ISSUES AND CONFLICTS IN RESERVOIRS

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INTRODUCTION

All solutions to problems create their own unforeseen ramifications. Reservoirs are no exception to this rule. At the conception of large man-made reservoirs several decades ago, it was thought that a solution to the problem of non-uniform water supply was found. No longer would floods devastate property at certain times while drought threatened life at others. After several years have passed, however, we find that there are effects of reservoirs that were not predicted. Many of these effects have to do with sedimentation. In particular, the environmental and social effects are now becoming issues of growing concern.

In recent years the number and amount of chemicals used in our society has increased greatly. Farm pesticides and herbicides, transportation related chemicals washing off roads and highways, and industrial pollution all end up in rivers and reservoirs. These chemicals settle out of the water and adhere to sediments on the reservoir bottom. This creates a storehouse of chemicals in our reservoirs. The effects on wildlife are now becoming known. Bottom-spawning fish are being adversely affected by the chemicals. Algae and plankton cannot survive as well either, which interrupts the food chain. These problems are augmented when dredging of sediment stirs up the chemicals and re-exposes them. Urbanization increases contaminant supply through more chemical usage and better runoff conveyance on impervious surfaces. We must face the increased use of chemicals in our modern-day life style and explore mitigation issues both in reduction of chemical use and in treatment and disposal of existing contamination.

New reservoir construction is meeting fierce resistance lately. The side-effects of reservoirs are being seen as environmental hazards. For example, the resettlement of indigenous people groups is said to have long lasting effects on their health and adaptability. Flora and fauna of a region can be changed by the inundation of an area. Wildlife can be altered and, in extreme cases, a species become extinct. The economy of a region changes due to both resettlement and to newly created recreational opportunities. Flooding patterns change upstream of the reservoir if sedimentation causes blockage of stream conveyance. This blockage also may prevent the spawning of some fish species. If this sediment aggradation becomes exposed during periods of low flow, then wind can carry the sediment to picnic and other recreational areas. Decreased sediment supply downstream of the dam also causes problems due to reduction in sediment supply. This reduction increases the river's ability to scour river beds and banks, thereby causing the river to possibly change course. Transportation and recreation on reservoirs is reduced due to small clearance distances for boats and shoaling of harbors. Fish populations can diminish due to decreased storage capacity of the reservoir. Solutions must be found to these social issues for existing reservoirs if there is to be any hope for the future development of new reservoirs.

With these conflicts before us, the fate of reservoirs, both existing and proposed, is in question. Should new reservoirs be planned and constructed, or should we remove existing ones? Perhaps we should manage existing reservoirs in a more environmentally sound manner and discourage new projects. These are the questions that our society, and we as engineers, will have to grapple with in the future.

This paper reviews the mechanism of sediment deposition in reservoirs and lists some of the issues involved in chemical transport in reservoir sedimentation and the social effects of sedimentation. Finally some recommendations for the future are explored.

MECHANISMS OF SEDIMENTATION NEAR RESERVOIRS

To understand better why building a dam and reservoir on a river causes environmental and social concerns, a brief overview of the impact on sedimentation of reservoirs is helpful. With the addition of a dam and the resulting reservoir on a river, the natural sedimentation patterns of the river are altered not only in the reservoir itself, but also upstream and downstream of the reservoir.

As water enters the reservoir, the velocity is greatly decreased. This velocity reduction allows sediment that would normally be in suspension to deposit. Over time, the sediments occupy valuable reservoir storage space. The sediment deposits occurring in varying patterns and locations within the reservoir depend on incoming flow rates, sediment size and distribution, and reservoir configuration. This lost storage space must be recovered to sustain the life and utility of the reservoir.

Pooling of the water in the reservoir causes the river upstream of the reservoir to aggrade with sediment. This can cause additional flooding and damage to any existing river structures and the river reach. During low-flow periods, the deposited sediment can be exposed and blow to undesirable locations.

Since most of the sediment is captured in the reservoir the water downstream of the dam is clear. This means that the sediment carrying-capacity of the downstream water is enhanced, resulting in scour. This scoured material is then deposited downstream after the water has had a chance to lose its scouring potential.

The following is a partial list of work done describing sedimentation at reservoirs in chronological order.

Table 1. Publications regarding reservoir sedimentation.

Author/s	Year	Description
Borland and Miller	1960	Presents 2 methods of predicting distribution of sediment with time.
Buttling and Shaw	1971	Review of processes of thermal, pollution, and suspension effects.
Posey	1971	Method of preventing reservoir capacity loss
Dendy and Champion	1973	Survey of reservoir sediment deposition in the U. S.
McHenry	1974	Summary of sedimntn. rates in U. S. reservoirs. Problems discussed.
Murthy	1980	Survey of sedimentation deposits in several dams in India
Strand and Pemberton	1982	Disc. of methods of determining sed. infl., dep., and dwnstrm effects.
Mertens	1986	Experimental study of bed-load reservoir sedimentation
Chane	1987	Description, estimation, and prediction of sed. deposits in reservoirs.
Luo et. al.	1987	Summary and analysis of backwater region of reservoirs.
Mahmood	1987	Role of, physical phenomena, survey of, and resrch. areas of res. sed.
Bhargava et. al.	1989	Hydrographic surveys of 4 reservoirs in India
Committee on Reservoir Sed.	1989	Discusses sediment yield, deposits, control, and secondary effects.
Williams	1991	Case study of Roseires dam and reservoir in Sudan
Sloff	1994	Methods of modeling turbidity currents in reservoirs
Zhao	1994	Theoretical approach regarding sediment forces on gravity dams
USCOLD	1995	Papers on all aspects of reservoir sedimentation.

HISTORY AND ISSUES OF ENVIRONMENTAL IMPACTS OF RESERVOIR SEDIMENTATION

Reservoir sedimentation causes many varying effects on the environment of the surrounding region. A modification of the river discharge regime, an alteration of river channel morphology in the reservoir region, and a significant shift in the conditions of sediment transport occur when a dam is built in a river valley. There are significant effects of impoundment on the reservoir, the river reach upstream and downstream of the reservoir, and the influence of sediments on the aquatic life. The very safety of the dam can sometimes be endangered by sediment deposits. Sediment influences the bottom outlets, gates and valves, the dam itself, and the underwater supervision of the dam. There are also impacts on the social and economic objectives of the project. They depend upon the size and the characteristics of the deposits. The consequences are very complex, because the dam usually serves multiple objectives that may evolve over the years. There are also effects of impoundment on energy production, agriculture and industry, public health, and discharge regulation. In addition to these, there are effects on the reduction of the water surface, water sports, and fire fighting. A chronological history of studies follows, highlighting pertinent issues.

In the early years of dams and reservoirs, the effects of chemicals on the sediments deposited in reservoirs were not recognized widely. In a paper by Dieffenbach (1950), the main concerns of that day were to conserve the wildlife through studying the situation and possibly by changing operating procedures of dams. This was deemed important only so that recreational use by humans was not to suffer. There was little talk of a certain species of animal becoming extinct, for example. By 1970, there was more talk about water pollution and the effect on sedimentation. Livesey (1970) addresses the problem and calls for more research to be done to better understand the reaction rates and interactions between chemicals and sediments.

The late 1970s marked an increase in the attention paid to ecology and contamination issues. The U. S. Bureau of Reclamation (1977) examined the effects on the ecology of Banks Lake in Washington of irrigation operation and pumped storage. The lake limnology and its relation to fish entrainment in irrigation intakes was examined. It was concluded that operation of the irrigation and pumped storage scheme has an adverse effect on the ecology of the lake. Physical, chemical, and biological changes all occur to reduce fish populations. These are principally caused by draw-down of the lake pools. Fish entrainment occurred in the irrigation canals and intakes, as well. Keeley et al. (1978) call for the further study of the effects of operations on the environmental aspects of reservoirs. In addition to operations of existing reservoirs, the factors affecting fish production and fishing quality in new reservoirs is presented by Ploskey (1981). Guidance is provided on timber clearing, basin preparation, and filling. In relation to sediment, it is noted that sediment not only houses contaminants, but valuable nutrients for fish. Disposing of sediment will increase storage capacity, but will also waste nutrients. Water quality of a proposed reservoir is examined by Yahnke (1981); it is concluded that certain types of algae would probably grow and that most fish species now present in the river will be eliminated. The reservoir would have to be re-stocked as a cold water fishery. The sudden growth of interest in contaminants in reservoirs prompted a literature survey of reservoir contaminant problems by Khalid (1981). At that time, there was limited information available on the loss of sediments from watersheds, sediment transport in streams and rivers, sedimentation in reservoirs, and sediment discharge in reservoir release waters. Information such as this is crucial for basing guidelines for managing reservoir contaminants.

New methods for improving the environment of fish were then started. The effect of improving fish populations is presented by the Iowa Conservation Commission (1983). Summer aeration is examined and found to de-stratify the reservoir, which increases plankton and fish growth. Pastorok, Lorenzen, and Ginn (1982) also studied aeration of reservoirs and present a review of theory, techniques, and experiences.

It was not until 1988 that the quality of reservoir bottom sediment was studied. Sediment accumulations can not only reduce storage capacity, but also do damage to turbine runners and penstocks. The need to sluice sediments out of reservoirs also entails the release of contaminants adhered to these sediments into the river. Garrison and Shipp (1988) detail these effects for three reservoirs. A method is proposed by Waldo (1988) for using reservoir sediment samples for determining issues of reservoir management. Avnimelech and Wodka (1988) collected data on nutrients in the bottom sediment of a new reservoir and detailed their several-fold increase. Low and Mullins (1990) present a report on the effect of irrigation drainage on water quality, bottom sediment, and biota of a reservoir in Idaho. In general, irrigation did not significantly increase the amount of toxic chemicals in the sediment of the reservoir. Some were actually lowered from the reservoir as they were transported to the irrigation canals and eventually to the fields. In addition, an entire conference was dedicated to the impact of large water projects on the environment that included many papers on dams and reservoirs. The conference was entitled "The Impact of Large Water Projects on the Environment." Only a few, however, discussed sediment problems at any length. This oversight underscores further the lack of attention paid to sediment problems in reservoirs. Suschka and Napica (1990) present findings of sediment behavior from the Cabora Bassa Dam in Africa. After ten years, they found little alteration of the river bed configuration. A longer time period may be needed to see the effects on the rivers for that particular reservoir. Le Hir, Guillaud, and Salomon (1989) present a mathematical model for dissolved and particulate contaminant transport for cohesive sediments. Istvanovics, Herodek, and Szilagyi, (1989) studied phosphate adsorption by sediments in a reservoir and found that desorption occurs whenever the sediments are re-suspended and adsorption occurs only in the sediment. Gunnison et al. (1989) examine the interactions between sediment, water, and contaminants in reservoir projects overseen by the U. S. Army Corps of Engineers and conclude that: 1) many reservoirs are experiencing problems resulting from the presence of contaminants, 2) acid mine drainage varies widely over the country, and 3) the principle difficulty in managing contaminant problems is lack of suitable methods for quantifying contaminants. Tobin and Hollowed (1990) present findings on water quality and sediment transport in Kenney Reservoir in Colorado. When inflows are small and nutrient counts large, there can be blooms of algae. Suspended sediment was dominant in the inflow and gradually cleared up towards the outlet. Sediment capture rate by the reservoir is typically 95 percent. GIS is used for assessing risk of polluted mud deposits in reservoirs by Ruland and Rouve (1993). Issues of what to do with polluted sediment and how to balance competing interests are examined. UNEP (1994) gives a cursory treatment of the pollution of reservoirs and concludes that a sustainable method of management is needed in the future in the face of burgeoning population growth. Sediment-water phosphorus exchange is examined by Mhamdi, Aleya, and Devaux (1994). It was found that exchanges were regulated by both physical-chemical variability of the environment and geology of the area. Phosphorous control in the tributaries is recommended. Mastran et al. present findings regarding the distribution of polyaromatic hydrocarbons in sediment due to boating activity on a drinking water reservoir. It is found that boating significantly increases the amount of this contaminant in both the water and sediment. Other sources of contaminants are hydrology, atmospheric deposition, and urban runoff. A description of approaching the sediment contamination prediction problem by comparing many models is presented by Rose et al. (1993). Sediments in a reservoir in Germany are polluted to the extent that flushing would create a great risk to water quality. Spork, Ruland, and Kongeter (1995) present this case study and a 2-D modeling approach to the problem. It is found that drawing down the reservoir level for maintenance of the weir will cause high contamination and should be avoided.

SOCIAL ISSUES OF RESERVOIR SEDIMENTATION

The impacts of reservoirs are not limited to the technical domain. There are also many social considerations. The aforementioned downstream effects of reservoirs cause property damage. Dam overtopping or breakage can be catastrophic. Archeological sites can be inundated. Increased urbanization can exacerbate sedimentation resulting in decreased reservoir life. These social aspects will need to be prioritized and quantified better in the future.

Not only do reservoirs have implications for us socially, but our social patterns have implications for reservoir sedimentation. Guy and Ferguson (1962) examine the effects of urbanization on sedimentation in small reservoirs. Construction activities remove large quantities of earth that is eventually carried off by rivers to end up in downstream reservoirs. This construction activity can cause a higher concentration of course sediments than usual. Regulations need to be expanded to cope with the increasing sedimentation caused by construction. Rivers and streams running through urban areas are widened either artificially or naturally, thereby further increasing sedimentation. With the ever-increasing urbanization occurring in many areas, this can mean even shorter useful lives for reservoirs. Many urbanization activities also vie for reservoir land. It seems there is a viscous cycle of urbanization causing increased sedimentation in the reservoirs that we need to be built to support our increasing urbanization.

Not only can reservoirs cause damage to property and life, but valuable archeological treasures can be inundated by reservoirs. Lenin et al. (1981) examine this issue in detail and have the following general conclusions:

1. reservoir induced inundation of archeological resources is detrimental,
2. a greater effort must be placed on delineating which reservoir processes cause the various kinds of damage to remain rather than the current approach of prioritizing sites according to importance,
3. site protection is a viable alternative to excavating the remains only in specific circumstances,
4. there is a lack of understanding of the effects of different zones of the reservoir on cultural resources,
5. managerial action must also be taken after inundation, and
6. there needs to be better communication between reservoir planning and construction personnel.

These conclusions point to the need to carefully consider the implications of damaging important clues to the past for immediate, relatively short-term benefits.

Social and economic aspects of reservoir sedimentation are inextricably intertwined. Much of economics is predicting social habits. Hitzhusen, Macgregor, and Southgate (1984) present a cost-benefit model of private and social aspects of sediment management in developing countries. Conclusions such as the following can be made with the use of the mode:

1. the effects of sedimentation on electrical production,
2. people groups most affected by sedimentation,
3. the sensitivity of watershed management benefits to the accounting method,
4. the comparability of social and private analyses, and
5. the need for more precise evaluation of property rights, soil conservation, and balance of payments policies.

This type of economic model is tempting, but without a complete understanding of the assumptions and associated uncertainties, one can be fooled into believing that the results are without error. Attempts must be made, however, to attack this problem because we must make decisions now that depend on future uncertainties regarding reservoir sedimentation.

The quantification of sedimentation rates along with the determination of which social behavior is attributed to sedimentation flux can be difficult. An attempt at such quantification is presented by McIntyre (1993). Land use was determined by examining subsequent aerial photographs and sedimentation found by taking core samples of the reservoir sediment. It was determined that the primary cause of reservoir sedimentation decrease in the years spanning 1934-1967 was the conversion of crop field to perennial pastures for a watershed in central Oklahoma. These methods may show promise for examining other watersheds.

In addressing some of the legal issues related to reservoirs, Hamilton (1995) brings up some social issues as well. Two downstream impacts are identified as potentially important. The first is erosion caused by the sediment-free release water. This can cause unnecessary property damage and harm to wildlife habitat. The second issue is that of removal of the dam and reservoir at the conclusion of its useful life. The resulting sudden release of sediment can cause blockage not only to the normal river passage, but also to any river structures built to operate with reduced sediment loads. In addition to these impacts, there are the potentially catastrophic impacts of dam overtopping. Overtopping can cause more damage than if the dam were never built due to the fact that development has occurred on the banks of the river downstream of the dam since the dam construction. Due to the recent legal climate of standard of care and ability to foresee, government agencies and private developers may be held responsible for social implications of dams they build. Design immunity may be withheld in the future.

These social effects may seem obvious after reading them here, but sediment concerns in hydropower schemes are often ignored completely. In a bibliography of electric generating stations (Chiang and Snead 1976), none of the 52 studies listed under Internal Costs even mentioned sediment concerns at all. This highlights the fact that few planners and engineers take into consideration one of the main things that can shorten the life of their project considerably: sediment.

RECOMMENDATION FOR FUTURE WORK

Much progress has been made on documenting and dealing with the problem of environmental and social issues of reservoir sedimentation, but more work needs to be done to attain a sustainable and safe use of reservoirs. Some recommendations are given here for future work.

Environmental Impacts Of Reservoir Sedimentation

* find better field measurement methods of sediment contaminants
* find ways of contaminant tracking to determine contaminant sources
* understand chemistry of adsorption to sediment under differing flow regimes
* examine, as a society, the relative worth of continuing to use contaminants
* explore new disposal techniques
* investigate methods of post-treatment to neutralize contaminants

Social Issues Of Reservoir Sedimentation

* find ways to reduce property damage caused by altered sediment characteristics
* decide worth of building in areas in danger of dam collapse
* evaluate risks of using contaminants versus consuming polluted seafood
* increase awareness among engineers and the public of sediment contamination issues
* continue to debate the utility of reservoirs in regard to sediment contamination
* discuss issues involved in polluted sediment rehabilitation and disposal.

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