Chapter 8
Water Surface Profiles

8-1. Introduction

a. General. Water surface profiles are required for most reservoir projects, both upstream and downstream from the project. Profile computations upstream from the project define the “backwater” effect due to high reservoir pool levels. The determination of real estate requirements are based on these backwater profiles. Water surface profiles are required downstream to determine channel capacity, flow depths and velocities, and other hydraulic information for evaluation of pre- and post-project conditions.

b. Choosing a method. The choice of an appropriate method for computing profiles depends upon the following characteristics: the river reach, the type of flow hydrograph, and the study objectives. The gradually varied, steady flow profile computation (e.g., HEC-2), is used for many studies. However, the selection of the appropriate method is part of the engineering analysis. EM 1110-2-1416 provides information on formulating a hydraulic study and a discussion of the analytical methods in general use. The following sections provide general guidance on the methods and the potential application in reservoir related studies.

8-2. Steady Flow Analysis

a. Method assumptions. A primary consideration in one-dimensional, gradually varied, steady flow analysis is that flow is assumed to be constant, in time, for the profile computation. Additionally, all the one-dimensional methods require the modeler to define the flow path when defining the cross-sectional data perpendicular to the flow. The basic assumptions of the method are as follows:

(1) Steady flow - depth and velocity at a given location do not vary with time.

(2) Gradually varied flow - depth and velocity change gradually along the length of the water course.

(3) One-dimensional flow - variation of flow characteristics, other than in the direction of the main axis of flow may be neglected, and a single elevation represents the water surface of a cross section perpendicular to the flow.

(4) Channel slope less than 0.1 m/m - because the hydrostatic pressure distribution is computed from the depth of water measure vertically.

(5) Averaged friction slope - the friction loss between cross sections can be estimated by the product of the representative slope and reach length.

(6) Rigid boundary - the flow cross section does not change shape during the flood.

b. Gradually varied steady flow. The assumption of gradually varied steady flow for general rainfall and snowmelt floods is generally acceptable. Discharge changes slowly with time and the use of the peak discharge for the steady flow computations can provide a reasonable estimate for the flood profile. Backwater profiles, upstream from a reservoir, are routinely modeled using steady flow profile calculations. However, inflow hydrographs from short duration, high intensity storms, e.g., thunderstorms, may not be adequately modeled assuming steady flow.

c. Downstream profile. Obviously, the downstream profile for a constant reservoir release meets the steady flow condition. Again, the consideration is how rapidly flow changes with time. Hydropower releases for a peaking operation may not be reasonably modeled using steady flow because releases can change from near zero to turbine capacity, and back, in a short time (e.g., minutes) relative to the travel time of the resulting disturbances. Dam-break flood routing is another example of rapidly changing flow which is better modeled with an unsteady flow method.

d. Flat stream profiles. Another consideration is calculating profiles for very flat streams. When the stream slope is less than 0.0004 m/m (2 ft/mile), there can be a significant loop in the downstream stage-discharge relationship. Also, the backwater effects from downstream tributaries, or storage, or flow dynamics may strongly attenuate flow. For slopes greater than 0.0009 m/m (5 ft/mile), steady flow analysis is usually adequate.

e. Further information. Chapter 6 of EM 1110-2-1416 *River Hydraulics* provides a detailed review of the assumptions of the steady flow method, data requirements, and model calibration and application. Appendix D provides information on the definition of river geometry and energy loss coefficients, which is applicable to all the one-dimensional methods.

8-3. Unsteady Flow Analysis

a. Unsteady flow methods. One-dimensional unsteady flow methods require the same assumptions listed in 8-2(a), herein, except flow, depth, and velocity can vary with time. Therefore, the primary reason for using unsteady flow methods is to consider the time varying nature of the problem. Examples of previously mentioned rapidly changing flow are thunderstorm floods, hydroelectric peaking operations, and dam-break floods. The second application of unsteady flow analysis consideration, mentioned above, is streams with very flat slopes.

b. Predicting downstream stages. Another application of unsteady flow is in the prediction of downstream stages in river-reservoir systems with tributaries, or lock-and-dam operations where the downstream operations affect the upstream stage. Flow may not be changing rapidly with time, but the downstream changes cause a time varying downstream boundary condition that can affect the upstream stage. Steady flow assumes a unique stage-discharge boundary condition that is stable in time.

c. Further information. Chapter 5, "Unsteady Flow," in EM 1110-2-1416 provides a detailed review of model application including selection of method, data requirements, boundary conditions, calibration, and application.

8-4. Multidimensional Analysis

a. Two- and three-dimensional modeling. Multi-dimensional analysis includes both two- and three-dimensional modeling. In river applications, two-dimensional modeling is usually depth-averaged. That is, variables like velocity do not vary with depth, so an average value is computed. For deep reservoirs, the variation of parameters with depth is often important (see Chapter 12, EM 1110-2-1201). Two-dimensional models, for deep reservoirs, are usually laterally-averaged. Three-dimensional models are available; however, their applications have mostly been in estuaries where both the lateral and vertical variation are important.

b. Two-dimensional analysis. Two-dimensional, depth-averaged analysis is usually performed in limited portions of a study area at the design stage of a project. The typical river-reservoir application requires both the direction and magnitude of velocities. Potential model applications include areas upstream and downstream from reservoir outlets. Additionally, flow around islands, and other obstructions, may require two-dimensional modeling for more detailed design data.

c. Further information. Chapter 4 of EM 1110-2-1416 provides a review of model assumptions and typical applications.

8-5. Movable-Boundary Profile Analysis

a. Reservoirs. Reservoirs disrupt the flow of sediment when they store or slow down water. At the upper limit of the reservoir, the velocity of inflowing water decreases and the ability to transport sediment decreases and deposition occurs. Chapter 9 herein presents reservoir sediment analysis. Reservoir releases may be sediment deficient, which can lead to channel degradation downstream from the project because the sediment is removed from the channel.

b. River and reservoir sedimentation. EM 1110-2-4000 is the primary Corps reference on reservoir sedimentation. Chapter 3 covers sediment yield and includes methods based on measurement and mathematical models. Chapter 4 covers river sedimentation, and Chapter 5 presents reservoir sedimentation. Section III, of Chapter 5, provides an overview of points of caution, sedimentation problems associated with reservoirs, and the impact of reservoirs on the stream system. Section IV provides information on levels of studies and study methods.

b. Further information. Chapter 7 of EM 1110-2-1416 presents water surface profile computation with movable boundaries. The theory, data requirements and sources, plus model development and application are all covered. The primary math models, HEC-6 *Scour and Deposition in Rivers and Reservoirs* (HEC 1993) and *Open-Channel Flow and Sedimentation* TABS-2 (Thomas and McAnally 1985) two-dimensional modeling package, are also described. The focus for the material is riverine.