APPENDIX D
ORDER OF MAGNITUDE ESTIMATES

D-1. Purpose. The purpose of an order of magnitude estimate is to provide quick and general insight into water quality characteristics, phenomena, or processes occurring within the reservoir. Table 2-2 summarizes the algorithms used in order of magnitude analyses. These should be used only as "first cut" or preliminary computations to more detailed analyses.

D-2. Morphometric and Hydrologic Characteristics.

a. Collated Characteristics. Collated characteristics are the intrinsic physical properties of the reservoir that are used in order of magnitude computations. These parameters are usually reported in Design Memoranda and include shoreline length (L_s), surface area (A), volume (V), reservoir length (L), maximum depth (Z_m), outlet elevation (Z), normal pool elevation (Z_n), spillway elevation (Z_s), and watershed drainage area (DA). These properties must be known before any calculated characteristics are determined.

b. Calculated Characteristics. One or more of the collated characteristics is often used in an expression to define other water quality characteristics. These include:

(1) Mean depth, the volume (V) divided by the surface area (A) (both at normal pool unless specified otherwise). In general, mean depth is inversely related to productivity. Reservoirs with large mean depths generally are less productive than reservoirs with small mean depths.

$$Z = V/A$$

(2) Development of volume, mean depth (Z) divided by maximum depth (Z_m). A value of 0.33 represents a perfect conical depression.

$$Z/Z_m$$

(3) Mean breadth, the average width of the reservoir determined by dividing the surface area (A) by the maximum length of the reservoir (L) (see Ref. 110, Appendix A). Large mean breadth ratios indicate the potential for large fetches and waves.

$$\bar{b} = A/L$$

(4) Drainage area to surface area ratio, which is usually large for reservoirs with the potential for high sediment and nutrient loads, shorter residence times, and greater areal water loads.

$$DA/SA$$

(5) Shoreline development ratio, the ratio of the shoreline length (L_s) to the circumference of a circle of area equal to the surface area (A) of the reservoir (Ref. 110). Large ratios indicate very irregular or dendritic systems. Dendritic systems usually have numerous coves and embayments, or extensive littoral areas and, therefore, the potential for greater biological activity.

$$D_L = L_s/(2\sqrt{\pi A})$$

(6) Mean hypolimnion depth, product of mean depth (Z) and percentage of the total depth below the thermocline (Ref. 107). This can provide an estimate of the volume of oxygen available to satisfy oxygen demand. Shallow hypolimnetic depths can indicate the potential for anoxia.

$$Z_H = Z(1 - Z_T/Z_m)$$

(7) Relative depth, ratio of the maximum depth (Z_m) as a percentage of a "diameter" of the reservoir (derived from its surface area, A) (Ref. 110). In general, the smaller the relative depth, the greater the influence of wind in disrupting thermal stratification.

$$Z_r = 50\ Z_m\sqrt{\pi/A}$$

(8) Hydraulic residence time, ratio of reservoir volume (V) to outflow rate. A short residence time is indicative of a high flushing rate in the pool.

$$\tau = V/Q$$

(9) Flushing rate, inverse of the hydraulic residence time (τ). If $\alpha < 10$, the reservoir may stratify; if $\alpha < 20$, the reservoir may be well mixed. Values around 10 can indicate a weakly stratified system (Ref. 32).

$$\alpha = 1/\tau$$

(10) Single storm flushing rate, the average inflow rate for a given storm event (Q_s) divided by the reservoir volume (V) (Ref. 32). If $\beta < 0.5$, the storm inflow may not mix the reservoir. If $\beta < 1$, the storm inflow may mix the reservoir.

$$\beta = Q_s/V$$

(11) Densimetric Froude number, the ratio of inertial to buoyancy forces in a stratified system. The system is classified as strongly stratified if $F_d << 1/\pi$. When $F_d >> 1/\pi$ the system is well mixed. The system is weakly

or intermittently stratified when F_d is approximately equal to $1/\pi$ (Ref. 32).

$$F_d = 320 * \frac{LQ}{ZV}$$

(12) Plunge point depth, the point at which denser inflowing river water plunges beneath the surface water of the pool and becomes a density current (Ref. 67). The critical densimetric Froude number, F_p, typically varies between 0.1 and 0.7. The normalized density difference, $\Delta\rho/\rho$, is the density difference between the inflow and the surface water divided by the density of the surface water.

$$D = \left(\frac{1}{F_\rho}\right)^{1/3} \left[Q^2 / \left(W^2 \cdot g \cdot \frac{\Delta\rho}{\rho}\right)\right]^{1/3}$$

D-3. Physical Relationships. Various physical relationships can be approximated by simple algorithms and are presented herein. Table 2-2 summarizes these relationships.

a. Water Density. This can be expressed in terms of contributions from temperature, total dissolved solids (TDS), and suspended solids (SS).

$$\rho_W = \rho_T + \Delta\rho_{TDS} + \Delta\rho_{SS}$$

$$\rho_T = 1{,}000 - \frac{(T - 3.98)^2 \; (T + 283)}{(503.57)(T + 67.26)}$$

$$\Delta\rho_{TDS} \sim 0.00078 * C_{TDS}$$

$$\Delta\rho_{SS} \sim 0.00062 * C_{SS}$$

b. Viscosity. This describes the inertial "friction" of a fluid. A fluid with a high viscosity offers high resistance to shear stress. The viscosity of a fluid can be estimated given the temperature and density of the fluid. Since viscosity decreases with increasing temperature, particulate matter (i.e., algae, SS) will settle faster at higher temperatures.

$$\nu = \rho(0.069\ T^2 - 5.3T + 177.6)$$

c. Settling Velocity. This defines the velocity of a particle of diameter D and density ρs settling in a fluid of density ρ and viscosity (Ref. 106).

$$v_s = \frac{gD^2}{18\nu} (\rho s - \rho)$$

d. Sedimentation Index. This is the ratio of the hydraulic residence time τ to the theoretical mean velocity through the reservoir $Q/(V/L)$ (Ref. 75). The sedimentation index indicates the sediment retention in the reservoir (i.e., trap efficiency).

$$S_I = \tau/(QL/V)$$

e. Areal Erosion. This is the percentage of lake bed area subject to the processes of erosion and transportation (Ref. 72). It may be estimated knowing only the surface area and mean depth of the reservoir.

$$a_{E+T} = 1{,}090 \sqrt{A}/Z * \exp (Z/\sqrt{A})$$

D-4. Chemical Relationships. Several chemical relationships also can be approximated by simple algorithms. These relationships are also summarized in Table 2-2.

a. Dissolved Oxygen Saturation Concentration. This can be approximated given the water temperature (T,°C), and elevation sea level (h, km) (Ref. 90). Since oxygen concentration regulates many aquatic processes, including the life of many organisms, the relation of the actual DO concentration to potential saturated concentrations can indicate if significant oxygen demand is occurring.

$$DO_{sat} = \exp (7.7117 - 1.31403 * \ln (T + 45.93) + 5.25 * \ln (1-h/44.3))$$

b. Oxygen Supply. This is the effective number of days of oxygen supply present in the hypolimnion at the onset of stratification (Ref. 107). It is defined as the ratio of the product of the oxygen supply at the onset of stratification (DO_i, g/m^3) and mean hypolimnion depth (Z_H, m) to the rate of change of the hypolimnetic oxygen deficit (ΔHOD, $g/m^2 \cdot$ day). If the stratified period is longer than the days of oxygen supply, anoxic conditions can occur.

$$T_{DO} = DO_i * Z_H/\Delta HOD$$

c. Un-ionized Ammonia. The potentially toxic fraction of total ammonia in solution can be estimated given effluent and upstream flow rates (Q_e and Q_u, respectively) and total ammonia concentrations ($NH_4 + NH_3^o$ expressed as nitrogen) (C_e^T and C_u^T, respectively) and downstream temperature and pH (T_d and pH_d , respectively) (Ref. 112). This value can be compared with the water quality criterion or standard for un-ionized ammonia.

$$NH_3^{UI} = [(1 + 1/\ln (0.09019 + 2{,}729.92/T_d - pH_d)]$$

$$* (C_e^T Q_e + C_u^T Q_u)/(Q_e + Q_u)$$

d. Nitrogen Supersaturation Potential. Several methods for determining the potential for gas supersaturation at dams with deep stilling basins are discussed in detail in ETL 1110-2-239.

e. Total Dissolved Solids. This may be roughly estimated from specific conductance concentrations. TDS concentrations can influence inflow patterns.

$$TDS - 0.6 * \text{Specific Conductance}$$

f. Soluble Reactive Phosphorus (SRP). This may be estimated as approximately 40 to 50 percent of total phosphorus concentrations (TP) (Ref. 34). SRP is generally considered as biologically available and may indicate the potential for algal blooms.

$$SRP \sim (0.4 \text{ to } 0.5) * TP$$