ABSTRACTING WATER FROM SEDIMENT-LADEN STREAMS

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Summary

Principles are outlined for successfully abstracting water from streams and rivers that convey much sediment in the form of suspended or bed load. Distinctions are made between mildly sloping rivers and steeply sloping streams. The former conduct fine sediments and the latter coarse. For the first case weir-type abstraction structures are detailed, and for the latter Tirolean-type coarse sediment rejection intakes are customary. Causes of sediment related problems are listed and the effects on reservoirs noted. Various types of installations and their principal details are described and illustrated.

1. Introduction

This article deals specifically with sediment related problems encountered in the abstraction of water from sediment laden rivers and streams. An overview is given of specific problems that have been encountered and of practical measures for overcoming them.

In semiarid regions, highly variable discharges are dealt with that often carry heavy loads of suspended sediments. These works have to operate under flood conditions, as well as when the flows reduce to virtual trickles. The main emphasis in these guidelines is on dealing with these variable conditions. It must be added, however, that the threedimensional flow patterns, which are usually generated at abstraction works, are very complex. Physical model studies have proven to be valuable in optimizing intake layouts in terms of efficiency.

In recommending suitable layouts for water abstraction works, rivers that carry loads of mainly fine sediments (clays, silts and sands) are treated separately from those that also carry coarser materials, in the form of gravel, cobbles and boulders. In the case of rivers that carry fine materials, mainly as suspended loads, a number of components, which have proven to be successful, have been integrated into an abstracting layout which may serve as a basis for site specific designs (see Sediment Exclusion at Intakes in The Uses of River Water and Impacts; Intakes on Sediment-laden Rivers; Sediment Phenomena).

Where streams also carry significant loads of coarse materials, it has been found that a completely different layout, known as the Tirolean type weir, that emanates from Europe, provides the best solution. Technology that has been developed in the mountainous regions of Europe can readily be applied to similar mountain streams elsewhere.

2. Areas of Application

The layout presented in Figure 1 below (see Section 8) is recommended primarily for rivers that carry heavy suspended loads, but can also be used for streams carrying sediments up to gravel sizes. The Tirolean weir, (Figure 2, see Section 9), is recommended for streams that carry coarse sediments, including cobbles and boulders. Differentiation is, therefore, made between:

- mildly sloping rivers which carry suspended loads of predominantly fine sediments (particles typically smaller than 0.3mm in diameter); and,
- steeply sloping streams that carry coarse sediment bed loads which may include gravel, cobbles and boulders.

Exclusion of suspended sediments is achieved by inducing higher concentrations of sediments in certain flow zones and by extracting water from the clearer flow zones. This can only be achieved where sediment particles with relatively high settling velocities are involved.

In those rivers that carry mainly finer sediments, such as sands, silts and clays, a large proportion of the annual loads will be carried during flood events. Suspended sediment concentrations then tend to vary only slightly across flow cross-sections. Under these circumstances, separation can only be achieved in large settling basins. The ease with which small suspended sediment particles become accelerated, causes their dispersion from flow zones into quiet zones of low sediment transporting capacity (see *Sediment Phenomena*).

3. Causes of Sediment Related Problems

Conditions that are ideal at pump intakes, i.e., low velocities and especially low vorticity, thus also tend to favor accumulation of suspended particles from passing streams. Even when water is not being pumped, sediments can be continuously drawn in into a pump's wet well through the connecting opening. Wet-well intakes in pumping stations, and other spaces containing slow moving water, which are connected to sediment-laden streams, tend to become filled with sediments. Pump houses, even with small intakes, have been found to be more than 80% filled with sediment after inundation by a single flood event. Relatively small, rapid-flowing streams even have the ability to transfer gravel and even cobbles in similar fashion.

Other causes of sediment-related problems encountered at water extraction works include:

- Changes with time in river channel positions and in cross-sectional shapes.

- Sediment build-up due to:
  - flow retardation caused by dams or other structures further downstream,
  - flood attenuation caused by dams upstream, particularly in deep river pools, and
  - increased sediment loads.

- Bank encroachment, particularly during periods without major floods which would normally have reestablished full-channel width.

- Increased sediment and flood levels caused by vegetation that established on sediment deposits in the delta regions of reservoirs, as well as far downstream of dams. The growth is often stimulated by nutrient-rich runoff from irrigated areas, especially if such runoff occurs during periods when the rivers would naturally have run dry.

- Damage to pumps caused by high sediment concentrations and/or large-sized particles. The damage is often increased due to high intake vorticity levels, which may cause cavitation.

- Differing flow patterns during high and low flows and slumping of deposits of finer sediment, causing blocking of intakes when water levels are rapidly drawn down.

- Sediment deposition in unexpected areas, e.g., on the outsides of bends in rivers, as found in steep, rocky rivers where hydraulic jumps are formed within the upstream legs of bends.

In the case of deposits that have undergone consolidation, and which are cohesive, more sophisticated analyses are required to determine when erosion will start.

What is of importance is the equilibrium sediment profile which develops upstream of a weir. With sediment introduced into a small reservoir without low level gates, equilibrium build-up is soon reached. The remaining storage capacity is thus determined by the sediment profile, which represents a balance between the hydraulic sediment transporting capacity and the resistance to scour offered by deposits. It has been found that for a given type of deposited material, the equilibrium profile upstream of a weir can be readily predicted—relationships which have been calibrated on comparable reservoirs can be used for modeling flushing and sluicing operations.

4. Bed Load

Where the sediment carrying capacity of a stream exceeds the critical bed-shear stress value, sediment transport mostly takes place close to the bed and this mode of transport is referred to as bed load. The main application of bed load formulae would be in the calculation of equilibrium profiles—upstream of weirs and other obstructions. Such calculations need to be performed employing relationships that have been specifically calibrated with reservoir data (see *Sediment Phenomena*).

5. Suspended Load

Sediment particles that are carried by a stream above its bed constitute what is known as suspended load. In the design of water extraction works it is important to consider the mechanisms by which suspended particles are transported in both the vertical and the horizontal direction. Comprehensive mathematical analysis of suspended sediment transport confirms that the particles are transferred by their centrifugal acceleration within rotating eddies. With very small particles in fast-flowing streams, sediment concentrations will vary very little across flow cross-sections and suspensions are, therefore, nearly homogeneous. As the particle size increases, the concentration near the bed becomes higher than the average, eventually reaching a stage where suspended load transport ceases and only bed load transport occurs.

In addition to true turbulent suspended load transport, very small clay particles are carried in colloidal suspension as a result of electrostatic charges. These particles only settle out when the electrostatic charges are neutralized by some external agent.

The majority of water abstraction works, for example in Southern Africa, are located on rivers that transport mainly fine sediments, including clays, silts and sands. The remaining works are found mostly on steep rivers that carry coarse sediments that may include gravel, cobbles and boulders, in addition to fine sediments.

Fine sediment loads are normally availability limited. On the other hand, coarse sediment loads are generally determined by the carrying capacities of the streams. The main characteristic of fine sediment loads, therefore, is their variability. Long-term sampling records are required to obtain accurate estimates of average annual sediment loads.

In the design of water extraction works, information may not only be required regarding the average long-term sediment load, but also regarding the maximum suspended sediment concentrations that need to be allowed for. As extreme flood events tend to occur over limited local areas, the river discharges that carry the highest concentrations may in fact be small. High variability is not only a characteristic of suspended sediment concentrations but also of daily and even annual sediment loads.

Sampling programs over long periods (five to seven years) are required to determine suspended sediment loads accurately and may be cumbersome and expensive. Therefore, sediment load data are generally obtained from sediment yield maps for areas where sediment loads are known to be availability limited.

6. Sediment Accumulation in Reservoirs

In many cases weirs form essential components of river extraction works. Not only do weirs serve to direct low flows towards intakes, they also provide the necessary heads required to flush and scour sediments from intake areas. Unless large gates are provided, a large proportion of the original depth and storage capacity behind a weir is likely to be lost due to sedimentation.

The nature and shape of sediment deposits behind weirs need to be analyzed not only in terms of the threat that they may pose to the extraction works, but also in terms of sediment build-up upstream of reservoirs. Serious problems have arisen due to underestimation of the extent of sediment build-up well upstream of the actual reservoir basins, and hence large additional areas had to be expropriated. In most unfavorable situations, sediment build-up could approach the weir height for a considerable distance upstream of the original full supply limit.

Vegetation that becomes established on sediment deposits can complicate matters further by inducing higher rates of build-up of sediments, as well as increasing the resistance to scour of these deposits.

The two main options available for the extraction of water are:

- Installing pumps where there is sufficient natural water depth available and where, therefore, a control structure across the river is not necessary.
- Creating controlled conditions for water and sediment discharge by means of weirs and auxiliary intake works.

Where low flow conditions are common to rivers and readily available stable natural pools do not exist, weirs form essential components of extraction works.

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Biographical Sketches

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