could be mutually beneficial.

Typically, the most difficult information to find is the original contour elevations beneath accumulated sediment deposits. Sometimes detailed maps and historical records or surveys are available. When such data are not available, mapping technology or core samples can be taken that may be able to define the upper sediment surface and simultaneously the original land surface before sediment began accumulating. If this is not possible, two reservoir surveys taken several years apart can help estimate the sediment accumulation rate.

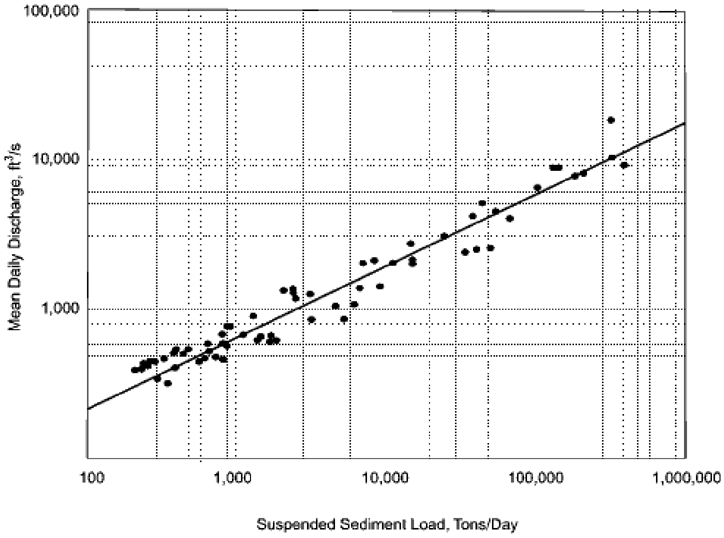
5. Assess Economic Impact

Develop an estimate of what the accumulated sediment is currently costing stakeholders in monetary terms and other disadvantages. Cost estimates for crop loss during drought can be made. The Utah Division of Water Resources may be able assist in this. Other mitigation advantages include time and money saved from operation and maintenance after implementing sediment management structures and strategies. This will allow comparison to the cost of engineered structures and other sediment management options. See Chapter 5 for economic details.

6. Develop a Monitoring Plan

This plan should be created as soon as possible, before any sediment management projects are constructed and definitely before any sediment is released below the dam. The sediment monitoring program should include the watershed above the reservoir, the reservoir itself (especially at the inlets), and the stream below the reservoir. Monitoring is intended to determine the long-term effectiveness of sediment management structures and strategies, and protect the stakeholders from false damage claims, especially downstream of the reservoir. Unfortunately, such claims have occurred. Downstream monitoring should include canals, secondary water distribution works, M&I diversions, and other locations where sediment released from the reservoir could possibly cause problems. Also include streambed conditions such as macroinvertebrate population surveys and pictures of fish reproduction areas. Monitor, establish and document baseline conditions before management strategies are implemented and before the first downstream sediment release. Appropriate photos are recommended. Appendix C has details on what and how to monitor.

Given that sediment releases will likely be an ongoing activity over many years, it is recommended to install equipment for a definitive monitoring program. Monitoring of sediment releases on the Logan River by the Utah Water Research Laboratory includes real time flow and turbidity measurement.[1] Gauges for both parameters are located above and below the dam and provide turbidity and discharge data. Along with sampling of suspended solids, this enables development of relationships between discharge, suspended solids and turbidity. See the graph above.[2] Concentration multiplied by discharge gives the sediment mass flow rate. The difference between the values upstream and downstream of the reservoir is the sediment volume deposited in the reservoir. The result is a continuous sediment balance for the reservoir.[3] While this is an involved process, once established it enhances the ability to make sound sediment management decisions. Stream bed load is a major contributor to reservoir filling, and that is not subject to automated monitoring. It is advisable to do a range or contour survey at intervals appropriate to each reservoir.



7. Regulatory Compliance

This step will make the difference between success or failure of sediment releases. Contact the appropriate state and federal agencies for their input and assistance, and to obtain copies of relevant publications. Based on discussions and agency input, determine what laws are applicable to the actions contemplated. Read the laws and comply with them. Know the regulations as well as, or better than, the regulators. Obtain concurrence from the agencies with contemplated actions *before* they are taken. Permits will be necessary and must be obtained. As noted in Chapter 6, a joint meeting with the Utah Division of Water Quality and Utah Division of Wildlife Resources is recommended to plan and implement reservoir sediment releases. Other relevant information is also contained in that chapter.

8. Public Relations (PR)

Decide when and how public input will be obtained, if required by law or decided as beneficial. Determine the elements of an ongoing public relations program to inform people of proposed actions in a timely and effective manner. Include who and when to notify before every sediment release downstream of the reservoir; include estimates of water and sediment volumes to be released. A well-informed public is crucial to the ongoing success of a sediment management program. Regardless of good operations, bad publicity will quickly create opposition to the program.

9. Study Sediment Management Options

Development of a watershed management plan is probably the most important element of a sediment management program since the sediment in every reservoir comes from the watershed. A watershed management plan is necessary in addition to other management options employed. It will be necessary to include landowners in the drainage above the dam to define and implement this plan. In the case of off-stream sites, the drainage area immediately upstream of the reservoir itself may, or may not, be the greatest sediment source. See Chapter 4 for details of developing a watershed management plan.

The U.S. Department of Agriculture, National Resource Conservation Service (NRCS) has considerable expertise in watershed management. Their programs include Rapid Watershed Assessments, Emergency Watershed Protection, Small Watershed Program (PL-566), and Resource Conservation and Development Program (RC&D). Their assistance will undoubtedly enhance watershed management. See Chapter 5 for details.

A critical element of watershed management is identifying where in the watershed the sediment entering the reservoir originates. It's common for sediment sources to be unevenly distributed over the watershed drainage area. Stated another way, one or two streams in sub-drainages may contribute most of the sediment that reaches the reservoir. The challenge is to identify those sub-drainages to most efficiently use the time and money spent on watershed management efforts. See Appendix B for a comprehensive discussion of how this is accomplished.

List, evaluate, and decide on engineered sediment control structures and strategies. Several such structures have been employed for decades. Typically these include diversion works and sediment basins that are emptied when appropriate. In addition, several engineered structures and sediment removal strategies have been described in Chapter 4. These are technically complex and should only be designed by professional engineers experienced in sediment control. Their services should include cost estimates for the various options.

Land above the stream is slumping and sliding downward.

10. Establish a Timeline for Sediment Management Activities

It is advisable to carry out numerous small sediment releases from a dam frequently, as opposed to a few, larger and potentially detrimental, releases. Several dam operators have found this to be the most beneficial operation for everyone concerned. The Utah Department of Environmental Quality recommends making multiple, annual sediment releases of smaller quantities rather than allowing sediment to build up for years, possibly necessitating larger releases less frequently.[4]

Simply passing more of the spring runoff sediments through or around the dam reduces sediment build-up in the reservoir.[5] Sediment concentrations in the spring are already at naturally high levels. Thus, carefully managed reservoir sediment releases at this time will have a minimum impact on downstream aquatic resources and water users. Similarly, reservoir sediment releases can be timed to coincide with upstream storm events.[6] In the long term, small and frequent sediment releases "will result in fewer and less serious downstream sediment problems."[7]

Timing of sediment management activities is very important. Putting sediment into a stream that has been deprived of sediment for some time could have significant and long-lasting impacts. Moreover, the time spent to study and prepare can be lost if the sediment management activity is not timed to consider the many varied activities potentially impacted by that activity. Should damages occur, governmental and public objections could put future sediment management activities in jeopardy. Finally, repair of damages incurred by those downstream could add substantially to the project cost.

The advice given here is based on years of experience by sediment management professionals pursuing activities that put sediment into streams below reservoirs. When working with downstream stakeholders, it is important to notify them several months in advance of intended sediment releases. This allows them time to consider any changes they may want to request, and to perform any baseline studies they feel are necessary. In addition, another notification a week or so before is advisable. It's also advisable to involve downstream stakeholders in the monitoring program described in this chapter. This will help make stakeholders aware of likely sediment release impacts.

While not the only ones, the most important stakeholders to involve in the timing of sediment management activities include irrigation interests, wildlife organizations, and the Utah Division of Water Quality (DWQ). Time constraints of all must be considered, especially pertaining to their activities and interests which may preclude putting sediment into the stream. Typically, the "window of opportunity" for moving sediment will be rather small, on the order of a month. This often occurs in the early spring as the stream flow is increasing but before the peak spring season runoff.[8] This is a desirable time since natural flows are high enough to move the sediment without adding to the peak flow.

Irrigation Interests

Agricultural stakeholders often constitute the most important group to involve when considering when to implement sediment releases. When the irrigation seasons of various crops are considered, a large portion of the year may be unavailable for putting sediment into the stream, as the sediment could be deposited in canals and ditches. Sediment on crops is usually, but not always, detrimental and should be prevented.

Fish and Wildlife Interests

Although discussed in previous chapters, the significance of potential impacts from sediment release to fish and wildlife is important enough to reemphasize. When considering such releases, it is essential to know what fish species are present, and when they spawn. Sediment deposited into the Logan River in the Fall of 2001 involved no less than 12 different fish species, each with slightly different spawning seasons during the year.[9] The Utah Division of Wildlife Resources (DWR) has a keen interest in the fish and the stream habitat so it is essential to involve that agency. They employ fisheries biologists who can advise on these matters. Some universities may also have similar talent on the faculty. DWR will issue notices of violation should fish injury or habitat damage occur. At the very least, provide them with official notification of the project and the upcoming sediment releases. One option that has been used successfully to avoid impacts to fish in relatively short stretches of a stream is to electroshock and remove them from the stream during the sediment release operation. The fish are stored and then returned to the stream after clear water is again running in the stream. DWR has equipment, personnel and experience in electroshocking.

Utah Division of Water Quality

While discussed in previous chapters, the importance of working with the Utah Division of Water Quality (DWQ) is important enough to reemphasize. Contact them to provide details of the intended sediment releases and get input on requirements. As discussed in Chapter 6, DWQ will work with dam owners on a case-by-case basis to facilitate sediment releases.

11. Secure Project Funding

Develop funding options to pay for all aspects of the sediment management plan, especially the engineered structures. Engage those stakeholders that will benefit from improved sediment management and request their financial input, especially since financial aid usually involves cost-sharing. Apply to those agencies that can potentially provide financial assistance. See Chapter 5 for a comprehensive list of federal and state agencies potentially able to provide funds.

12. Develop an Operation and Maintenance Plan

This plan is also an essential component of every sediment management program. The plan should be written as a comprehensive and detailed description of the entire reservoir as it is operated day-to-day, seasonal and year-to-year basis. The intent is for those who operate the project to have instructions to follow. When a new person takes over, there is a plan to follow. Lack of a plan has had significant negative consequences. Carefully designate, using drawings and text, physical components and the decision process involved in operating these facilities. Revise and improve the plan as dictated by experience. Parts of the plan would include:

- ➢ Operation of sediment control structures, including valves.
- ➢ Operation of pressurized pipeline irrigation systems in conjunction with ponds, distribution structures, valves and pumps.
- ➢ Diversion of water from the reservoir, including canals.
- ➢ Monitor human activities and natural events in the drainage area. At least annually inspect the drainage area to assess the effectiveness of the Watershed Management Plan.
- ➢ Implement Operation and Management Plan actions over time. This would include:
    - o Inspect, clean out, and maintain check dams and other structures.
    - o Evaluate and enhance vegetative cover condition.
    - o Review, and possibly revise, livestock grazing practices in the drainage.
- ➢ Monitor the effectiveness of the entire Sediment Management Program.

See Appendix C for detailed information on developing a sediment management program.

The Utah Division of Water Resources has a plan available from an active reservoir for use as an example and guide for dam owners.

NOTES

[1] Personal communication with Mac McKee, Director, Utah Water Research Laboratory, College of Engineering, Utah State University, December 9, 2008.

[2] Retrieved from the Internet website www.haestad.com January 28, 2010.

[3] Personal communication with Mac McKee, Director, Utah Water Research Laboratory, College of Engineering, Utah State University, December 9, 2008..

[4] Personal communication with DWQ personnel, Michael Allred (Scientist), Carl Adams (Environmental Program Manager, TMDL), and Amy Dickey (Scientist), November 30, 2009.

[5] Mac McKee and Lizette Oman, *Managing the Impacts of Small Reservoir Flushing*, 2009, page 7.

[6] Ibid. page 15.

[7] Ibid. page 7.

[8] Ibid.

[9] Personal communication with Mac McKee, Director, Utah Water Research Laboratory, College of Engineering, Utah State University, December 9, 2008.

8

RESERVOIR SEDIMENT MANAGEMENT CASE STUDIES

This chapter contains seven case studies from Utah reservoirs and three from other reservoirs around the world. The Utah case studies focus on reservoirs that are currently affected by sediment. The severity of the problem and historical background is presented and applicable management strategies are discussed. The non-Utah case studies offer successful examples of flushing, watershed management and hydrosuction bypass. In all cases, the sediment management strategy at each reservoir is shown in parenthesis next to the reservoir name.

UTAH RESERVOIRS

Wide Hollow Reservoir *(Sediment Basin on Inlet Canal and Dam Enlargement)*

Wide Hollow Reservoir is located approximately two miles northwest of Escalante, Utah. Completed in 1954, this off-stream reservoir was constructed primarily for agricultural purposes with recreation as a secondary use. Escalante Petrified Forest State Park is located on the shore of the reservoir. The reservoir's main water source is the nearby Escalante River, which is commonly diverted entirely through a canal to the reservoir. Some natural inflow comes from a small natural drainage above the reservoir.

Sedimentation in Wide Hollow Reservoir was recognized as a significant problem not long after it was built. A 1969 study identified the sediment sources as the Escalante River via the feeder canal and Wide Hollow Wash. Wide Hollow Wash contributes sediment during thunderstorms. Evidence suggests that runoff from these storms contains a high sediment load, but the actual sediment contribution from the wash has never been quantified. The Escalante River is laden with sediment in the spring as it collects snowmelt form the Upper Valley watershed. Summer flash floods also contribute sediment.[1]

Wide Hollow Reservoir

Built: 1954
Dam: Earth fill
Dam Height: 50 feet
Surface Area: 145 acres
Original Storage Capacity: 2,325 acre-feet
Watershed: 10 mi^2 *
Maximum Depth: 23 feet
Mean Depth: 16 feet
Length/Width: 0.61/0.42 miles
Off-stream Source: Escalante River
On-Stream Source: Wide Hollow Wash (ephemeral)
Current Uses: Irrigation and recreation

Sedimentation Rate/Loss of Capacity: Average annual loss of 0.91% of original capacity per year (1954-2007) or 48% lost capacity as of 2007
Sediment Characteristics: Fines with sand. 90% of sand is over 0.15 mm diameter

Management Strategies: Sediment basin and sluice gates installed in initial reach of canal. A dam-safety rebuild and concurrent enlargement are proposed.

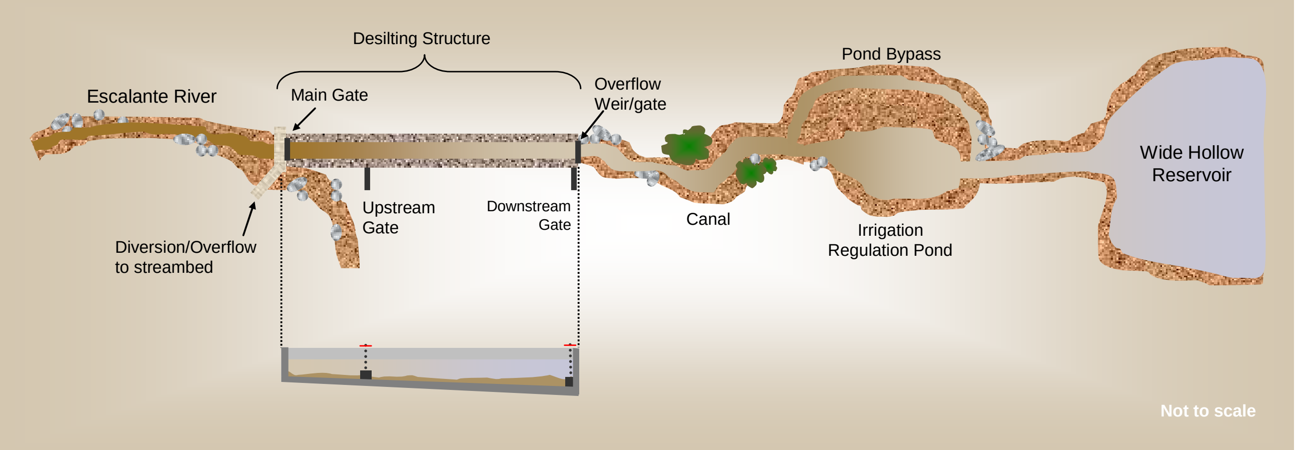
Benefit: Raising the dam will restore almost all of the original reservoir capacity.

*Natural drainage watershed is roughly 4% of the total watershed of 273 mi^2 (Utah Department of Water Quality).

In the early 1950s, the U.S. Geological Survey measured sediment at a gauging station near the mouth of Escalante Canyon. The sediment load in the Escalante River at this location was found to be

FIGURE 20

Schematic of Wide Hollow Reservoir Inlet Canal



extremely high during periods of frequent and high intensity storms. In August of 1951, it was estimated that 21,120 acre-feet of runoff contained a sediment load of 2,180,000 tons. In August of 1953, a discharge of 11,100 acre-feet carried a sediment load of 1,249,000 tons. During periods of lower discharge, ranging from 4,040 to 9,720 acre-feet, the sediment load ranged from 7,720 to 65,150 tons.[2]

In August of 1969, 20 percent of the total volume of inflow to the reservoir via the canal was determined to be sediment.[3] The reservoir was full at the time and water from the canal was passing through the reservoir and not being stored. However, the reservoir was efficiently trapping the sediment. Although there is a sedimentation structure at the inlet of the canal, it has not always been operated as effectively as it could have been until more recent years. The sediment structure consists of an in-line sediment basin (essentially a deeper section of the canal with a v-shaped cross section) and two hand-operated sluice gates that allow sediment to be periodically flushed from the basin back into the Escalante River. At the end of the sediment basin, the water flows over an elevated weir and continues to the reservoir via an unlined canal. See Figure 20.

In the past, the sedimentation structure was not emptied often enough and thus filled with sediment. This allowed sediment to pass into the canal and the reservoir. The regulating pond (used for pressurized irrigation) downstream of the sedimentation structure, had also filled with sediment and has required dredging to maintain capacity. In addition, some parts of the canal are erodible and have contributed to the sediment load. The 1969 study suggested that improved operational procedures and additional sediment removal structures could eliminate much of the sediment load entering the reservoir from the Escalante River.[4]

A range survey of the reservoir conducted in 1968 determined the reservoir capacity had decreased to 1,810 acre-feet,[5] approximately 514 acre-feet or 22 percent less than the original capacity. Over the 14 year period from 1954 to 1968, an average of 1.58 percent of original capacity was lost per year due to sedimentation. It was estimated that, at this sedimentation rate, the reservoir would be 63 percent filled with sediment by the time the reservoir would be paid for after 40 years.[6] The following sediment management measures were proposed in the 1969 study:[7]

- Operate the diversion so that when the reservoir is full, the canal is not dumping sediment-laden water into the reservoir resulting in premature sedimentation.
- Regularly and frequently open the gate to clean out the sediment basin. The basin is small and in order to be even moderately effective, it requires frequent cleaning.
- Install additional sediment-removal structures at the inlet and outlet of the canal.
- Build a settling basin at the outlet of the canal before it enters the reservoir.
- Line the canal or pipe certain parts of it.

Left: Entire flow of Escalante River being diverted into the inlet canal to Wide Hollow Reservoir. Note sediment.
Middle: Sediment being flushed from the sediment basin in the enlarged canal.
Right: Sediment leaving the sediment basin through the downstream sluice gate at a right angle to the basin. Flow and sediment return to the Escalante River. Also see the upper left photo on the cover of this report.
(Photos courtesy of Franson Civil Engineers.)

The 1968 report also suggested raising the dam. It states that, "by raising the Wide Hollow Dam just ten feet, an additional 1,300 acre-feet could be obtained."[8] However, raising the dam or installing additional sediment removal structures apparently could not be justified at that time. As a result, seasonal water shortages were reported as early as 1973 due to ongoing storage capacity losses.[9] Due to the loss of storage from sedimentation (capacity decreased from 2,325 to 1,810 acre-feet), the land that could be adequately irrigated dropped from 2,421 to 1,376 acres. Also, the reservoir capacity formerly used for flood management greatly diminished, resulting in significant expenditure to protect land from flooding.[10] A 1973 assessment of the situation estimated that the reservoir's useful life was only 10 to 15 more years and suggested the following actions be taken:[11]

- Watershed management:
    - Revegetate 4,749 acres of erodible soils in the watershed. (These acres make up only 3.2 percent of the watershed, but are a large sediment contributor.)
    - Construct sediment catchments upstream to reduce sediment load in Escalante River.
- Control sediment entering the reservoir with additional structures.
- Construct a new reservoir directly north of the present reservoir location.
- Increase water use efficiency by upgrading the distribution system to increase delivery efficiencies to farms and replacing flood irrigation systems with sprinklers.

In 1979, under the Utah Dam Inspection Act, Wide Hollow Dam was inspected and found capable of only passing 27 percent of the probable maximum flood without overtopping the dam. Because of the dam's close proximity upstream of the Town of Escalante, it was subsequently labeled as a high hazard dam by the State Engineer and placed on a priority list for rehabilitation.

Engineers again surveyed the reservoir capacity in 1992 and found it to be about 1,400 acre-feet, or 40 percent less than original capacity.[12] This corresponds to an average annual capacity loss of 0.74 percent from 1968 to 1992. This was an improvement over the earlier rate of 1.58 percent. The overall rate of capacity loss over the 38 year period from 1954 to 1992 was 1.05 percent. Due to its status as a high hazard dam, it was required that the dam be upgraded and improved. Because of the extensive foundation work required to bring the dam up to current safety standards, the 1992 report recommended that the dam be completely removed and replaced with a larger structure that would restore its original storage capacity.

In 2007, engineers estimated that about 48 percent of the original reservoir capacity has been lost due to sedimentation resulting in the current capacity of 1,200 acre-feet. From 1992 to 2007, the annual loss was 0.57 percent. This is better than the 0.74 rate experienced from 1968 to 1992 and considerably better than the 1.58 rate experienced during the 1954 to 1968 period. This makes the overall capacity loss due to sedimentation from 1954 to 2007 approximately 0.91 percent per year. The steady improvement suggests that both watershed health and sediment management at the sedimentation structure has improved over the years. However, all of these rates are considerably greater than the statewide average of 0.2 percent.

Winsor Dam, downstream of Gunlock Reservoir on the Santa Clara River, diverted water for the Ivins Canal and Reservoir. Built in 1933, the impoundment has entirely filled with sediment.

New dam sites have been investigated since 1990. However, due to environmental objections and other considerations, the reservoir will remain at the present location. Currently, the plan is to remove the dam and replace it with a larger one, roughly nine feet higher, thus recovering the original storage capacity. As part of the state funding that has been approved for the project, the Utah Board of Water Resources recommended that a sediment management plan be prepared and implemented for the reservoir. The total cost of the dam replacement project is estimated to be $13 million.

Gunlock Reservoir *(Upstream Trapping, Dredging and Excavation)*

Gunlock Reservoir is located about 20 miles northwest of St. George and just south of the town of Gunlock. The earth-fill dam across the Santa Clara River was completed in 1971. The reservoir's watershed is composed of alluvial fans, mesas, upland plains, terraces, plateaus, rocklands and mountains. The highest point in the watershed is Signal Peak at elevation 10,365 feet. Above the reservoir, the average stream gradient is 4.7 percent.[13] The Santa Clara is a sediment-laden river with stream banks vulnerable to erosion during high flows. The primary sediment source is the upstream watershed which contains highly erodible soils. Finally, Santa Clara river flow volumes vary widely. About two-thirds of the time flows are below average, while one-third of the time they are above average.

In 2004 a sediment survey was completed below elevation 3,562 feet. The water elevation when the reservoir is full is 3,584 feet, a difference of 22 feet. This survey revealed that the storage capacity decreased by 3,101 acre-feet or approximately 29 per-

<u>Gunlock Reservoir</u>

Built: 1971
Dam: Earth fill
Surface Area: 266 acres
Original Storage Capacity: 10,884 acre-feet
Watershed: 306 mi^2
Maximum Depth: 115 feet
Mean Depth: 77 feet
Length/Width:1.8/0.7 miles
On-Stream Source: Santa Clara River
Current Uses: Irrigation and recreation

Sedimentation Rate/Loss of Capacity: 0.86% per year (1971-2004) or 28% as of 2004
Sediment Characteristics: Fines and sand

Management Strategies: Trap and excavate sediments upstream. Drain and excavate sediments near outlet.

Benefit: Restore outlet works function.

cent. The 2004 capacity was 7,783 acre-feet. This is a loss of roughly 94 acre-feet or 0.86 percent per year of the original capacity over the time period from 1971 to 2004. This estimate understates the actual sedimentation rate because there are sediment deposits in the reservoir that were not surveyed above the 3,562 ft elevation.

Gunlock Reservoir. Debris, left over from flooding, can be seen in lower left-hand corner. Debris, such as this, covered the entire surface of the reservoir after the large flooding events of 2005 and 2007.

In addition to the shortcomings of the 2004 reservoir survey, two significant flooding events have occurred since then, depositing more sediment into the reservoir.

During the summer of 2005, wildfires within the watershed burned the vegetative cover exposing the soil and increasing its vulnerability to erosion. The wild fires were followed by a very wet winter. The high snowpack resulted in a 100-year flood event.

In January of 2005, peak flow into the reservoir was estimated to be 5,200 cfs. By comparison, the overall average flow before 2005 was 23.4 cfs and the average January flow was only 20.7 cfs at the Gunlock stream gauge.[14] During the 2005 flooding event, the sediment and debris laden water tore through the town of Gunlock and entered the reservoir, depositing sediment and debris.

This flood transported fine-grained sediment the entire length of the reservoir to the base of the dam. The intake works for the pressurized irrigation system were clogged for three weeks. At a cost of about $60,000, large air compressors were brought in and connected to the irrigation line to blow out the sediment and debris from around the 30-inch intake pipeline.[15] Trees and other debris covered the entire surface of the reservoir and a community-wide effort was required to remove them.

Several different layers of sediment are visible along the banks of the Santa Clara River immediately upstream of Gunlock Reservoir.

In 2007 another flood event occurred, further exacerbating the sediment problems at the intake. During the fall of 2008, the intake was again cleared using compressed air, and the reservoir was drained. As it drained, sediments deposited in the upper reservoir were eroded and moved further into the reservoir. Sediment was excavated to a depth of about eight feet from the area adjacent to the low level outlet. The outlet works were modified as a result of these experiences. The outlet pipeline through the dam was retained and a new intake structure was connected to that outlet. That structure lies along the upstream face of the dam and has multiple openings at regular intervals. This allows water to be removed from the reservoir at several elevations should sediment encroach on the structure in the future.

The Washington County Water Conservancy District (WCWCD) has looked at various alternatives to address the sedimentation problem at Gunlock Reservoir. The cost of dredging and excavation of sediments within the reservoir was investigated, but was found to be too expensive. Instead, it was decided to renew a stream alteration permit for a local sand and gravel company to excavate sediment from the streambed and sediment delta above the reservoir. The district believes that by constructing a small catchment in the stream above the reservoir, the bed load in the Santa Clara River can be captured, removed and sold. The district believes this will improve the channel hydraulics and help avoid flooding just upstream in the town of Gunlock.[16] Although the modest mining operation will help reduce the sediment entering the reservoir during normal and low-flows, it is unlikely to reduce the greater part of sediment that enters the reservoir during future high-flow events.

Millsite Reservoir *(Sediment Pass-through, Enlarge Dam and Hydrosuction Dredging)*

Millsite Reservoir is located at the mouth of Ferron Canyon on Ferron Creek, approximately two miles west of Ferron City in Emery County. It was completed in 1971 and had an original capacity of 18,000 acre-feet. The watershed is a high desert with the highest point being 11,130 feet. The stream has an average gradient of 4.7 percent.[17] The primary source of sediment is difficult to determine. Some believe it to be higher elevation shale deposits which are transported to the reservoir during spring runoff and summer thunderstorms. Others consider the un-vegetated Mancos Shale formation immediately upstream of the reservoir to be the main contributor. It is likely a combination of the two.

The Natural Resources Conservation Service (NRCS) surveyed the reservoir in 2004 and found the capacity had declined by about 2,600 acre-feet to 15,400 acre-feet. This is a decline of about 14 percent of the original capacity.[18] This equates to an annual capacity loss of 79 acre-feet or 0.44 percent per year. This is more than twice the statewide average sedimentation rate.

Millsite Reservoir was initially designed with a dead pool of 5,800 acre-feet near the dam to allow for sedimentation. However, most of the sediment is deposited at the upper end of the reservoir and therefore reduces active storage capacity. During drawdown, Ferron Creek meanders through exposed sediment and erodes them to a depth of about 12 feet. See photos below. This transports sediment closer to the dam.

Currently, sediment is minimally managed by sediment pass-through. The primary outlet from the reservoir is a 54-inch diameter pipe. It is used to convey irrigation water. During high flow events, when the reservoir is spilling, the gate to this pipe is opened in order to pass sediment. This only removes sediment from the immediate area around the intake structure and routes possible density currents at the same time. This strategy has delayed the need to raise the intake structure, which was planned in the original design.

Millsite Reservoir

Built: 1971
Dam: Earth fill
Dam Height: 125 feet
Surface Area: 435 acres
Original Storage Capacity: 18,000 acre-feet
Watershed: 157 mi^2
Maximum Depth: 102 feet
Mean Depth: 46 feet
Length/Width: 1.38/0.66 miles
On-Stream Source: Ferron Creek
Current Uses: Recreation and irrigation

Sedimentation Rate/Loss of Capacity: 0.44% per year (1971-2004) or 14% as of 2004
Sediment Characteristics: Fines
Sediment Load: 441 tons/day

Current Management Strategy: Sediment pass-through to remove sediment around intake structure during high flow
Recommended Management Strategy: Hydrosuction Dredging
Cost: $302,000 capital, $14,000 annual

Benefit: Maintain current reservoir capacity and possibly restore some original capacity.

Extensive sediment deposits exposed after drawdown of Millsite Reservoir. Ferron Creek has eroded a distinct path through the sediment as evidenced by the snow-filled meander. Note the barren gray Mancos Shale immediately above the reservoir.

Close-up of deposited sediment in Millsite Reservoir. Also see the cover of this report.

The reservoir typically spills for four to six weeks, depending on the runoff volume. It usually starts in late May. Spilling continues until the inflow subsides or the irrigation demand outpaces inflow.[19] The spilled water could be used in a sediment management strategy to remove or bypass sediment. Dam upgrades are being considered that will help mitigate sediment-caused capacity losses. NRCS is planning to nearly double the spillway capacity and raise the dam by 2.5 feet. These are required since the present spillway does not pass the maximum probable flood, and the reservoir cannot contain that flood until it has passed through the spillway. Raising the dam will increase the flood storage capacity of the reservoir by 500 acre-feet and also extend the reservoir life.

In February 2008, Ferron Canal Company contracted with a consultant to assess the sediment situation at Millsite and to define potential sediment management methods. Five methods were identified: reduce upstream soil loss through watershed management, dredging, sediment bypass, sediment flushing, and hydrosuction dredging. Reducing upstream soil loss was deemed not feasible due to the size of the watershed and erodable soils that do not vegetate. Neither flushing nor sediment pass-through is feasible due to potential negative effects to downstream water users.

TABLE 6
Feasibility Analysis of Managing Sediment in Millsite Reservoir

Alternative	Technical Potential	Economic Feasibility	Environmental Feasibility	Comments
Reduce Erosion	Not feasible	-	-	Not feasible
Dredging (dry)	High	$33.5 million	Low impact	Extends life about 15 years
Sediment Bypass	Medium	$805,000 Capital $650,950 Annual O&M	Low impact	Extends life indefinitely
Flushing & Sediment Pass-through	Not feasible	-	-	Not feasible
Hydrosuction Dredging (barge)	High	$302,000 Capital $13,790 Annual O&M	Desirable	Extends life indefinitely
Hydrosuction Dredging (hydraulic)	High	$637,000 Capital $13,790 Annual O&M	Desirable	Extends life indefinitely

Source: Adapted from Table 5, Rollin H. Hotchkiss, *Millsite Dam and Reservoir Sediment Management Feasibility Study,* July 21, 2008, page 20.

The analysis of these various methods is shown in Table 6.

Mechanically dredging the reservoir could restore and maintain water storage. However, the estimated cost of $34 million is prohibitive. Bypassing the sediment to a detention pond would cost roughly $800,000 in capital and also $650,000 annually. The most cost-effective, and thus recommended, management strategy is hydrosuction dredging. This strategy would utilize overflow water to remove and transport sediment from the upper end of the reservoir to the spillway. This has the potential to maintain the current storage capacity indefinitely.

The estimated set up cost for a hydrosuction dredging system is about $300,000 to $640,000 depending on the type of system with annual operation and maintenance costs of about $14,000.[20] This system could possibly restore some of the original capacity during wet years when there is additional water available to continue dredging over a longer time period. No outside energy would be required for a hydrosuction dredging system to operate at Millsite Reservoir. However, should the sediments be compacted and not break up easily, an electrically-powered mechanical device would be needed to disrupt them at the suction pipe inlet.

Piute Reservoir *(Enlarge Dam)*

Piute Reservoir was completed in 1908 and is located just below the confluence of the East Fork Sevier River and the Sevier River. The reservoir is shallow relative to its capacity. The highest point in the watershed is the Fish Lake Hightop Plateau at 11,633 feet. Two large reservoirs are located upstream, Panguitch Lake (located on the Sevier River) and Otter Creek Reservoir (located at the confluence of Otter Creek and East Fork Sevier River). The average stream gradient is 1.3 percent or 69 feet per mile.[21] The reservoir's immediate surroundings are composed largely of sagebrush rangeland. The watershed contains eroded volcanic rock in the high elevation areas and alluvial deposits nearer to the reservoir. The dam has been upgraded since the original construction for safety reasons, most recently between 2002 and 2005.

Sedimentation has been a concern at Piute Reservoir for many years. Although upgrades were done for safety reasons, the influence of sedimentation was considered, and some reservoir capacity was regained by raising the dam. Original reservoir capacity was 81,200 acre-feet. The reservoir was surveyed in 1938. This revealed the storage capacity had declined by 7,190 acre-feet, about nine percent of original capacity, to 74,010 acre-feet.[22] Averaged over the 30 years from 1908 to 1938, the sedimentation rate is 0.32 percent, or 257 acre-feet per year. The reservoir was recently surveyed again. The results indicate another nine percent of capacity was lost from 1961 to 2004. This corresponds to a sedimentation loss rate of 0.21 percent over the 43-year period.[23] The reservoir currently has a storage capacity of 71,826 acre-feet.

The outlet works were upgraded as part of the dam rehabilitation from 2002 to 2005. The original guard gate was inoperable and the gate structure was not seismically adequate. In addition, the original system was inadequate to meet downstream water demands and reservoir evacuation requirements. As a result of the upgrade, 90 percent of the reservoir can

Piute Reservoir

Built: 1908
Dam: Earth fill
Dam Height: 90 feet
Surface Area: 2,508 acres
Original Storage Capacity: 81,200 acre-feet
Watershed: 2,440 mi^2
Maximum Depth: 66 feet
Mean Depth: 33 feet
Length/Width: 6.9/0.9 miles
On-Stream Source: Confluence of Sevier and East Fork Sevier River
Current Uses: Recreation and irrigation

Sedimentation Rate/Loss of Capacity: 0.32% per year (1910-1938); 0.21% (1961-2004)/ 18% as of 2004.
Sediment Characteristics: Fines from alluvial and volcanic rock

Management Strategy: Dam upgrade. Indirect sediment mitigation.
Project Completion Date: 2005
Cost: $8.2 million (dam upgrade)

Benefit: Dam was upgraded for dam safety reasons. This increased storage capacity to about 71,826 acre-feet.

be evacuated or drained within 30 days. Although not currently used for sediment management, the new outlet works could be used for this purpose by flushing or sediment pass-through. Additional investigation would be needed to determine the feasibility of these strategies. Sedimentation will continue to be an issue until a permanent management strategy is developed and successfully implemented.

Otter Creek *(Raised Spillway)*

Otter Creek Reservoir is located a few miles north of Antimony and roughly 15 miles southeast of Piute Reservoir. Similar to Piute Reservoir, Otter Creek Reservoir is relatively shallow. Otter Creek Dam was completed in 1897, making it one of the oldest dams in the state. The watershed is 364 square miles between the Awapa Plateau and Sevier Plateau. The highest point is the Fish Lake Hightop Plateau at 11,633 feet. The streams have an average gradient of 2.1 percent in the Otter Creek drainage and 0.8 percent in the East Fork Sevier River drainage. Upstream of Otter Creek Reservoir are Koosharem and Tropic Reservoirs on the Otter Creek and East Fork Sevier drainages, respectively. The soil within the watershed is predominately made up of volcanic rock in the higher elevations and alluvial deposits at the lower elevations.[24]

In 2004, a survey was conducted to determine reservoir capacity. It was estimated that from 1961 to 2004, a 43-year period, the reservoir storage capacity decreased by nine percent (4,500 acre-feet) from its 1961 capacity. This translates to a sedimentation rate of 0.21 percent or 105 acre-feet per year.[25] Extrapolating this rate all the way back to 1899 when the reservoir was built would mean the reservoir has lost approximately 22 percent of its total capacity as of 2004.

Much of the sediment is believed to be from the East Fork Sevier River drainage with less from the Otter Creek drainage. Some sediment is attributed to the feeder canal.[26] In 2005, a prescribed burn unintentionally denuded a large area leaving it barren and susceptible to erosion. Rainstorms soon caused substantial erosion. As a result, the feeder canal filled with sediment which required 12 days to clean out. It is not known how much sediment reached the reservoir during this period.

Otter Creek Reservoir

Built: 1897
Dam: Earth fill
Surface Area: 2,520 acres
Current Storage Capacity: 52,660 acre-feet
Watershed: 364 mi^2
Maximum Depth: 37 feet
Mean Depth: 20.6 feet
Length/Width: 6.55/0.73 miles
On-Stream Source: Otter Creek
Off-Stream Source: East Fork Sevier River (East Fork Canal)
Current Uses: Recreation and irrigation

Sedimentation Rate/Loss of Capacity: 0.21% per year (1961-2004) or an estimated 9% as of 2004
Sediment Characteristics: Fines from alluvial and volcanic rock

Management Strategy: Raise spillway to regain capacity
Cost: $224,000 (estimate)

Benefit: Raise water level two feet. Restore some of original storage capacity and increase water

The Otter Creek Reservoir Company was concerned that capacity loss due to sediment did not allow full storage. Water users have shares in the company. The amount of water actually delivered is based on the maximum storage capacity of the reservoir. Sedimentation resulted in the shareholders receiving less water per share.

In 2006, the Otter Creek Reservoir Company received financial assistance from the Utah Board of Water Resources to install two radial gates (about three feet high and 14 feet wide) in the service spillway. This raised the reservoir level two feet. The purpose of this upgrade was to recover storage capacity lost to sedimentation. This increased capacity to the current 52,660 acre-feet. Previous to these upgrades, the reservoir company placed flash boards in the service spillway to raise the water level and regain some of the lost storage capacity.[27]

First Dam *(Flushing and Sediment Pass-through)*

First Dam is located on the Logan River at the mouth of Logan Canyon in Logan, Utah. The river is managed as a blue ribbon coldwater fishery. It is a very visible river as it meanders along the highway in Logan Canyon and through residential sections of Logan itself. First Dam is one of a series of dams within Logan Canyon. There are two small dams located upstream which are completely filled with sediment: Second Dam and Third Dam.

In 2002, First Dam was upgraded to meet dam safety requirements. The dam was fortified with compacted concrete fill, and new spillways and pneumatic crest gates were installed. The hydroelectric power generation system was also replaced.[28]

There is a history of fish kills associated with maintenance activities at First Dam. In order to facilitate the 2002 upgrades, the reservoir was drained in 2001. Scheduling the reservoir draining was complicated due to potential negative impacts to irrigation and to the riparian environment. Draining also had to coincide with optimal hydrologic conditions. Before the release and flushing of the reservoir was begun, discussion with water users and stakeholders took several years. It proved difficult to get all the major stakeholders to cooperate.[29]

Utah State University owns the dam and maintenance personnel operate it. Since maintenance people are not hydrologists or Civil Engineers, they are not fully aware of reservoir water conditions and how flushing affects saturated sediments. In October of 2001, the low level outlet of the dam was opened with the intent of releasing water and sediment in a controlled manner. Unfortunately, a slug of anaerobic and sediment-laden water was released downstream. The impacts of the release were apparent within hours as about 2,000 Brown Trout and Whitefish were killed. Additionally, aquatic habitat was temporarily impaired and irrigation canals accumulated considerable sediment since they were open at the time. This resulted in poor publicity for the university and fines from the Utah Department of Environmental Quality.[30]

This case highlights the difficulty of flushing a reservoir without negatively impacting downstream

First Dam Reservoir

Built: 1914
Dam: Compacted concrete-fill
Dam Height: 30 feet
Crest Length: 250 feet
Original Storage Capacity: 70 acre-feet
Watershed: 226 mi^2
On-Stream Source: Logan River
Current Uses: Recreation, Irrigation Hydropower, and Research Lab

Sedimentation Rate/Loss of Capacity: 0.74% per year (1914-2001) or 64% as of 2001

Management Strategy: Sluicing

Benefit: Maintains current storage capacity

Cost: Difficult to manage. Potential environmental impacts and current turbidity & water quality requirements are difficult to achieve.

Left: Upstream view of sediment behind First Dam when it was drawn down for repair.
Right: Downstream view of First Dam after upgrade. (Photos courtesy of Utah Water Research Laboratory.)

Dead fish downstream of First Dam after flushing the reservoir. (Photo courtesy of Utah Water Research Laboratory.)

aquatic life, riparian habitat and water users when done irregularly. If done regularly to coincide with high flows, the impacts would be less. It also underscores the need for effective sediment management practices to be determined on a case-by-case basis and to have effective dialogue between reservoir operators, water quality officials and other stakeholders.

The Utah Water Research Laboratory (UWRL), located just downstream of the dam, has studied the sediment management challenges at First Dam. The scope of their studies does not include sediment management practices that requires additional infrastructure. Rather, it focuses on management strategies and monitoring that utilize existing facilities. To do this, the laboratory developed a rating curve showing the relationship between real-time stream turbidity levels (Nephelometric Turbidity Units) and stream sediment load. These are monitored above and below the reservoir. This system now monitors release events in real time.

Sediment pass-through was identified as the most appropriate sediment management technique. This involves partial drawdown of the reservoir followed by routing sediment-laden spring runoff through the reservoir. However, even with sediment pass-through, turbidity levels below the dam can increase above water quality standards required by Utah's regulatory agencies. The challenge for dam operators is to match incoming turbidity levels with similar outgoing turbidity levels. This requires monitoring and careful adjustment of outgoing flows in real time.

Currently, UWRL estimates that without sediment pass-through activities, First Dam would lose about 0.5 acre-feet per year of storage capacity. From 1914 to 2001 (87 years) the reservoir is estimated to have lost 45 acre-feet of storage capacity. Thus, the current capacity is approximately 25 acre-feet. This storage capacity loss equates to 0.52 acre-feet per year during that period or an annual sedimentation rate of 0.65 percent per year.

Quail Creek Diversion Dam *(Sediment Pass-through and Dredging)*

The Quail Creek Diversion Dam is located on the Virgin River, a few miles south of La Verkin, in Washington County. The dam is a concrete gravity structure that spans the Virgin River Gorge. Completed in 1984, the structure has the capacity to impound 295 acre-feet. The watershed is large, covering almost 1,000 square miles. As the name implies, this structure diverts water to Quail Creek and Sand Hollow reservoirs. These are offstream reservoirs used for recreation, agriculture and drinking water. The combination of a large watershed and erosive soils results in the Virgin River transporting relatively high sediment loads. Combined with the small storage pool behind the dam, this necessitates frequent sediment removal. In addition, aquatic life in the region is strictly managed. The Woundfin, Virgin River Chub, Virgin Spinedace, and Flannelmouth Sucker, which inhabit the Virgin River below the diversion, are either federally listed as threatened species or otherwise eligible for special protection. Thus, sediment management at the diversion dam

Quail Creek Diversion

Built: 1984
Dam: Concrete gravity
Dam Length: 95 feet
Original Storage Capacity: 295 acre-feet
Watershed: 1,000 mi^2
On-Stream Source: Virgin River
Current Use: Divert water to the Quail Creek and Sand Hollow reservoirs for agriculture, recreation and drinking water.

Management Strategy: Follow sediment management plan. Sluicing and mechanical cleanout requires careful consideration of water quality and effects on the downstream ecosystem.

Before 2004, there was no official procedure for sediment management at the diversion. It was, however, common practice to conduct sediment pass-through releases during high flow events. One such event took place in September 2003, six months after a previous sediment pass-through event. This resulted in killing many fish, temporary increases in turbidity and temporary decreases in dissolved oxygen. The situation also resulted in an investigation by the U.S. Fish and Wildlife Service in conjunction with the Utah Division of Wildlife Resources.[31] The fish kill demonstrated the need for a sediment management plan.

In 2004, the Washington County Water Conservancy District (WCWCD) developed a sediment management plan which provides guidelines for sediment releases below the diversion. The intent is to limit water quality impacts and to restore natural fluvial processes.[32] Successful implementation of the sediment management plan has resulted in minimal damage to aquatic life and the environment.

Quail Creek Diversion Sediment Management Plan[33]

The plan specifically addresses accumulated sediment releases at the diversion by providing guidelines for those releases. It also provides for water quality monitoring. The plan is intended to protect beneficial uses and environmental conditions downstream of the diversion. Virgin River hydrology was analyzed to define the frequency and duration of high flows, and to estimate sediment transport and deposition at the diversion structure. The plan assumes the worst case scenario applies to sediment releases – namely that released sediments have a high biochemical oxygen demand. A downstream river channel survey was conducted to quantify sediment transport and deposition under different flow conditions. From these surveys and hydraulic calculations, minimum flow rates were identified that would prevent downstream sediment deposition. See Figure 21 for a sample of recommended releases or accumulated sediments in conjunction with Virgin River flows for the 1996 water year.

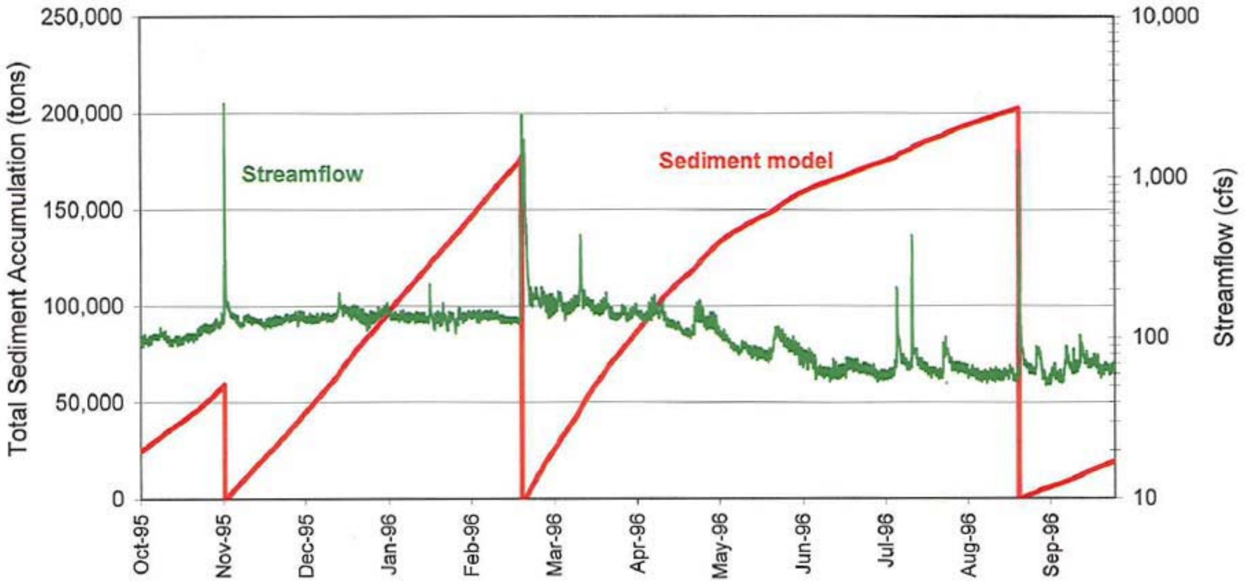
The plan involves ongoing modeling of accumulated sediments and identifies river discharge rates that are suitable for release of varying amounts of accumulated sediments. The model allows for the release of sediments and the creation of suspended solids conditions naturally experienced in the river. This method also provides a good management tool to prevent oxygen demand problems.

The plan recommended the following actions be taken to help ensure successful sediment releases:

- Install a low flow sediment bypass system or siphon to remove the top layer of sediment and combine it with the constant three cubic feet per second fish release flow.
- Remove sediment mechanically near intake pipes to avoid sediment releases via the sluice gate when flows are below 700 cfs.

Quail Creek Diversion Dam on the Virgin River near Hurricane Utah. (Photo by Ron Ollis).

FIGURE 21
Sample of Recommended Sediment Releases from Quail Creek Diversion Using Virgin River Hydrograph for 1996 Water Year



The red line shows estimates of sediment accumulation behind the dam and subsequent sediment removal when flows rise above 700 cfs.
Source: Olsen, Darren, *Quail Creek Diversion Interim Sediment Management Plan,* (Logan: BIO-WEST Inc., 2004), B-7.

- Open the sluice gates during flows above 700 cfs to evacuate accumulated sediment and minimize downstream Total Suspended Solids concentrations.
- Implement thorough water quality monitoring and reporting .
- Modify sediment removal guidelines as necessary to improve effectiveness of future sediment releases.

As part of that last recommendation, WCWCD prepares a regular summary of sediment pass-through activities and makes necessary adjustments to future release schedules based on analysis of the summary. The sediment management plan is coordinated with the Utah Division of Wildlife Resources and the U.S. Fish and Wildlife Service.

OTHER RESERVOIRS

Gebidem Reservoir, Switzerland *(Flushing)*[34]

Gebidem Reservoir is located in the Valais Canton (state) of Switzerland's Alps region. The dam is on-stream and includes a hydroelectric generating plant which harnesses the power of the Massa River, a tributary to the Rhone. The dam is 400 feet high with a crest length of 1,073 feet. Due to topography, a narrow gorge, and a 5 percent stream slope, the dam only impounds about 7,460 acre-feet of water. This is a small volume of water for a dam this height.

The majority of the Gebidem Reservoir's watershed is covered by the d'Aletsch Glacier. Glacial till is the primary source of sediment. In addition to glacial melt, flow into the reservoir also comes from snowmelt and summer storms. The sediment yield of the d'Aletsch Glacier is much higher than that of nearby unglaciated mountain areas.[35] Roughly 324 acre-feet of sediment (4.3 percent of the reservoir's total capacity) enters the reservoir each year. Civil engineers anticipated a high sediment load and designed it with sediment management in mind. Had they not, the reservoir would have filled with sediment after about 25 years and the hydroelectric function might have been impaired even sooner.

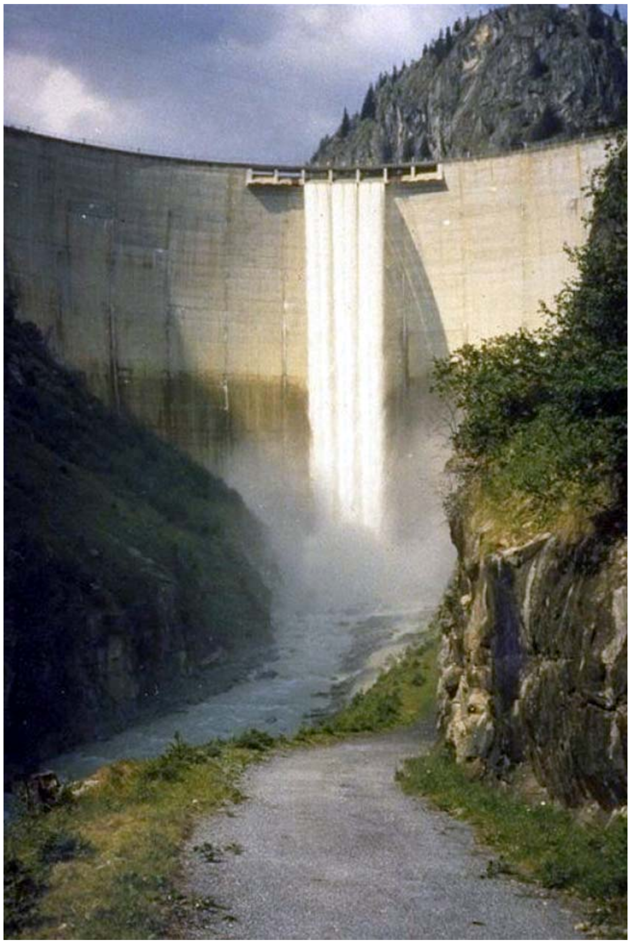
Gebidem Reservoir

Built: 1967
Capacity: 7,460 acre-feet
Dam Height: 400 ft
On-stream Source: Massa River
Current Use: Hydropower
Reservoir Length: 0.93 mi

Sedimentation Rate/Information: 324 acre-feet per year
Sediment Characteristics: very fine sand to gravel

Management Strategy: Emptying and Flushing
Sediment Removed: About equal to annual accumulation
Cost: 0.8 franc per 35 ft^3 sediment removed (1970 currency)

Benefit: Substantially increased longevity of the hydroelectric facility



Gebidem Dam, free overspill spillway.
(Photo from Swiss Committee on Dams web site.)

During dam design, several sediment management strategies were proposed. However, only three were studied. These included sediment bypass, periodic dredging and the chosen strategy of emptying and flushing. In addition to being the most economically feasible option, flushing also used the least amount of water. It was originally estimated at 6,490 acre-feet per year, but in practice proved to be much less at 2,432 acre-feet per year.[36] Sediment is flushed through the bottom outlets annually during a two- to four-day period between May and June. These are the original low-level outlets designed to empty the reservoir. There is a radial gate downstream and a flap gate upstream. Flushing has kept sediment from accumulating in the reservoir bottom. Despite the overall success of annual flushing, the dam was modified in 1996 to further minimize sediment impacts. Sediment passage during normal operation caused deterioration of the hydroelectric turbines. In addition, there was wear on the sluice gate seals due to sediment passage during flushing. A multi-level intake tower was installed to reduce these impacts.

In order to dilute the discharged sediment load, flushing is timed when the Massa River flow is low and flow in the Rhone, the receiving stream, is high.[37] Flushing is preceded by lowering the reservoir to its minimum operating level by releasing water through the turbines. The sluice gates are then gradually opened over a two-hour period. Free flow conditions are reached after three to six hours. If needed, the gates are closed and then opened again after about 20 minutes (pressure flushing) to better scour and remove sediment around the base of the dam.[38] This flushing strategy has greatly increased the longevity and operational value of the dam as a hydroelectric facility.

North Fork Feather River, California *(Watershed Management)*

Pacific Gas and Electric Company (PG&E) operates three small hydroelectric dams on the North Fork Feather River. This stream drains a portion of the Sierra Nevada Mountains. Rock Creek Dam, Cresta Dam and Poe Dam are in series. The three reservoirs are downstream of the larger Oroville Reservoir, located nine miles east of Oroville, California.

North Fork Feather River Watershed

Size: 656,600 acres
Management Strategy: Watershed restoration
Projects Completed: Over 30
Cost: Varies per project. 10 projects were completed in Pumas County at a cost of $2,063,000.
Benefit: 50% decrease in sediment yield over 30 years. Increased environmental quality. Increased power production.
Lower maintenance costs.

Benefit: Substantially increased longevity of the hydroelectric facility

Sediment management was considered during design of the Poe Dam. It has underflow radial gates for sediment passage. This dam has reached a state of equilibrium where sediment input about equals output. Rock Creek Dam and Cresta Dam, however, are not well suited for sediment passage and are effective sediment traps. Sediment reaches these reservoirs from the surrounding East Branch watershed primarily during the spring snowmelt and winter storm events.

Operational difficulties and downstream environmental impacts caused by reservoir sedimentation and watershed erosion led PG&E to initiate sediment management. This was achieved through a combination of long-term watershed management and reservoir sediment management techniques. All of this involved the coordinated and cooperative efforts of several agencies and institutions. This resulted in formation of a Coordinated Resource Management (CRM) group. The group's goals are "to identify erosion sources, coordinate between public and private landowners, implement erosion control projects where practical, ensure project cost-effectiveness for contributors, and develop a cooperative regional erosion control plan."[39] Historic land uses, such as mining, logging and grazing, degraded the watershed and riparian environments. All of these exacerbated and perpetuated erosion and sediment transport downstream.

CRM has initiated more than 30 restoration projects to treat erodible soils and other problem areas within the watershed. Projects include stream and meadow restoration and stabilization. The projects have increased the overall health of the watershed. In addition, it is estimated that completion of such projects could result in additional power production of 15.7×10^6 kwh per year, plus reduction of $75,000 per year in turbine maintenance costs.[40]

In addition to the long-term watershed projects, PG&E initiated onsite reservoir activities such as dredging and routing to minimize sediment impacts in the short-term while the watershed management plan comes to fruition.

Valentine Mill Pond, Nebraska *(Hydrosuction Bypass)*

Valentine Mill Pond is located about 10 miles south of the South Dakota – Nebraska border in Cherry County near the city of Valentine. The reservoir was constructed in the early 1890s to provide energy for a flour mill and later to harvest ice. This on-stream reservoir is very shallow (maximum depth approximately 12 feet) and is fed by Minnechaduza Creek. Until the 1970s, the reservoir was a popular recreation destination. However, sedimentation eventually limited the reservoir's recreation appeal. The reservoir's original surface area of 30-plus acres had steadily shrunk to less than 15 acres resulting in ex-

Valentine Mill Pond

Built: Early 1890s
Size: 37 acres surface area
Maximum Depth: 12 feet
On-stream Source:
Minnechaduza Creek
Current Use: Recreation

Sedimentation Rate/Information: By the 1970s over half the capacity was lost
Sediment Characteristics: Sand

Management Strategy: One-time dredging. Hydrosuction bypass sediment removal system
Sediment Removed: 160,000 yd^3
Project Completion Date: Summer 2002
Cost: $1.6 million

Benefits: Improved water quality, recreation, aquatic life, & aesthetics. Sediment reduction.

Labyrinth spillway design at Valentine Mill Pond. (Photo by John Bender, Nebraska Department of Environmental Quality.)

posed mud and sediment bars.[41] Funding to properly diagnose and assess the problem was not available until the mid-1990s under the "Clean Lakes Program" administered by the Nebraska Department of Environmental Quality (NDEQ). The Middle Niobrara Natural Resources District conducted a study and estimated that as much as 60 tons of sediment was deposited in the reservoir daily. The reservoir's longevity was seriously challenged, and by 1995 only ten acres of the pond was greater than two feet deep.[42] This and other information prompted inclusion of the reservoir in the NDEQ's section 303(d) list for impaired water bodies, specifically for impairment to aquatic life due to sediment.[43]

In response, a cooperative effort to restore the reservoir was initiated and a plan of action developed. The plan outlined two main strategies to regain and maintain storage capacity in the reservoir: (1) mechanical dredge it to remove deposited sediments and reestablish reservoir capacity; and (2) install a unique labyrinth spillway coupled with a hydrosuction bypass system to maintain reservoir capacity.

A total of 160,000 cubic yards of sediment was removed during the dredging operation. 110,000 cubic yards were transported offsite with the remainder used onsite for rehabilitation purposes. The labyrinth spillway was the first of its kind in Nebraska. It allows large storm flows to pass through the reservoir automatically. See photo at left. The hydrosuction bypass system features a fixed inlet or sediment collection structure upstream of the sediment deposition zone within the reservoir. The collected sediment and water mixture is transported in a fixed pipe and discharged downstream of the dam.[44] This mimics the natural flow of bedload sediment before the dam was in place. There is limited outside power required in this process and it is ideal for small reservoirs that meet certain criteria. The total cost of the restoration project was $1.6 million.

The project has been successful at addressing the sedimentation issues. The result is higher water quality including reductions in phosphorus, nitrates and total suspended solids. The reservoir has a much more stable storage capacity. However, as operation and maintenance staff at the reservoir have changed, the new staff has become less and less aware of how to properly operate and maintain the system. As a result, it has not been operated as efficiently as it could be.[45] This emphasizes the importance of written operating procedures in order to operate the system properly through time.

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[3] Barton, James R., *"A Report on the Water Resources and the Needs of the Present Irrigation Systems – Escalante River Basin Near Escalante, Utah,"* Salt Lake City: Utah Department of natural Resources, 1969, page 2.

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[7] Ibid, pages 5-6.

[8] Ibid, page 5.

[9] Utah Division of Water Resources, 1973, page 1.

[10] Ibid, page 48.

[11] Ibid, pages 1-2.

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[16] Information obtained from a stream alteration permit application submitted to the Utah Division of Water Rights by Corey Cram of the Washington County Water Conservancy District, January 6, 2009.

[17] Cameron Jenkins, Andrew Barney and Tamara Rabadi, *Sediment Removal Study of Millsite Reservoir*, Provo: Brigham Young University, 2008. This report was written by the students of the CeEN 470 class in conjunction with the Ferron Canal Company contract with Dr. Rollin Hotchkiss to study sediment management options at Millsite Reservoir. Dr. Hotchkiss was functioning in two roles. One as a student supervisory instructor and the other as a consultant to the canal company.

[18] Ibid.

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[24] Ibid.

[25] Personal communication with Ivan Cowley, president of Otter Creek Reservoir Company, September 2008. Data cited are estimates only.

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[36] Ibid, 21.3.

[37] Ibid, 21.4.

[38] Ibid, 21.5-21.6.

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9

CONCLUSIONS AND RECOMMENDATIONS

By publishing this report, the Utah Division of Water Resources has detailed what is currently known about reservoir sedimentation in Utah and presented various available techniques and strategies that prevent measure and mitigate the problem. The sedimentation situation has been reasonably defined and the case presented to justify further efforts. This chapter presents the key conclusions derived from the study and makes specific recommendations for further actions.

CONCLUSIONS

1. Information about sedimentation rates in Utah is limited. Sedimentation data exist for only a few Utah reservoirs. Much of these data comes from reservoir surveys conducted between 1930 and 1975 by the U.S. Soil Conservation service and the U.S. Bureau of Reclamation. In total, sedimentation data could be found for only 25 reservoirs in the state. These reservoirs are listed in Table 2 of Chapter 3, but only represent approximately 16 percent of the total capacity of all Utah reservoirs.

2. Utah's estimated average sedimentation rate is 0.2 percent per year. This figure is based on the limited available data and rough estimates for other reservoirs. Based on this, the total capacity loss would be about 12,340 acre-feet per year. The individual reservoirs for which data is available, are losing capacity somewhere in the range of 0.02 to 4.1 percent per year, with nearly one-third of those reservoirs losing capacity at an alarming rate above 0.75 percent per year. The statewide sedimentation rate is consistent with the national average of 0.20 to 0.21 percent per year; but is well below the international average of 1.0 percent per year. It should be remembered, however, that sedimentation is not a constant value each year. A large flood can deposit the equivalent of a decade of sediment in just a few days.

3. Although sedimentation may not be an urgent concern, it is still a very important issue. The volume of storage lost due to sedimentation in Utah's reservoirs is small when compared to an annual water supply that can fluctuate 50 to 100 percent from year to year. Thus, the losses due to sediment may not be noticed until droughts occur and storage requirements are critical.

Utah's population is the fastest growing in the entire country. Every year, water for about 69,000 additional people must be provided. M&I water needs will increase for the foreseeable future. Adequate water storage capacity is very important to a sustained water supply. The annual net loss in storage capacity, coupled with the increased need for storage, will no doubt cause future problems.

Because sedimentation is a LONG TERM issue, the need for action is now. Once the situation becomes "critical" it may be too late for the most cost-effective alternative, some options may not be available at all, and remediation costs will be much greater. Most mitigation actions take years to fund and implement. There is still time to take effective action if those responsible act appropriately.

4. Sedimentation is already a critical concern for a number of individual reservoirs. Although sedimentation may not yet be critical statewide, there are

several individual sites where sedimentation has already had significant impacts on reservoir operations. Some of the affected reservoirs include: Wide Hollow, Millsite, Gunlock, Piute and Otter Creek. In addition to the identified reservoirs, there are undoubtedly many others that will soon feel the impact of accumulating sediment. Over 88 percent of Utah's reservoirs have no sedimentation data at all. Each individual reservoir needs to be evaluated for sedimentation impacts. The evaluation should include future increased M & I demand.

5. Utah's net reservoir storage capacity has been declining since the mid-1990s. Since Utahns first started building reservoirs in the 1870s, the state experienced an increase in reservoir storage capacity at an average of about 16,000 acre-feet per year. Since 1992 the rate of new reservoir storage capacity has declined to an average of only 3,000 acre-feet per year. Meanwhile, sediment is accumulating in Utah's reservoirs at a rate of about 12,000 acre-feet of storage capacity each year. Consequently the State's net reservoir storage capacity has been declining since about 1992, and will continue to decline unless something is done to mitigate it.

6. Sediment management can effectively mitigate sedimentation in reservoirs. There are several mitigation strategies that can be employed by reservoir owners to: 1) Reduce the amount of sediment entering the reservoir, 2) minimize deposition of sediment within the reservoir, 3) remove deposited sediment from the reservoir, and 4) otherwise compensate for the loss of storage capacity caused by sedimentation. Methods used to reduce the amount of sediment entering the reservoir include watershed management, upstream trapping of sediment, and locating reservoirs off-stream. All of these strategies have been employed in Utah. Minimizing the deposition of sediment within a reservoir can be accomplished through sediment pass-through, density current venting, sediment bypass and hydrosuction bypass. Many Utah reservoir owners are less familiar with these strategies; consequently they have been less employed than other methods of sedimentation reduction. The removal of sediment from reservoirs can be accomplished through flushing, excavation and dredging. These strategies have been used by a few Utah reservoir owners to prolong the life of their reservoir. Finally, the loss of reservoir storage can be mitigated in a number of ways including enlarging the dam, constructing a new dam, conjunctive management, aquifer storage and recovery, and increasing the efficiency of water use.

7. Active watershed management has reduced Utah's sedimentation rate over time. Utah's limited data indicates that the sediment deposition rate has been significantly lower during the latter part of the 20th century, as compared to the first half of the century. There is good reason to believe that this reduction resulted from improved watershed management techniques and strategies initiated since the 1960s in response to the growing environmental movement to better manage the nation's natural resources. In the early part of the 20th century, the primary goal of land and resource management agencies was to maximize the immediate economic benefit resulting from grazing, mining and logging activities. The economic benefits of these activities are still important. In addition, today's land and resource management agencies have made a concerted effort to supervise these activities with the overall health of the watershed as an increasingly important goal. This helps sustain the land's productivity. The improved health of Utah's watersheds has resulted in an important secondary benefit of reducing the amount of sediment reaching Utah's reservoirs. Continual effort is needed to retain, and improve, these benefits.

8. Annual drawdown has likely reduced sedimentation in many of Utah's smaller reservoirs by flushing them. In Utah, many small reservoirs are drained completely to meet irrigation demands in the late summer or early fall. The fact that these reservoirs are emptied each year means that it's likely some of the deposited sediments get flushed from the reservoir annually. While perhaps unintended, sediment mitigation is a welcome consequence of this operational strategy that is common for many of Utah's small reservoirs. While there may be some negative consequences to receiving streams and downstream reservoirs, this has helped prolong the lives of those reservoirs.

9. Sediment management efforts can impact downstream environment and infrastructure. Flushing sediments from a reservoir can potentially impact downstream aquatic wildlife. In addition to high sediment loads, flushed organic material can dramatically raise the Biochemical Oxygen Demand

(BOD), producing low oxygen conditions and fish kills. Pollutants entrained in reservoir sediments can cause problems downstream. The size distribution of the released sediment can impact downstream biota, for example, destruction of spawning areas by selective release of fine particles and retention of coarse material. Sediment management activities are also likely to impact recreational activities at, and below, the reservoir. The impact of sediment releases on downstream facilities must be considered.

RECOMMENDATIONS

1. Reservoir owners should be proactive in addressing sedimentation. They should collect data to assess their situation, determine when significant shortages may occur, and develop long-range sediment management plans. That is, begin now to prevent or minimize future problems.

2. The Utah Division of Water Resources should help reservoir owners collect, analyze and interpret the data to determine the extent of sedimentation and possible impacts to reservoir users. In addition, the division should help identify potentially applicable sediment management alternatives. The division should also establish and maintain a long-term database of sedimentation data and reports. These data could be used to track the effectiveness of sediment mitigation efforts at individual reservoirs and throughout the state.

3. Water users should support organizations that are already involved in watershed management, for example the Utah Partners for Watershed Development, so they can continue to improve watershed management programs and target problem areas. One viable option for mitigating reservoir storage losses is to construct new storage capacity and/or add sub-surface storage (aquifer storage and recovery). The Division should continue to identify storage sites and take steps to insure that these sites are protected to retain their availability. The Division should also provide data and make recommendations to water providers.

4. Those organizations already involved in watershed management, for example the Utah Partners for Watershed Development, should continue to improve watershed management programs and target problem areas. State and Federal agencies charged with managing human activities and natural resources in the watersheds need to continue to do so in ways that maintain and improve the health of the land and water. A great deal of effective work has been done to recover regions that suffered in the past from over-grazing, mining, logging, and other human activities. These activities need to be accomplished in responsible ways that maintain the long-term availability of these resources. Government agencies charged with regulating these activities have done a better job in recent years. However, there is still room for improvement. There are undoubtedly lessons being learned that can be used to further reduce erosion and improve water quality.

> **We can't solve problems by using the same kind of thinking we used when we created them.**
>
> —Albert Einstein

5. The Utah Division of Water Resources, should identify and make the most of opportunities to educate and inform the water community about sedimentation issues. This might include the annual Water Users Workshop, American Water Resources Association meetings, Utah League of Cities and Towns meetings and other water supplier gatherings.

6. State agencies involved with sediment release from reservoirs should establish a point of contact to assist reservoir operators. These would be the Utah Division of Water Quality, the Utah Division of Wildlife Resources and the Utah Division of Water Resources. Sediment releases are unique and require special expertise and experience. Moreover, by working together with the same persons in the various agencies, the specialists develop an understanding of the other agencies requirements and working procedures. They can work together to achieve their own, and the other agency's goals. This synergy is beneficial to all stakeholders and has been successfully employed in other subject areas.

Appendix A

Utah Reservoir Sediment Survey
2008

In 2008 the Division of Water Resources conducted a survey of the twenty-one dams listed in the accompanying table. These dams were selected primarily because of their age. They were built between 1889 and 1949 and represent some of the oldest dams in the state still in operation. Using the average sedimentation rate of 0.2 percent per year, the Division estimated the half-lives for these and other reservoirs throughout the state. These reservoirs were selected for the survey either because they have already passed their estimated half life, or they are relatively close to it. The survey was conducted in order to assess how much sedimentation has impacted the operation of these reservoirs over the years of their use.

The following questions were posed to all of the reservoir owners:

- What is the primary use(s) of the reservoir?
- Has any action been taken to mitigate, reduce or otherwise address sedimentation?
- Has any data been collected, or any analysis been performed in an attempt to determine how much storage capacity has been lost due to sedimentation
  - If Yes:
    - When was the data or analysis performed?
    - What type of data or analysis was performed?
    - Can the Division get copy of the data?
  - If No:
    - Has there been a noticeable loss of reservoir capacity due to sedimentation?
    - Do you have any plans in place to address the issue of sedimentation in the near future?
- Do you consider sediment accumulation to be an issue that needs to be addressed?
- Would you be interested in seeing a comprehensive study of sedimentation problems in Utah, including a discussion of potential mitigation measures?

Every reservoir owner responded positively to the last two questions, affirming that they consider sedimentation to be an important issue, and expressing interest in seeing a study about sedimentation issues in Utah. However, only two of twenty-one reservoir owners answered affirmatively that they have actually conducted a sedimentation survey to assess just how much reservoir storage capacity has been lost to sedimentation. These were the owners of Otter Creek Reservoir and Piute Reservoir. Additionally, only five reservoir owners acknowledged employing mitigation efforts in an attempt to reduce sedimentation at their reservoirs. These reservoirs were Otter Creek and Piute along with Blue Creek, Gunnison and Mountain Dell. Ultimately, only seven of the twenty-one reservoir owners surveyed expressed concern that sedimentation has become a critical issue with the potential of impacting their reservoir's operation in the near future. These reservoirs were: Juab, Blue Creek, Gunnison, Mountain Dell, Upper Enterprise, Otter Creek and Piute.

With so many owners of the State's ageing reservoirs indicating that sedimentation in their reservoir is not yet a critical issue or concern, the Division had to give consideration to why this should be so. Two possible reasons were considered. First, because sedimentation is such a slow process, it is quite possible that although a significant portion of the original reservoir storage capacity has been lost over the years, it has gone largely unnoticed by the users. There are several factors that may contribute to this. Yearly changes in weather can produce such vast differences in the annual water supply that a steady loss of 0.2 percent of storage capacity per year pales in comparison. Even after 20 years, the loss of about four to five percent of reservoir storage would seem insignificant in comparison with a 50 to 100 percent variation in annual runoff. Additionally, over the past century there have been many improvements in the irrigation systems and irrigation management methods. When water rights were first issued it was standard procedure to estimate irrigation watering efficiency to be about 50 percent. This meant that farmers were allowed to divert 4 acre-feet per acre of water to irrigate a crop that only needed 2 acre-feet per acre. Consequently it is quite possible that the real impacts of sedimentation are being masked by both variation in weather and water supply, and the improvements in irrigation efficiencies and management practices.

A second reason sedimentation may not have surfaced as an important issue for many of Utah's older reservoirs may be a function of how they are operated. Throughout the world most reservoirs are operated with a significant dead pool or carry-over storage. Even in Utah, most reservoirs are operated in this manner. This is particularly true for reservoirs that are operated as multi-purpose facilities, or at least with a recreational component attached to the reservoir. When a reservoir is operated in this manner the dead storage pool acts as a sediment trap or sink. But many of Utah's older and smaller reservoirs are operated solely for irrigation. This operation style means that the reservoir is completely drained on an annual basis. When the reservoir is operated in this fashion, some of the sediments deposited each spring are flushed annually from the reservoir as it is drawn down in the late summer and early spring. Even when a reservoir is not drawn down entirely, there may be a considerable amount of sediment flushing taking place. This natural flushing of sediments may also be enhanced by Utah's late summer and early spring thunderstorm activity which coincides with the reservoir basin's dewatered conditions.

As discussed in the mitigation section of Chapter 4, flushing is one of the most effective mitigation measures that can be employed to remove sediment from reservoirs. Many of the reservoirs included in the Division's survey fall into this category of being small and entirely used for irrigation and consequently drawn down completely or very nearly completely in the late summer and early spring.

Once it was realized that late season flushing of these smaller reservoirs may very well be mitigating sedimentation, the following question was also asked of the remaining owners that were contacted: *Do you feel that in the late season when the reservoir is drawn down, sediments are flushed from the reservoir?* The six reservoir owners to which this question was posed (Gunnison, Koosharem, Forsyth, Twin Pots, Rocky Ford, and Three Creeks Reservoirs) all answered affirmatively. Although they were unable to provide quantitative data, several provided anecdotal information about late season sediment loads in the downstream canals and/or stream.

In conclusion, it is believed that because many of Utah's older and smaller reservoirs are drawn down completely each year, the effects of sedimentation are being mitigated by natural flushing. Also, because of the high variability of Utah's water supply, and improvements in irrigation efficiencies, the impacts of sedimentation are being masked from reservoir owners and operator. Despite the fact that sedimentation has not surfaced as a major issue or problem for many of the dams included, this survey should not be construed as evidence that sedimentation does not impose a long range threat to the storage capacity of Utah's reservoirs.

The following is a summary of the reservoirs that were surveyed:

Juab Lake (Chicken Creek Reservoir)

Juab Lake, also known as Chicken Creek Reservoir, is located two miles southwest of Levan in Juab County on tributary streams: Chicken Creek and Little Salt Creek. The reservoir is used exclusively for irrigation and is drained completely on a regular basis. The owners reported that the canal washed out a few years ago and emptied a significant mud flow into the reservoir, but it has not yet affected the operations of the reservoir.

Gunnison Bend Reservoir

Gunnison Bend Reservoir on the Sevier River is located about a mile west of Delta, in Millard County. The Reservoir is used for both irrigation and recreation. Although Gunnison Bend Reservoir is not drained on a regular basis, it is very low in the basin. The Sevier River likely carries only very fine sediments at this location, much of which either stays in suspension and passes through the reservoir, or is re-suspended as large flows pass through this relatively small reservoir. This is possibly why the owner has reported that sedimentation has not been a problem.

Ninemile Reservoir

Ninemile Reservoir is located in the San Pitch River drainage approximately 5 miles east of Gunnison in Sanpete County. Ninemile Reservoir is actually an off-stream site with an estimated two-thirds of its inflow coming from springs. Due to this sedimentation is not considered to be a critical issue although the reservoir is over 100 years old.

Blue Creek Reservoir

Blue Creek Reservoir is located about a mile north of Howell in Box Elder County. The reservoir is used exclusively for irrigation and is completely drained on a regular basis. Between 10 to 15 years ago the owner built a sediment collection pond above the reservoir and the NRCS terraced the hillsides to reduce sediment runoff. Since that time sedimentation has not been an issue. Although the reservoir has been raised a couple of times in the past and the sedimentation pond was built to trap sediment, the owner reports that they do not have any real data on file.

Cleveland Reservoir

Cleveland Reservoir is located about 21 miles northwest of Huntington. The reservoir is used solely for irrigation. In addition to being drained periodically Cleveland Reservoir is an off-stream site and has not had problems with sedimentation thus far.

Gunnison Reservoir

Gunnison Reservoir is located on the San Pitch River about four miles southwest of Manti in Sanpete County. The reservoir is used for irrigation and some boating, although fishing is not very good. Although they don’t have any hard data, the owner estimates a loss of about 20 percent of the reservoir’s 20,000 acre-feet of capacity to sediment accumulation. This loss has occurred despite efforts to dredge and haul material from the reservoir over the years. Although they have periodically dredged and hauled sediment from the reservoir basin they have not document how much or when material has been removed.

Mountain Dell Reservoir

Mountain Dell Reservoir is on Parley’s Creek, approximately 8 miles east of Salt Lake City. It is used for M&I and flood control. Salt Lake City, the owner of the reservoir, reports that in the near future they plan to perform an aerial survey of the reservoir to assess sedimentation. This will coincide with the reservoir being drained to replace a valve. Salt Lake City also reports that they no longer open the bottom outlet of the reservoir due to concerns with sediment deposits in the proximity of the dam. Otherwise they are not aware of other sediment related impacts at this time.

Koosharem Reservoir

Koosharem Reservoir is located on Hole Creek approximately 6 miles north of Koosharem in Sevier County. The reservoir is used solely for irrigation and is drained routinely. Although the owner has not noticed any impacts from sedimentation, the topic is discussed periodically at meetings as a concern. The owner indicated that it is quite possible that late season releases do flush sediments from the reservoir.

Forsyth Reservoir

Forsyth Reservoir is located approximately 10 miles northeast of Loa in Sevier County. It is located at the junction of several creeks that are tributary to the Sevier River. The reservoir is used solely for irrigation and is completely drained on an annual basin. The owners report that they have noticed an accumulation of sediments in the reservoir, but do not believe that it is disruptive to service or delivery of water. They do feel that annual drawdown of the reservoir does reduce the sediment load by flushing out sediments.

Johnson Valley Reservoir

Johnson Valley Reservoir is located immediately downstream of Fish Lake on the Fremont River in Sevier County. The reservoir is used solely for irrigation. The owners have noticed sedimentation in the reservoir but do not believe that it has affected the use or reduced deliveries.

Upper Enterprise

Upper Enterprise Reservoir is located on Little Pine Creek approximately 8 miles southwest of Enterprise in Washington County. The reservoir is used entirely for irrigation. With the reservoir drained this year for repairs the owners noted that sediment elevation was 12 feet higher than the inlet to the original outlet pipe. Despite this fact they report that the owners have not noticed any impacts to their irrigation supplies.

Mona Reservoir

Mona Reservoir is located on Current Creek about 10 miles north of Nephi in Juab County. The reservoir is used for irrigation and some recreation. However, there is no conservation pool for recreation. The owner can draw the reservoir down completely when they need the water for irrigation. They have not had any problems due to sedimentation. Central Utah Conservancy District had an aerial survey performed a couple of years ago when the reservoir was drawn down, although the topographic information has not been developed from the data.

Twin Pots

Twin Pots Reservoir is located approximately 24 miles north of Duchesne in the foot hills of the Uintah Mountains. The reservoir is used solely for irrigation. The owners have not noticed any loss of capacity due to sedimentation. The reservoir is drained regularly for irrigation water and they regularly clean sediment from the canals so the owner believes that the sediment is being flushed regularly from the reservoir.

Rocky Ford (aka Minersville Reservoir)

Rocky Ford Reservoir is located approximately 5 miles east of Minersville, in Beaver County. The reservoir is used primarily for irrigation. However, there is a 2000 acre-foot conservation pool for fishing. They have not collected any data but the reservoir was drawn down completely in 1999 or 2000 and they noted the flat silty bottom that was not present when the reservoir was built. Their engineer noticed at the time of the draw down that there was 6 or 7 feet of sediment by the tunnel outlet. However, sedimentation has not created a problem for the operation of the reservoir.

Three Creeks Reservoir

Three Creeks Reservoir is located 12 miles east of Beaver in Beaver County. The reservoir is used for irrigation and power production. Recently, $3 million dollars worth of improvements were completed to comply with dam safety requirements. Improvements included earthquake resistance and spillway enlargement. The owner has not noticed any serious impacts due to sedimentation. However, the owner is concerned about the future development that is planned upstream of the reservoir at the Mount Holly Resort.

Oaks Park Reservoir

Oaks Park Reservoir is located approximately 20 miles north of Vernal in Uintah County. The reservoir is used for irrigation only. The owner reports that the inflowing water is very clean and sediment has not been an issue in the reservoir or canals.

Birch Creek No. 2 Reservoir

Birch Creek No. 2 Reservoir is located on Birch Creek approximately 8 miles west of Woodruff in Rich County. It is used solely for irrigation. The owners report that they have not noticed any impact to their operation of the reservoir due to sedimentation.

Fool Creek No. 2 Reservoir

Fool Creek No. 2 Reservoir is located approximately 12 miles northeast of Delta, in Millard County. The reservoir has not been in use for several years due to dam safety issues. When it was used, it was solely for irrigation. The owner reports that they had not notice any impacts due to sedimentation.

Otter Creek Reservoir

Otter Creek Reservoir is located approximately 9 miles east of Kingston, in Piute County. The reservoir is used for irrigation and recreation. In 1961, the NRCS mapped the reservoir basin. In 2004, the reservoir company again mapped the basin and found that the storage had lost 9% or 4,500 acre-feet in the last 43 years (.21% per year). In 1999, $4,000,000 in dam safety improvements were completed. This included raising the spillway to increase the storage capacity to compensate for the losses due to sedimentation. In 2005, a fire in the upper watershed and subsequent erosion caused sediment to fill the tributary canal. There are concerns that the reservoir may have received a large amount of sediment that year.

Piute Reservoir

Piute Reservoir is located approximately 6 miles north of Junction, in Piute county. The reservoir is used for irrigation and recreation. In 1961, the NRCS mapped the reservoir basin. In 2004, the reservoir basin was mapped by the owner. The results indicated that the storage capacity had decreased by 9% or 6,500 acre-feet in the last 43 years (.21% per year). In 1999, $12,000,000 in dam safety improvements were completed.

Appendix B

Sediment Sources Identification

INTRODUCTION

It is common for sediment sources to be unevenly distributed over the watershed drainage area. Stated another way, one or two streams in sub-drainages may contribute most of the sediment that reaches the reservoir. The challenge is to identify those sub-drainages in order to most efficiently use the time and money spent on sediment control efforts.

Sometimes the sediment source will be obvious and little investigation is needed. However, usually the services of a consulting geologist will be necessary. A listing of geologists can be found in the phone directory. Other considerations include the following.

- If available, a geologic map of the drainage area is very helpful. Geologic maps are obtainable from the Utah Geologic Survey. They can be contacted at http://geology.utah.gov/
- Maps showing soil type are useful. These are available from the U. S. Department of Agriculture, National Resource Conservation Service (NRCS). See www.nrcs.usda.gov/ . NRCS has offices in Salt Lake City and in other Utah cities.
- A water chemistry analysis laboratory may be needed. Such laboratories are located in Salt Lake City and other Utah cities.
- Specialized testing may be necessary, depending on the complexity encountered. The cost of such tests will need to be compared to the benefits derived, as well as the confidence of results obtained from less costly methods. When compared to expending effort in the wrong area, they may very well be cost effective. These methods are discussed below.
- Sediment sampling during the lowest possible reservoir level is suggested to make sampling easier. Similarly, sampling in streams is easiest at low flow levels.
- Photographs documenting the efforts are recommended.

Sediment samples will be taken from representative areas of the delta regions at the head of the reservoir and areas where the sediment extends out into the reservoir. These samples are compared to soil and rock from the contributing sub-basins in the watershed.

Land slump enters the stream as a major contributor of downstream sediment.

The more difficult task is to identify the relative proportions of the total sediment load derived from each formation. Then, sediment control actions specific to those locations and formations can be implemented. The U. S. Department of Agriculture, National Resource Conservation Service, indicates:

> "In planning a program to reduce sediment yield, the relative importance of the various sources and the methods for treating them must be determined before the physical and economic feasibility of the program can be determined."[1]

SEDIMENT SOURCES IDENTIFICATION

This section provides considerations, references and advanced techniques to aid in the investigation.

Considerations

- Some sediments may be derived from many sources in the watershed. Silicon dioxide sand (SiO_2) is one example. Similarly, clay could be eroded from soils, mudstones and claystones, altered Tertiary volcanic rocks, and altered igneous rocks.

- Clays in water can release or absorb a variety of elements (exchangeable cations such as Ca, K, Na) depending on water chemistry and pH. When doing water chemistry analysis it might be appropriate to look for trace element anomalies, such as high sodium and potassium from a salt-bearing unit like the Jurassic Arapien Shale, phosphate from the Permian Phosphoria Formation, and selenium or chromium from black shale. A geochemist could advise on what types of trace element anomalies would be associated with the various geologic formations in the watershed.

- When a Geographic Information System (GIS) is available, the watershed evaluation could be conducted with a geologic and soils map of the drainage basin, with accompanying tables characterizing each polygon. These could include area of the polygon, geologic formation or soil unit, steepness of polygon, density of vegetation, erosional character, distance to the stream, and amount of precipitation on the polygon.

References

- The following is an excellent reference to use when investigating the stream bed load, especially immediately before it enters the reservoir.

  Sampling Surface and Subsurface Particle-size Distributions in Wadable Gravel-and Cobble-bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring.
  Gen. Tech. Rep. RMRS-GTR-74. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 428 p. This document is available as a free download from www.fs.fed.us/rm/pubs/rmrs_gtr74.html

- *Reservoir Sedimentation, Developments in Water Science 29,* G. W. Annandale.

- The following are available from several Utah college libraries and from the Utah Division of Water Resources.
    - *Reservoir Sedimentation Handbook,* Gregory L. Morris and Jiahua Fan. A free Adobe Acrobat (pdf) version is available.
    - *Sedimentation Engineering*, American Society of Civil Engineers.
    - *Exclusion and Removal of Sediment from Diverted Water*, Arved J. Raudkivi.
    - *Sediment Management with Submerged Vanes*, A. Jacob Odgaard, available from the American Society of Civil Engineers.

- The U. S. Geological Survey has done numerous reservoir sediment studies. It may be beneficial to look at the methodologies used. These can be found at http://ks.water.usgs.gov/studies/ressed/ .

Advanced Techniques

These techniques can identify the elemental chemicals making up the minerals in the sediment, and their respective proportions. This information indicates the geologic formations from which the sediment is derived. Each method has strengths and weaknesses. In practice commercial labs often use two or three methods on a sample to determine sediment chemistry. Methods include:

X-ray fluorescence (XRF)

X-ray fluorescence (XRF) is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by bombarding with high-energy X-rays or gamma rays. The phenomenon is widely used for elemental analysis and chemical analysis, including geochemistry.[2]

Atomic Absorption Spectroscopy

Atomic Absorption Spectroscopy is a technique for determining the concentration of a particular metal element in a sample. The technique can be used to analyze the concentration of over 70 different metals in a solution.[3]

Neutron Activation Analysis

Neutron Activation Analysis is one of the most sensitive and accurate methods of trace element analysis. It requires no sample preparation or solubilization and can therefore be applied to objects that need to be kept intact. It is a non-destructive analysis method.[4]

Inductively Coupled Plasma, Mass Spectrometry (ICP-MS)

Inductively Coupled Plasma, Mass Spectrometry (ICP-MS) is a type of mass spectrometry that is highly sensitive and capable of the determining of a range of metals and several non-metals at concentrations below one part in 10^{12}.[5]

Inductively Coupled Plasma, Optical Emission Spectrometry (ICP-OES)

Inductively Coupled Plasma, Optical Emission Spectrometry (ICP-OES), is an analytical technique used for the detection of trace metals. It is a type of emission spectroscopy that uses the inductively coupled plasma to produce excited atoms and ions that emit electromagnetic radiation at wavelengths characteristic of a particular element. The intensity of this emission is indicative of the concentration of the element within the sample.[6]

X-ray Crystallography

X-ray Crystallography is a method of determining the arrangement of atoms within a crystal, in which a beam of X-rays strikes a crystal and scatters into many different directions. From the angles and intensities of these scattered beams, a crystallographer can produce a three-dimensional picture of the density of electrons within the crystal. This method determines the size of atoms, the lengths and types of chemical bonds, and the atomic-scale differences among various materials, especially minerals. This can be used to determine mineralogy (rather than chemistry) of the detrital grains in the sediments which could be particularly helpful if any of the source areas for the sediments contains metamorphic or igneous rock.

Sediment Source Fingerprinting

This is a relatively new science with initial studies beginning in about 1990.[7] It uses "environmental radionuclides" which are commonly occurring, widely distributed in the environment, and are readily measurable. They can be natural or human-produced. These radionuclides are rapidly and strongly adsorbed by soils, accumulate at or near the surface of the ground, and accompany the soils that are eroded.[8] Tracers used commonly include Caesium-137 (^{137}Cs), unsupported Lead-210 (^{210}Pb), and Beryllium-7 (^{7}Be). Used alone, and in combination with one another, radionuclide analysis can indicate which soil formations contribute what proportion of accumulated sediments. It is still advised, "to employ several sediment properties within a composite fingerprint…"[9] These might include fallout radionuclides. This is a highly specialized field that requires expertise in sediment source fingerprinting. The University of Utah has expertise in using geologic isotopes.

NOTES

[1] U. S. Department of Agriculture, Soil Conservation Service, *National Engineering Handbook*, Section 3 Sedimentation, *Chapter 6 Sediment Sources, Yields, and Delivery Ratios*, March 1968, page 6-2. There has not been an update to this publication as of March 31, 2009 per personal communication on this date with Norm Evenstad, USDA, NRCS, Salt Lake City office.

[2] http://en.wikipedia.org/wiki/X-ray_fluorescence July 18, 2009.

[3] http://en.wikipedia.org/wiki/Atomic_absorption_spectroscopy July 18, 2009.

[4] http://en.wikipedia.org/wiki/Neutron_activation July 18, 2009.

[5] http://en.wikipedia.org/wiki/Inductively_coupled_plasma_mass_spectrometry July 18, 2009.

[6] http://en.wikipedia.org/wiki/Inductively_coupled_plasma_atomic_emission_spectroscopy July 18, 2009.

[7] D. E. Walling, *Using Environmental Radionuclides as Tracers in Sediment Budget Investigations*, Erosion and Sediment Transport Measurement in Rivers: Technological and Methodological Advances, Proceedings of the Oslo Workshop, June 2002, IAHS Publication 283, 2003, page 64.

[8] Ibid. page 58.

[9] Ibid. page 75.

Appendix C

Managing The Impacts Of Small Reservoir Flushing

THIS DOCUMENT IS EXPECTED TO BE UPDATED BY THE AUTHORS SOME TIME IN 2010

SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM

INFORMATION/EDUCATION/TRAINING/DEMONSTRATION PROJECT

"MANAGING THE IMPACTS OF SMALL RESERVOIR FLUSHING"

by:

Mac McKee
Lizzette Oman

sponsor:

Ronald Sims

This project was conducted in cooperation with the State of Utah and the United States Environmental Protection Agency, Region 8.

Grant #040058

EXECUTIVE SUMMARY

PROJECT TITLE: "MANAGING THE IMPACTS OF SMALL RESERVOIR FLUSHING"

PROJECT START DATE: July 1, 2003 PROJECT COMPLETION DATE: June 30, 2009

FUNDING:	TOTAL BUDGET:	$196,610
	TOTAL EPA GRANT:	99,100
	TOTAL EXPENDITURES OF EPA FUNDS:	99,100
	TOTAL SECTION 319 MATCH ACCRUED:	97,510
	BUDGET REVISIONS:	0
	TOTAL EXPENDITURES:	$196,610

SUMMARY ACCOMPLISHMENTS

This study examined the issue of management of small, run-of-river reservoirs from the perspective of minimizing the negative consequences of sediment releases from reservoirs on downstream aquatic resources and water quality. This topic was examined using First Dam on the Logan River, Logan, Utah, as a case study. The principal accomplishments of the study are development of: (1) management, monitoring, and reporting protocols for sediment control at First Dam; (2) a set of general guidelines for construction of sediment management plans and for conducting sediment flushing and sluicing events on small dams in Utah; and (3) a detailed sediment management plan for the operators of First Dam. In total, these accomplishments represent a set of recommendations for best practices with respect to releasing sediment from small run-of-river reservoirs in order to protect valuable downstream aquatic resources.

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EXECUTIVE SUMMARY

This project identified and examined inexpensive techniques for managing sediment releases from small reservoirs so as to reduce the rate at which sediments are deposited into the reservoir and to protect downstream aquatic resources from damage that might be sustained from sediment releases. The project was conducted from July 1, 2003, through June 30, 2009. It was funded by USEPA §319 money ($99,100), and with financial matching funds from the Utah State University Facilities and Planning Department ($10,000), the Utah Division of Wildlife Resources ($20,000), the Utah Water Research Laboratory at Utah State University ($26,060), and the Office of the Vice President for Research at Utah State University ($41,450).

The goal of the project was to develop and disseminate management guidelines for the flushing/sluicing of sediments from small reservoirs to minimize environmental impacts on water quality and aquatic resources, with emphasis on reservoirs located in regions with arid climates, such as Utah. These guidelines are based on hydrology and geology of the watershed within which the reservoir is located, on the requirements of downstream aquatic species and water users, and on the hydraulic characteristics of the dam, itself. The project used First Dam, a small dam owned by Utah State University on the Logan River at the mouth of Logan Canyon, as a case study. Management guidelines were developed by the project and implemented in the form of a sediment management plan for First Dam. Dissemination of this information has taken the form of presentations at statewide water users conferences, meetings with representatives of numerous state regulatory and planning agencies, and development of electronic distribution facilities.

Significantly, the project identified and documented general procedures for preparing and implementing a sediment management plan for small reservoirs. This includes detailed recommendations for using hydrologic information, for understanding the limitations of dam outlet works and spillways in supporting sediment flushing/sluicing, for determining the water quality constraints that must be met in order to protect downstream species during a sediment release event, for minimal but necessary monitoring of stream flow and water quality, and for documenting the results of sediment management activities. Essentially, this represents a first design of a new best management practice (BMP) to be employed in sediment control for small reservoirs. The project materials and lessons learned will be employed by the state NPS Task Force Sub-committee to assist in revising and upgrading the state NPS Management Plan for Hydrologic Modification.

INTRODUCTION

The Problem

Sediment eventually fills reservoirs, quickly in some cases, but usually not for many years. In percentage terms, the highest rates for loss of storage are found in the smallest reservoirs, while the lowest rates are in the largest reservoirs. The life span of a reservoir is determined by the rate at which sediments reduce the storage capacity. The rate at which storage is lost for a given reservoir depends upon the sediment yield from the catchment area and the rate at which sediments from the catchment accumulate in the reservoir. The sediment yield is dependent upon the rate of erosion and the transport, by water, of the sediment within the catchments. Generally, coarser materials are deposited at the upstream end of the reservoir, often creating a form that is recognizable as a delta. Finer materials may reach the dam and affect the design and operation of the outlet works.

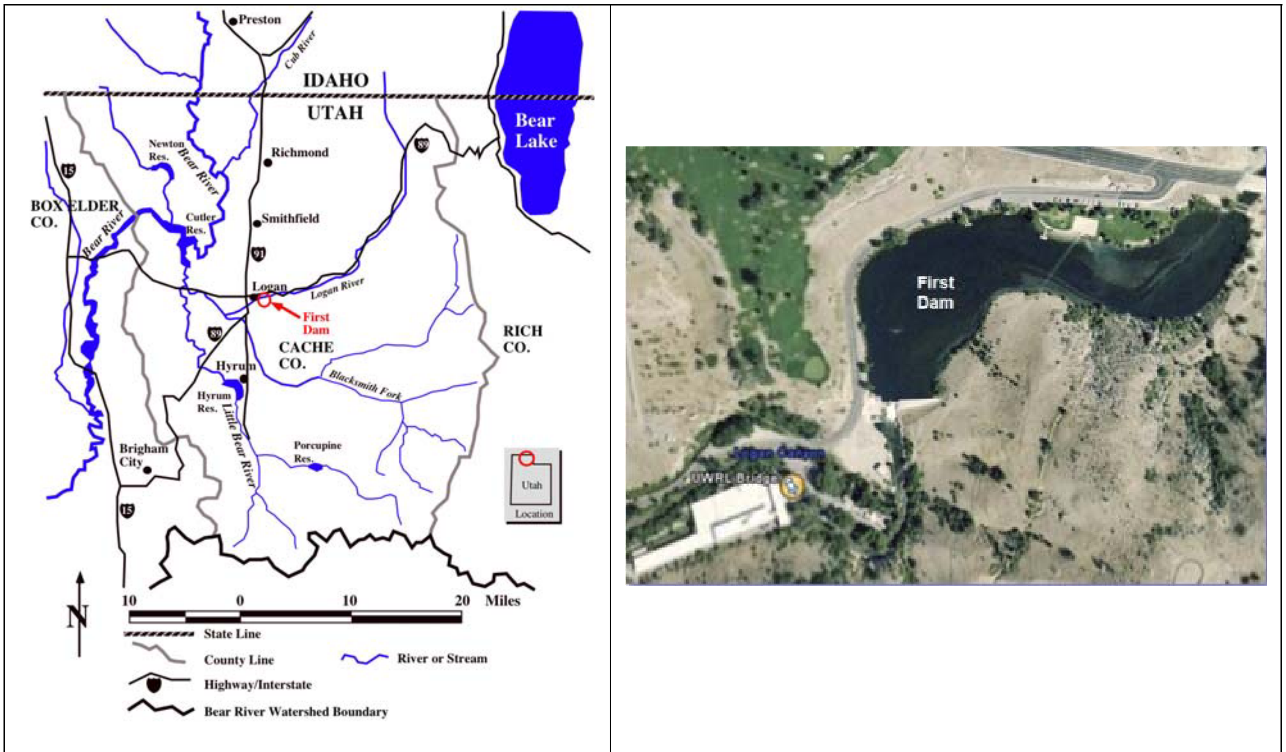
One way to preserve reservoir storage is to flush or sluice sediments through outlet works within the dam. Sediment flushing is a technique in which the flow velocities in a reservoir are increased to such an extent that deposited sediments are remobilized and transported though bottom outlets. Sediment sluicing involves the establishment of temporary changes in the flow patterns through a reservoir, such as by opening an outlet from the reservoir that is normally closed, in order to provide greater capacity for the moving water to pass sediments that are entering the reservoir through (or sometimes around) the system, rather than depositing them in the reservoir.

Research on sediment management methods has focused almost exclusively on maintaining reservoir capacity and extending the economic lifespan of the dam, and little work has been done to understand the consequences that flushing or sluicing might have on downstream biotic resources. The sediment releases that result from these sediment management activities can produce a significant impact on downstream water quality and deleteriously affect the fish and invertebrate populations in the tailraces, often for many miles in the stream channel downstream of the dams.

The purpose of this study is to develop and present a set of guidelines intended to help in the generation of sediment management plans for small run-of-river reservoirs in Utah. The objective of such plans is to minimize the negative consequences of sediment flushing or sluicing on downstream aquatic resources and water quality. Recommendations are also made for monitoring the effectiveness of sediment management activities and for reporting sediment management results. The work reported here is based on research done at First Dam on the Logan River in Logan, Utah, and draws heavily upon the results and experience of sediment management over the course of the project to provide examples of the various components of a sediment management plan.

Logan River Case Study Area and History

First Dam is located on the Logan River at the mouth of Logan Canyon (see Figure 1). The impoundment behind the dam is a popular recreational place, and the river downstream of the dam provides habitat for various cold-water fish and is a very popular trout stream. First Dam is a small diversion facility with very little storage (approximately 60 acft). In addition to recreational opportunities, First Dam is used to generate power and to supply water to the hydraulics research facilities at the Utah Water Research Laboratory at Utah State University. It was constructed in 1911, and in many ways it is similar to hundreds of small dams in Utah. Over its life, the reservoir has accumulated sediment at an average rate of about 0.5 acft per year.



a. Location of First Dam and Its Reservoir **b. Aerial View of First Dam**

Figure 1: Location Map and Aerial View of First Dam on the Logan River

First Dam has had a history of creating downstream fish-kills as the result of infrequent maintenance actions that have been required on the dam from time to time. In 2000, a new set of repairs was scheduled to address upstream and downstream structural damage to the dam from waves, concrete spalling, etc. In addition, the mass of the dam had to be increased in order to address seismic issues. In October of 2001, the reservoir pool elevation was drawn down so this rehabilitation work could be conducted. This resulted in a flushing event that killed an estimated 2,000 catchable size game fish for a two-mile reach of the river downstream of First Dam (see Figure 2). The flushing of sediment and the prolonged drawdown of the reservoir deposited sediments in the downstream channel of the Logan River (Figure 3), which affected fish spawning beds and invertebrate populations. Some of the sediment that was released from the reservoir was deposited in downstream irrigation canals, which generated substantial clean-up costs for the affected irrigation systems.

Figure 2: Fish Killed by the October 2001 Flushing of First Dam

Prior to the event, the dam owners of the dam had worked with the design engineer, the contractor, and various representatives from the Utah Department of Natural Resources and the Department of Environmental Quality to acquire the necessary stream alteration permit, to schedule and plan for the lowering of the reservoir pool elevation, to conduct the required construction activities, and to re-commission the dam. The plan called for a very slow and gradual lowering of the pool so that minimal mobilization of sediments would result. However, subsequent enquiries into the event revealed that those responsible for planning the reservoir pool drawdown and rehabilitation activities were poorly informed about several factors, including:

- the real risk of flushing sediment and the potential for causing downstream damage
- legal water quality requirements
- the rights of other water users on the Logan River

In addition, prior to the 2001 event, sediment management had never been a focus in the operation of First Dam. Since loss of storage volume does not affect the uses of the dam, and since there had never been a sediment management plan put into place, sediments have simply been allowed to accumulate in the reservoir until maintenance activities required that the pool elevation be drawn down. Such activities have always resulted in the generation of downstream environmental problems. In this regard, First Dam is representative of many small dams in Utah, with respect to both the sediment problem and the need to provide basic sediment management guidelines and tools for the owners and operators of small dams.

Following the 2001 event, research was conducted to develop a sediment management plan for First Dam. The intent of this research was two-fold: (1) prepare a sediment management plan for First Dam that would minimize the potential for downstream damage that might result from future maintenance work on the dam, and (2) use the experience gained in these activities to prepare a set of suggested general guidelines that could be used by the owners and operators of small dams in Utah to develop their own sediment management plans and, if followed, to conduct sediment flushing/sluicing activities.

In the research conducted to understand and plan for sediment management at First Dam, it became clear that several factors should be addressed in the design of a sediment management plan for small reservoirs and in conducting flushing or sluicing events. These include:

- characterization of the sediment management problem
- sediment management plan formulation
- monitoring guidelines and recommendations
- recommendations for reporting

These issues have been specifically documented in the sediment management plan prepared for the owners and operators of First Dam, and have been outlined in the proposed general guidelines, submitted to the Utah Department of Environmental Quality under separate cover.

Figure 3: Sediment Deposition Downstream of First Dam after the October 2001 Flushing Event

Consistency with State NPS Management Program

The project supports the information and education (I&E) needs of Utah as identified in the State's NPS management Plan (Utah Department of Environmental Quality, 2000). This plan calls for continued support of I&E projects by §319 funds, especially those that have potential statewide impact. By developing and disseminating a set of guidelines for management of sediment in small reservoirs, the project will have such a significant impact.

The problem is not an isolated one. Utah alone has hundreds of low-head power dams and irrigation storage and diversion dams, as do each of the Mountain West states. All of these require periodic dam maintenance, which includes flushing and/or sluicing. These dams are also on streams that are cold-water habitat for trout and the basis for economically important recreation fisheries, as well as a source of water for agriculture and domestic uses.

PROJECT GOALS, OBJECTIVES, AND ACTIVITIES

The goal of this project is to develop and disseminate management guidelines for the flushing and sluicing of sediments from small reservoirs to minimize environmental impacts on downstream water quality and aquatic resources, with emphasis on reservoirs located in regions with arid climates, such as Utah. These guidelines are based on hydrology and geology of the watershed within which the reservoir is located, on the hydraulic characteristics of the reservoir itself, on the requirements of other water users and of downstream fisheries and aquatic resources.

The objectives and tasks of the project were:

Objective 1: "Develop and document a detailed conceptual approach to sediment flushing for small reservoirs." To achieve this objective, two tasks were accomplished. The first was a thorough literature review to touch on the physical and chemical aspects of sediment flushing. Using this as a basis, the second task was to develop a detailed conceptual approach for flushing sediments, using First Dam as an illustrative example.

Objective 2: "Evaluate the extent and toxic potential of anoxic bottom sediments that might be rapidly released at the initiation of reservoir flushing/sluicing." This first required sampling and testing of reservoir sediments and river water quality. A second task to accomplish this objective was to design, implement, and monitor sediment mobilization procedures for the case study reservoir, First Dam.

Objective 3: "Design, test, evaluate, and help implement a recommended plan for managing the sediment budget of the case study reservoir and the toxicity of its anoxic bottom sediments, with the goal of minimizing the negative downstream impacts of flushing/sluicing procedures." To achieve this objective, information generated from previous tasks was used to design, implement, and monitor sediment mobilization procedures for First Dam. These procedures were tested over a series of years during high runoff periods in the spring.

Objective 4: "Utilize the information collected on the case study reservoir to develop management guidelines for implementing these procedures on other small reservoirs, and disseminate these guidelines to operators of small reservoirs in Utah." Drawing from the multi-year experience of sediment flushing/sluicing at First Dam, the project developed a general set of recommendations for management of sediments in small reservoirs. Further, a sediment management plan was prepared for the operation of First Dam, and project personnel have worked with the operators of First Dam to implement the plan. Information has also been disseminated to interested parties through two presentations at the annual Utah Water Users Conference and through the preparation for electronic distribution of sediment management guidelines and other materials prepared by the project.

Planned and Actual Products and Completion Dates

Activity on the planned and actual project products is summarized in Table 1. All but one of the project products were successfully developed over the course of the project. However, Product 9 relates to activities required by the Utah Department of Environmental Quality that must be performed after completion of this project.

Table 1: Summary of Project Products

Product	Description	Date Met
1	A report detailing the conceptual approach for reservoir flushing/sluicing, including a summary of the literature.	January, 2005
2	Data on sediment and water quality samples.	continuous
3	A report on recommendations for managing sediment toxicity during flushing/sluicing operations.	April, 2006
4	A report identifying and evaluating the hydraulic constraints on managing flushing flows through First Dam and the hydrologic conditions appropriate for flushing/sluicing sediments from the bottom of the reservoir.	April, 2006
5	A report recommending general procedures for evaluating the watershed hydrology in conjunction with the hydraulic operational characteristics of a small dam for purposes of conducting sediment flushing/sluicing.	April, 2006
6	A report documenting recommendations for sediment management for First Dam.	May, 2007
7	A report summarizing recommended guidelines for sediment management in small reservoirs.	May, 2009
8	Dissemination in electronic and hard copy form of the general guidelines to Utah water resources agencies, river commissioners, water conservation districts and dam owners and operators.	on-going
9	Preparation of a portion of the revised Hydromod Plan related to management and operation of reservoirs related to flushing of sediment storage.	N/A
10	Preparation and submittal of required project reports.	various

Evaluation of Goal Achievement

The issue of unwanted sediment release from First Dam as the result of infrequent maintenance requirements has created problems for downstream water users and threatened valuable downstream aquatic resources on numerous occasions over the nearly 100-year live of the facility. The sediment management plan developed and implemented for First Dam will serve to (1) reduce the rate at which sediments accumulate in the reservoir, thus extending the value of the resource for recreational and other uses, and (2) reduce the amount of sediment that will be discharged from the reservoir in future maintenance activities. Further, the activities conducted over the duration of the project to prepare for and conduct sediment flushing/sluicing events have revealed specific issues that must be addressed anytime that an operational or maintenance action at First Dam will produce the possibility of sediment releases. Key among these issues are: (1) implementation of monitoring protocols that can be used to manage flushing/sluicing and maintain downstream conditions within boundaries that protect valuable aquatic resources; (2) development of a better understanding of how the dam owner can interface with local water users and the several state agencies that might be involved with management of aquatic resources and enforcement of state water quality regulations; (3) identification of the limits of sediment management actions that are feasible for First Dam, and design of emergency procedures that can be followed in order to protect the most valuable downstream aquatic species if future maintenance activities will produce sediment releases that cannot be suitably controlled; and (4) identification of limitations in Utah water quality regulations that present constraints on the effective management of sediment releases from small reservoirs.

LONG-TERM RESULTS IN TERMS OF BEHAVIOR MODIFICATION AND STREAM QUALITY

Over time, sediment accumulates in the reservoir behind First Dam in the absence of regular management activities to control this phenomenon. When infrequent maintenance activities on the dam require a lowering of the reservoir pool elevation, these accumulated sediments can be rapidly released, causing serious damage to downstream water users and fisheries. This project has designed and implemented sediment management protocols that minimize the rate of sediment accumulation and reduce the amount of sediment that will be released during infrequent maintenance activities. Essentially, the sediment management protocols that have been developed for First Dam pass more of the spring runoff sediments through the facility than would be the case in the absence of their implementation. This is done during a time of the year when sediment concentrations are already at their natural high levels, so downstream aquatic resources are not harmed. Great care must be taken to effect flushing/sluicing at times when river flows and natural background sediment concentrations are sufficiently high in order to take maximum advantage of the limited hydraulic capacity of the reservoir release structures and to protect downstream aquatic resources and water users. The owner and operator of First Dam are committed to following the protocols that have been designed. In the long term, this commitment will result in fewer and less serious downstream sediment problems on the Logan River.

BEST MANAGEMENT PRACTICES (BMPs) DEVELOPED

The BMP developed and implemented in this project is directed at managing sediments in small run-of-river reservoirs. The guidelines for designing and implementing a sediment management plan for a small, low-head dam incorporate information about watershed hydrology and geology, dam hydraulics, downstream fisheries and aquatic habitat requirements, coordination with local water users and state water management agencies, and legal requirements such as water rights and water quality regulations. Results of flushing/sluicing events conducted on First Dam on the Logan River indicate that, given the hydraulic limitations of the structure of the dam itself, it is possible to route much of the spring runoff sediment through the reservoir instead of allowing it to accumulate in the reservoir. This is illustrated in Figure 4, which shows river turbidity at real-time gauges located immediately upstream and downstream (labeled, respectively, "USGS Turbidity" and "UWRL Turbidity") during a flushing/sluicing event that was conducted in the spring of 2007. This illustrates that the sediment released when the low-level outlet valves were opened produced an initial spike that was much lower than earlier spring time turbidity levels in the river, and, as a result, insufficient to cause downstream damage. However, total sediment releases from the reservoir during this period slightly exceeded total sediment inflows, indicating that little net sediment accumulation occurred during this portion of the runoff period.

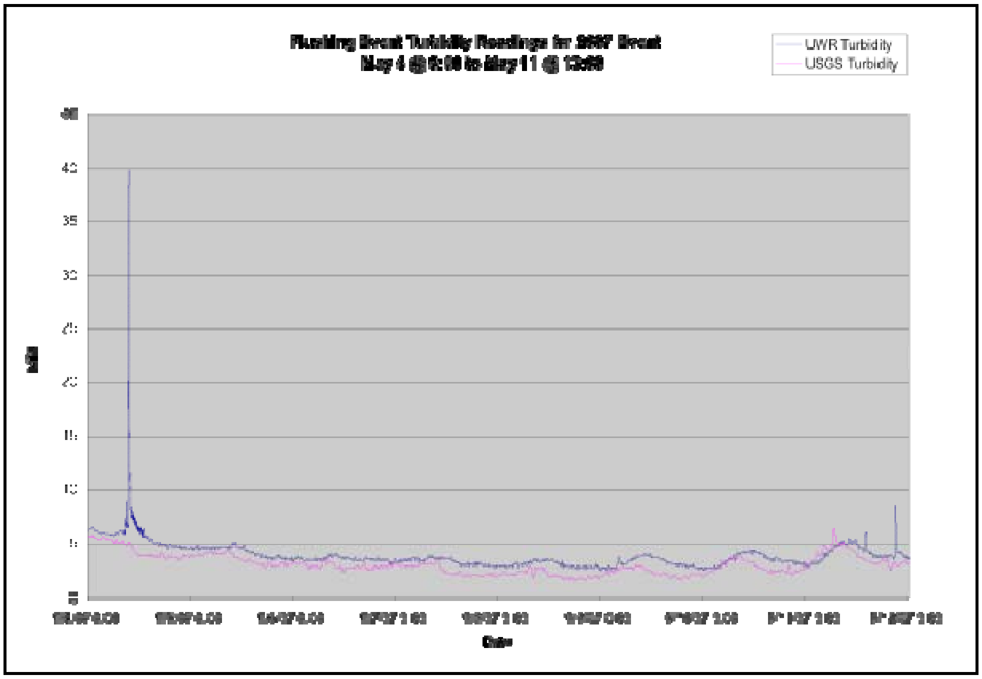


Figure 4: Turbidity Time Series Data from the 2007 Flushing/Sluicing Event at First Dam

MONITORING RESULTS FOR DEMONSTRATION PROJECTS

This project is actually a combination of I&E and BMP development and demonstration. The principal product for the I&E portion of the project consists of the set of general recommendations for the design and implementation of a sediment management plan for small reservoirs. To that end, a document detailing the general guidelines, including monitoring and reporting recommendations, has been submitted to the Utah Department of Environmental Quality. Further, presentations have been made before water users groups and a at variety of meetings with representatives of various state agencies including the Utah Division of Water Resources and the Utah Division of Water Rights. I&E activities will continue after the project in the form of electronic distribution of the project materials and data, and in the form of participation by faculty at the Utah Water Research Laboratory in the NPS Task Force.

Given the almost total lack of research on reservoir sediment management measures to protect downstream aquatic resources, this project also by necessity had to take on a BMP development and demonstration aspect. The nature of the procedures developed during the project and the effectiveness of the BMP design, insofar as this can be estimated, are briefly discussed in the following section.

BMP Design Procedures and Effectiveness

There is no manual of Best Management Practices for releasing sediment from small reservoirs while ensuring the health and safety of downstream aquatic resources. The work conducted in this project represents an exploration of what might be possible to accomplish those mutually inconsistent goals (i.e., release of sediment from reservoirs while protecting downstream resources from sediment damage) at one case study dam on the Logan River. The lessons learned by this work and the resulting set of general guidelines for design of a flushing/sluicing plan for small dams represent, essentially, the first attempt at a design of a new BMP.

The general guidelines for design of a flushing/sluicing plan include components for long-term and real-time monitoring, and address issues of long-term sediment budget estimation, real-time control of sediment flushing/sluicing events, and documentation of the consequences of sediment management actions. Careful attention is given to the design of specific protocols for mobilization of reservoir sediments through water releases that take into consideration the hydraulic capacity of the dam to pass flows, versus the natural hydrology of the river. The general guidelines also address details of monitoring design that are needed to provide both real-time assessment of sediment loading during flushing/sluicing events and long-term sediment budget calculations. This is illustrated, for example, by the need to develop real-time monitoring capability for measuring turbidity in order to acquire a relationship between turbidity and total suspended sediment load (as illustrated in Figure 5). Such relationships will have to be generated uniquely at each reservoir site and will require simple, but significant water quality sampling and laboratory analysis to provide mechanisms to translate real-time field data into estimates of total suspended sediments. For example, the TSS-turbidity relationships shown in Figure 5 were developed from a series of grab samples that were processed in the laboratory and that related field measurements of turbidity (obtained with real-time sampling equipment installed by the project) to TSS concentrations as measured in the laboratory. Once this relationship is quantified, it is used to convert real-time turbidity measurements into real-time estimates of TSS concentration. This, in turn, is multiplied by flow rate, measured in real time at the same site, to get sediment loading rates. All of this is used to monitor the sediment budget for the reservoir, both over the period of a flushing/sluicing event and over the entire year. Similar rating curves had to be developed at the real-time monitoring site above First Dam, and for monitoring of stream flow below the dam.

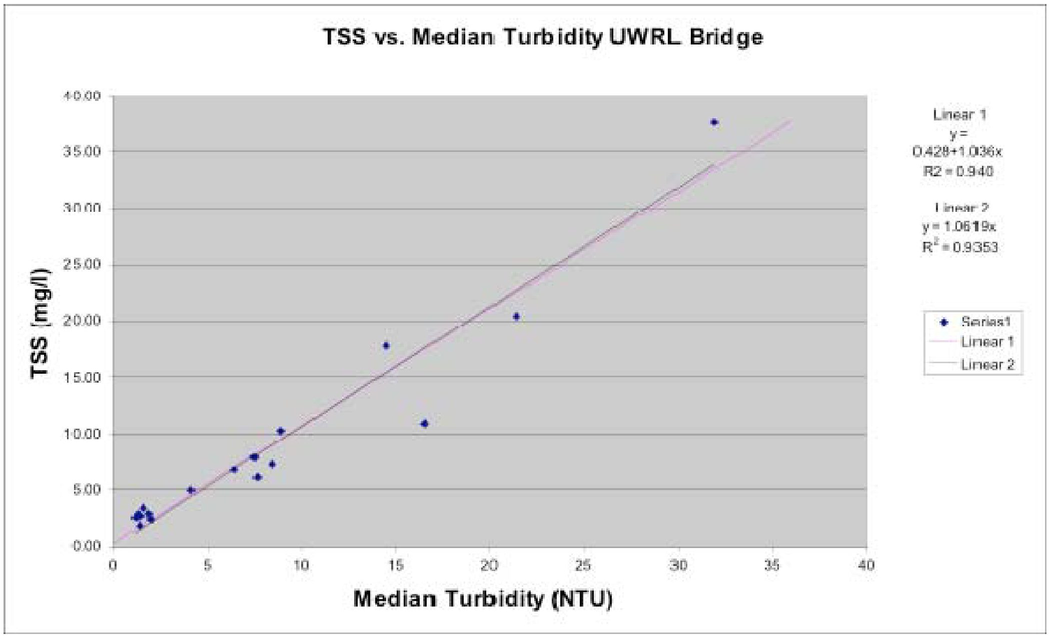


Figure 5: TSS Versus Turbidity Relationship for Conditions at the UWRL Bridge

Most owners of small dams in Utah will not have large amounts of money that they can spend on additional requirements for reservoir operations. In terms of BMP effectiveness, the project was designed to identify those sediment management options that could be feasible at First Dam without incurring huge additional expense in reservoir operations. The philosophy in this approach is that owners and operators of these small facilities in the state will not embrace sediment management protocols if they cannot afford them. With this in mind, the project has identified monitoring and laboratory analyses that are minimal in extent and cost, that could be initially implemented with help that is readily available from private local consultants, and that, with minimal training, could be maintained by the dam operator. This is proving to be effective in the case of First Dam, wherein the owner/operator has taken ownership of the sediment management system and now works annually to implement effective sediment flushing/sluicing activities. In this regard, the BMP as applied at First Dam appears to be effective. This will only be fully testable at some future time when serious maintenance requirements will once again require that the reservoir at the dam be de-watered, however.

Surface Water Improvements

It should be understood that, on average, the sediment management practices employed at First Dam will not produce better water quality. In fact, during brief periods of sediment flushing, water quality will be slightly worse downstream of the dam. However, when conducted following the rules of monitoring and management that are set out in the First Dam sediment management plan, these sediment releases will not cause harm to downstream fisheries or water users. Further, by reducing the rate at which sediment accumulates in the reservoir, less sediment will be released when serious maintenance efforts are required on the dam, thus resulting in less concern for the potential damage to downstream resources.

Quality Assurance Reporting

Both a Quality Assurance Project Plan (QAPP) and a Sampling and Analysis Plan (SAP) were prepared and implemented for this project. Procedures detailed in the QAPP for assuring the basic components of accuracy, precision, completeness, representativeness, and comparability were closely followed. This included:

- Detailed rules for sample handling and custody,

- QA/QC procedures, including identification of outlier data, implementation of corrective actions, repetition of the analytical batch, calibration controls, and so forth,
- Use of appropriate analytical methods, instrument calibration frequency, and so forth, and

- Data reduction and reporting requirements, both in written and electronic form.

Procedures described in the SAP were also closely followed. These focused on river quality sampling, and on monitoring sediment mobilization during flushing/sluicing events. The sampling process design addressed stream flow monitoring through the use of USGS gauge facilities above First Dam and the installation and maintenance of a real-time gauge at the Utah Water Research Laboratory below the dam; river quality sampling, including issues of location, number, and frequency of samples for temperature, pH, DO, turbidity, and laboratory determination of total suspended sediments, both throughout the year on a periodic schedule to assess ambient river conditions, and, more intensively, during flushing/sluicing events. Sampling methods requirements, as specified in USEPA (1986) and APHA (1988), were followed. All water quality parameters, with the exception of TSS, were measured in-situ. Sample handling and custody requirements, both for the field and in the laboratory, were addressed through the use of field logs, field tracking reports, and laboratory notebooks. Analytical methods requirements were met following USEPA (1986) and/or APHA (1998). Quality control measures implemented for both field and laboratory activities included:

- matrix spike duplicates and matrix spikes

- blanks

- laboratory check samples

- instrument set-up procedures
- calibration requirements and procedures

Instrument calibrations and frequency followed standard operating procedures, including the use of calibration logs.

PUBLIC INVOLVEMENT AND COORDINATION

State Agencies

Over the course of the project, state agency involvement was sought and received from the Utah Department of Environmental Quality, and, in the Department of Natural Resources, the Utah Division of Water Rights, the Utah Division of Water Resources, and the Utah Division of Wildlife Resources. Representatives of these agencies facilitated outreach opportunities, provided valuable information on important aquatic species in the Logan River, and gave frequent and thoughtful recommendations on how to conduct and monitor flushing/sluicing activities at First Dam.

Local Governments and Other Groups

Local groups involved in the project included irrigators and related water users groups, such as the operators of local canal companies and the Logan River Commissioner. These people provided input regarding timing of flushing/sluicing events and agreed to targets that limited turbidity levels that could be allowed during such events. The operators of First Dam were heavily engaged in the project, especially during flushing/sluicing events when they had to manage the hydraulic structures on First Dam in order to address sediment release targets. Numerous faculty at the Utah Water Research Laboratory also participated in the project to provide guidance in sampling protocols and conduct laboratory analyses consistent with the project QAPP and SAP, to measure reservoir bottom sediment distributions, and to assist in understanding the hydraulic limitations of First Dam. Representatives of the local chapter of Trout Unlimited helped in designing the monitoring program for sediment flushing/sluicing events and in understanding the major fish species that were the principal targets of protection during these events.

Other Sources of Funds

Matching funds were provided by the Division of Wildlife Resources in the Utah Department of Natural Resources, the Facilities and Planning Unit of Utah State University, and the Utah Water Research Laboratory at USU. Total matching funds, not counting in-kind match from Trout Unlimited and faculty at the Utah Water Research Laboratory, was $97,510. In addition, the

Utah Water Research Laboratory will continue to support monitoring costs for flushing/sluicing events at First Dam on an on-going basis.

ASPECTS OF THE PROJECT THAT DID NOT WORK WELL

A key component of the project that slowed the work in the initial few years was the requirement to negotiate the schedule for sediment flushing/sluicing activities with local water users. The owner of First Dam has a junior, non-consumptive water right on the Logan River. Releases from First Dam must be scheduled so as not to interfere with the more senior water rights held by downstream irrigators. In combination with these legal water rights restrictions, further constraints on when sediment flushing/sluicing can be done are imposed by the biotic requirements of downstream fish species. For example, downstream irrigators would not be opposed to sediment flushing/sluicing during non-irrigation periods, such as in November when flows in the river are low and when flushing would be more hydraulically efficient. However, during these periods various fish species are spawning, and would be negatively affected if increased sediment concentrations were to be placed into the river as a result of flushing activities. As a result, the period during the year when flushing/sluicing could be allowed was restricted to a very short time during high spring runoff conditions. Even during this period, flushing/sluicing was seriously constrained by water quality conditions imposed by downstream irrigators before they would agree to flushing/sluicing activities at First Dam. Superimposed on these organizational issues were a series of low-flow drought years that generated unusual flow conditions on the Logan River and limited the extent to which flushing/sluicing experimentation could be done. These difficulties were eventually overcome, in part by extending the period of the project contract to allow for more opportunity to work with local water users and to capture a better sampling of annual flow conditions on the river. However, these sorts of issues will no doubt arise in other locations in the state when reservoir operators attempt to conduct controlled flushing/sluicing activities.

A less serious problem encountered during the project was with regard to the intent to evaluate sediment toxicity and, more importantly, the value of this information in managing sediment flushing/sluicing activities in real-time. Initially, it was thought that better data on the constituents of sediments deposited in the reservoir at First Dam could yield valuable information on the potential toxicity to fish should those sediments be released. This information, in turn, might be useful in designing sediment flushing activities. This proved to not be the case because of the limited control over releases that is possible with the outlet works that are part of First Dam. As a result, the weight of sampling and monitoring activities was shifted entirely away from reservoir sediments in favor of greater attention on real-time monitoring of in-stream water quality conditions during flushing/sluicing events. Further, maximum aeration was achieved when flows in the Logan River were high enough by simultaneously releasing water and sediments through low-level outlets and passing water over the spillways on the dam. This generated significant turbulence and aeration of anoxic sediments (see Figure 6), thereby increasing dissolved oxygen concentrations and minimizing the deleterious effects of sediment on downstream fish populations.

Figure 6: Use of Spillway Releases to Aerate Discharge from the Low-Level Outlets on First Dam (shown on the spillway on the left)

FUTURE ACTIVITY RECOMMENDATIONS

Lessons learned during the course of this project will be of potential value to owners and operators of small reservoirs and who must contend with the issue of deleterious impacts on downstream resources of sediment releases, and future work should be aimed at information and outreach needs in this area. In addition to this, however, the experience gained during the research for this project has identified possible areas in state water quality policy and standards that should be reconsidered in the light of their implications toward sediment management. Finally, there are additional experiments that could be conducted at First Dam that could generate valuable information about sediment management options if local water users could be persuaded to allow them to be conducted. Recommendations for possible future activity also focus on these issues.

Information and Education Outputs

The guidelines for sediment management in small reservoirs that have been prepared by this project will be posted on a web site managed by the Utah Water Research Laboratory, along with the sediment management plan that has been prepared and implemented for First Dam. These materials, along with other supporting information and data that continue to be used on a real-time basis to improve the management of First Dam, should serve as useful educational devices for managers of small run-of-river facilities in Utah.

Importantly, personnel who have served on the project will continue to work with the Utah Department of Environmental Quality to assist the NPS Task Force Sub-committee in revising and upgrading the state NPS Management Plan for Hydrologic Modification. Lessons learned over the course of the project with respect to the technical procedures for flushing/sluicing sediment, for monitoring and managing sediment release activities, and for maintaining a sediment balance for the reservoir will be of potential value in this regard. So, too, will be the lessons learned with respect to the necessary interfaces between dam operators, other water users, and state regulatory agencies. Of particular value, perhaps, will be the experience gained during the project with the very real physical results of sediment flushing/sluicing activities and the water quality regulations in Utah that, if rigidly enforced, present serious limitations to what might actually be possible in managing sediments in small reservoirs. The following section briefly addresses this issue.

Evaluation of Water Quality Laws Hindering Sediment Management

Utah water quality regulations place strict limits on the amount by which turbidity can be allowed to increase in the stream. Utah limits the allowable increase in turbidity to no more than 10 NTU above background levels. Further, total suspended solids may not exceed 90 mg/l (Utah Administrative Code, R317-5-14). In consideration of the biotic requirements of downstream aquatic life, these standards are far too strict when applied to sediment flushing/sluicing activities. By these standards, a flushing/sluicing event anywhere in the state will be in violation of state law because the turbidity will almost certainly rise above the 10 NTU incremental limit. This is an issue that should be addressed by water quality enforcement agencies if sediment flushing/sluicing is to be allowed as a tool for managing reservoir sediments in protection of downstream fisheries. Currently, the state doses not require a permit for flushing events. However, terms and conditions could potentially be included in the body of stream alteration permits and/or sediment management plans to address these concerns. It should be noted that the 10 NTU incremental limit is extremely prohibitive to flushing/sluicing plans, especially when such events can be conducted with confidence that they will not produce serious consequences for downstream users or fish populations. Researchers at the Utah Water Research Laboratory will be available to participate in future discussions of these issues.

Future Experiments

Continuous stream flow and turbidity data collected both above and below First Dam during the course of the project indicate that significant spikes of sediment are sent down the Logan River as the result of storm events. These spikes create very much the same sort of turbidity/TSS behavior shown by the flushing/sluicing event illustrated in Figure 4, and can happen during various periods of the year during which fish are spawning and farmers are irrigating. However, these sediment spikes cause no untoward damage to downstream aquatic resources or irrigators. It should be possible to conduct more frequent but small sediment flushing events at First Dam during these periods that would mimic the sediment spikes that are normally seen as the result of natural storm conditions, and to do so without endangering downstream aquatic communities or causing harm to irrigation facilities. Further, should it be possible to conduct flushing events that mimic natural storm conditions, it might be possible to both sluice sediments during spring and summer storms, as well as mobilize additional bottom sediments during clear-sky conditions. It is recommended that the feasibility of these experiments be explored with local water users.

Appendix D

U. S. Army Corps of Engineers
Guidance on the Discharge of Sediments From or Through a Dam

US Army Corps of Engineers®

REGULATORY GUIDANCE LETTER

No. 05-04 Date: August 19, 2005

SUBJECT: Guidance on the Discharge of Sediments From or Through a Dam and the Breaching of Dams, for Purposes of Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act of 1899

1. Purpose and applicability

a. Purpose. The purpose of this document is to provide guidance to Corps Districts Engineers regarding which releases of sediments from or through dams require Department of the Army (DA) permits. Nothing in this guidance is intended to require a DA permit for routine high water flow dam operations that allow sediment-laden waters to flow from or through a dam; however deviations from normal dam operations resulting in the discharge of bottom sediment may require a DA permit.

b. Applicability. For purposes of Section 404 of the Clean Water Act (CWA) and Section 10 of the Rivers and Harbors Act of 1899 (RHA), this guidance applies to the releases of water and water-carried sediment that may result in the transportation, reduction, or elimination of bottom sediment accumulations from or through dams. Dams, as used in this guidance include, but are not limited to, barriers that create impoundments of water. Depending on factors discussed below with regard to exempted maintenance activities and de minimis impacts, these releases may or may not result in a regulated discharge of dredged material. Regulated discharges may occur in association with the breaching of dams but do not include breaching that results solely from acts of nature.

2. Background

a. Sediment transportation in a stream or river is a natural process that helps to maintain the geomorphology of a stream channel. However, when a dam is constructed on a stream, it tends to interrupt the natural transportation of sediments, which build up behind the dam. This can result in sediment-starved sections of a stream downstream of a dam, leading the stream to down cut or erode away its bed and banks. Sediment accumulation behind a dam also reduces the capacity of a reservoir to store water, and can interfere with operation of the dam.

b. Sediment may be removed from a reservoir basin using many different mechanical methods, including draglines, bulldozers, or other equipment. Sediment that has been removed by such mechanical means can then be transported to a site above the Ordinary High Water Mark (OHWM) of the reservoir and stabilized. Under certain specific circumstances and when authorized by a DA permit, such sediments can be re-introduced into (i.e., discharged into) the river below the dam.

c. If a dam operator modifies or deviates from normal operation of the dam in such a manner that bottom sediment accumulated behind a dam could be removed and transported downstream through the dam, either deliberately or accidentally, that activity may require a DA permit pursuant to Section 404 and/or Section 10, as explained further below. (Note: CWA Section 404(f) exemptions from the permit requirement may apply in situations where only CWA jurisdictional waters are involved). DA permits may require special conditions minimizing the potential adverse effects on the downstream aquatic environment of releases of sediments subject to DA regulation. For example, the discharge of sediments through a dam that allows those sediments to be washed downstream may, in some circumstances, provide beneficial sediment material to sediment-starved sections of a stream below the dam. However, sediments proposed for discharge through a dam may also be of the wrong type to benefit a stream (e.g., mud or fines as opposed to gravel). Such fine sediments can seriously degrade important aquatic habitat, as when silt or mud sluiced through a dam covers up spawning areas for fish at critical times in their lifecycles, or fills in niches for invertebrates in large cobble bottom systems. Sediments proposed to be discharged through a dam may also be out of sync with the natural pre-dam sediment flow regime of that stream, which historically moved much of the sediment in the stream immediately before, during and after high flows such as spring run-off. The uncontrolled discharge of sediments may kill thousands of fish due to the impairment of their ability to process oxygen. The natural, pre-dam flow regime originally produced the stream channel geomorphology, so much of the stream biota is adapted to that historic pre-dam flow regime and sediment load and size.

d. One recent court case specifically addressed the need for a DA permit for sediment sluicing activities. The case of Greenfield Mills v. Macklin originated when employees of the Indiana Department of Natural Resources sluiced large quantities of accumulated sediments through a dam into the river below the dam without having first obtained a DA permit under CWA Section 404. Before deciding the case, the U.S. Court of Appeals for the Seventh Circuit asked the U.S. Department of Justice (DOJ) to provide the consensus views of the Federal Government (i.e., of the U.S. EPA and the Corps of Engineers) regarding whether the sluicing of sediments through the dam under consideration in that case required a DA permit. The DOJ provided an Amicus Curiae brief to the Circuit Court as requested, and the Court in large measure based its decision on the legal positions that the Federal Government presented in that brief. The Amicus brief may be found at http://www.usace.army.mil/inet/functions/cw/cecwo/reg/02-1863_005.pdf. Both the Federal Government's brief and the Court of Appeals decision clearly hold that the sluicing of sediments through the dam constituted hydraulic dredging and the discharge of dredged material from a point source (i.e., the dam), which occurred when the dam's lower gates were opened and the bottom sediments were sluiced downstream. The discharge of dredged material under those circumstances was an activity that required a DA permit pursuant to Section 404 of the CWA, unless that discharge was exempt from the Section 404 permit requirement under CWA Subsection 404(f).

e. These types of discharges of sediments may also be potentially regulated as fill material. Final revisions to the CWA Section 404 Regulatory Program definitions of ``fill material'' and ``discharge of fill material'' were issued in the final rule of May 9, 2002. That final rule defined ``fill material'' in both the Corps and EPA regulations as material placed in waters of the U.S. where the material has the effect of either replacing any portion of a water of the U.S. with dry land or changing the bottom elevation of any portion of a water. Based on this "effect" determination, DA permits are generally required for the discharge of sediments from dams when such activities would have the effect of raising the bottom elevation of the downstream waters to a discernible, substantial degree. For example, when accumulated sediments are discharged through a dam by opening the lower gate(s) of the dam to move substantial quantities of sediments, that discharge could reasonably be expected to raise the bottom elevation of the downstream waters, thereby constituting the discharge of fill material into that water body.

3. Types of Discharges

a. Discharges that are not regulated. Even when using the upper or middle gates of a dam to release water, some sediment is always included in suspension in the water releases. However, the release of sediments that are incidental to normal dam operations (i.e., the release of water through the dam to provide irrigation water or drinking water, to provide water for downstream depth for navigation, to restore reservoir capacity to store spring run-off or potential flood waters from storm events, etc.) are considered de minimis discharges of dredged material. For purposes of the Corps regulatory program, these de minimis discharges of suspended bottom sediments generally do not trigger the need for a DA permit so long as they are consistent with those sediment loads entering the reservoir from the upstream waters.

b. Applicability of 404(f) Exemptions. The discharge of large quantities of sediment through a dam will rarely (if ever) qualify as exempt from CWA regulation under CWA Subsection 404(f), for the reasons explained at length in the Greenfield Mills decision. (Note: There are no statutory exemptions that apply to such large-quantity discharges of sediments for purposes of the Section 10 permit requirements in Section 10 waters.) In summary, CWA Subsection 404(f)(1) exempts from CWA regulation " . . .the discharge of dredged or fill material . . . for the purpose of maintenance, including emergency reconstruction of recently damaged parts, of currently serviceable structures, such as . . .dams . . . ." unless the discharge is "recaptured" under Subsection 404(f)(2) (emphasis added). Consequently, the discharge of sediments through a dam cannot be exempted from CWA regulation under Subsection 404(f)(1) unless those sediments must be released for the purpose of dam maintenance, and not for any other purpose such as maintenance of the reservoir pool. Moreover, as a general rule, the Subsection 404(f) exemptions are construed narrowly to avoid their misapplication as well as the resultant adverse environmental impacts, either site-specific or cumulative. As the Greenfield Mills decision explains, for the discharge of sediments to qualify for the Subsection 404(f) exemption for dam maintenance, such discharges of sediments through a dam would have to be both necessary to allow essential dam maintenance to occur, and would have to be proportional to the dam maintenance activities that necessitate the release of sediments. Given the fact that sediments that have accumulated behind a dam can usually be removed practicably and more precisely by mechanical means, with little or no serious adverse downstream environmental effects, it is rarely necessary to sluice substantial quantities of sediments through a dam in order to accomplish essential dam maintenance. The Subsection 404(f) exemption will rarely, if ever, be applicable to the discharge of large quantities of sediments through a dam.

c. Discharges requiring DA permits. As stated above, sediment frequently builds up behind a dam. At times, rather than remove such accumulated sediments by mechanical means, a dam operator may open the bottom gates of the dam, allowing water to flow at high velocity over the sediment and flush it downstream. This can result in significant amounts of accumulated bottom sediment from upstream of the structure being allowed to move downstream with a composition or at a time period that is inconsistent with the viability and health of the downstream system. Discharging large amounts of sediments through a dam may not be planned, but may result when the sediment is mobilized due to increased water releases through a dam when the reservoir pool is low. Similarly, when a dam is breached, it generally causes the sediment behind the dam to be eroded rapidly, usually in a discrete (single) event or a series of discrete events, which move the sediments downstream.

Regardless of whether the dam operators had the intent to discharge sediment through the dam and out of the water impoundment, the opening of the lower gates of the dam has the effect of allowing substantial quantities of sediment material to travel downstream, thereby constituting the discharge of dredged material (and possibly fill material, as well) from a point source, thereby requiring a DA permit.

4. **Analysis and Policy**

a. As a general rule, the discharge of substantial quantities of accumulated bottom sediment from or through a dam into downstream waters constitutes a discharge of dredged material (and possibly of fill material) that requires a CWA Section 404 permit. The discharge of substantial quantities of sediment through a dam will rarely, if ever, qualify as exempt under 404(f). Such activities may also require a DA Section 10 permit if they occur in "navigable waters of the United States", and no statutory exemptions apply to Section 10 for such discharges into navigable waters. This policy includes the human-induced breaching of dams when sediment has accumulated in the reservoir basin and is released downstream.

b. Activities that are not usually considered regulated discharges of dredged material and do not require DA permits include actions such as the operation of continuously sluicing structures that mimic the natural increase and decrease of sediment in a stream (i.e., the amount of sediment discharging from or through a structure is comparable to the amount of material entering the reservoir from upstream); breaching or removal of a dam that results in the movement of only de minimis amounts of material or that results solely from an act of nature; releases during times of high water or flood stages for purposes of passing flood waters through the dam; and the lowering of lake or pond levels that results in the release of only de minimis amounts of sediment.

It should be noted that there is often high variability in the amount of sediment and water carried by rivers and streams over an annual cycle. Such high flows may occur as a result of storm runoff or seasonal runoff of melting snow pack. Larger amounts of sediment may be considered de minimis in relationship to location of the dam and the normal amount of erosion in the watershed; and thus may not require DA authorization. This guidance does not propose to set a specific amount of sediment that could be considered de minimis or "more than de minimis". When evaluating whether any discharge is de minimis, or may be exempt from the Section 404 permit requirement under CWA Section 404(f)(1) exemption for dam maintenance activities, District Engineers should consider whether the discharge of dredged or fill material through the dam is necessary for dam maintenance, and proportional to the proposed activity and the size of the facility (i.e., size of the dam/structure and the surface acres and storage volume of the resulting impoundment). Other factors in this consideration should include the time of year and normal seasonality of high volume flows, the size of incoming and outgoing stream/river and the intended release volume, the natural hydrograph of the system, the speed of the drawdown, the normal amount of sediment in the watershed, and the potential for environmental harm. These factors should be documented as part of the decision regarding whether a DA permit will be required for the proposed release of sediments through a dam or would have been required in after-the-fact evaluations.

c. On a case-by case basis, District Engineers may consider the need to reduce the level of the reservoir through one or more flood gates and the resultant discharge of dredged material downstream, to avoid potential catastrophic dam failure, to be an emergency subject to the emergency permitting procedures found at 33 CFR 325.2(e)(1). Sluicing through a dam of less than 25 cubic yards of material may be authorized under Nationwide Permit 18, if all other conditions of that nationwide permit are met. Districts may also consider developing Regional General Permits for larger amounts of sediments to be released through a dam, if such Regional General Permits would include appropriate conditions to protect the environment and the overall public interest. Small impact releases of sediments might possibly be authorized under Nationwide Permit 23 if an agency has an approved Categorical Exclusion.

d. When discharging sediment from or through a dam or breaching a dam, reasonable measures should be implemented to reduce potential harm to downstream waters. Reasonable measures include, but are not limited to, prior dewatering by pumping or by releasing water from the upper control structures on a reservoir; mechanical dredging or excavation of sediments and appropriate disposal; timing releases to coincide with high water periods for better dilution; more frequent flushing to keep the discharges small; releasing a sediment amount that is dependent on the amount of water flow; and installing temporary barriers to prevent exposed sediments from being transported by runoff from subsequent storm events.

6. Duration

This guidance remains effective unless revised or rescinded.

FOR THE COMMANDER:

DON T. RILEY
Major General, U.S. Army
Director of Civil Works

As of January 20, 2010 this guidance letter has not been revised or rescinded.

GLOSSARY

Acre-Foot (ac-ft) - the volume of water it takes to cover one acre (a square 208.7 feet on each side) of land with water one foot deep. It is 43,560 cubic feet or 325,850 gallons. One acre-foot is approximately the amount of water needed to supply a family of four with enough water for one year.

Active Storage – also known as “live” storage, this is the portion of a reservoir’s volume from which water can be released for use. Inactive or “dead” storage (sometimes called a conservation pool) is the stored water which cannot be released.

Aggradation – to fill and raise the level of the bed of a stream by sediment deposition.

Aquifer - a geologic formation that stores and transmits water. A confined aquifer is bounded above and below by formations of impermeable or relatively impermeable material. An unconfined aquifer is made up of loose material, such as sand and gravel, that is not confined on top by an impermeable layer.

Aquifer Storage and Recovery (ASR) – a method of storing water in an aquifer and then removing (recovery) it at a later date.

Bed Load – the material which is moved along a river bed by rolling and pushing, usually at a velocity much less than that of the river. Bed load is usually composed of sands and gravels but when the water level is high and the current strong, boulders may be moved.

Beneficial Use - use of water for one or more of the following purposes including but not limited to, domestic, municipal, irrigation, hydropower generation, industrial, commercial, recreation, fish propagation, and stock watering.

Biochemical Oxygen Demand (BOD) – a measure of the oxygen that aerobic bacteria need to breakdown the organic compounds in wastewater. Treatment plants seek to meet this demand before effluent is discharged to natural waterways with insufficient oxygen levels to accomplish such treatment.

Conservation - according to Webster’s Dictionary, conservation is the act or process of conserving, where conserve is defined as follows: (1) To protect from loss or depletion, or (2) to use carefully, avoiding waste. In this document, the second definition is used exclusively. However, in the water resources field the first definition is also used. Using the first definition, constructing a reservoir to capture excess runoff in order to more fully utilize the water is also considered conservation.

Check Dam – this is a small, permanent barrier constructed across a drainage ditch, swale, or channel to lower the speed of concentrated flows for a certain design range of storm events. It’s purpose is to trap sediment and limit erosion.

Culinary Water - water meeting applicable safe drinking water requirements for residential, commercial and institutional uses. This is also known as drinking water or potable water.

Contour Survey - a method of estimating the storage volume of a reservoir by using a sonar device to measure the depth of water and a Global Positioning System (GPS) device to measure geographic location. Also known as a bathymetric survey.

Debris Basin – a small basin designed and constructed for the purpose of trapping and containing silt, sediment, and other water borne debris.

Deforestation – the removal and clearing away of trees and forest.

Density Currents - sediment-laden water from a stream, being denser than the relatively clearer water of a reservoir, can create a current flow along the bottom of the reservoir to the face of the dam.

Deposition – the process of sediment dropping on the bed of a water course or floor of a reservoir. It is essentially the opposite of erosion.

Diversion - water directed away from supply sources such as streams, lakes, reservoirs, springs or wells for a variety of uses including cropland irrigation and residential, commercial, institutional, and industrial purposes. This is often referred to as withdrawal.

Dredging – the removal of sediment from the reservoir floor by mechanical means, including scooping or suction.

Drinking Water – see Culinary Water

Economic Life – a time period over which a project is expected to be usable, with normal repairs and maintenance, for the purpose for which it was built. In this report, the project can include a dam, reservoir, or sediment mitigation structure or undertaking.

Effluent - liquid discharge from any unit of a wastewater treatment works, including a septic tank. This is frequently referred to as wastewater effluent or, in portions of the Utah Code, as sewage effluent.

Erosion Velocity – this is the speed at which water begins to lift and transport sediment particles. Erosion velocity varies depending upon the sediment characteristics such as particle size, density and shape.

Fall Velocity – this is the velocity at which a particle drops out of the moving water. The fall velocity depends on sediment particle characteristics such as size, shape, and density.

Flushing – the re-suspension and removal of deposited sediments from a reservoir basin by means of high velocity flows. Flushing is accomplished when high flows occur while the reservoir level is drawn down.

Gabions – a wire basket or cage filled with rocks and used to stabilize a stream bank against erosion or as a support or abutment.

Grazing Allotments – this allocation provides the bearer with the right to graze sheep, cattle or other herd animals on federal lands, typically Bureau of Land Management or Forest Service lands. Allotments are paid for.

Ground Water - water that is contained in the saturated portions of soil or rock beneath the land surface. It does not include water held by capillary action in the upper unsaturated zones of soil or rock.

Hydrology - a science dealing with the properties, distribution, and circulation of water on and below the earth's surface and in the atmosphere.

Hydrosuction Bypass – the use of a sediment collection structure at the reservoir inlet, and a pipeline, to conduct the sediment and water mixture through the reservoir, taking it downstream.

Hydrosuction Dredging – the use the hydraulic head of the reservoir to remove sediment from the bottom of the reservoir, this method is often called siphoning.

Industrial Use – the amount of water associated with the manufacturing and/or assembly of products. It may include the same uses as a commercial business. However, the volume of water used by industrial businesses can be considerably greater than that used by commercial businesses.

Irrigation Efficiencies – because of system losses and inefficient application, not all water diverted for irrigation is used by the crops. The amount of water used by the crop, compared to the amount diverted, is the irrigation efficiency.

Land Terracing – a method of reducing erosion by means of excavating a series of horizontal benches along a mountain slope.

Limnoplankton –exceptionally small (generally microscopic) plant and animal organisms that dwell in lakes and reservoirs.

Live Storage – see Active Storage

Mancos Shale – a geologic formation consisting of thick, inter-bedded sandstone and compressed clay, silt, or mud that were deposited in a marine environment. It weathers to characteristic badlands topography that is devoid of vegetation. Erosion of this formation yields large amounts of fine grained sediment and soluble salts.

Mean Annual Runoff – average amount of water volume that flows in a stream during one year. It's measured in acre-feet.

Mitigation – an action or project that moderates or eliminates the impacts of a natural activity. The result is conditions become less harsh or difficult.

Multi-purpose Water Storage – a reservoir constructed to store water for more than one specific use.

Municipal and Industrial (M&I) Use - This term is used to include residential, commercial, institutional and industrial uses.

Nephelometric Turbidity Units (NTU) - A measure of the clarity of water. An instrument called a nephelometer is used to measure the amount of light scattered by suspended matter in the water. Turbidity is visually detectable at 5 NTU and above. Drinking water requires 0.5 NTU or below.

Nutrient Loading – Quantity of nutrients entering an ecosystem in a given period of time. Nutrients include the approximately 20 chemical elements known to be essential for the growth of living organisms, including nitrogen, sulfur, phosphorus, and carbon.

Off-stream Reservoir – This is a reservoir located away from the main stream channel. It is typically in a small drainage basin, which receives minimal inflow. Water is diverted from the main stream and conveyed by canal or pipeline to the off-stream reservoir site.

Organic Detritus – fine particles of material based on living things.

Public Water Supply - water supplied to the general population through a public or private water system. This includes residential, commercial, institutional, and industrial purposes, including irrigation of publicly and privately owned open areas. As defined by the State of Utah, this supply includes potable water supplied by either privately or publicly owned community systems which serve at least 15 connections or 25 individuals at least 60 days per year.

Range Survey – a method of estimating the storage volume of a reservoir by using a sonar device to measure the depth of water along preset range lines that cross the reservoir at regular intervals.

Regression Analysis (R^2 value) –a statistical method of analyzing and evaluating the interdependence and reliability of correlated a data set.

Residential Use - water used in private houses for cooking, drinking, washing clothes, personal grooming and sanitation, watering lawns, gardens, and landscapes, washing automobiles, driveways, and miscellaneous cleaning.

Rip-Rap – a layer of large rocks and boulders placed on or against an earthen bank to protect it from erosion.

Riverine Environments – wildlife habitat within, and adjacent to, a river. It includes aquatic, wetlands, riparian and upland habitats.

Secondary Water System – a pressurized pipe or open canal providing water that does not meet drinking water standards. The water is used for watering privately or publicly owned lawns, gardens, parks, golf courses and other open areas. This system is separate and distinct from the culinary water system.

Sediment Bypass – the routing of sediment-laden flows around a reservoir via pipeline or open channel.

Sediment Detention Basin – a relatively small pond or pool in the side channel of a stream. It is designed to trap suspended sediment in order to control and improve water quality.

Sediment Management – an organized program intended to reduce the amount of sediment accumulating in a reservoir. It includes minimizing sediment entering a reservoir, minimizing deposition of sediment in the reservoir, removing sediment from the reservoir, and compensating for sediment accumulated in the reservoir.

Sediment Transport – movement of sediment from one point to another. This can occur with rainfall flowing over the land, a stream cutting into the soil, or the stream carrying a given amount of sediment.

Sedimentation – the process of depositing sediment. This can occur in a stream or a still water body.

Siphoning – a siphon is a tube bent to form two legs of unequal length by which a liquid can be transferred to a lower level over an intermediate elevation by the pressure of the atmosphere in forcing the liquid up the shorter branch of the tube immersed in it while the excess of weight of the liquid in the longer branch, when once filled, causes a continuous flow. This principle is used to remove sediment and water from a reservoir using a pipeline.

Stream Morphology – The study of the structure and form of a watercourse .

Sustainable Use (Sustainability) – the current use of a natural resource (water, land, forests) does not negatively impact the ability of future generations to satisfy their needs.

Total Maximum Daily Load (TMDL) - As defined by the EPA, a TMDL "is the sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources. [Its] calculation must include a margin of safety to ensure that the water body can be used for the purposes the State has designated. The calculation must also account for seasonal variation in water quality." The TMDL must also provide some "reasonable assurance" that the water quality problem will be resolved. The states are responsible to implement TMDLs on impaired water bodies. Failure to do so will require the EPA to intervene.

Total Suspended Solids (TSS) – sum total of particulate matter suspended, but not dissolved, in solution.

Turbidimeter – a meter that measures turbidity.

Turbidity – the measurement of sediment or foreign particles stirred up or suspended in water, giving it a cloudy appearance.

Upstream Trapping – collection of sediment in a retention basin or check dam located in the upper watershed.

Watershed Management – judicious use of resources in the upland area which drains water and sediment to a reservoir. It includes trees, plants, and soil. The intent is to reduce sedimentation to a minimum.

Wetlands - areas where vegetation is associated with open water and wet conditions including high water table.

Withdrawal - see "Diversion."

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