CHAPTER 5

RESERVOIR SEDIMENTATION

Section I. Introduction

5-1. Purpose. The purposes of this chapter are to present the philosophy for measuring the impact of a project on the stream system morphology, to identify potential sedimentation problems in the reservoir, to associate those problems with project purposes, and to propose approaches for analyzing them.

5-2. Scope. The scope of problems addressed in this chapter is limited to flood control and navigation. Related reservoir uses are included only as they occur in multiple purpose projects. Recreational problems are mentioned but not addressed in detail. The basic processes are the same as those causing flood control and navigation problems, but recreational problems require a considerable refinement to the spatial and temporal resolution in analytical techniques. Water quality aspects of sedimentation problems are extremely important in reservoir design; they should be addressed using water quality manuals. The physical problems, as opposed to water quality problems, are caused primarily by inorganic sediments. Although there is recent evidence that organic sediments affect water chemistry to the point of influencing the behavior of the clays, information to quantify that influence is not available.

5-3. Philosophy of the Sedimentation Investigation. The impact of the reservoir on stream system morphology should not be determined by comparing a "future condition with the proposed reservoir project in operation" to a static condition of the stream system depicted by either current or historical behavior. A more appropriate measure of impact is to develop a "base condition" by forecasting a future condition of the stream system without the proposed project, i.e., a "do-nothing condition." Then forecast a future condition for that stream system with the proposed project in operation to develop a "project condition." Then compare those two future conditions to determine the impact of the project on the stream system morphology. Notice, the "do-nothing condition" should contain all future changes in land use, water yield, sediment yield, stream hydraulics and basin hydrology except those associated with the proposed project.

a. System Response to Catastrophic Events. The floods in northern California and Oregon during December of 1964 so disturbed the stream systems that sediment yields, and river problems associated with them, were abnormally high even a decade later. These stream systems are in transition because of changes in sediment yield and water runoff hydrographs. Two points are significant:

(1) The water and sediment yields are the "Boundary Conditions" describing the amount of sediment that would enter a proposed reservoir project, and field data taken during the past decade would not be representative of future years on these streams because a catastrophic event has occurred.

(2) Secondly, if a reservoir project should be constructed on such disturbed streams, it should not be blamed for all changes which would occur during its operation because that stream system was already in transition prior to the construction of the reservoir. This point demonstrates: "always evaluate potential reservoir sites and report whatever transition may be in progress historically."

b. System Response to Normal Events. In the absence of field data, it is not possible to predict, with much accuracy, the sediment yield from such a catastrophic event as the December flood of 1964, but annual fluctuations in hydrology or sediment yield can cause a stream to be in transition. A data base can be acquired and future conditions can be predicted sufficiently well to minimize big surprises in this case.

Section II. Evaluation of the No-Action Condition

5-4. Indicators of Change in the Stream System. Trends, over the last decade or so, in any of the following parameters suggest the stream system is in a period of transition:

a. water yield from the watershed,

b. sediment yield from the watershed,

c. water discharge duration curve,

d. concentration of sediment,

e. size of sediment particles,

f. stage-duration curve,

g. depth, velocity, slope or width of the channel, or

h. bank caving

i. trends in "specific gage" plots (i.e., the stage for a constant discharge plotted versus time.)

Section III. Evaluation of Modified Conditions

5-5. Points of Caution. The following are sedimentation problems associated with reservoir projects. They should be forecast over the economic life of the project and reported via reservoir sedimentation studies.

a. Fallacies. Historically, some have pictured sediment as occupying a "dead storage" zone at the very lowest depths in the reservoir, and even described such space as "allocated for sediment retention", Figure 5-1. Others show deposits as if they occur only at the upstream end of the reservoir then vanish leaving clear water to the dam. A third fallacy can be seen in sketches which picture all deposition within the reservoir proper. Avoid these fallacies. Eventually, all reservoirs will fill with sediment.

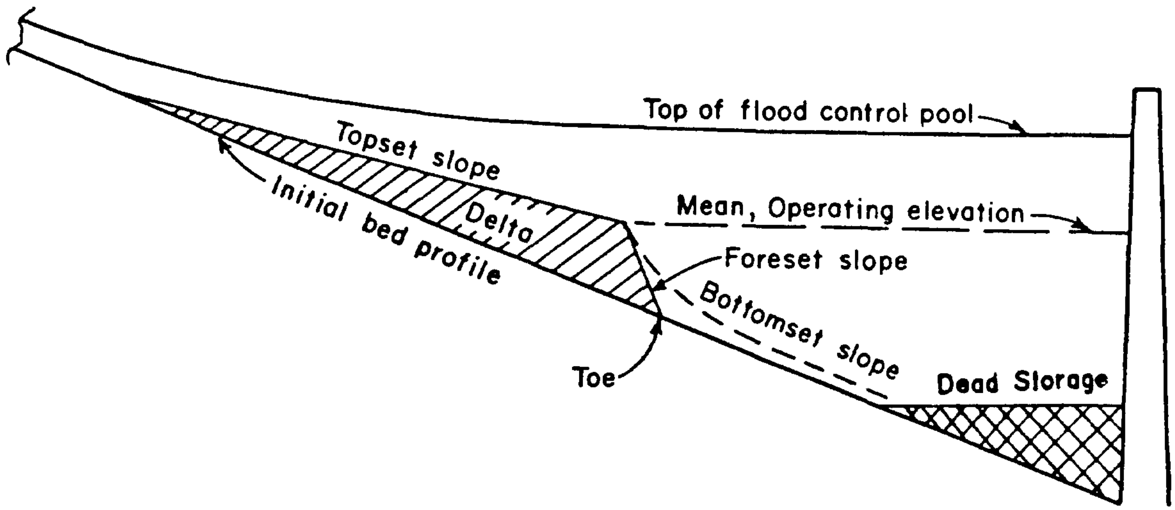

Figure 5-1. Incomplete Concept of Reservoir Deposition

The time can range from a single storm event to hundreds of years depending on sediment yield and reservoir operation. The sedimentation report should forecast sedimentation during the life of the project.

b. Topset Slope. A rule of thumb for the ultimate topset slope is that it should be 50 percent of the original stream bed profile. There is no physical reason for that value, however. Beware of any such assumption because the ultimate topset slope will be constructed by the river to be in regime with the river system. Numerical modeling is presently the most effective method for predicting that ultimate value.

c. Impact of Increased Stages Beyond Reservoir Limits. Sand and gravel will start to deposit upon reaching the backwater curve of the reservoir which is usually upstream from the reservoir boundaries. Those deposits increase the elevation of the bed surface profile which causes the water surface elevations to rise. Of course such increases will not continue indefinitely; the ultimate elevations will be in regime with the water-sediment hydrographs entering the reservoir from the upstream basin/sub-basins. As in the case of the topset slope, numerical modeling is the most effective method for predicting the ultimate values of both the water surfaces and bed surface profiles.

5-6. Sedimentation Problems Associated with Reservoirs. The impact of sedimentation on reservoir performance can be measured by quantifying:

a. volume of deposition,

b. location of deposits,

c. rise in water surface elevations,

d. aesthetics of deposited sediment,

e. turbidity,

f. density current,

g. water quality aspects of sedimentation,

h. shoreline erosion,

i. shifting location of channels,

j. downstream degradation,

k. changes in downstream channel capacity,

l. local scour at the dam, spillway and stilling basin.

5-7. Impact of a Reservoir Project on Stream System Morphology.

a. rise in base-level, and associated aggradation, of the main stem upstream from the dam due to the reservoir impoundment,

b. fall in base-level of the main stem downstream from the dam due to modified hydrographs,

c. fall in base-level of the main stem downstream from the dam due to degradation of the channel bed,

d. changes in downstream channel capacity,

e. This is not an exhaustive list of problem areas. They are included because substantial resources have been expended to correct them at existing reservoirs; and consequently, they should be considered in all reservoir sedimentation studies. A reservoir will likely have additional problems which are unique to it and will need to be added. The following paragraphs illustrate why these problems have occurred.

5-8. Volume of Deposition. Land use change from natural forest to strip mining has so increased sediment yields that the useful life of some reservoirs will be reduced to a fraction of the 100-year design life unless action is taken to control the deposition problem. The volume of sediment material deposited in the reservoir delta IS NOT a function of the 100-year project life. That time period is an economic parameter, not a physical limitation. Consequently, delta growth will not cease simply because the project life has been reached. Eventually a new channel and flood plain will exist in the reservoir. Flood stages and the ground water table will reflect that condition adjacent to and upstream from the reservoir area.

5-9. Location of Deposits. This is a more precised term than "distribution of deposits". Location means the (x,y,z) location of deposits and not just deposition volume by project purpose. Also, the term "distribution of deposits" should refer to volume depletion by project purpose rather than spatial location of that deposit.

a. If volumetric reductions of reservoir storage space allocated for each project purpose represented the only problem associated with reservoir sedimentation, it would not be necessary to forecast the distribution of deposits in the reservoir. It would only be necessary to reassign reservoir elevations for the desired capacity as indicated by periodic resurveys. Such is not possible with hydropower machinery, however, because it is designed to operate within a prescribed head range.

b. Even if the total volume of sediment deposits is small, they may occur in locations where navigation, conservation storage, marinas, or other project features can not function as designed for project economics. Consequently, the spatial location must be predicted in addition to the elevation of deposits.

c. Deposition problems are often more severe on tributaries than on the main stem, and tributary locations are usually the most desirable for developing recreational facilities. Analysis is complicated by two factors: (1) the lack of basic sediment data because there is usually less on a tributary than on the main stem itself, and (2) the small size of the study area. However, recreation sites are a limited resource and their useful life should be evaluated in considerable detail so alternatives that maximize that life can be formulated.

d. Sediment deposits have raised water surface elevations (i.e., the stage-duration curve) sufficiently to raise the ground water table.

e. Aggradation affects not only the main stem, but also tributary channels and can reduce the capacity of, and even block, drainage structures along the channels at locations upstream from the normal operating pool elevation of the reservoir but within the backwater curve of the reservoir.

f. In existing reservoirs, the United States Fish and Wildlife Service is utilizing delta and back swamp areas in the propagation of wildlife. Since the characteristics of this delta area are so closely controlled by the operating policy of the reservoir, any reallocation of storage would need to consider the impact on present delta and back swamp areas. This represents a type of problem that may be more important in the future if changing priorities among project purposes demand reallocation of storage in reservoirs.

5-10. Rise in Water Surface Elevations. Water surface elevations become higher for the same water discharge when both the sediment deposits and vegetation, which is attracted to those sediment deposits, combine to decrease hydraulic conveyance. These factors are significant because they produce higher water surface elevations after the project has been in operation for a while than were forecast for the initial impoundment. In both shallow and deep reservoirs, sand and gravel will deposit in the upstream direction thereby raising stages upstream from the reservoir area proper. The extent of these conditions can be calculated using numerical modeling, and such calculations should be reported because the amount of stage increase has proven to be significant within the life of existing projects.

a. Shallow Reservoirs. Deposits forming the delta may raise the water surface elevation, during some flows, above that of preproject elevations. Consequently, additional land must be acquired. That is, floods of equal frequency may cause higher water surface elevations after a delta begins to form than was experienced before the project was constructed even though the water discharge has been decreased by upstream projects. The controlling floods are often the more frequent events as opposed to the rare events.

b. Deep Reservoirs. The land taking elevation within the reservoir area is generally controlled by project purposes and not sedimentation.

c. Phreatophytes. Because of their high moisture content, reservoir deltas will attract phreatophytes which raise backwater profiles because they increase hydraulic roughness. In addition, the phreatophytes contribute to water use problems due to their high evapotranspiration rate.

5-11. Aesthetics of Deposited Sediment. Reservoir delta deposits often contain large, aesthetically undesirable, mud flats. Since reservoir operating rules are responsible for the deposit, a change in operating the project can expose a delta that was previously covered with water.

5-12. Turbidity. Turbidity has impacted strongly on the recreational usage of some projects. In addition, the presence of sediments in reservoirs has an effect on light penetration, thermal budget, nutrient budget, and benthic activity.

5-13. Density Current. The chemical state of the clay-water mixture can cause clay to stay dispersed creating a turbidity problem for recreational sites in the reservoir. On the other hand, it can cause the clay to flocculate and deposit in the the still water zones of the reservoir. Or, it can cause the water-clay mixture to form a density fluid, plunge and flow out the outlet works as a highly turbid discharge which affects recreational usage downstream from the reservoir. Density currents occur under conditions of high sediment concentrations, steep slopes (greater than 1 foot per mile), and large depths.

5-14. Water Quality Aspects of Sedimentation. Because other manuals address in detail water quality aspects of reservoirs, an extensive discussion is not presented. Project purposes often need a quality of water which requires the accurate accounting of sediment movement and the chemical and biological effect of the sediments, whether in suspension or deposited on the bed.

5-15. Shoreline Erosion. The shoreline erosion process stems from wind wave action, boat wave action and water surface fluctuation. Long distances of open water which are oriented with prevailing winds will allow the generation of large enough waves to make beach and shoreline erosion a potential problem. As the shoreline erodes, the eroded material tends to move to lower elevations thereby reducing the reservoir storage capacity allocated for specific purposes at those elevations.

5-16. Shifting Location of Channels. In navigation projects which utilize a combination of lock/dam structures and channel contractions work to develop a navigation channel, the channel contraction is designed for the upstream end of the navigation pools. As the delta develops, however, those works will need to be extended toward the dam, a condition occurring early in the life of some projects.

5-17. Downstream Degradation. Looking downstream from the dam, the predominant problems are associated with degradation of the main channel (i.e., a general lowering of the channel bed). Not only is the tailwater at the dam affected but also bridge crossings, pump intakes, diversion structures, local drainage structures, and recreational uses are affected. Consider the following conceptual model of the system behavior:

a. When a reservoir is first impounded, the hydraulics of a given water release (velocity, slope, depth and width) remain unchanged from conditions in the natural river.

b. However, the reservoir has trapped sediment material, especially the bed material load. This reduction in coarse sizes of sediment allows the surplus energy in the flow to entrain material from the stream bed. That produces a degradation trend.

c. Degradation refers to the general erosion of the channel bed over a substantial distance and for an extended period of time such that the elevation duration curve trends downward. It is different from the local scour that will occur at a structure.

d. The degradation trend will start at the dam and migrate in the downstream direction as time passes. The downstream migration causes a decrease in channel slope which helps to reduce velocities and, therefore, to retard the degradation process.

e. Several other factors are also working to establish the new equilibrium condition in this movable boundary flow system. The bed surface is becoming coarser which shields particle sizes beneath it. Discharge hydrographs are not peaking as high as preproject conditions. Tributaries are contributing more sediment than under preproject conditions because the base-level has been lowered.

f. As the bed degrades, the finer sediment sizes will move out faster than the coarser sizes. The bed surface will become coarser with time and consequently will move at slower and slower rates until finally, movement under normal reservoir releases will cease.

g. Coarse gravel and cobbles move only during the more extreme flood discharges and some reservoirs eliminate such flood events.

h. Degradation of the main channel plus the modified discharge hydrographs from the reservoir combine to produce a base-level lowering along the downstream channel. The potential energy gradient at the downstream end of each tributary will increase which results in degradation migrating up the tributary. That supplies additional sediment to the main stem which tends to offset the effect of the reservoir and arrest degradation of the main channel. However, it can produce tributary degradation with associated geotechnical failures of banks.

i. The time required for degradation problems to become noticeable depends on the size of sediment grains in the stream bed and banks. That is, fine sands will move at the water velocity so degradation is quite rapid in such material.

j. The extent of degradation is complicated by the fact that the reservoir also changes the water discharge duration curve. This will impact for great distances down stream from the project because the existing river channel reflects not only peaks but also 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.

5-18. Changes in Downstream Channel Capacity. Early in the life of many projects, bank full capacity of the channel has become less than it was before the dam was built. Consequently the reservoir can not discharge the rate of water needed to maintain the reservoir operating rules used for project design studies. Two factors are believed to be responsible: the flow duration curve is modified by reservoir operation such that the dominant discharge becomes smaller with the project than it was without it. Consequently, a smaller channel develops. The second factor results from the continuous releases from the reservoir. Vegetation will be encouraged to grow at lower elevations along the channel resulting in higher bank roughness plus sediment deposition in the vegetation. Both factors contribute to a loss in conveyance for channel flows. Design studies must account for that reduction in flood releases. The degradation trend reverses the decrease in channel capacity as time passes, but downstream movement is usually slow.

5-19. Local Scour at the Dam, Spillway and Stilling Basin. Local scour is always a problem at hydraulic structures. Abutments are the weakest zone and should be designed to either prevent flow from short-circuiting the overbanks and cascading down the tie between the structure and the channel bank line or accommodate such a flow path. Another critical zone is the emergency spillway. These are usually designed for infrequent, if ever use, and flow is left to seek a path of return to the channel. Make sure that path is as long and tortuous as possible. In the late 1970's emergency spillways were overtopped at two reservoirs near major metropolitan areas. Although the discharge peaked at only 10% of the spillway design discharge and flow continued for a limited duration, extensive erosion of the land occurred as flow sought a return path to the channel. In one of those cases the erosion pattern was that of a waterfall, or head-cut, which moved in the upstream direction. Unlike the description of a head-cut on a tributary, this head-cut got taller as it moved upstream toward the spillway. It came within a few hundred yards of reaching the apron of the stilling basin before the overflow stopped. Once such an event is underway all one can do to it is take pictures. Therefore, give careful attention to safety when reservoirs are located upstream from urban areas. Major failures can occur in a single flood event. Land use change during the life of the project should be a major consideration downstream from such structures.

Section IV. Levels of Sedimentation Studies and Methods of Analysis

5-20. Staged Sedimentation Investigations. The basis for staged sedimentation studies is given in Chapter 1. Words of caution to those who follow the staged concept are "be prepared to modify basic project features as cited in Chapter 1 if the preliminary assessment is in error."

a. Staged sedimentation studies should adopt the "safety factor-project impact" concept in which a safety factor from 1.5 to 2 times the best initial estimate of the sediment impact is used to develop an impact on project costs. If the problem is sediment deposition in the reservoir the sediment yield should be adjusted by the safety factor. If the problem is bed degradation downstream from the dam, or any where in the study area, the safety factor concept should be applied to stability coefficients and transport capacity. Providing such an impact does not affect basic go/no-go decisions about the project, the sedimentation study can be staged and refined as the project moves through planning and design stages. However, if sediment problems appear to dominate project design and economics, the staged concept should be avoided in favor of a more defendable sedimentation study based on field data.

b. Two stages are proposed for a reservoir sedimentation study: the Sediment Impact Assessment and a Detailed Sedimentation Study. The objective is the same in each stage. The scope of the study is the same in both, but the depth of study is controlled by project formulation economics in the impact assessment whereas in the detailed study it is controlled by the technical details of the problems.

5-21. Sediment Impact Assessment. The purpose of the sediment impact assessment report is to convey to reviewing authorities (1) the amount of effort expended to date in investigating sedimentation problems; (2) the amount and type of field data available for the assessment; (3) the anticipated impact of sedimentation on project performance and maintenance, and (4) the anticipated impact of the project on stream system morphology. This assessment is expected in the initial planning document with amplification as necessary in subsequent reports. It should recommend additional studies, if needed, and serve as the basis for preparing the sediment Studies Work Plan described in Chapter 2. A negative report is as important as one identifying problems.

5-22. Scope. This report should discuss, at a minimum, reservoir sedimentation problems and the impact of the project on stream system morphology. It should present the data itemized above in as complete form as it is available from office files and the field reconnaissance.

5-23. Approach. Usually field data are not available for this level of study. The approach is to use data from office files, from references and from regionalize data gathered at nearby projects to predict what will happen at the one under study. As in physical modeling, a procedure to assess similitude between projects is needed. The following is considered an acceptable level of similitude: demonstrate the reservoir purposes are similar, the water yield and sediment yield unit rates from the basin are similar, the sediment properties are similar, and reservoir operating rules are similar.

a. Always consider the occurrence or absence of extreme hydrologic events when using or transferring historical data. Develop a "safety factor" for the anticipated sediment yield rate and establish resulting project performance.

b. Acceptable analytical techniques for making the necessary calculations are summarized in appendices of this manual and are referenced in the topic statements below.

5-24. Topics to Report. The following list of topics not only suggest items to include in the sedimentation report but also show the general sequence of tasks for performing the study.

a. Basic Background Information. Report the pertinent data for the dam:

(1) Basin and site location maps. The general geographical location and site location for the dam are needed. Study area and reservoir maps are needed to develop the boundaries of the project area and the boundaries of the study area.

(2) Project purposes and life. A statement of the project purposes and storage allocations for each is needed. In flood control reservoirs the project life for sedimentation is 100 years. In navigation projects a 50 year life is used.

(3) Design details for the dam. Only the proposed spillway crest elevation is needed for this level.

(4) Reservoir storage allocations. The proposed elevations for storage pools are major factors in establishing the location of the reservoir delta.

(5) Stream bed profiles through the study area

(6) The rational for establishing study area boundaries (This includes establishing the sources of water, sources of sediment, presence of upstream projects, hydraulic and sediment conditions at boundaries of project, and the impact of the project on those boundary conditions)

b. Results of the River Morphology Study.

(1) Land use. Report historical and probable future land use in the basin. Knowledge of historical land uses in the basin will help in understanding historical sediment records. Predicted future land use is essential for estimating future sediment yield. (Chapter 3)

(2) Annual water yield. Annual water yield is necessary but 90 percent of the sediment is transported during the flood events. Therefore, if information is available for floods, present it also. Both historic and future conditions should be estimated. (Chapter 3)

(3) Erosive mechanisms and soil types. Consider the possibility that erosive mechanisms are associated with land use. Report the erosive mechanisms and soil types. Where sheet and rill are the dominant erosion mechanisms, unit values based on drainage area (i.e., tons per acre per year) are appropriate for estimating sediment yield from the basin. If the soil is sandy, the proximity of the sand source to a water course is as significant as the surface area in determining the delivery to the channel. Consequently, yield from gullying and bank erosion are probably better correlated with miles of channel in the basin than they are the surface area.

(4) Sediment yield analysis. The suggested topics to include here are given in the chapter on sediment yield. Total sediment yield into the reservoir, during the project life, is necessary. If refinement is needed determine what percentage of that total is made up of silt and clay. (Chapter 3)

(5) Sediment properties of channel. At a minimum, describe the type of sediment material forming the stream bed and banks from records and photographs made during the field reconnaissance trip, (Appendix E). A few samples of the bed material are desirable.

c. Analysis of Reservoir and Watershed Parameters.

(1) Trap efficiency of reservoir and volume depletion, (Appendix F).

(2) Specific weight of deposits, (Appendix G).

(3) Estimated depletion of reservoir volume by pool elevation, (Appendix H).

(4) Estimated elevations for real estate requirements (Water Surface Profile Calculations with sediment deposits.)

(5) Predicted effect of sediment deposits on future river stages upstream from reservoir (Numerical modeling)

(6) Report the possibility of turbidity in the reservoir. Turbidity is associated with soil type. For example, soil types which erode as colloidal particles will create turbidity problems in the reservoir.

(7) Possibility of bank erosion. A soils map will provide soil types at reservoir operating levels. A assessment can be made as to the potential for shoreline erosion.

(8) Possibility of a density current.

d. Analysis Downstream from the Dam.

(1) Modified stage duration curve at dam. Get this graph from the modified flow duration curve and use it to indicate base-level lowering due to regulation.

(2) Degradation of the channel bed. Use this study to estimate lowering of the tailwater rating curve for the stilling basin and hydropower head, (Appendix J).

(3) Predicted future tributary degradation. Combine the modified stage duration curve with degradation predictions on the main stem to forecast the need for stabilizing tributary degradation problems. Adapt the method in Appendix J to estimate the upstream limit of degradation.

5-25. <u>Detailed Reservoir Sedimentation Study.</u> The purpose of the detailed reservoir sedimentation study is given in Chapter 1.

5-26. <u>Scope.</u> The breadth of a detailed study encompasses the same problems identified in the impact assessment but is greater in depth because of the need to calculate rates and volumes of erosion, transportation and deposition in both time and space and to propose and rank alternative designs.

5-27. <u>Method of Analysis.</u> This level of study is designed for numerical modeling techniques because the analysis of the data set is more labor intensive than one can afford manually. Numerical modeling techniques are structured entirely for computer solution.

5-28. <u>Approach.</u> The amount of data that has to be analyzed includes all the basic geometric and hydraulic data required for water surface profile calculations plus data describing the size and gradation of sediment material in the stream bed and banks, the size, gradation, and amount of inflowing sediment material and the water discharge hydrograph. In addition, long periods of hydrograph record are generally utilized since sediment studies attempt to predict trends throughout the project life. The number of calculations is extremely large. For example, predicting deposition in a shallow reservoir having a 50 year design life can require the calculation of 1000 to 6000 water surface profiles plus the routing of sediment material through the reservoir for the water discharge associated with each of the profiles.

a. Shallow Impoundments. For reservoirs which do not modify the hydrographs significantly, set the inflow boundary upstream from the reservoir and out of the influence of it and set the outflow boundary at the downstream end of the downstream study reach. The dam will be an internal control point where stages are controlled, and the sediment discharges passing the dam will be feed directly into the downstream reach.

b. Deep Impoundments. For reservoirs which modify the water discharge hydrographs, break the numerical model at the dam. Use the inflowing hydrographs and operating rule for boundary conditions for the upstream model, but use the modified hydrographs and sediment discharges passing the dam for inflows to the downstream model. The downstream boundary of the downstream model will be a stage discharge rating curve or a stage hydrograph. It should be beyond the influence of degradation.

5-29. <u>Topics to Report.</u> Topics suggested for the Detailed Sedimentation Study are shown in the following sub-paragraphs. Note that many are the same as in the Impact Assessment, but they are in more detail.

a. Basic Background Information. Report the pertinent data for the dam:

(1) Basin and site location maps. The general geographical location and site location for the dam are needed. Study area and reservoir maps are needed to develop the boundaries of the project area and the boundaries of the study area.

(2) Project purposes and life. A statement of the project purposes and storage allocations for each is needed. In flood control reservoirs the project life for sedimentation is 100 years. In navigation projects a 50 year life is used.

(3) Design details for the dam. Plan and elevation views of dam, outlet works and spillway.

b. Analysis Upstream from the Dam. The volume and location of deposits; new storage curves at selected future dates; elevations for real estate requirements; the effect of sediment deposits on future river stages upstream from reservoir on the main stem and tributaries; and navigation dredging requirements will come directly from the numerical model output. The following data are required

(1) Reservoir and river geometry. Cross sections and stream bed profiles through the study area

(2) Sediment properties of bed material

(3) Top of rock profile

(4) Water inflow hydrographs. Annual water yield is necessary but not sufficient for detailed reservoir sedimentation studies because 90 percent of the sediment is transported during the flood events. Therefore, provide water discharge hydrographs also. Both historic and future conditions should be

developed for each subbasin in the model.

(5) Inflowing sediment concentrations and properties.

(a) Sediment concentrations. The inflowing sediment concentration is needed for each water discharge in the hydrograph. Rather than constructing a concentration hydrograph, use the sediment discharge rating curve obtained from measurements of sediment concentrations. This should be after adjusting the curve for future conditions when analyzing proposed project conditions.

(b) Sediment properties. Sediment properties refer to size, density, shape, and chemistry of individual particles of sediment. Next to concentration, the most significant parameter in determining storage depletion in a reservoir is particle size. That is determined by analyzing suspended sediment samples. In addition to size, particle density, shape, and electro-chemical activity is required. Suspended sediment samples are needed for a wide range of water discharges.

(c) Adjustment for future land use. Knowledge of historical land uses in the basin will help in understanding historical sediment records. Predicted future land use is essential for estimating future sediment yield. Consider, also, the probable erosion mechanisms and how they will change with land use.

[1] Where overland flow, gullying, and channel bank caving are the dominant mechanisms, unit values are not sufficient to determine basin yield. Divide the sediment into wash load and bed material load categories. Use unit sediment yields for the wash load portion, but calculate the bed material discharge using transport theories and compare that result to the unit production quantities of sands.

[2] Soil type will greatly influence erosion rate, and thereby, sediment yield from the basin. That is, once silts and colloidal particles become detached the particles move easily through the water courses. Sandy soils detached by sheet or rill mechanism, on the other hand, are likely to settle out a short distance away. Consequently, proximity of the sand source to a water course is as significant as the surface area parameter in determining the delivery of sands.

(6) Operating rule curve. The operating pool elevations and rule curve provide the downstream control for sediment routing through the reservoir.

(7) Specific weight of deposits. Whereas sediment properties refer to the individual particles, specific weight of deposits refers to the bulk property of the mass of the sediment deposit. It is expressed as pounds/cubic foot, dry weight, and is the key for converting units between weights and volumes. Such conversions are common because sediment movement computations are made in mass units and reservoir storage depletion requires a volume unit, (Appendix G).

(a) The major factor affecting specific weight of deposits is particle size. Coarse sediments such as sands and gravels deposit at a density very near their ultimate density.

(b) As particle size decreases into the silts and clays, secondary factors become important. Silt and clay will deposit as a "fluffy" mass (i.e., at a low specific weight) and as time passes that deposit will consolidate. Time, the drying due to reservoir draw-down, and the overburden pressure of more deposits are factors determining the rate of consolidation. A method is available to estimate the initial specific weight and the consolidation coefficients so future conditions can be predicted.

(c) Elevation-capacity curve. The relationship developed for hydrologic studies which shows initial volume in the reservoir versus elevation at the dam is needed. The volume of storage allocated for each project purpose should be shown on that relationship. These should be reconstituted by the sediment model to confirm the geometry has modeled reservoir volumes adequately.

(8) Topics not addressed by the numerical sediment movement model are density currents, turbidity, and shoreline erosion.

(a) Report the possibility of turbidity in the reservoir. Turbidity is associated with soil type. For example, soil types which erode as colloidal particles will create turbidity problems in the reservoir.

(b) Possibility of a density current.

(c) Possibility of shoreline erosion. A soils map will provide soil type at reservoir operating levels. A assessment can be made as to the potential for shoreline erosion from estimated wind wave heights, erosive forces and riprap requirements.

c. Analysis Downstream from the Dam. The reservoir causes this portion of the system to be sediment starved. Classical transport theory would indicate catastrophic consequences, and such will likely occur only if sediment concentration is the only variable affected by the reservoir. However, the water discharge-duration curve, hydraulic roughness and local inflow of sediment from tributaries are all affected by the reservoir and are factors in the degradation process. Report the following:

(1) Rationale for limits of study area. The study area should start at the dam and go, uninterrupted, to a stable control such as a bed rock outcrop or some other hard point across the channel. Laterally, the study area should extend up each tributary where degradation is not arrested by bed rock or some other resistant material. Maps showing study area boundaries are needed. They should show all points where flow enters or leaves the study area and all structures, either on or across the streams, in the study area.

(2) Selection of geometry. Justify the cross sections and reach lengths used for water surface profile computations on the main stem and up each tributary where significant degradation problems seem likely.

(3) Hydraulic roughness. The n-values will change with time and should be related to grain size and sediment transport.

(4) Sediment inflow. Justify the sediment discharge, by particle size, passing the dam.

(5) Bed material gradation. Justify the gradation of the bed surface and the gradation at depths beneath the bed surface through the study area. Top of rock or clay profiles are needed.

(6) Tributary data. Justify the discharge of the bed material load, by grain size class, for each major tributary. As in the case of upstream data, land use change should be considered in developing this data.

(7) Hydrologic data. Show the modified discharge hydrographs for dam releases and on each major tributary at the study area boundary. Water temperature is needed at each inflow point. Justify the stage-discharge relation used for the downstream boundary of the degradation study reach.

Section V. Reservoir Sedimentation Investigation Program

5-30. Reservoir Sedimentation Investigation Program. This is a post-construction activity which monitors for sedimentation problems resulting from the reservoir. The Corps of Engineers cannot control land use sufficiently well to control future sediment yield,and it is imperative that the rate and location of sediment deposits be known. Checking for aggradation of channels upstream from the reservoir and degradation of channels downstream from the dam is also included in this monitoring program. To insure that information is available for other design studies and to provide general information on reservoir sedimentation, a systematic, reservoir sedimentation investigation program is required at each reservoir. The program is described in this manual in Appendix K, "Reservoir Sedimentation Investigation Program". It is to be implemented even if the Sediment Impact Assessment study identified no adverse sediment effects.

Section VI. Debris Basin Design

5-31. Debris Basins. Debris basins, sometimes called sediment retention basins, are reservoirs designed to trap sediment and debris. In this usage, debris refers to the assortment of sand, gravel, cobbles, boulders, logs and other large pieces of material that deposit in a channel causing flood flows to spill out before design conditions are reached. Generally, debris basins are used where channel slope becomes flatter, for example, where a stream leaves hills and flows across a flood plain. The need is easily identified by noting channel meander and braiding patterns on aerial photographs.

5-32. Design Considerations. Debris basins are growing in popularity; however, little work has been done to aid in their design and evaluation except in the southern California area, and that work is not portable to other locations.

a. Design Guidelines. The Federal Highway Department has published guidelines for sedimentation basin design, reference [53].

b. Safety. It is imperative that project safety be a key factor in sizing the basin. Project safety requires not only design flood considerations but also the proper consideration of conditions anticedent to a design flood. Also, the debris basin should function so if a flood should occur which exceeds the design flood, the project will not make conditions worse than would have occurred without the project.

c. Location. Debris basins are placed upstream from flood protection or navigation channels. Access and shape are important considerations because they affect clean-out and trap efficiency, respectively.

d. Basin Size. They are usually small and designed to be cleaned out from time to time. However, the size is not arbitrary. It must be justified by project economics and available sites. Some basins are sized for only one or two major storms. Others may have a 50 or 100 year capacity.

e. Topset Slope. The volume available for sediment storage in the debris basin is considerably different from the horizontal planes used in water storage calculations. A delta will form in these basins just as it does in a reservoir. Starting at the crest of the dam the topset slope of the delta can be estimated to be 50 percent of the original valley slope. That is adequate for the impact assessment, but numerical modeling should be used to calculate a topset slope for the detailed sedimentation study. It will often exceed the 50% approximation. Of course, trap efficiency of the basin decreases as it fills, and that will determine how much material can be stored before removal is required.

f. Sediment Yield. Sediment yield estimates for debris basin design should include two kinds of hydrological events: the normal, long term records and the design flood events. Long term average sediment concentration records should be used for the long term hydrologic events. The long term average concentration is determined from the best fit line through the log-log plot of water discharge versus sediment discharge. It assumes flood data are available and low flow data were not extrapolated up to the range of water discharges in the design flood peak.

g. Analysis by Particle Size Class. Sediment yield studies for debris basin design always require grain size data. Methods which seem to ignore that data, such as Tatum, actually have it built into the coefficients and procedures. They should be used only in the region for which they were developed.

h. Single Event Sediment Concentrations. The best fit line on the water discharge-sediment concentration plot should be adjusted upward to develop a concentration for large floods. For example, in a flood having a chance, or less,1 or 2% , the sediment concentrations may exceed long term averages by a factor of 2 or 3.

i. Sediment Discharge Curve Extrapolation. If flood measurements are not available, use the transport capacity approach described in Chapter 3 to extrapolate the water-sediment discharge relationship. If the concentration of fines exceeds 10,000 ppm, (10063 mg/l), they will begin to increase transport capacity. By the time they reach 100,000 ppm (106,640 mg/l) that influence can be as much as a factor of 10 or 20 times the normal transport capacity.

j. Staged Design Studies. Usually the debris basin design can be staged as discussed above for the sedimentation investigation, but a detailed sedimentation study is recommended by the time the feasibility level of project formulation is reached in projects where debris basins are required.

k. Embankment Height. The height of the top-of-embankment above the spillway crest should be designed for the condition when the active flow channel has become the width of the inflowing channel and is located adjacent, and parallel to, the embankment. Calculate the height of embankment using a slope equivalent to the valley slope transporting sediment into the basin and the distance from the spillway to the end of embankment. Add freeboard and velocity head to that height as appropriate to turn the approaching flow. That will accommodate an energy loss for a flow that is the width of the natural river channel and flowing along the face of the embankment.

5-33. Design Method. The trap efficiency of the basin can be calculated using numerical sediment models such as HEC-6 provided the proper skill is used in defining the geometry for the hydraulics calculations. The objective is to calculate the reduction in sediment discharge by particle size so the outflowing load curve is defined as a function of basin capacity. The end product will be a size and shape of basin to provide the required storage capacity for sediment for the period between clean out operations.

a. Defining the Geometry. Initially flow is 3-dimensional; however, the rapid deposition of sediment seems to cause a rapid return to the 1-dimensional channel hydraulics problem. Therefore, a 1-dimensional numerical model is proposed provided the following flow field-sediment deposition concepts are followed.

b. Conveyance Limits. The inflowing water-sediment mixture will not expand instantaneously.

c. Longitudinal Profile. Deposition will occur quickly for sands and gravels and the location will start near the inlet.

d. Lateral Shape of Deposits. Deposition of sands and gravels will first fill the channel under the expanding jet until the loss in conveyance causes the jet to deflect to one side or the other.

e. Sorting by Particle Size. The design must be analyzed by particle size. Whereas the coarse particles settle out under the expanding jet, 1 to 2 fps is enough energy to keep the fines in suspension. Fines in the slower velocity water adjacent to the jet will be entrained by eddys and deposit toward the sides of the basin if at all. If the deposition of fines is of primary importance, a 2-Dimensional Model such as TABS-2 is recommended.

f. Channel Regime. As the basin fills the fluid jet will tend toward the same width as the natural channel width rather than remaining a uniformly distributed velocity across a wide basin.