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ORGANIZATION OF A MONITORING SYSTEM IN RESERVOIRS

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Abstract.

Growing demand for fresh water and constant depletion of water resources are among the problems of the 21st century. The issues of increasing the efficiency of using existing reservoirs, restoring damaged ones and building new ones are becoming increasingly urgent.

The history of building large reservoirs is only 100 years old. At the same time, most of them have managed to fill with sediment, as a result of which the useful volume of reservoirs has decreased. In the near future, many reservoirs will cease to perform their main functions.

On the other hand, over many years of operation, dams and hydraulic structures could lose their safety indicators due to long-term impacts of various external factors.

Improving the reservoir monitoring system is one of the most important engineering issues of our time.

Keywords: dam, reservoir, water discharge, sediments, useful volume.

Introduction

At the beginning of the 21st century, a database of monthly climate observations from meteorological stations was created. The database includes six climate elements and covers the global land surface. The database is checked for inhomogeneities in the station records using an automated method that refines previous methods by using incomplete and partially overlapping records and identifying inhomogeneities with opposite signs in different seasons. The method involves developing reference series using adjacent stations. Information from different sources about one station can be combined, even without an overlapping period, using a reference series. In this way, a longer station record can be obtained and fragmentation of the records is reduced. The reference series also allows the calculation of 1961–90 norms for a larger proportion of stations [1].

Reservoir storage space is required to provide reliable flood management, power, and water supply services. The demand for reservoir storage space is likely to increase as the effects of climate change set in. Increased hydrologic variability due to climate change will result in greater demand for reservoir storage, and the fact that it is in limited supply increases the importance of preserving storage space. Reservoir sedimentation occurs when sediment carried by a river flowing into a reservoir is deposited in the reservoir upstream of a dam. The sediment carried by the inflowing river is deposited in a reservoir because the water slows down after entering it and no longer has the ability to transport the sediment. Such deposits consume reservoir storage space that was originally intended for water storage, thereby impeding the intended function of the dam and reservoir. Sediment deposition in reservoirs also leads to smaller amounts of sediment being released to river reaches downstream of dams, which results in changes to river morphology, degradation of the downstream river channel and aquatic habitat, and reduction of food sources consumed by fish in rivers downstream of dams. This chapter discusses the importance of reservoir storage and the impacts of reservoir sedimentation up- and downstream of dams. The importance of reservoir sediment management is emphasized, and the global impact of reservoir sedimentation is presented [1, 12].

No achievable level of quality control can guarantee to exclude all errant data from a large dataset, because of the myriad ways in which the data may be evaluated and the elusive defnition of ‘errant’. Te disparate users of CRU TS (Climatic Research Unit gridded Time Series) subject the data to many kinds of statistical processing, and on occasion this can reveal potential issues for further exploration and perhaps correction [2].

Current design and economic analysis paradigms consider benefits and costs over a finite period, known as the design life. Although this approach is defensible for some civil infrastructure such as roads and bridges, it is not appropriate for designing dams and determining their economic value. When designing and operating dams, a life-cycle management approach is appropriate because of the unique characteristics of reservoir storage

space. Reservoir storage space created by dams is a natural resource with a dual character; it can either be exhaustible or renewable depending on the developer's decisions. If a reservoir is allowed to fill with sediment unhindered, it is deliberately and consciously classified as an exhaustible resource. However, if designed with reservoir sediment management and storage preservation in mind, the storage space is consciously classified as a renewable resource. In contrast with the design life approach, the life-cycle approach allows sediment management technology in new dam designs to be considered right from the start. Applying the same concept to existing dams and reservoirs requires refurbishment to allow for reservoir sediment management to promote sustainable development. Designing new dams in accordance with the life-cycle management approach and refurbishing existing dams with this approach in mind aims at, in theory at least, using these facilities in perpetuity and thereby respecting the tenets of sustainable development [5, 11].

River cross-sections and documentation of bed material grain size at fixed locations below the dam may also be required to monitor geomorphic changes due to dam construction and operation. Additional sediment monitoring concepts are presented by Morris [3].

The silting of a reservoir is an unavoidable process. Although it cannot be halted, silting can be slowed down and controlled. Reservoir sedimentation is a worldwide problem with the annual loss in storage capacity due to sedimentation estimated at 1% of the original storage capacity. Reservoir sedimentation is a worldwide problem with the annual loss in storage capacity due to sedimentation estimated at 1% of the original storage capacity. This equates to a replacement cost estimated by the World Bank at USD 13 billion per year needed to maintain the current total storage capacityReservoirs have already trapped more than 100 billion metric tons of sediment, representing 26% of the global sediment delivery to the ocean [4, 15, 16].

All projects should be monitored for sedimentation during the operational phase, with the type and frequency of monitoring dependent on project characteristics. For storage reservoirs, including run-of-river projects with pondage, monitoring should generally include the following types of data: All projects should be monitored for sedimentation during the operational phase, with the type and frequency of monitoring dependent on project characteristics. For storage reservoirs, including run-of-river projects with pondage, monitoring should generally include the following types of data [5]:

- Bathymetric surveys should be performed soon after initial filling; after 5, 10, and 15 years of operation; and thereafter as appropriate to the site. At projects with high rates of sedimentation, a survey interval of one or two years may be appropriate.
- Sediment cores should be taken or delta sediments should be sampled during drawdown to determine particle size distribution and bulk density at selected locations. In some reservoirs the delta sediment will be too weak to support field crews (mud, quicksand) and there may be ponding water. In these cases, sampling along the more accessible banks of the river channel crossing the delta will represent the coarser fraction of the deposited delta sediment. To obtain more representative sediment samples on deltas with large areas inaccessible by foot, performing sampling of submerged sediment once the delta is submerged may be a better approach. Multiple samples across the width of the delta, at several cross-sections, can better represent the overall grain size distribution of the delta deposit as compared to channel-bank samples only.

- The suspended sediment concentration and particle size distribution of water delivered to hydropower turbines or other outlet works should be characterized. At storage projects this may include sediment delivered by turbid density currents and sediment scoured from the delta by flood flows during drawdown. At run-of-river projects, daily data (including near-continuous data during high flow periods) may be needed to better characterize the changing sediment load on the equipment and to monitor the performance of desanding operations during seasonally high flows.

Conflict setting

The deposition of fine sediment in the basin of reservoirs causes economic and environmental consequences. The definition of appropriate reservoir management procedures requires accurate tools to predict sediment dynamics both in the reservoir and downstream.

Over many years of operation, dams and other hydraulic structures lose their safety indicators due to long-term impacts of various external factors. Reservoirs fill up with sediments, as a result of which their useful volume decreases.

To improve the reservoir monitoring system, the task is to analyze the experience of some scientific approaches to solving this problem.

Research Results

Simply flushing, involves emptying the reservoir to allow the river to flow across and erode the exposed deposits, transporting the eroded sediment through low-level outlets beyond the dam.

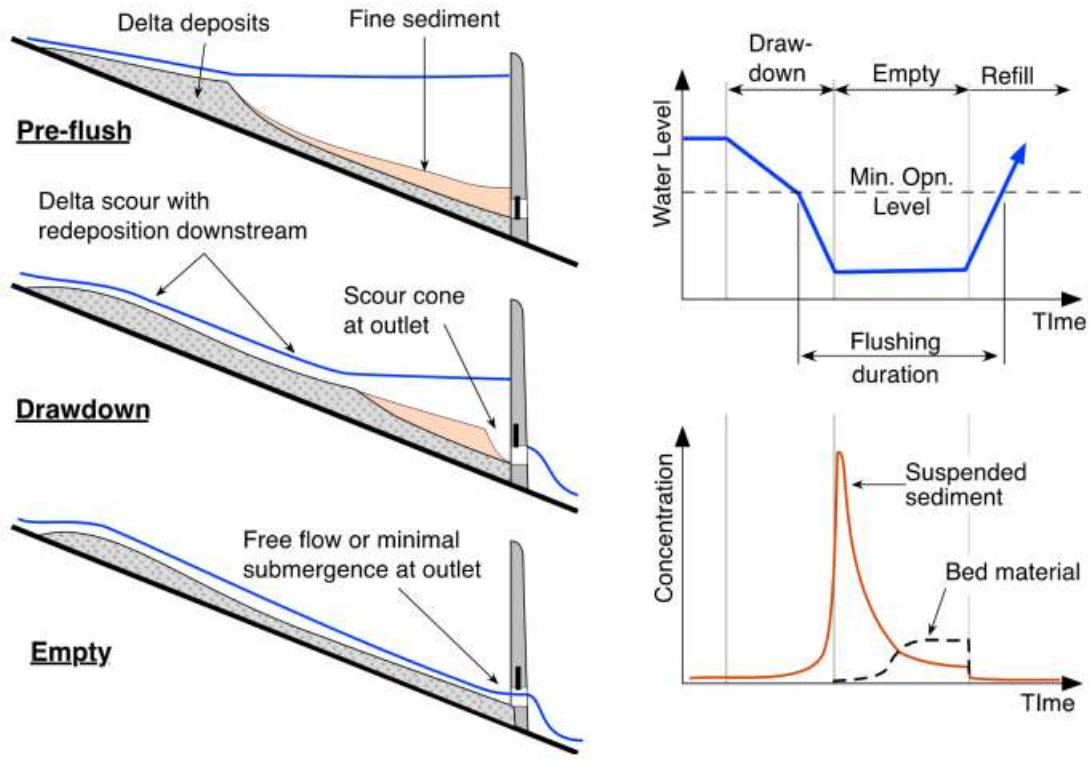


Fig. 1 Reservoir flushing sequence

The sequence observed during empty flushing is summarized in Fig. 1. The flushing process involves three stages [5]:

- **Drawdown water**. As the reservoir is drawn down, upstream sediment deposits are scoured, transported closer to the dam and redeposited. Opening the through low-level outlets during this period typically does not result in large amounts of sediment release.
- **Empty**. As shown by the graphs in Fig. 1, as the level drops to near empty to initiate the free-flow period, sediment that has been incrementally transported toward the dam during drawdown is now flushed out of the reservoir, producing peak concentrations.
- **Refill**. When reservoir refill begins, it may be necessary to continue to release clear water downstream to help flush released sediment through the downstream river channel.

It should be noted that flows with large amounts of sediment are no longer Newtonian due to high concentrations and the corresponding hydraulic equations lose accuracy.

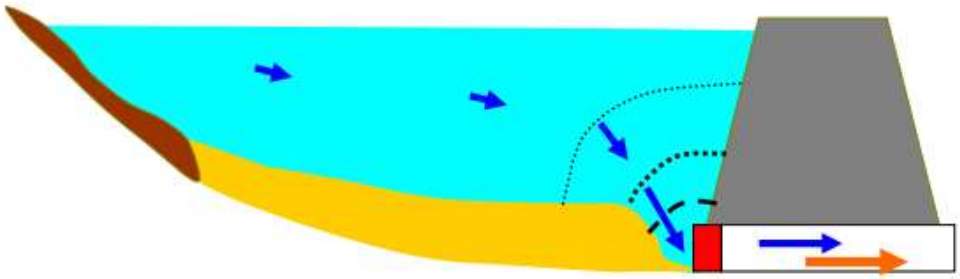


Fig. 2 Reservoir flushing sequence (Hard Flushing)

First idea to flush the reservoir is to open sometimes the bottom gate. The level of the reservoir remains the same in order not to loose water. For safety reason the bottom gate must be always ready to work, so to keep free of sediment the area close to the gate is necessary (Fig. 2). Nevertheless Pressure Flushing it is not consistent for flushing the whole reservoir because velocities are too low, except very close to the bottom gate. Hard Flushing is efficient but too high and uncontrolled concentrations are sent downstream. Damages on environment can be huge. Aquatic life is damaged, fishesare directly killed and spawning areas are clogged [6].

When water is supplied without flushing from the middle and upper levels of reservoirs, visible sedimentation problems may not be observed for decades. But materials slowly settle in the reservoir until equilibrium is reached, when the reservoir is almost full. There is then almost no storage capacity left for agriculture (Fig. 3). When water is supplied without flushing from the middle and upper levels of reservoirs, visible sedimentation problems may not be observed for decades. But materials slowly settle in the reservoir until equilibrium is reached, when the reservoir is almost full. There is then almost no storage capacity left for agriculture (Fig. 3) [6].

Fig. 3 Reservoir long profile with No Flushing

An module has been developed to account for water intake locations and vertical distribution of suspended sediments in areas with greater water depth near dams [7].

Sediment flushing can tackle reservoir siltation and improve sediment flux through regulated rivers, which commonly result sediment depleted due to trapping behind dam structures. However, sediment flushing can be highly detrimental for downstream environment and instream structures. To limit these drawbacks, sediment flushing through reservoirs can be controlled [8].

Flushing use scour during drawdown to create and sustain a channel along the length of the reservoir. The long-term volume that can be sustained is determined by this channel geometry, defined by the average channel width, longitudinal profile, and channel side slope (Fig. 4) [5].

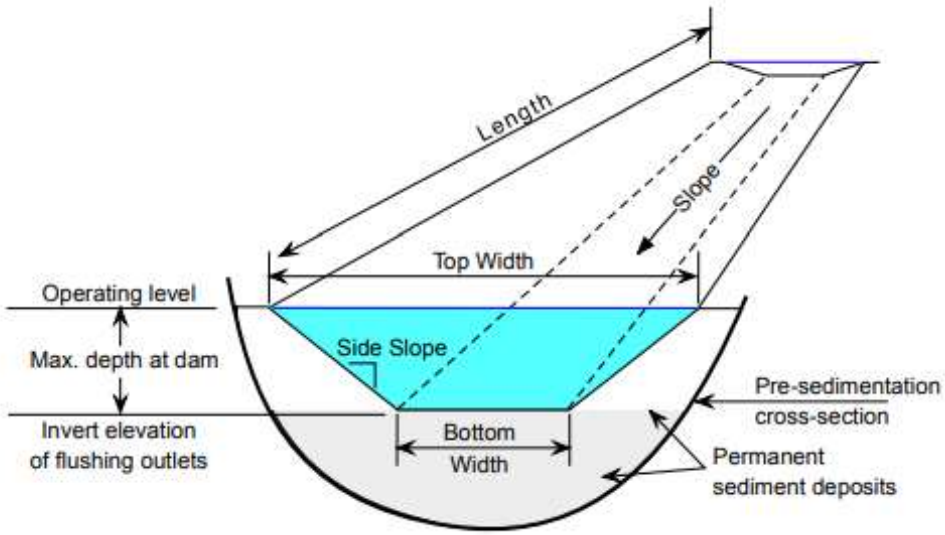


Fig. 4 Geometry of scour channel that can be sustained by either flushing or sluicing

The tasks posed in [9] are as follows:

- Dam reservoir flushing efficiency influenced by spring hydrology;
- Dam flushing events influenced by initial fine sediment stocks and river geometry;
- Fine sediment balance estimated from flows estimated at different locations.
- Uncertainty in the flow proposed to assess the significance of the mass balance.

Because erosion will never stop, and reservoir capacity is limited, sediment trapping is only a transitory phenomenon.The equilibrium between sediment inflow and outflow will be restored after the reservoir becomes filled and storage benefits are lost, or it may be achieved while sustaining reservoir functions through sediment management actions [5].

To sustain long-term reservoir capacity is a management decision (Fig. 5). Despite knowledge of sediment management alternatives for reservoirs prior to the dam construction boom that began in the 1950s, nearly all reservoirs worldwide have been designed on the basis of the “life of reservoir” paradigm. Sediment inflows have been calculated using a 50 to 100 year planning horizon and the corresponding sediment storage volume allocated in the storage pool. No consideration was given to sedimentation consequences beyond this planning horizon. Reservoir design and operation without a long-term sediment management strategy is not a

sustainable approach, and no longer represents an engineering best-practice [10, 20].

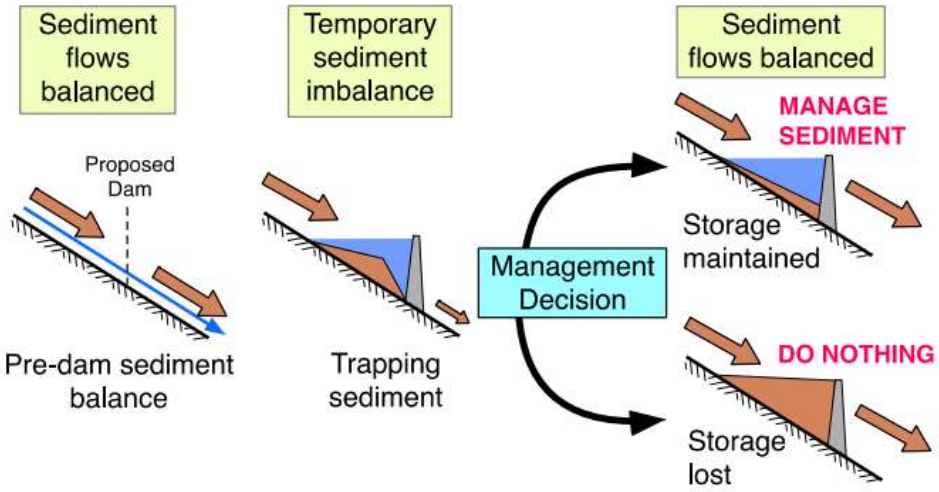


Fig. 5 Alternative transitions from pre-impoundment to post-impoundment sediment equilibrium

Most civil and hydraulic infrastructure such as highways, buildings and mechanical systems can be replaced or reconstructed after they have aged. However, dams cannot be reconstructed to serve their intended purpose once the storage pool becomes sedimented because the removal of large sediment volumes is rarely economically feasible. Sites suitable for new dam and reservoir construction are limited by topography, geology, hydrology, and competing land uses. Today's reservoirs already occupy the best sites and represent a unique and limited [5, 11].

In theory, scarcity of high-quality reservoir sites would be reflected in the opportunity cost of services provided by the reservoir—in other words, if other water and electric energy supply sites are more expensive than the reservoir currently in use, then the value of the services provided by that site ought to be higher. In practice, estimating the value of storage is quite difficult. Consequently, in economic analyses of this type, no allowance for a direct measure of the value of reservoir storage itself is made, only of the services the reservoir offers [11].

When sand settles into a reservoir it quickly reaches its ultimate bulk density, but fine sediment compacts slowly. During the first several years of sedimentation, the fine sediment in a reservoir accumulates on top of the original bottom and occupies a relatively large unit volume (low bulk density). As sedimentation continues, however, the underlying fine sediment deposits compact, meaning that the more recent sediment is being deposited on top of a subsiding bottom. About half of the ultimate compaction typically occurs during the first 15 years following deposition. As a result, given a constant rate of fine sediment deposition, successive bathymetric surveys following initial impounding will report a declining rate of volume loss, which may be erroneously interpreted as a decline in sediment yield [12].

Sampling the grain size distribution of sediments can provide calibration information for sediment transport modeling, document the grain size transported and deposited by turbid density currents, and monitor the size of sediment approaching power intakes. However, the sampling locations must be selected to properly capture both longitudinal and horizontal

variation in grain size of reservoir deposits. The longitudinal variation in grain size is much more pronounced than the horizontal variation. Vertical variations in grain size can also be important. Sediment deposits are often layered, especially in the delta deposits, reflecting different inflow events and water levels. For example, fine sediment may be deposited downstream of the delta with the reservoir at high level, but a large inflow event that flows across the top of the delta during drawdown may scour, transport, and deposit sands on top of the previously deposited fine sediment, thereby producing a layered deposit. Also, the delta will advance over the top of older fine sediment deposits. A sample of the deposit surface will represent only the most recent sediment inflow, which may not be representative of the overall deposits, especially if the sample is taken at the end of a dry period with limited sediment inflow consisting primarily of fines [12].

Sediment may eventually encroach on and impact critical structures such as intakes, spillways, gates, and hydropower equipment. The toe of the advancing reservoir delta corresponds to the transition from sandy delta sediment to fine sediment. Gradual encroachment by fine sediment will typically not represent a major problem for mechanical equipment such as pumps and turbines, and to maximize sediment release from the reservoir it is preferred to pass this fine sediment downstream. However, delta sediments are highly abrasive and will severely damage hydro-mechanical equipment, making itnecessary to exclude them from intakes. As delta deposits approach the dam, deep intakes may be raised to avoid encroaching sand, turbine runners may receive abrasion-resistant coatings as the sand load increases, etc. Upstream of the reservoir, highway or other infrastructure may be threatened andrequire modification as the delta g rows vertically and extends upstream of the normal pool level [13, 14].

Worldwide the average age of reservoirs is now about 35 years. Most of the existing reservoirs will be completely silted up in 200 years time, assuming no intervention. Fig. 6 shows the growth in the storage capacity and sediment deposition worldwide [14, 17].

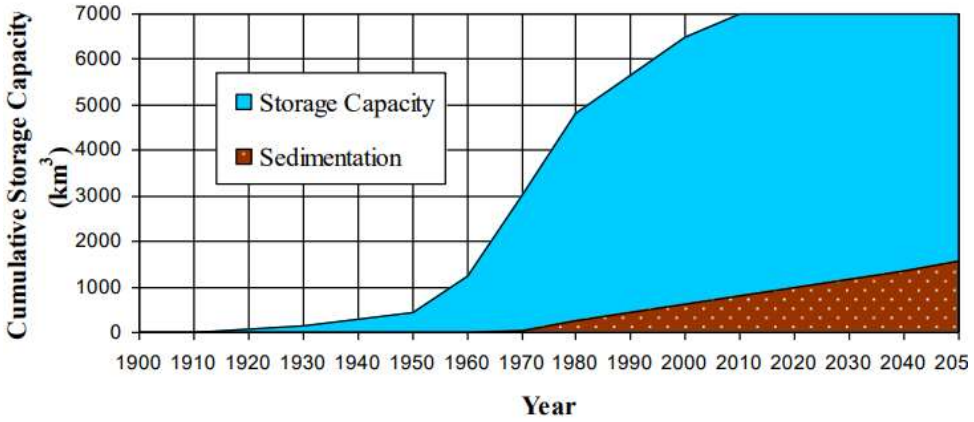


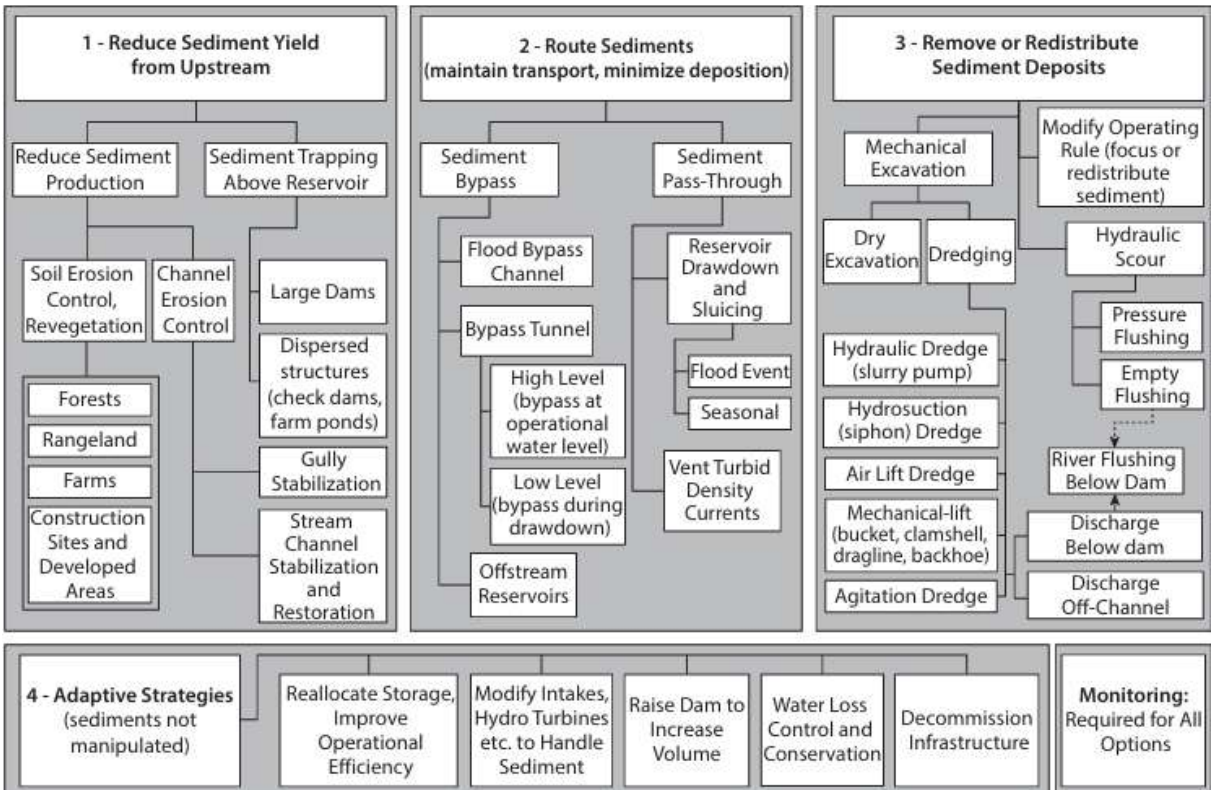
Fig. 6 Projected growth in storage capacity and sediment deposition worldwide

The suspended sand transport is found to be strongly dependent on particle size and on current velocity. The modeling of wash load transport in river flow based on the energy concept of Bagnold shows that an extremely large amount of very fine sediment (clay and very fine silt) can be transported by the flow [18].

To sustainably develop a new dam, sediment management strategies that will be needed in the future should be identified and incorporated into the original design. Sustainable use of existing reservoirs may require changes in operating rules, structural modifications, and adaptation by users to new operating conditions. Management activities to address reservoir sedimentation may be classified into four broad categories: (1) methods to reduce sediment inflow from upstream, (2) methods to pass sediment through or around the impoundment to minimize sediment trapping, (3) methods to redistribute or remove sediment deposits, or (4) methods to adapt to sedimentation. These strategies are outlined in tab. 1, which may be used as a checklist for ensuring that all classes of strategies have been considered at a given site. A classification system based on the location in which the sediment management technique will be applied is suggested by Kantoush and Sumi [11, 19].

Table 1

A classification system



A combination of management strategies will usually be used, and the techniques most suitable for implementation will change over time as the reservoir fills with sediment. The optimum sediment management strategy may consist of a sequence of different techniques to be applied as the reservoir volume diminishes. For example, the venting of turbid density currents may initially be the only feasible technique for passing sediment through a deep and hydrologically large reservoir, but this method may no longer work and other methods may become feasible when reservoir volume has been diminished by sedimentation [11, 19].

The most extreme case of channel erosion is associated with gullies—erosional features characterized by a steep headcut that advances upstream, a transport zone, and a zone of deposition at the downstream end (Fig. 7) [11].

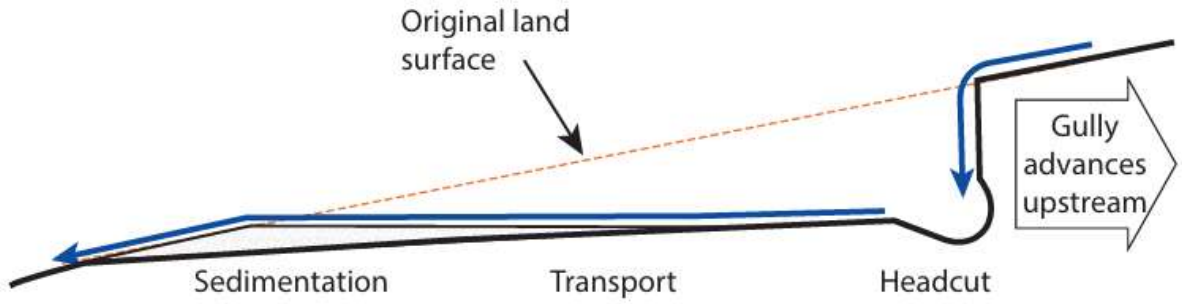


Fig. 7 Conceptual Longitudinal Profile of Gully Erosion

The basic features headworks are illustrated in Fig. 8, which includes a weir or dam in the river to provide additional head and sufficient water depth in front of the intake, sluice gates for scouring accumulated sediment from the intake area, an intake structure that admits flow while minimizing the capture of sediment and debris (maximizing the continued downstream transport of both sediment and debris), a trash rack to remove debris from the diverted water, and sedimentation basins to remove sand from the water used for power.

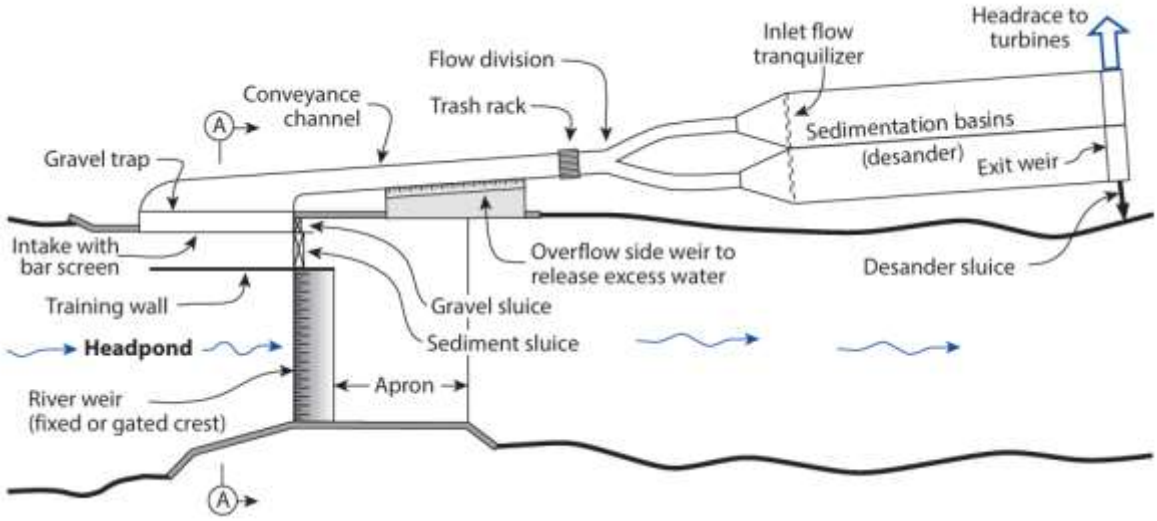


Fig. 8 Main characteristics of the structures of the hydroelectric power station [11]

Although rivers are normally thought of as flowing downstream, secondary or rotational currents are also present that move water and sediment from one side of the channel to the other. These secondary currents modify the channel geometry, creating zones of scour as well as zones of sediment deposition that create sand and gravel bars. Secondary currents also contribute to the variation in sand concentration within the wetted cross-section. For example, sand concentration is usually higher near the river bed than at the water surface. Because of secondary currents, from the standpoint of sediment management locating an intake on the exterior of a river bend is generally preferable. When the current flows against the outer bank

of a river bend, the surface water with lower sediment concentration plunges, creating a rotational current that scours a deep pool at the toe of the outer bank as shown in Fig. 9. The flow then crosses the river bed, carrying bed material that is deposited to create the point bar that occupies the interior of the bend. Because of this rotational flow pattern, the concentration of sand entering an intake located at the exterior of a bend is reduced because it abstracts flow from the top of the water column, and the scouring action keeps the intake free of bed material. Conversely, the interior of the bend is an unfavorable intake location because it will have higher sand concentration plus the tendency to accumulate bed material (Fig. 10). [11].

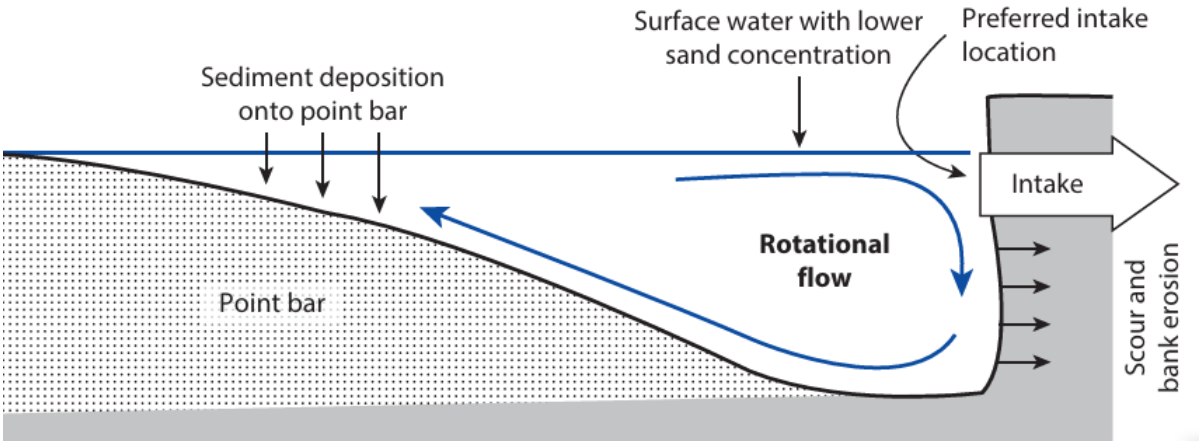


Fig. 9 Plunging Flow at Exterior of River Meander

By trapping sediment in reservoirs, dams interrupt the continuity of sediment transport through rivers, resulting in loss of reservoir storage and reduced usable life, and depriving downstream reaches of sediments essential for channel form and aquatic habitats. With the acceleration of new dam construction globally, these impacts are increasingly widespread. There are proven techniques to pass sediment through or around reservoirs, to preserve reservoir capacity and to minimize downstream impacts, but they are not applied in many situations where they would be effective.

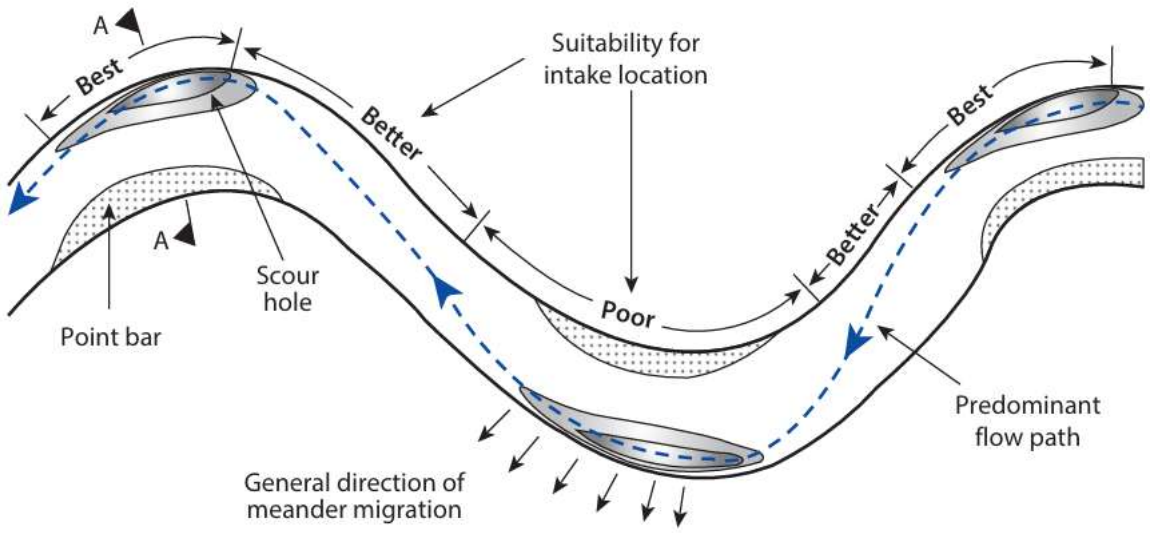


Fig. 10 Idealized Schematic of River Meanders and Suitability for intake Location

Where geometry is favorable it is often possible to bypass sediment around the reservoir, which avoids reservoir sedimentation and supplies sediment to downstream reaches with rates and timing similar to pre-dam conditions. Sluicing (or drawdown routing) permits sediment to be transported through the reservoir rapidly to avoid sedimentation during high flows; it requires relatively large capacity outlets. Drawdown flushing involves scouring and re-suspending sediment deposited in the reservoir and transporting it downstream through low-level gates in the dam; it works best in narrow reservoirs with steep longitudinal gradients and with flow velocities maintained above the threshold to transport sediment. Turbidity currents can often be vented through the dam, with the advantage that the reservoir need not be drawn down to pass sediment [21].

Conclusion

Reservoirs and other hydraulic structures lose their safety indicators over many years of operation due to the long-term impact of various external factors. Dams, holding sediment in reservoirs, disrupt the continuity of sediment transport along rivers, which leads to a loss of reservoir capacity and a reduction in its service life, depriving the lower reaches of rivers of the sediment flow necessary for the formation of the channel and habitat of aquatic organisms. With the acceleration of the construction of new dams around the world, these impacts are becoming more common. Therefore, improving the reservoir monitoring system is one of the most important engineering problems of our time.

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ՋՐԱՄԲԱՐՆԵՐԻ ՄՇՏԱԴԻՏԱՐԿՄԱՆ ՀԱՄԱԿԱՐԳԻ ԿԱԶՄԱԿԵՐՊՈՒՄԸ

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Ակադեմիկոս Ի.Վ. Եղիազարովի անվան ջրային հիմնահարցերի և հիդրոտեխնիկայի ինստիտուտ

Քաղցրահամ ջրի աճող պահանջարկը և ջրային ռեսուրսների շարունակական նվազումը XXI դարի մարտահրավերներից են: Գործող ջրամբարների օգտագործման արդյունավետության բարձրացման խնդիրները, վթարվածների վերականգնումը և նորերի կառուցումը ձեռք են բերում կարևոր նշանակություն:

Մասշտաբային ջրամբարաշինարարությունը ընդամենը 100 տարվա պատմություն ունի: Այդ ընթացում, դրանց մեծ մասը հասցրել է լցվել ջրաբերուկներով, որի հետևանքով փոքրացել է ջրամբարներիի օգտակար ծավալը: Մոտ ապագայում ջրամբարից շատերը կդադարեն կատարել իրենց հիմնական գործառույթները:

Մյուս կողմից երկար տարիների շահագործման ընթացքում պատվարները և հիդրոհանգույցի մյուս կառուցվածքները, ենթարկվելով տարբեր արտաքին ազդեցությունների, կարող էին կորցնել իրենց անվտանգության հատկանիշները:

Ջրամբարների մշտադիտարկման համակարգի կատարելագործումն այս առումով, առկա կարևորագույն ինժեներական խնդիրներից է:

Բանալի բառեր: պատվար, ջրամբար, ջրհեռ, ջրաբերուկներ, օգտակար ծավալ:

ОРГАНИЗАЦИЯ СИСТЕМЫ МОНИТОРИНГА НА ВОДОХРАНИЛИЩАХ

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Растущий спрос на пресную воду и постоянное истощение водных ресурсов являются одними из проблем XXI века. Большую актуальность приобретают вопросы повышения эффективности использования существующих водохранилищ, восстановления поврежденных и строительства новых.

История строительства крупных водохранилищ насчитывает всего 100 лет. При этом большая часть из них успела наполнятся наносами, в результате чего полезный объем водохранилищ уменьшился. В ближайшем будущем многие водохранилища перестанут выполнять свои основные функции.

С другой стороны, за многие годы эксплуатации водохранолища и другие Водохранилища и другие гидротехнические сооружения в течение многих лет эксплуатации теряют показатели безопасности из-за длительного воздействия различных внешних факторов. Плотины, задерживая наносы в водохранилищах, нарушают непрерывность транспорта наносов по рекам, что приводит к потере емкости водохранилища и сокращению срока его службы, лишая низовья рек необходимого для формирования русла и среды обитания водных организмов потока наносов. С ускорением строительства новых плотин по всему миру эти воздействия становятся все более распространенными. Поэтому совершенствование системы мониторинга водохранилищ является одной из важнейших инженерных проблем современности.

Ключевые слова: плотина, водохранилище, водосброс, наносы, полезный объем.

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