Sedimentation of Dams

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Abstract— Dams and reservoirs are useful tools to control water resources to allow irrigation, and to avoid high-flood disasters. Nevertheless, these useful capacities to store water also lead to unintended consequences which affect the erosion/transport processes through watersheds. Some dams no longer serve the purpose for which they were constructed. When a dam has significantly deteriorated, the costs of repair may exceed the expected benefits, and dam removal may be a less expensive alternative. Hydropower reservoirs are loses their capacity due to sedimentation processes, and are therefore seriously threatened in their performance.

Key words: Dam Sedimentation, Erosion, Sedimentation

I. Introduction

Rainfall runoff, snowmelt, and river channel erosion provide a continuous supply of sediment that is hydraulically transported and deposited in reservoirs. Because of the very low velocities in reservoirs, they tend to be very efficient sediment traps. Reservoir sediment disposal (through mechanical methods) can be very costly for large volumes of sediment. Therefore, the management of reservoir sediment is often an important and controlling issue related to dam removal (ASCE, 1997). The sediment erosion, transport, and deposition are likely to be among the most important physical effects of dam removal.

Approximately 1% of the storage volume of the world's reservoir is lost annually due to sediment deposition [Morris and Fan, 1998]. In some developing countries, where watershed management measures are not carried out effectively, reservoir storage is being lost at much larger rates. Although the reduction of sediment yield via a watershed management program is the best option for reducing the rate of reservoir sedimentation, flushing may be one of the most economic methods which offer recovering of lost storage without incurring the expenditure of dredging or other mechanical means of removing sediment. Flushing is the scouring out of deposited sediments from reservoirs through the use of low level outlets in a dam by lowering water levels, and thus increasing the flow velocities in the reservoir. The technique is not widely practiced because of the damages caused by the injection of high sediment concentrations to the downstream river system; involving large volumes of water being passed through the dam; being usually only effective in narrow reservoirs and requiring the reservoir to be emptied.

II. Sedimentation

Sediment is a naturally occurring material which is broken down by processes of weathering and erosion, and is subsequently transported by the action of wind, water, or ice, and by the force of gravity acting on the particle itself.

III. Sedimentation Problems with Dams

All rivers contain sediments: a river, in effect, can be considered a body of flowing sediments as much as one of flowing water. When a river is stilled behind a dam, the sediments it contains sink to the bottom of the reservoir. The proportion of a river's total sediment load captured by a dam – known as its "trap efficiency" – approaches 100 per cent for many projects, especially those with large reservoirs. As the sediments accumulate in the reservoir, so the dam gradually loses its ability to store water for the purposes for which it was built. Every reservoir loses storage to sedimentation although the rate at which this happens varies widely. Despite more than six decades of research, sedimentation is still probably the most serious technical problem faced by the dam industry.

The rate of reservoir sedimentation depends mainly on the size of a reservoir relative to the amount of sediment flowing into it: a small reservoir on an extremely muddy river will rapidly lose capacity; a large reservoir on a very clear river may take centuries to lose an appreciable amount of storage. Large reservoirs in the US lose storage capacity at an average rate of around 0.2 per cent per year, with regional variations ranging from 0.5 per cent per year in the Pacific states to just 0.1 per cent in reservoirs in the northeast. Major reservoirs in China lose capacity at an annual rate of 2.3 per cent.

IV. Impact of Erosion and Sedimentation

Erosion and sedimentation cause both environmental and economic impacts. Both are important, but are often only an economic impact that spurs a jurisdiction to take action. Environmental impacts are harder to see and quantify as they tend to build slowly and do not produce dramatic results for many years, when it may be too late to correct the problem. Erosion and sedimentation can cause expensive site damage and construction delays. Lack of maintenance often results in failure of control practices and costly clean up and repairs.

Many environmental impacts from sediment pollution are cumulative and the ultimate results and costs may not be evident until years later.

- Eroded soil contains nitrogen, phosphorus, and other nutrients. When carried into water bodies, these nutrients trigger algal blooms that reduce water clarity, deplete oxygen, lead to fish kills, and create odors.
- Erosion of stream banks and adjacent areas destroys streamside vegetation that provides aquatic and wildlife habitats.
- Excessive deposition of sediments in streams smothers the bottom fauna, seals stream beds, and destroys fish spawning habitat.
- Turbidity from sediment reduces in-stream photosynthesis, which leads to reduced food supply and habitat.

- Turbidity increases the amount of sunlight absorbed in water, raising stream temperatures. Suspended sediment abrades and coats aquatic organisms.
- Erosion removes the smaller and less dense constituents of topsoil - those clays, fine silt particles and organic materials that hold nutrients that plants require for healthy establishment. The remaining subsoil is often hard, rocky, infertile, and droughty; thus making reestablishment of vegetation difficult.

Many economic impacts are hard to quantify. How can a dollar value be assigned to loss of aquatic habitat or diminished water clarity? Other impacts may be readily quantified, for example the cost of dredging and disposing of the accumulated sediment in a silted-up reservoir.

- Excessive sediment accumulation reduces reservoir storage capacity and more frequent sediment removal is required.
- The cost of building new reservoirs to replace lost reservoir capacity is high. Increasing land values and lack of available sites are making this alternative much less feasible.
- Sediment deposited into streams reduces flow capacity, interferes with navigation, and increases the risks of flooding. Regular maintenance dredging is required.
- Erosion severely diminishes the ability of the soil to support plant growth. To restore this ability is costly.
- Listing additional wildlife as endangered species increases time and fees for permitting, design, and construction in the affected watersheds. Some costs are directly assessed to specific projects while many other costs are distributed statewide by spending additional monies for habitat restoration.

V. Principles of Erosion and Sedimentation

Effective erosion and sedimentation control requires first that the soil surface is protected from the erosive forces of wind, rain, and runoff, and second that eroded soil is captured on-site. Erosion control is the prevention or minimization of soil erosion. Sediment control is the trapping of suspended soil particles. Erosion control is the preferred approach. Sediment control is necessary because some erosion is unavoidable. The following principles are not complex but are effective. They should be integrated into a system of control measures and management techniques to control erosion and prevent off-site sedimentation. Fit site construction to the terrain. Review and consider all existing conditions in the initial site selection for the project. When construction is tailored to the natural contours of the land, little grading is necessary and erosion potential is consequently reduced. Time grading and construction to minimize soil exposure. Scheduling can be a very effective means of reducing the hazards of erosion. Stage construction activities to minimize the exposed area and the duration of exposure. In scheduling, take into account the season and the weather forecast. Time grading to coincide with a dry season or a period of lower erosion potential. Stabilize disturbed areas as quickly as possible. Retain existing vegetation whenever feasible. Vegetation is the most effective form of erosion control. Very little erosion occurs on a soil covered with undisturbed natural vegetation. Reestablishing vegetation can be a difficult and costly process. If possible, strip only the area where construction will actually occur, street and driveway lines, and cut and fill slopes. Try to integrate existing trees and other natural vegetation into the site improvement plan. Vegetate and mulch denuded areas. Seed and mulch denuded soils as soon as possible after grading is completed. Mulch helps seedlings to become established and protects the soil from raindrop splash until vegetation takes over. Soils may be planted with temporary or permanent vegetation. If the soil will be exposed during the winter months, protective measures other than vegetation must be used.

Divert runoff away from denuded areas. When vegetative cover is removed from land, the soil becomes highly susceptible to erosion. Runoff from areas that have been denuded should not be allowed to cross the exposed soils, particularly when the denuded areas are on slopes. Use diversion dikes or swales to divert upland runoff away from a disturbed area to a stable outlet. Minimize length and steepness of slopes. Slope length and steepness are among the most critical factors in determining erosion potential. Increasing slope length and steepness increases the velocity of runoff, which greatly increases its erosive energy. If slope steepness is doubled while other factors are held constant, soil loss potential is increased 2-1/2 times. If both slope steepness and length are doubled, soil loss potential is nearly 4 times greater. To prevent erosive velocities from occurring on long, steep slopes, interrupt the slopes at regular intervals using barrier or trap techniques. Keep runoff velocities low. The energy of flowing water increases as the square of the velocity, that is, the velocity doubles, the erosive energy quadruples and the water can theoretically move particles 64 times larger by volume. Channel velocities can be kept low by lining drainage ways with rough surfaces such as vegetation and riprap, by designing broad, shallow flow areas, and by constructing check dams at frequent intervals. Concrete channels, although efficient and easy to maintain, remove runoff quickly, often resulting in downstream channel erosion and flooding Prepare drainage ways and outlets to handle concentrated or increased runoff. Construction changes the characteristics of runoff. The creation of impervious surfaces, removal of plant cover, and compaction of soil by construction traffic allows less water to percolate into the soil and therefore increases the volume of runoff. Alternatively, if a project can be so designed that runoff from development areas is allowed to infiltrate into the soil on site, no off-site channel enlargement or protection should be necessary. To prevent channel erosion from occurring, design drainage ways to withstand the peak flows without erosion, select lining materials appropriate for peak flows, and deenergize concentrated flows at outlets using energy dissipaters. If development substantially changes the natural drainage conditions in a watershed, merely protecting the drainage channels on a project site may not be sufficient to prevent erosion. Trap sediment on site. Some erosion during construction is unavoidable. The function of a sediment barrier is to prevent sediment from leaving a site after the soil has been eroded from its place of origin. Sediment laden runoff should be detained on-site so that the soil particles can settle out before the runoff enters receiving waters. Locate sediment basins and traps at low points below disturbed areas. Use earth dikes or swales to route drainage from disturbed areas into the basins. Sediment barriers and sediment fences can be placed below small disturbed areas on gentle to moderate slopes. Storm water temporarily ponds up behind these barriers, allowing sediment to settle out. Inspect and maintain control measures. Inspection and maintenance of control measures are vital to the success of an erosion and sediment control program. Most control measures require regular maintenance. Problems often develop during a single storm. Some problems left untreated can result in more erosion damage than might have occurred without any erosion control measures. Inspect control measures frequently, particularly before, during, and after storm events, to ensure that they are working properly. Correct problems as soon as they develop. Assign to an individual the responsibility for routine inspections of operating erosion and sedimentation control practices.

VI. Erosion Control Planning

The purpose of erosion and sediment control planning is to clearly establish the control measures which are intended to prevent erosion and off-site sedimentation during construction. The Erosion and Sediment Control Plan (ESCP) serves as a blueprint for the location, installation, and maintenance of practices to control erosion and prevent sediment from leaving the site during construction. It should also be understood that plans are only a blueprint and will require modification throughout the life of the project.

The driving consideration in creating and implementing an effective ESCP to provide erosion prevention measures rather than sediment control. Although every ESCP will have elements of both, it is often far more cost effective and practical to emphasize erosion prevention. Erosion prevention measures are designed to prevent exposed soil particles from becoming dislodged by rain or wind. Such measures include temporary ground covers (mulch, temporary grasses, straw mulch and tackifier, etc.), matting, plastic sheeting, and numerous other products designed to provide mechanical or physical protection to exposed soil. Sediment control involves techniques to re-capture transported sediment from runoff. Sediment control measures include sediment traps and basins, sediment fences, check dams, sediment barriers, catch basin filters, etc. The benefit of erosion prevention is that it seeks to prevent the problem before it starts. It is also often impractical to recover large amounts of sediment after it becomes dislodged and suspended in runoff. On projects where the predominant soil particle size is very small (fine silts and clays), the amount of time required to allow for settling of solids can reach days or even weeks. It is also generally true that erosion prevention measures are more reliable, whereas sediment control measures require continual and costly maintenance. Because successful erosion control requires minimizing disturbed areas, the ESCP should emphasize scheduling and phasing. Project scheduling and phasing is often driven by factors other than erosion control,\ however, so contingency planning is essential. Most importantly, the ESCP should be designed and implemented as a living, dynamic plan that can be adapted to address changes in the project as work progresses.

VII. Conclusion

Erosion and sediment control measures are required for the sole purpose of protecting sensitive areas such as: streams, rivers, lakes, and wetlands. Check with local jurisdiction for specific requirements, permits and inspection. Inspection and Maintenance of ESC measures throughout the life of the project are imperative to ensure their performance. Unless the measures are properly installed and maintained, there is a strong chance of failure during the construction period.

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