Chapter 2
General Considerations

2-1. General

a. Introduction. The successful design, construction, and operation of a reservoir project over the full range of loading require a comprehensive site characterization, a detailed design of each feature, construction supervision, measurement and monitoring of the performance, and the continuous evaluation of the project features during operation. The design and construction of earth and rock-fill dams are complex because of the nature of the varying foundation conditions and range of properties of the materials available for use in the embankment. The first step is to conduct detailed geological and subsurface explorations, which characterize the foundation, abutments, and potential borrow areas. The next step is to conduct a study of the type and physical properties of materials to be placed in the embankment. This study should include a determination of quantities and the sequence in which they will become available. The design should include all of the studies, testing, analyses, and evaluations to ensure that the embankment meets all technical criteria and the requirements of a dam as outlined in *b* below. Construction supervision, management, and monitoring of the embankment and appurtenant structures are a critical part of the overall project management plan. Once the project is placed into operation, observations, surveillance, inspections, and continuing evaluation are required to assure the satisfactory performance of the dam.

b. Basic requirements of an embankment dam. Dams are a critical and essential part of the Nation's infrastructure for the storage and management of water in watersheds. To meet the dam safety requirements, the design, construction, operation, and modification of an embankment dam must comply with the following technical and administrative requirements:

(1) Technical requirements.

- The dam, foundation, and abutments must be stable under all static and dynamic loading conditions.

- Seepage through the foundation, abutments, and embankment must be controlled and collected to ensure safe operation. The intent is to prevent excessive uplift pressures, piping of materials, sloughing removal of material by solution, or erosion of this material into cracks, joints, and cavities. In addition, the project purpose may impose a limitation on allowable quantity of seepage. The design should include seepage control measures such as foundation cutoffs, adequate and nonbrittle impervious zones, transition zones, drainage material and blankets, upstream impervious blankets, adequate core contact area, and relief wells.

- The freeboard must be sufficient to prevent overtopping by waves and include an allowance for settlement of the foundation and embankment.

- The spillway and outlet capacity must be sufficient to prevent over-topping of the embankment by the reservoir.

(2) Administrative requirements.

- Environmental responsibility.

- Operation and maintenance manual.

- Monitoring and surveillance plan.

- Adequate instrumentation to monitor performance.

- Documentation of all the design, construction, and operational records.

- Emergency Action Plan: Identification, notification, and response subplan.

- Schedule for periodic inspections, comprehensive review, evaluation, and modifications as appropriate.

c. Embankment. Many different trial sections for the zoning of an embankment should be prepared to study utilization of fill materials; the influence of variations in types, quantities, or sequences of availability of various fill materials; and the relative merits of various sections and the influence of foundation condition. Although procedures for stability analyses (see EM 1110-2-1902 and Edris 1992) afford a convenient means for comparing various trial sections and the influence of foundation conditions, final selection of the type of embankment and final design of the embankment are based, to a large extent, upon experience and judgment.

d. Features of design. Major features of design are required foundation treatment, abutment stability, seepage conditions, stability of slopes adjacent to control structure approach channels and stilling basins, stability of reservoir slopes, and ability of the reservoir to retain the water stored. These features should be studied with reference to field conditions and to various alternatives before initiating detailed stability or seepage analyses.

e. Other considerations. Other design considerations include the influence of climate, which governs the length of the construction season and affects decisions on the type of fill material to be used, the relationship of the width of the valley and its influence on river diversion and type of dam, the planned utilization of the project (for example, whether the embankment will have a permanent pool or be used for short-term storage), the influence of valley configuration and topographic features on wave action and required slope protection, the seismic activity of the area, and the effect of construction on the environment.

2-2. Civil Works Project Process

a. General. The civil works project process for a dam is continuous, although the level of intensity and technical detail varies with the progression through the different phases of the project development and implementation. The phases of the process are reconnaissance, feasibility, preconstruction engineering and design (PED), construction, and finally the operation, maintenance, repair, replacement, and rehabilitation (OMRR&R). A brief summary of each phase, concerning the required engineering effort, is presented. A complete civil works project process is defined in ER 1110-2-1150.

b. Reconnaissance phase. A reconnaissance study is conducted to determine whether or not the problem has a solution acceptable to local interests for which there is a Federal interest and if so whether planning should proceed to the feasibility phase. During the reconnaissance phase, engineering assessments of alternatives are made to determine if they will function safely, reliably, efficiently, and economically. Each alternative should be evaluated to determine if it is practical to construct, operate, and maintain. Several sites should be evaluated, and preliminary designs should be prepared for each site. These preliminary designs should include the foundation for the dam and appurtenant structures, the dam, and the reservoir rim. The reconnaissance phase ends with either execution of a Feasibility Cost Sharing Agreement or the major subordinate command (MSC) Commander's public notice for a report recommending no Federal action (ER 1110-2-1150).

c. Feasibility phase. A feasibility study is conducted to investigate and recommend a solution to the problem based on technical evaluation of alternatives and includes a baseline cost estimate and a design and construction schedule which are the basis for congressional authorization. Engineering data and analyses in the feasibility phase shall be sufficient to develop the complete project schedule and baseline cost estimate with reasonable contingency factors. Results of the engineering studies are documented in an engineering appendix to the feasibility report. The outline of the engineering appendix is given in Appendix C of ER 1110-2-1150. An operation and maintenance plan for the project, including estimates of the Federal and non-Federal costs, will be developed. All of the project OMRR&R and dam safety requirements should be identified and discussed with the sponsor and state during the feasibility phase.

d. Preconstruction engineering and design phase. The preconstruction engineering and design (PED) phase begins when the MSC Commander issues the public notice for the feasibility report and PED funds are allocated to the district. The PED ends with completion of the P&S for the first construction contract or as otherwise defined in the PED cost-sharing agreement. During the PED phase, the design is finalized, the plans and specifications (P&S) are prepared, and the construction contract is prepared for advertising. The design documentation report (DDR) covers the PED phase and the construction phase of the project. The DDR is not totally completed until after the P&S and construction are completed. During the PED, the production of DDR and related P&S shall proceed concurrently as one unified design phase. The design should be completed and documented in the DDR, in accordance with Appendix D, Content and Format of Design Documentation Report, ER 1110-2-1150. Any physical model studies required shall be conducted during the PED phase. In preparation for the beginning of each major construction contract, engineering will prepare a report, The Engineering Considerations and Instructions for Field Personnel, to provide field personnel the insight and background needed to review contractor proposals and resolve construction problems. Format of the report is presented in Appendix G, ER 1110-2-1150.

e. Construction phase. This phase includes preparation of P&S for subsequent construction contracts, review of selected construction contracts, site visits, support for claims and modifications, development of operation and maintenance (O&M) manuals, and preparation and maintenance of as-built drawings. Site visits must be made to verify that conditions match the assumptions used in designing the project features. Site visits may also be necessary to brief the construction division personnel on any technical issues which affect the construction. The O&M manual and water control manual will be completed and fully coordinated with the local sponsor during this phase of the project. As-built drawings are prepared and maintained by engineering during the construction phase (ER 1110-2-1150).

f. Operation and maintenance phase. The project is operated, inspected, maintained, repaired, and rehabilitated by either the non-Federal sponsor or the Federal Government, depending upon the project purposes and the terms of the project cooperation agreement (PCA). For PCA projects and new dams turned over to others, the Corps needs to explain up front the O&M responsibilities, formal inspection requirements, and responsibilities to implement dam safety practices. Periodic inspections will be conducted to assess and evaluate the performance and safety of the project during its lifetime. Modifications to the features of a project which occur during the operating life of a project will be reflected in the as-built drawings (ER 1110-2-1150).

2-3. Types of Embankment Dams

a. Introduction. The two principal types of embankment dams are earth and rock-fill dams, depending on the predominant fill material used. Some generalized sections of earth dams showing typical zoning for different types and quantities of fill materials and various methods for controlling seepage are presented in Figure 2-1. When practically only one impervious material is available and the height of the dam is relatively low, a homogeneous dam with internal drain may be used as shown in Figure 2-1a. The inclined drain serves to prevent the downstream slope from becoming saturated and susceptible to piping and/or slope failure and to intercept and prevent piping through any horizontal cracks traversing the width of the embankment. Earth dams with impervious cores, as shown in Figures 2-1b and 2-1c, are constructed when local borrow materials do not provide adequate quantities of impervious material. A vertical core located near the center of the dam is preferred over an inclined upstream core because the former provides higher contact pressure between the core and foundation to prevent leakage, greater stability under earthquake loading, and better access for remedial seepage control. An inclined upstream core allows the downstream portion of the embankment to be placed first and the core later and reduces the possibility of hydraulic fracturing. However, for high dams in steep-walled canyons the overriding consideration is the abutment topography. The objective is to fit the core to the topography in such a way to avoid divergence, abrupt topographic discontinuities, and serious geologic defects. For dams on pervious foundations, as shown in Figure 2-1d to 2-1f, seepage control is necessary to prevent excessive uplift pressures and piping through the foundation. The methods for control of underseepage in dam foundations are horizontal drains, cutoffs (compacted backfill trenches, slurry walls, and concrete walls), upstream impervious blankets, downstream seepage berms, toe drains, and relief wells. Rock-fill dams may be economical due to large quantities of rock available from required excavation and/or nearby borrow sources, wet climate and/or short construction season prevail, ability to place rock fill in freezing climates, and ability to conduct foundation grouting with simultaneous placement of rock fill for sloping core and decked dams (Walker 1984). Two generalized sections of rock-fill dams are shown in Figure 2-2. A rock-fill dam with steep slopes requires better foundation conditions than an earth dam, and a concrete dam (or roller-compacted concrete dam) requires better foundation conditions than a rock-fill dam. The design and construction of seepage control measures for dams are given in EM 1110-2-1901.

b. Earth dams. An earth dam is composed of suitable soils obtained from borrow areas or required excavation and compacted in layers by mechanical means. Following preparation of a foundation, earth from borrow areas and from required excavations is transported to the site, dumped, and spread in layers of required depth. The soil layers are then compacted by tamping rollers, sheepsfoot rollers, heavy pneumatic-tired rollers, vibratory rollers, tractors, or earth-hauling equipment. One advantage of an earth dam is that it can be adapted to a weak foundation, provided proper consideration is given to thorough foundation exploration, testing, and design.

c. Rock-fill dams. A rock-fill dam is one composed largely of fragmented rock with an impervious core. The core is separated from the rock shells by a series of transition zones built of properly graded material. A membrane of concrete, asphalt, or steel plate on the upstream face should be considered in lieu of an impervious earth core only when sufficient impervious material is not available (such was the case at R. W. Bailey Dam; see Beene and Pritchett 1985). However, such membranes are susceptible to breaching as a result of settlement. The rock-fill zones are compacted in layers 12 to 24 in. thick by heavy rubber-tired or steel-wheel vibratory rollers. It is often desirable to determine the best methods of construction and compaction on the basis of test quarry and test fill results. Dumping rock fill and sluicing with water, or dumping in water, is generally acceptable only in constructing cofferdams that are not to be incorporated in the dam embankment. Free-draining, well-compacted rock fill can be placed with steep slopes if the dam is on a rock foundation. If it is necessary to place rock-fill on an earth or weathered rock foundation, the slopes must, of course, be much flatter, and transition zones are required between the foundation and the rock fill. Materials for rock-fill dams range from sound free-draining rock to the more friable materials such as sandstones and silt-shales that break down under handling and compacting to form an impervious to semipervious mass. The latter materials, because they are not completely free-draining and lack the shear strength of sound rock fill, are often termed “random rock” and can be used successfully for dam construction, but, because of stability and seepage considerations, the embankment design using such materials is similar to that for earth dams.

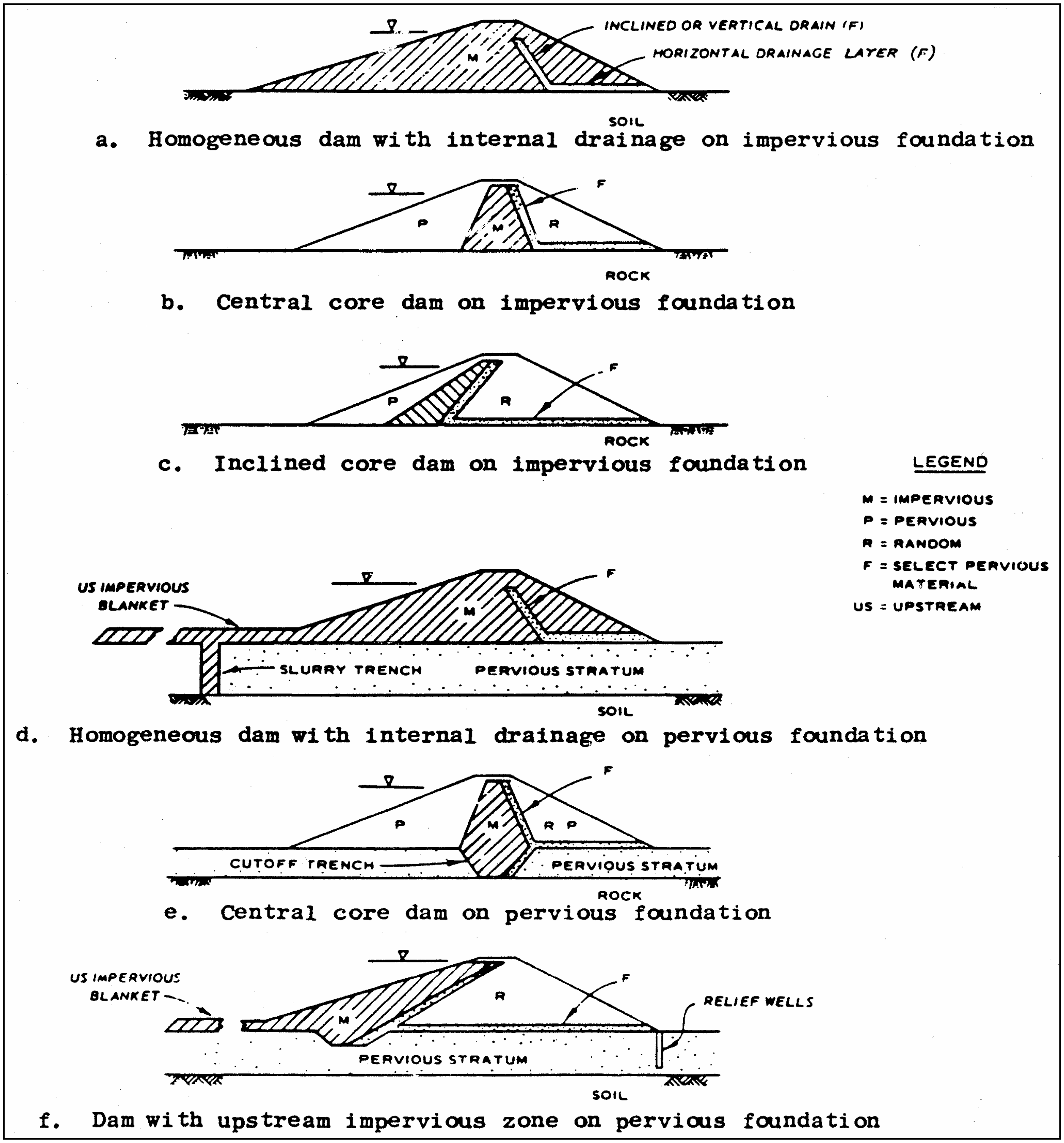

Figure 2-1. Types of earth dam sections

2-4. Basic Requirements

a. Criteria. The following criteria must be met to ensure satisfactory earth and rock-fill structures:

(1) The embankment, foundation, and abutments must be stable under all conditions of construction and reservoir operation including seismic.

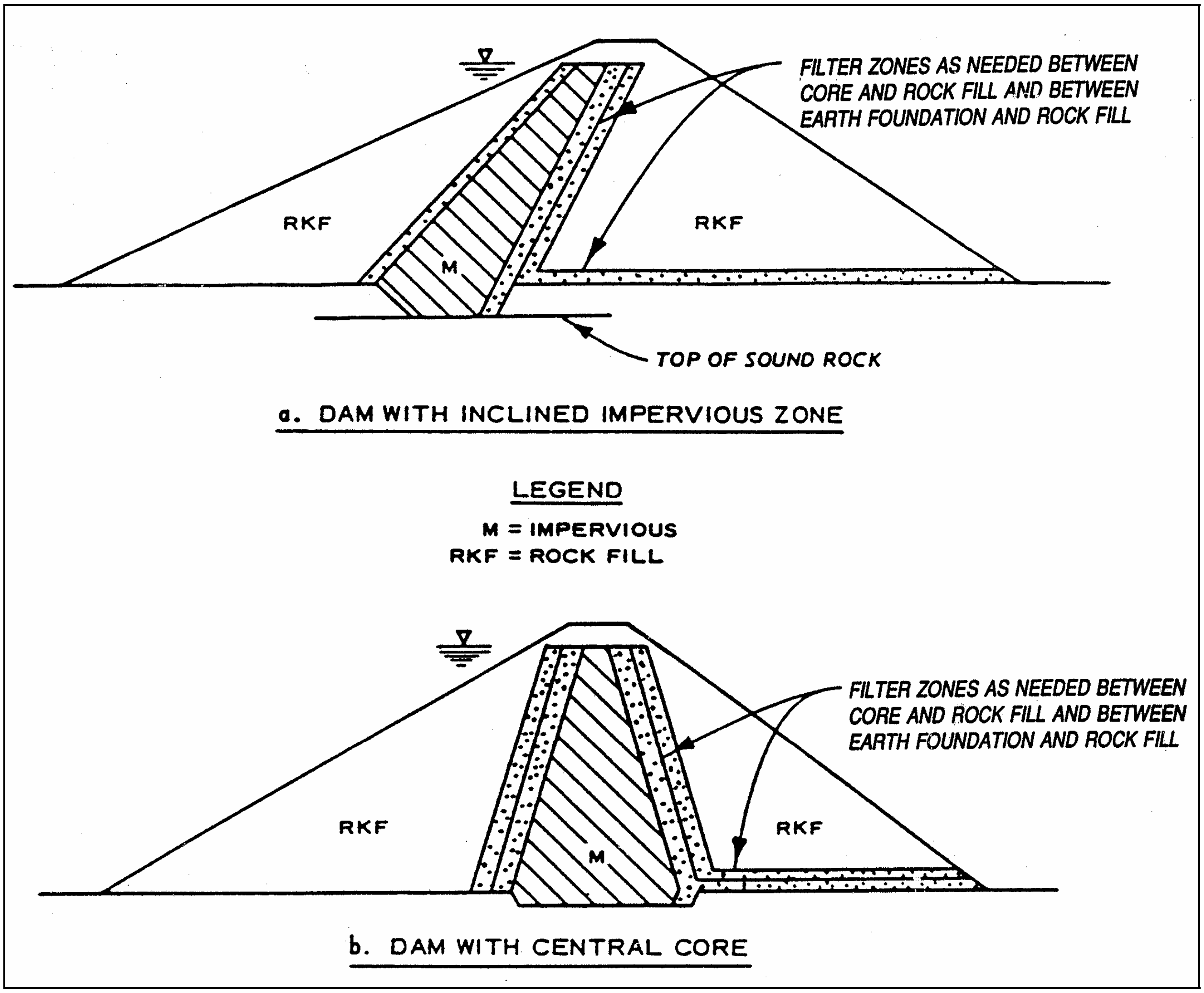

Figure 2-2. Two types of rock-fill dams

(2) Seepage through the embankment, foundation, and abutments must be collected and controlled to prevent excessive uplift pressures, piping, sloughing, removal of material by solution, or erosion of material by loss into cracks, joints, and cavities. In addition, the purpose of the project may impose a limitation on the allowable quantity of seepage. The design should consider seepage control measures such as foundation cutoffs, adequate and nonbrittle impervious zones, transition zones, drainage blankets, upstream impervious blankets, and relief wells.

(3) Freeboard must be sufficient to prevent overtopping by waves and include an allowance for the normal settlement of the foundation and embankment as well as for seismic effects where applicable.

(4) Spillway and outlet capacity must be sufficient to prevent overtopping of the embankment.

b. Special attention. Special attention should be given to possible development of pore pressures in foundations, particularly in stratified compressible materials, including varved clays. High pore pressures may be induced in the foundation, beyond the toes of the embankment where the weight of the dam produces little or no vertical loading. Thus, the strengths of foundation soils outside of the embankment may drop below their original in situ shear strengths. When this type of foundation condition exists, instrumentation should be installed during construction (see Chapter 10).

2-5. Selection of Embankment Type

a. General. Site conditions that may lead to selection of an earth or a rock-fill dam rather than a concrete dam (or roller-compacted concrete dam) include a wide stream valley, lack of firm rock abutments, considerable depths of soil overlying bedrock, poor quality bedrock from a structural point of view, availability of sufficient quantities of suitable soils or rock fill, and existence of a good site for a spillway of sufficient capacity.

b. Topography. Topography, to a large measure, dictates the first choice of type of dam. A narrow V-shaped valley with sound rock in abutments would favor an arch dam. A relatively narrow valley with high, rocky walls would suggest a rock fill or concrete dam (or roller-compacted concrete). Conversely, a wide valley with deep overburden would suggest an earth dam. Irregular valleys might suggest a composite structure, partly earth and partly concrete. Composite sections might also be used to provide a concrete spillway while the rest of the dam is constructed as an embankment section (Golze 1977, Singh and Sharma 1976, Goldin and Rasskazov 1992). The possibility of cracking resulting from arching in narrow valleys and shear cracks in the vicinity of steep abutments must be investigated and may play a role in the selection of the type of dam (Mitchell 1983). At Mud Mountain Dam, arching of the soil core material within a narrow, steep-sided canyon reduced stresses making the soil susceptible to hydraulic fracturing, cracking, and piping (Davidson, Levallois, and Graybeal 1992). Haul roads into narrow valleys may be prohibited for safety and/or environmental reasons. At Abiquiu and Warm Springs Dams, borrow material was transported by a belt conveyor system (Walker 1984). Topography may also influence the selection of appurtenant structures. Natural saddles may provide a spillway location. If the reservoir rim is high and unbroken, a chute or tunnel spillway may be necessary (Bureau of Reclamation 1984).

c. Geology and foundation conditions. The geology and foundation conditions at the damsite may dictate the type of dam suitable for that site. Competent rock foundations with relatively high shear strength and resistance to erosion and percolation offer few restrictions as to the type of dam that can be built at the site. Gravel foundations, if well compacted, are suitable for earth or rock-fill dams. Special precautions must be taken to provide adequate seepage control and/or effective water cutoffs or seals. Also, the liquefaction potential of gravel foundations should be investigated (Sykora et al. 1992). Silt or fine sand foundations can be used for low concrete (or roller-compacted concrete) and earth dams but are not suitable for rock-fill dams. The main problems include settlement, prevention of piping, excessive percolation losses, and protection of the foundation at the downstream embankment toe from erosion. Nondispersive clay foundations may be used for earth dams but require flat embankment slopes because of relatively low foundation shear strength. Because of the requirement for flatter slopes and the tendency for large settlements, clay foundations are generally not suitable for concrete (or roller-compacted concrete) or rock-fill dams (Golze 1977, Bureau of Reclamation 1984).

d. Materials available. The most economical type of dam will often be one for which materials can be found within a reasonable haul distance from the site, including material which must be excavated for the dam foundation, spillway, outlet works, powerhouses, and other appurtenant structures. Materials which may be available near or on the damsite include soils for embankments, rock for embankments and riprap, and concrete aggregate (sand, gravel, and crushed stone). Materials from required excavations may be stockpiled for later use. However, greater savings will result if construction scheduling allows direct use of required excavations. If suitable soils for an earth-fill dam can be found in nearby borrow pits, an earth dam may prove to be more economical. The availability of suitable rock may favor a rock-fill dam. The availability of suitable sand and gravel for concrete at a reasonable cost locally or onsite is favorable to use for a concrete (or roller-compacted concrete) dam (Golze 1977, Bureau of Reclamation 1984).

e. Spillway. The size, type, and restrictions on location of the spillway are often controlling factors in the choice of the type of dam. When a large spillway is to be constructed, it may be desirable to combine the spillway and dam into one structure, indicating a concrete overflow dam. In some cases where required excavation from the spillway channel can be utilized in the dam embankment, an earth or rock-fill dam may be advantageous (Golze 1977, Bureau of Reclamation 1984).

f. Environmental. Recently environmental considerations have become very important in the design of dams and can have a major influence on the type of dam selected. The principal influence of environmental concerns on selection of a specific type of dam is the need to consider protection of the environment, which can affect the type of dam, its dimensions, and location of the spillway and appurtenant facilities (Golze 1977).

g. Economic. The final selection of the type of dam should be made only after careful analysis and comparison of possible alternatives, and after thorough economic analyses that include costs of spillway, power and control structures, and foundation treatment.

2-6. Environmental Considerations

Public Law 91-190, National Environmental Policy Act of 1969, as amended, and the Clean Water Act of 1977 established the national policy for promoting efforts that will prevent or mitigate damage to the Nation's rivers and to the environment. The goal is to achieve clean and healthy watersheds that support aquatic life, economic development, and human needs. Managing water resources in a river basin has an impact on its natural water cycle. The scale of the impact depends on the actual size and natural condition of the area to be developed and the extent of development. Mitigation measures are essential elements in the planning, design, construction, and operation of a project, including clearing of vegetation in the area to be flooded, multilevel outlet structures to optimize downstream water temperature and quality, provisions for the migration of fish and other aquatic organisms, and operational rules for regulating downstream flows at critical times to protect habitat for reproduction or migratory routes. Appropriate site selection, together with the implementation of these techniques, will result in both new and rehabilitated projects that minimize unacceptable environmental impacts. Environmental conservation includes mitigation and enhancement for new projects, maintaining the existing conditions and restoration where appropriate.