Chapter 9
Reservoir Sediment Analysis

9-1. Introduction

a. Parameters of a natural river. Nature maintains a very delicate balance between the water flowing in a natural river, the sediment load moving with the water, and the stream's boundary. Any activity which changes any one of the following parameters:

- water yield from the watershed.
- sediment yield from the watershed.
- water discharge duration curve.
- depth, velocity, slope or width of the flow.
- size of sediment particles.

or which tends to fix the location of a river channel on its floodplain and thus constrains the natural tendency will upset the natural trend and initiate the formation of a new one. The objective of most sediment studies is to evaluate the impact on the flow system resulting from changing any of these parameters.

b. Changes caused by reservoirs. Reservoirs interrupt the flow of water and, therefore, sediment. In terms of the above parameters, the reservoir causes a change in the upstream hydraulics of flow depth, velocity, etc. by forcing the energy gradient to approach zero. This results in a loss of transport capacity with the resulting sediment deposition in the reservoir. The reservoir also alters the downstream water discharge-duration relation and reduces the sediment supply which may lead to the degradation of the downstream channel.

c. Areas of analysis. Sedimentation investigations usually involve the evaluation of the existing condition as well as the modified condition. The primary areas of reservoir sediment analysis are the estimation of volume and location of sediment deposits in the reservoir and the evaluation of reservoir releases' impact on the downstream channel system. Sediment deposits start in the backwater area of the reservoir, which increase the elevation of the bed profile and the resulting water surface profile. However, reservoirs may also cause sediment deposits upstream from the project, which affect the upstream water surface profiles.

d. Further information. The primary Corps reference for sediment analysis is EM 1110-2-4000. Major topics include developing a study work plan, sediment yield, river sedimentation, reservoir sedimentation, and model studies.

9-2. Sediment Yield Studies

a. General. Sediment yield studies determine the amount of sediment that leaves a basin for an event or over a period of time. Sediment yield, therefore, involves erosion processes as well as sediment deposition and delivery to the study area. The yield provides the necessary input to determine sedimentation impacts on a reservoir.

b. Required analysis. Each reservoir project requires a sediment yield analysis to determine the storage depletion resulting from the deposition of sediment during the life of the project. For most storage projects, as opposed to sediment detention structures, the majority of the delivered sediment is suspended. However, the data required for the headwater reaches of the reservoir should include total sediment yield by particle size because that is where the sands and gravels will deposit.

c. Further information. Corps of Engineer methods for predicting sediment yields are presented in Appendix C of EM 1110-2-4000. A literature review, conducted by the Hydrologic Engineering Center under the Land Surface Erosion research work unit, showed numerous mathematical models are available to estimate sediment discharge rates from a watershed and the redistribution of soil within a watershed. An ETL on the methods will be issued soon.

9-3. Reservoir Sedimentation Problems

a. Sediment deposition. As mentioned above, the primary reservoir sediment problem is the deposition of sediment in the reservoir. The determination of the sediment accumulation over the life of the project is the basis for the sediment reserve. Typical storage diagrams of reservoirs, showing sediment (or dead) storage at the bottom of the pool can be misleading. While the reservoir storage capacity may ultimately fill with sediment, the distribution of the deposits can be a significant concern during the life of the project. The reservoir sedimentation study should forecast sediment accumulation and distribution over the life of the project. Sediment deposits in the backwater area of the reservoir may form deltas, particularly in shallow reservoirs. A number of problems associated with delta formations are discussed below.

(1) Deposits forming the delta may raise the water surface elevation during flood flows, thus requiring special

consideration for land acquisition. In deep reservoirs, this is usually not a problem with the reservoir area because project purposes dictate land acquisitions or easements. Deltas tend to develop in the upstream direction. In shallow reservoirs, the increase in water surface elevation is a problem even within the reservoir area. That is, floods of equal frequency may have higher water surface elevations after a project begins to develop a delta deposit than was experienced before the project was constructed. Land acquisition studies must consider such a possibility.

(2) Aggradation problems are often more severe on tributaries than on the main stem. Analysis is complicated by the amount of hydrologic data available on the tributaries, which is usually less than on the main stem itself. Land use along the tributary often includes recreation sites, where aggradation problems are particularly undesirable.

(3) Reservoir deltas often attract phreatophytes due to the high moisture level. This may cause water-use problems due to their high transpiration rate.

(4) Reservoir delta deposits are often aesthetically undesirable.

(5) Reservoir sediment deposits may increase the water surface elevation sufficiently to impact on the groundwater table, particularly in shallow impoundments.

(6) In many existing reservoirs, the delta and backwater-swamp areas support wildlife. Because the characteristics of the area are closely controlled by the operation policy of the reservoir, any reallocation of storage would need to consider the impact on the present delta and swamp areas.

b. Upstream projects. It is important to identify and locate all existing reservoirs in a basin where a sediment study is to be made. The projects upstream from the point of analysis potentially modify both the sediment yield and the water discharge duration curve. The date of impoundment is important so that observed inflowing sediment loads may be coordinated with whatever conditions existed in the basin during the periods selected for calibration and verification. Also, useful information on the density of sediment deposits and the gradation of sediment deposits along with sediment yield are often available from other reservoirs in the basin. Information on the rate of sediment deposition that has occurred at other reservoir sites in the region is the most valuable information when estimating sediment deposition for a new reservoir.

9-4. Downstream Sediment Problems

a. Channel degradation. Channel degradation usually occurs downstream from the dam. Initially, after reservoir construction, the hydraulics of flow (velocity, slope, depth, and width) remain unchanged from pre-project conditions. However, the reservoir acts as a sink and traps sediment, especially the bed material load. This reduction in sediment delivery to the downstream channel causes the energy in the flow to be out of balance with the boundary material for the downstream channel. Because of the available energy, the water attempts to re-establish the former balance with sediment load from material in the stream bed, and this results in a degradation trend. Initially, degradation may persist for only a short distance downstream from the dam because the equilibrium sediment load is soon re-established by removing material from the stream bed.

b. Downstream migratory degradation. As time passes, degradation tends to migrate downstream. However, several factors are working together to establish a new equilibrium condition in this movable-boundary flow system. The potential energy gradient is decreasing because the degradation migrates in an upstream-to-downstream direction. As a result, the bed material is becoming coarser and, consequently, more resistant to being moved. This tendency in the main channel has the opposite effect on tributaries. Their potential energy gradient is increasing which results in an increase in transport capacity. This will usually increase sediment passing into the main stem which tends to stabilize the main channel resulting in less degradation than might be anticipated. Finally, a new balance will tend to be established between the flowing water-sediment mixture and the boundary.

c. Extent of degradation. The extent of degradation is complicated by the fact that the reservoir also changes the discharge duration curve. This will impact for a considerable distance downstream from the project because the existing river channel reflects the historical phasing between flood flows on the main stem and those from tributaries. That phasing will be changed by the operation of the reservoir. Also, the reduced flow will probably promote vegetation growth at a lower elevation in the channel. The result is a condition conducive to deposition in the vegetation. Detailed simulation studies should be performed to determine future channel capacities and to identify problem areas of excessive aggradation or degradation. All major tributaries should be included.

9-5. Sediment Water Quality

a. Sediments and pollutants. When a river carrying sediments and associated pollutants enters a reservoir, the flow velocity decreases and the suspended and bed load sediments start settling down. Reservoirs generally act as depositories for the sediments because of their high sediment trap efficiency. Due to a high adsorption capacity, sediments act as sinks for contaminants in the reservoirs and, in agricultural and industrial areas, may contain PCB's, chlorinated hydrocarbon pesticides, oil and grease, heavy metals, coliform bacteria, or mutagenic substances. Burial of these contaminants by sedimentation may be an important factor and an effective process in isolating potentially toxic substances from surface waters and important biological populations. Toxic inorganic and organic contaminants associated with the sediments can also be bioconcentrated by the aquatic organisms present in reservoirs.

b. Monitoring chemical contaminants. These incoming sediments and associated pollutants significantly affect the water quality of the reservoir pool and downstream releases. Therefore, it is essential that these sediment reservoir interactions be characterized by their depositional behavior, particle size distribution, and pollutant concentrations to successfully plan a management strategy to quantify contaminant movement within reservoirs. Analytical and predictive methods to assess the influence of contaminated sediments in reservoirs have not been developed enough to be used in Corps field offices, but WES Instruction Report E-86-1, "General Guidelines for Monitoring Contaminants in Reservoirs" (Waide 1986), does provide general guidance on the design and conduct of programs for monitoring chemical contaminants in reservoir waters, sediments, and biota.

c. Sedimentation patterns. Sedimentation patterns can often be associated with water quality characteristics. There seems to be a relationship between longitudinal gradients in water quality (a characteristic of many reservoirs) and sediment transport and deposition. High concentrations of inorganic particulates can reduce light availability near inflows and thus influence algal production and decrease dissolved oxygen. The association of dissolved substances, such as phosphorus, with suspended solids may act to reduce or buffer dissolved concentrations, thus influencing nutrient availability.

9-6. Sediment Investigations

a. General. The level of detail required for the analysis of any sediment problem depends on the objective of the study. Chapter 1 of EM 1110-2-4000 describes staged sedimentation studies in Section I. Section II, of that chapter, provides reporting requirements. Problem identification and the development of a study work plan are covered in Chapter 2.

b. Sediment deposits. Considering a dam site as an important natural resource, it is essential to provide enough volume in the reservoir to contain anticipated deposits during the project life. If the objective of a sediment study is just to know the volume of deposits for use in screening studies, then trap efficiency techniques can provide a satisfactory solution. The important information that must be available is the water and sediment yields from the watershed and the capacity of the reservoir. Chapter 3 of EM 1110-2-4000 covers sediment yield. Section 3-7 provides information on reservoir sedimentation, including trap efficiency.

c. Land acquisition. If the sediment study must address land acquisition for the reservoir, then knowing only the volume of deposits is not sufficient. The location of deposits must also be known, and the study must take into account sediment movement. This generally requires simulation of flow in a mobile boundary channel. Sorting of grain sizes must be considered because the coarser material will deposit first, and armoring must be considered because scour is involved. Movable-bed modeling is useful to predict erosion or scour trends downstream from the dam, general aggradation or degradation trends in river channels, and the ability of a stream to transport the bed-material load. The computer program, HEC-6 *Scour and Deposition in Rivers and Reservoirs* (HEC 1993), is designed to provide long-term trends associated with changes in the frequency and duration of the water discharge and/or stage or from modifying the channel geometry.

d. Details of investigations. The details of reservoir sedimentation investigations are covered in Chapter 5 of EM 1110-2-4000. The primary emphasis is on the evaluation of the modified condition, which includes consideration of quality and environmental issues. The levels of sedimentation studies and methods of analysis are presented in Section IV of Chapter 5. Model studies and a short review of HEC-6 and the two-dimensional TABS-2 modeling system are covered in Chapter 6.