APPENDIX G

PROCEDURES AND EXAMPLE CALCULATIONS FOR DESIGN OF A CHEMICAL CLARIFICATION SYSTEM

G-1. Design Procedures.

a. Polymer Feed System.

(1) This design assumes that a low- to medium-viscosity liquid polymer is being used to minimize handling, pumping, and dilution problems. In most cases, the simplest system (shown in Figure G-l) is adequate. Polymer manufacturers should be able to inform the designer if this system is adequate. The experiments on polymer feed concentrations and aging should also indicate its adequacy. If the viscosity of the polymer is high or if low polymer feed concentrations are needed, systems like those shown in Figures G-2 and G-3 should be used. If the polymer requires aging prior to being fed, the two-tank system should be used. These systems are suitable for all but the smallest projects. Polymers requiring predilution should be avoided in systems like those in Figures G-2 and G-3 because they increase the equipment and operating labor requirements.

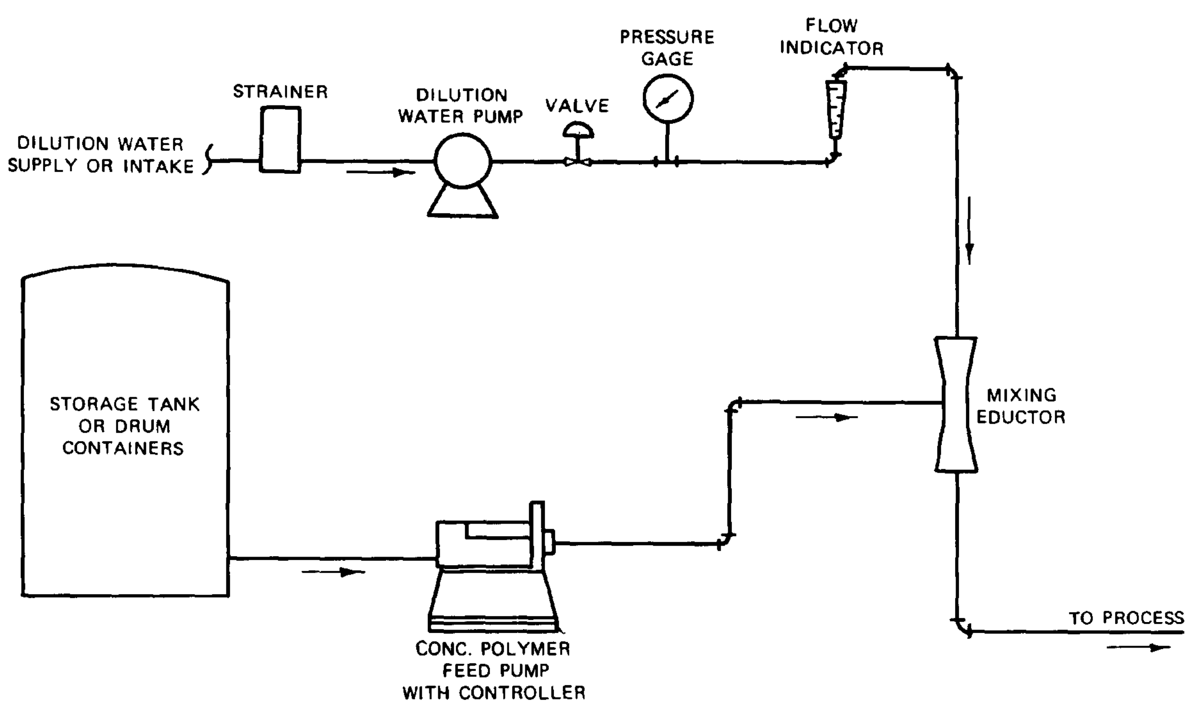

Figure G-1. Schematic of a simple liquid polymer feed system

(2) The polymer can be stored at the site in the delivery containers, either 55-gallon drums or bulk shipping tanks. The polymer can be fed directly from these containers or transferred to a polymer feed tank.

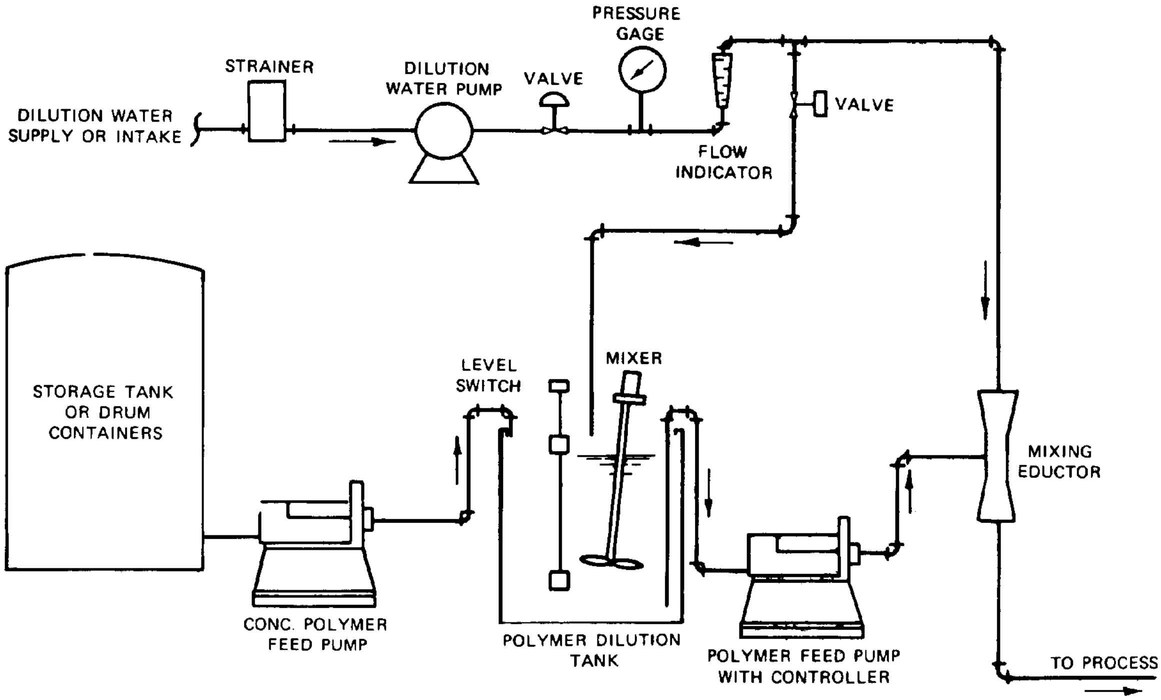

Figure G-2. Schematic of single-tank liquid polymer feed system

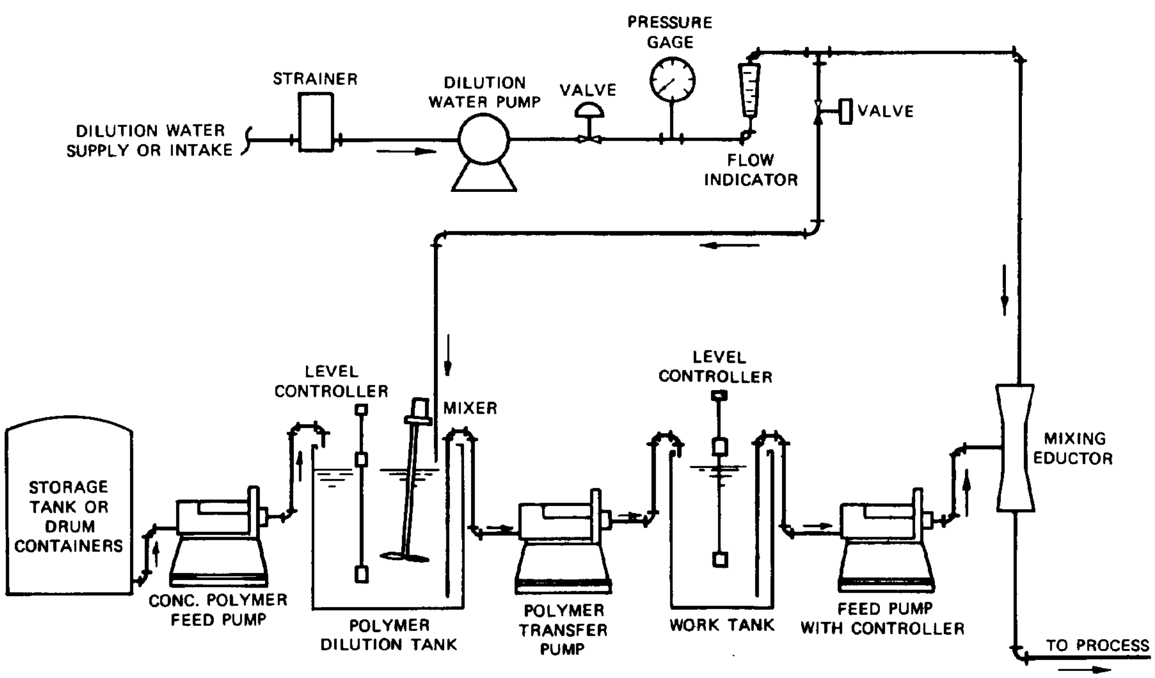

Figure G-3. Schematic of a two-tank liquid polymer feed system

Provisions should be made to guard against freezing. The feed tank may need to be heated or stored in a heated shelter to lower the viscosity and facilitate pumping on cold days. The size of the feed tanks and storage facilities is project dependent.

(3) The volume of polymer required for the project is calculated as follows:

$$\text{Total Volume of Inflow, } \ell = (\text{Volume to Be Dredged, yd}^3) \times (\text{In Situ Sediment Conc., g}/\ell) \times 764.4\ \ell/\text{yd}^3 \div (\text{Dredged Material Slurry Conc., g}/\ell) \quad \text{(G-1)}$$

$$\text{Total Volume of Settled Material, } \ell = (\text{Total Volume of Inflow, } \ell) \times (\text{Influent Slurry Conc., g}/\ell) \div (\text{Conc. of Settled Material, g}/\ell) \quad \text{(G-2)}$$

If the concentration of settled material is unknown, it is generally conservative to let

$$\text{Total Volume of Settled Material, } \ell = 2 \times (\text{Volume to Be Dredged, yd}^3) \times 764.4\ \ell/\text{yd}^3 \quad \text{(G-3)}$$

Then,

$$\text{Total Volume to Be Treated, } \ell = (\text{Total Volume of Inflow, } \ell) - (\text{Total Volume of Settled Material, } \ell) \quad \text{(G-4)}$$

$$\text{Total Volume of Polymer Required, gal} = (\text{Required Dosage, mg}/\ell) \times (\text{Total Volume to Be Treated, } \ell) \div (\text{Specific Weight of Polymer, kg/R}) \div 10^6\ \text{mg/kg} \div 3.785\ \ell/\text{gal} \quad \text{(G-5)}$$

$$\text{Total Poundage of Polymer, lb} = (\text{Total Volume of Polymer, gal}) \times 3.785\ \ell/\text{gal} \times (\text{Specific Weight of Polymer, kg/R}) \times 2.205\ \text{lb/kg} \quad \text{(G-6)}$$

(4) Concentrated polymer solutions should be fed using a positive displacement pump. The pump speed should be regulated by either a manual or automatic controller. The pump should be capable of discharging a wide range of flows to handle the possible range of required polymer dosages and flow rates of water to be treated. The pump capacity should be at least twice the maximum anticipated polymer feed rate or four times the average feed rate. The minimum pumping rate must be less than 10 percent of the average anticipated polymer feed rate to handle low flow conditions. The average polymer feed rate is

$$\text{Avg. Feed Rate, ml/sec} = (\text{Avg. Flow Rate, cfs}) \times (\text{Avg. Required Dosage, mg}/\ell) \times 28.31\ \ell/\text{ft}^3 \div (\text{Specific Weight of Polymer, g/ml}) \div 1{,}000\ \text{mg/g} \quad \text{(4-30)}$$

The polymer pump flow capabilities should range from about

$$\text{Pump Range, ml/set} = (0.1 \text{ to } 4) \times (\text{Avg. Feed Rate, ml/sec}) \quad \text{(G-7)}$$

Two polymer pumps operated in parallel may be required to provide the desired range of feed rates.

(5) If the polymer requires a tank for predilution, as in Figures G-2 and G-3, the polymer should be diluted by a factor of 10 or 20 in the tank. The polymer feed rate would then increase by this same factor.

(6) The polymer feed tanks and dilution tanks should be large enough to feed polymer for 1 to 2 days under average conditions. The average daily concentrated polymer feed volume is

$$\text{Daily Volume, gal/day} = (\text{Avg. Feed Rate, ml/set}) \times 86{,}400 \text{ set/day} \div 3{,}785 \text{ ml/gal} \quad \text{(G-8)}$$

(7) The polymer must be diluted to aid feeding and dispersion. The amount of dilution required can be determined from the manufacturer or experimentally. As a practical limitation, the dilution factor should not exceed 200 under average conditions due to excessive requirements for water at higher dilutions.

(8) Supernatant from the containment area, preferably treated supernatant from the secondary cell, can be used for dilution water. However, if the polymer is to be prediluted in a tank, water of good quality should be used to minimize deposition of material in the tank and to maintain the effectiveness of the polymer. The dilution water can be collected from a screened intake suspended near the surface at a place free of debris, resuspended material, and settled material.

(9) The dilution water may be pumped by any water pump. The pump capacity should be about 200 times the average polymer feed rate of concentrated polymer. A controller is not needed to regulate the dilution water flow rate since maximizing the dilution aids in dispersion. The polymer and dilution water may be mixed in-line using a mixing eductor.

(10) Any injection system can be used so long as it distributes the polymer uniformly throughout the water to be treated. It may consist of a single nozzle or a perforated diffuser pipe running along the weir crest. The system should be as maintenance-free as possible. Fine spray nozzles should be avoided because suspended material from the dilution water may clog them.

(11) The feed lines may be constructed of rubber hoses or PVC pipe. They must be designed to carry the design flows of the viscous polymer solution at low temperature. Provisions must be made to prevent freezing, particularly when the system is not operating.

b. Mixing System. The weir box and discharge culvert(s) should, if possible, be designed to provide adequate mixing. A 2-foot drop between the water surface of the first basin and the second basin is sufficient energy for mixing if efficiently used. Mechanical mixers should be considered if sufficient energy is unavailable. The design of mechanical mixing systems has been presented in item 22 and will not be duplicated here.

(1) Weir. The weir should be designed to collect supernatant from the primary containment area and to disperse the polymer thoroughly. The weir box does not provide efficient mixing, and, therefore, it is undesirable to lose all the energy of the water by a free fall into the weir box. The system should provide a small drop into the weir box and high head loss through the discharge culvert(s) between the primary and secondary containment areas.

(a) The weir box should be designed to prevent leakage; the bottom of the box should be sealed. Only one section of the box needs to be adjustable to the bottom of the box; this would minimize leakage. Weir boards with tongue and groove joints would also decrease leakage. The weir box should be submergible without the weir boards floating from their positions, All sections of the weir should be level and at the same elevation. An example is shown in Figure G-4.

(b) The height of the weir crest should be adjustable to stop the flow when the flow is too low to treat or to maintain the flow in order to keep treating when the dredge has stopped. The depth of flow over the weir must be controlled by increments of 1 to 2 inches to maintain a fairly constant flow rate. The weir must also be able to stop the flow when the treatment system is down for maintenance or repair. The simplest mode of operation would be to stop the flow over the weir by adding weir boards when the flow rate is low, and then to remove the added weir boards and resume operation after the elevation of the water surface returns to its height at average flow.

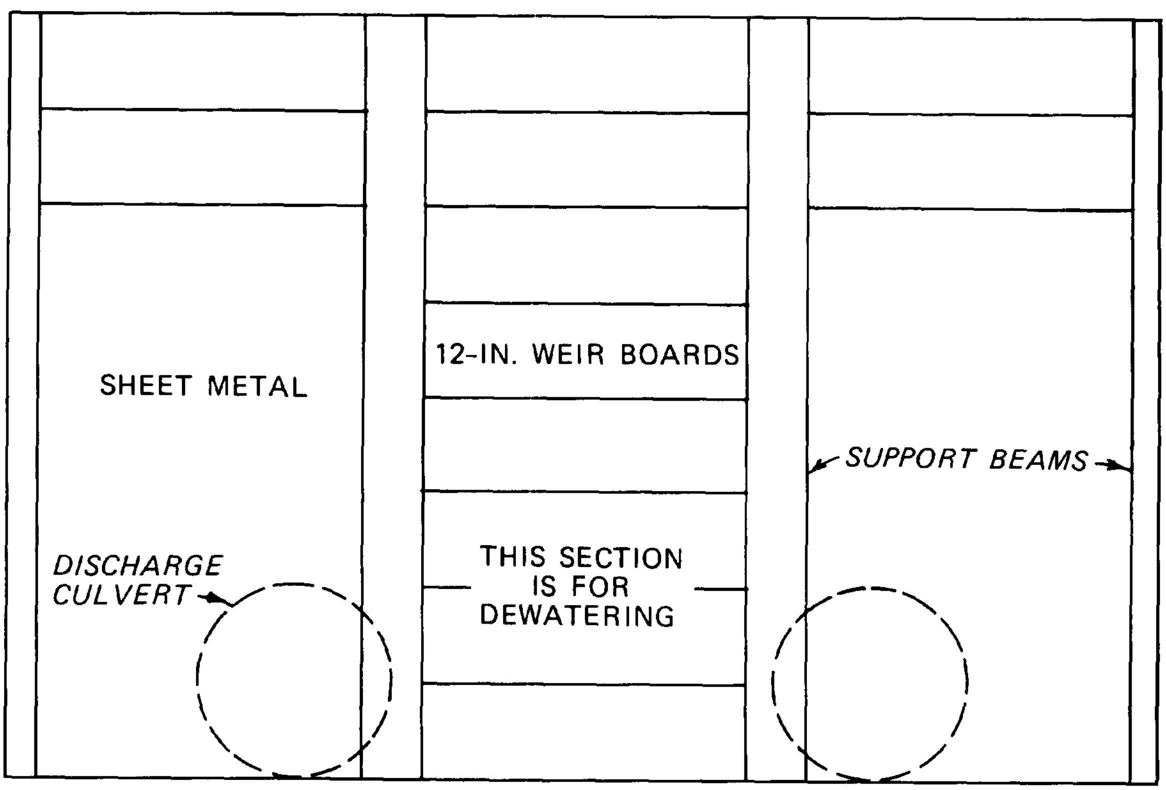

Figure G-4. Frontal view of a weir

(2) Discharge culvert. The discharge culvert(s) must be designed to provide the required mixing and to discharge the design flow rate safely. The design procedure presented here determines the length, diameter, and number of culverts that maximize mixing within the constraints of most projects. Frictional head loss provides the mixing and increases with increasing culvert length and decreasing diameter. Multiple culverts increase the duration of mixing but decrease the intensity of the mixing. Static mixers may be used in-line to increase the head loss of a culvert without increasing its length or decreasing its diameter. The use and design of static mixers will not be discussed herein, but information on their use is available from their manufacturers.

(a) The design approach is to size the culvert(s) for the maximum flow rate and the minimum available head and then to calculate the available mixing under average flow conditions. The maximum flow rate is assumed to be the average dredge flow rate with continuous, 24-hours-per-day production. The designer should also consider other possible sources of inflow. The average flow at the weir is assumed to be the product of average dredge flow rate and fractional production time ratio (generally about 0.75 or 18 hours-per-day). In this manner, the culvert(s) will be able to safely discharge the design flow. It is important to estimate the flow rates fairly accurately in order to properly size the culvert(s). Undersizing can result in overtopping the dikes or in forcing the dredge to operate intermittently. Oversizing can result in inadequate mixing. The amount of mixing can be compared with the mixing requirements determined experimentally to evaluate the design. If inadequate, the designer may wish to change the containment area design to provide a greater head for mixing. The required head can be determined using the design equations.

(b) The design procedure is as follows (see Figure G-5 for an example weir mixing system). Assume that the maximum flow rate is the average dredge flow rate with continuous production, 24 hours per day. Assume a 0.5-foot drop into the weir box under maximum flow. Determine the difference in elevation Δh , in feet, between the water surface of the basins at their highest operating levels from the design. Let H, in feet, $= \Delta h - 0.5$ where H is the maximum permissible head loss through the culvert at maximum flow. Assuming a submerged inlet and outlet and a corrugated metal culvert (though less head loss and better mixing for low flows would be realized if the outlet were not submerged), then

$$H = \left[1.5 + \frac{Lf}{D}\right] \frac{v^2}{2g} \qquad \text{(G-9)}$$

where

f = friction factor
D = culvert diameter, feet

Select the range of culvert lengths from containment area layouts. Let

Q = maximum flow rate, cubic feet per second
N_c = number of parallel culverts

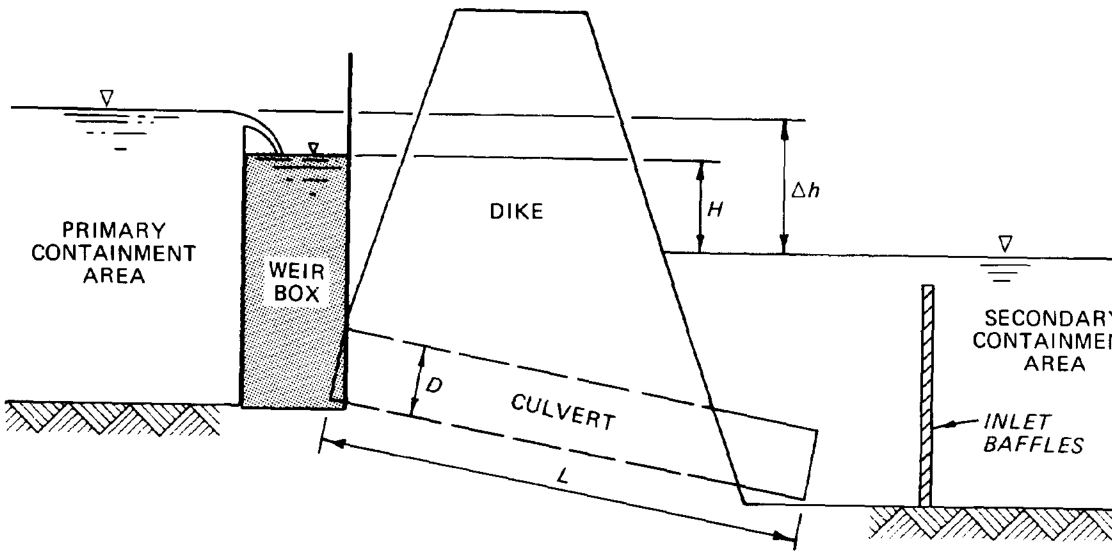

Figure G-5. Example weir mixing system

Then

$$H = \left[1.5 + \frac{185(0.025)^2 L}{D^{4/3}}\right] \frac{8Q^2}{g\pi^2 N_c^2 D^4} \qquad \text{(G-10)}$$

Rearranging the above equation gives

$$D = \left[\frac{8Q^2 \; 1.5D^{4/3} + 185(0.025)^2 L}{g\pi^2 H N^2}\right]^{3/16} \qquad \text{(G-11)}$$

This equation converges to the minimum diameter in three or four iterations by using 2 feet for the initial D and then substituting the calculated D for the next iteration. Solve the above equation using the minimum and maximum culvert length based on the containment area layout for up to five culverts. For each number of culverts, choose the largest commercially available diameter between the calculated diameters for the minimum and maximum culvert lengths. If there are not any commercial sizes between these diameters, select the next larger commercial size and the maximum length. Calculate the culvert length for the selected commercial sizes.

$$L = \left[\frac{g\pi^2 H N^2 D^4}{8Q^2} - 1.5\right] \left[\frac{D^{4/3}}{185(0.025)^2}\right] \qquad \text{(G-12)}$$

Calculate $\bar{v}$ and f for the selected sizes at average flow.

$$\bar{v} = 4\ \bar{Q}/\pi D^2 \qquad \text{(G-13)}$$

$$f = \frac{185\ (0.025)^2}{D^{1/3}}$$

where

$\bar{v}$ = mean velocity at average flow, feet per second
$\bar{Q}$ = average flow rate, cubic feet per second
f = friction factor

Calculate the mixing Gt of each design at average flow.

$$Gt = \sqrt{\frac{\gamma_s f \bar{v} L^2}{2g\mu_s D}} \qquad \text{(G-14)}$$

where

Gt = mixing effort

γ_s = specific weight, 62.4 pounds per cubic foot

μ_s = absolute viscosity, 2.36 x 10^{-5} pounds per second per square foot at 60" F

Calculate the head loss at average flow and the maximum carrying capacity of the culvert at a head of Δh to determine the limits of the design. Select the best overall design based on mixing, cost, operating flexibility, etc.

c. Secondary Containment Area.

(1) Design approach. The secondary area must be designed to provide adequate residence time for good settling and sufficient volume for storage of settled material. The total volume of the cell is the sum of the ponded volume and storage volume. The required ponded volume is a function of the hydraulic efficiency of the cell and the flow rate. The storage volume depends on the solids concentration entering the basin, the depth of the cell, the total volume to be treated, the flow rate, and the mud pumping schedule.

(2) Ponded volume. Effective settling requires a ponded depth of 2 to 3 feet and a minimum of 20 minutes of detention. Due to short-circuiting, the mean residence time should be at least 60 minutes and the theoretical residence time of the ponded volume should be at least 150 minutes. The shape of the cell should have a length-to-width ratio of at least 3:1 to reduce short-circuiting.

(3) Storage volume. The settling properties of flocculated dredged material resulting from chemical clarifications have not been well defined. Solids concentration or density profiles have been measured at only one field site. The settled material was very fluid and, as such, did not clog the inlet culvert, even though settled material accumulated near the inlet to a depth I foot higher than the top of the culvert. The kinetic energy of the inflow was capable of keeping the inlet clear of material. Resuspended material settled rapidly in the basin. The concentration of settled material at

the interface between the supernatant and settled layer was 50 grams per litre, and the concentration increased with increasing depth at a rate of 25 grams per litre per foot. Therefore, deeper basins stored more material in a given volume due to compaction. The concentration of the material increased rapidly upon dewatering.

(4) Storage requirements estimation. Knowing the average available depth of the secondary basin, the total storage requirements can be estimated as follows:

(a) The total mass of material to be stored M or pumped from the secondary area, M , is

$$M, g = (\text{Primary effluent conc.} - \text{Secondary effluent conc., } g/\ell) \times (\text{Volume to be treated, } \ell) \qquad \text{(G-15)}$$

(b) The average concentration of settled material C_S is

$$C_s, g/\ell = [2 \times 50\ g/\ell + 25\ g/\ell\text{-ft} \times (\text{Average depth of storage, ft})] \div 2 \qquad \text{(G-16)}$$

(c) Total volume of settled treated material V_s is

$$V_s, \ell = (M, g) \div (C_s, g/\ell)$$

$$V_s, ft^3 = (V_s, \ell) \div 28.32\ \ell/ft^3 \qquad \text{(G-17)}$$

(d) The maximum area required A_s is

$$A_s, \text{acre} = (V_s, ft^3) \div (\text{Average depth of storage, ft}) \div 43{,}560\ ft^2/\text{acre} \qquad \text{(4-42)} \qquad \text{(G-17b)}$$

(5) Ponded area. The required volume V_p and area for ponding A_p is

$$V_P = (\text{Average flow rate, cfs}) \times 9{,}000\ \text{sec} \qquad \text{(G-18)}$$

$$A_p = V_p \div (\text{Average depth of ponding, ft}) \qquad \text{(G-19)}$$

(6) Design area. The containment area should be designed to have a total depth of the sum of the ponded depth and the depth of storage. The area of the cell should be the larger of the areas required for ponding and for storage. If the area required for storage is greater than the area required for ponding, the depth of ponding can be reduced to a minimum depth of 2 to 3 feet, thereby increasing the available depth of storage. If the area for storage is still greater, the only way to reduce the area requirements further would be to decrease the required storage volume by transferring settled treated material from the basin to the primary containment area. In the overall basin design, it is important to use the greatest practical depth and to optimize its use to provide good mixing through the discharge culvert, ponding for good settling, and storage for treated material. To minimize the size of the secondary area and to maximize the energy available for mixing, the secondary area should be used only for temporary storage, except for small one-time projects. Therefore, the settled treated material should be regularly removed from the basin. This approach would also facilitate dewatering and recurring use of the area for chemical treatment.

(7) Mud pumping. If the settled material is to be pumped, the required pumping rate would be

$$\text{Mass Pumping Rate, g/day} = (\text{Influent conc., g}/\ell - \text{Effluent conc., g}/\ell) \times (\text{Average flow rate, cfs}) \times 28.31\ \ell/\text{ft}^3 \times (\text{Seconds of production per day}) \quad \text{(G-20)}$$

$$\text{Volumetric Pumping Rate, ft}^3\text{/day} = (\text{Mass Pumping Rate, g/day}) \div [20 \times 50\ \text{g}/\ell + 25\ \text{g}/\ell\text{-ft} \times (\text{Average depth of storage, ft})] \times 2 \quad \text{(G-21)}$$

(8) Inlet baffles. The inlet hydraulics of the secondary area can have a significant effect on settling performance. Inlet baffles as shown in Figure 4-18 can reduce the effects of short-circuiting and turbulent flow and assist in distributing the flow laterally. The baffles should be placed about one culvert diameter directly in front of the inlet. The baffle should be at least two diameters wide and may be either slotted or solid. Slotted baffles are better and may be made of 4- by 4-inch wooden posts spaced several inches apart. The main purpose of the inlet baffles is to dissipate the kinetic energy of the incoming water and reduce the velocity of the flow toward the weir.

(9) Effect on dewatering. Design of the secondary area must consider dewatering of the primary area. If the primary area is to be dewatered using the primary weir box to drain the water, the elevation of the surface of the water or stored material in the secondary area must be lower than the final elevation of the stored material to be attained during dewatering. The elevation difference should be at least 2 feet if the drainage is to be treated. The point is demonstrated in Figure G-6.

(10) Alternatives. There are several alternatives that can be used to provide for dewatering:

(a) The secondary area can be constructed at a lower elevation.

(b) The settled, treated material stored in the secondary area can be dewatered and thereby consolidated first.

(c) The material can be pumped out of the secondary area.

(d) The water can be pumped out of the primary area.

(e) A special drainage structure can be constructed to drain the primary cell.

(f) A channel can be cut through the settled material in the secondary area to permit drainage through the basin. The best approach depends on site- and project-specific considerations. The effect of treatment on dewatering of the primary area is just one example showing that the designer should consider the entire disposal operation when designing the treatment system. Treatment should not be added to a disposal operation as an afterthought.

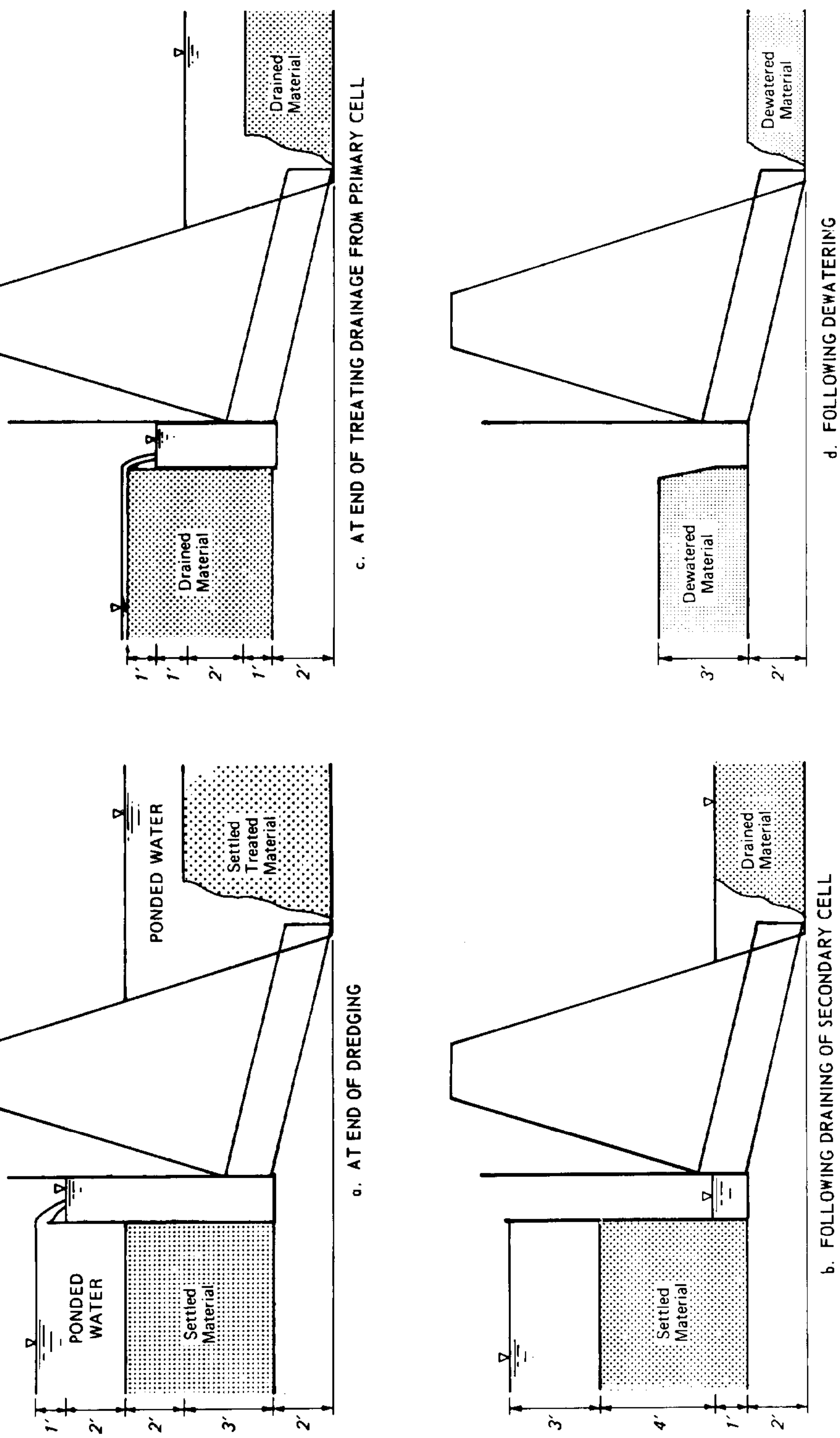

Figure G-6. Example elevations in containment areas during dewatering sequence

d. General Design Considerations.

(1) Shelter. A building should be provided to house the equipment and to furnish shelter for the operators. An 8- by 12-foot portable building is sufficient unless the polymer storage tank and dilution tanks must be housed.

(2) Equipment. The equipment should be simple, rugged, heavy-duty, continuous-duty, and low-maintenance. Backup equipment must be provided for all essential components.

(3) Safety. Good lighting must be provided for the entire work area. The weir must be furnished with a walkway and railings. Provisions should be made for safe, simple adjustments of the weir boarding.

e. Operating Guidelines. Prior to the start of the project, an operator's manual and treatment log book should be prepared to minimize problems during the operation of the treatment system. The operator's manual should contain the maintenance schedule, procedures for operating each piece of equipment and the weir, and the procedures for adjusting the polymer dosage. The treatment log book should be used to keep a complete record of the treatment operation. The record should include hours of operation, flow rate, polymer dosage, influent and effluent turbidity, basin depths, depth of settled treated material, maintenance actions, problems, and significant observations.

(1) Maintenance schedule. The maintenance schedule and operating procedures for the equipment are dependent on the equipment selection and should be developed specifically for the selected pieces. To set the polymer dosage, it is first necessary to calibrate the polymer pump. The polymer flow rate should be measured for the range of controller settings. Next, based on the laboratory results, a table should be prepared that gives the required dosage as a function of influent turbidity. Then, a table of controller settings should be prepared for a variety of dosages and flow rates. At low flow rates, there is less mixing, and the polymer is less effective. Therefore, higher dosages are often required at low flow. If a relationship between mixing and required dosage was developed in the laboratory, the relationship should be converted to relate flow rate and dosage so the operator can readily adjust the dosage. The required dosages must be verified during the start of operation, and the values in the tables must be adjusted accordingly. After verification, the operator would only have to measure the influent turbidity and flow rate to determine the controller setting for the polymer pump.

(2) Field dosage verification. During verification of the required dosages, the effectiveness of a particular dosage can be evaluated immediately by grabbing a sample of treated suspension from the end of the discharge culvert connecting the two containment areas and running a column settling test on the sample. If the supernatant is clear after 10 minutes of settling, the dosage should be decreased until the supernatant is slightly cloudy. Better clarification will be achieved in the settling basin, where the material can flocculate. This is especially true when the system has been operating continuously for a long period. After selecting a dosage, the effluent turbidity should be monitored to determine whether the dosage should be adjusted further. The dosage should be minimized to reduce chemical costs, but the

effluent quality should not be allowed to deteriorate beyond the effluent requirements.

(3) Flow measurement.

(a) The flow rate can be estimated by measuring the weir length and the depth of water flowing over the weir crest, as described in Chapter 4.

(b) A table relating the depth of flow over the weir h and the flow rate Q should be generated and included in the operator's manual. The weir length should be measured, not taken from design drawings, to ensure accuracy. With this table, the operator would easily be able to estimate the flow rate by measuring the depth of flow without performing any difficult computations or requiring additional information. The operator should measure the depths at several locations along the weir crest and average the resulting flow rates to determine the overall flow rate. This method would minimize the estimating errors caused by an unlevel or uneven weir crest.

(c) The weir crest may become submerged at flow greater than 20 percent above the average. The actual flow rate that submerges the weir is dependent on the weir length and culvert design. The flow rate over submerged weirs is controlled by the discharge capacity of the culvert.

(4) Weir operation.

(a) The weir must be properly operated to maintain good mixing conditions. The weir crest must be kept sufficiently high to maintain the required difference in elevation between the water surfaces of the two containment areas. The weir should also be used to maintain the required flow rate for good mixing. When the flow decreases below the minimum rate for good mixing, the operator should either lower the weir crest by 1 or 2 inches to increase the flow to its average rate, or raise the weir crest sufficiently to stop the flow.

(b) The minimum flow rate is based on the experimentally determined minimum acceptable mixing Gt for effective treatment. The minimum flow can be determined as follows:

$$Q_{min} = Q_{avg} \frac{Gt_{min}}{Gt_{avg}}^{2} \qquad \text{(G-22)}$$

An example computation is given below:

Given: Average flow = 25 cubic feet per second
Gt of average flow = 9,000
Minimum acceptable Gt = 6,000

The minimum allowable flow is

$$Q_{min} = 25 \text{ cubic feet per second } \frac{6,000}{9,000}^{2}$$

= 11.1 cubic feet per second

(c) In general, the weir crest should be operated at the highest practical elevation, and the primary containment area should be allowed to fill to this elevation before any water is discharged over the weir and treatment is started. This would maximize the depth and provide the best conditions for mixing, settling, and storage. Maintaining the maximum ponded depth in the primary area also minimizes the turbidity of the discharge to be treated and therefore reduces the required polymer dosage.

(5) Other considerations.

(a) General operation. During the project, the primary and secondary effluent turbidities and the flow rate should be measured at least six times per day, and the polymer flow rate should be adjusted as needed. Each piece of equipment should be inspected regularly, particularly the water intake, injection rig, and pumps. The fuel and chemical levels should also be checked as required. Regular maintenance must be performed throughout the project. The buildup of settled treated material should be followed, and the material should be pumped out of the basin as the storage volume is depleted.

(b) Leakage. The operator should try to eliminate leakage through the weir when the treatment system is turned off. The flow rate of the leakage is too low to treat, but after a couple of days of downtime, the leakage can completely exchange the contents of the secondary area if left unchecked. Since it is untreated, the effluent quality will deteriorate markedly.

(c) Dewatering. At the end of the project, the treatment system can be used to treat the drainage from the primary containment area during dewatering. The elevation of the interface of the settled material in the primary area must be greater than the elevation of the water surface of the secondary area. Therefore, the secondary area must be dewatered first to compact the settled treated material and to provide the depth required to treat the drainage at the lower weir height. It is possible that treated material may need to be pumped from the secondary area before the primary area can be dewatered through the weir.

G-2. Polymer Feed System Design Example. Given the following project information and laboratory results, the design would proceed as follows:

a. Project Information:

In situ sediment volume	200,000 cubic yards
In situ sediment conc.	900 grams per litre
Specific gravity of sediment	2.68
Dredged material slurry conc.	150 grams per litre
Dredge discharge pipe size	14 inches
Production time	100 hours per week
Avg. conc. of settled material	400 grams per litre
Mean daily temperature	50° F

Laboratory Results:

Selected polymer	low viscosity liquid
Specific weight of polymer	1.0 kilograms per litre
Required dosage at average flow and turbidity	10 milligrams per litre
Polymer feed concentration	20 grams per litre

b. Polymer Requirements:

$$\text{Volume of Inflow, } \ell = 200{,}000 \text{ yd}^3 \times 900 \text{ g}/\ell \times 764.4 \ \ell/\text{yd}^3 \div 150 \text{ g}/\ell = 9.17 \times 10^8 \ \ell \qquad \text{(G-23)}$$

$$\text{Volume of Settled Material, } \ell = 9.17 \times 10^8 \ \ell \times 150 \text{ g}/\ell \div 400 \text{ g}/\ell = 3.44 \times 10^8 \ \ell \qquad \text{(G-24)}$$

$$\text{Volume to be Treated, } \ell = 9.17 \times 10^8 \ \ell - 3.44 \times 10^8 \ \ell = 5.733 \times 10^8 \ \ell \qquad \text{(G-25)}$$

$$\text{Volume of Polymer Required, gal} = 10 \text{ mg}/\ell \times 5{,}733 \times 10^8 \ \ell \div 1.10 \text{ kg}/\ell \div 10^6 \text{ mg/kg} \div 3.785 \ \ell/\text{gal} = 1{,}380 \text{ gal} \qquad \text{(G-26)}$$

$$\text{Pounds of Polymer Required, lb} = 1{,}380 \text{ gal} \times 3.785 \ \ell/\text{gal} \times 1.10 \text{ kg}/\ell \times 2.205 \text{ lb/kg} = 12{,}640 \text{ lb} \qquad \text{(G-27)}$$

c. Storage. Since less than 2,000 gallons of polymer is required, drums should be used for storage instead of a bulk tank. The drums may be stored outside, since they are not expected to freeze during the project. However, barrel warmers should be used to aid in transferring the polymer to the feed tank due to the cool temperature. A hand pump or a small electric positive displacement pump should be used for the transfer from storage.

d. Polymer Pump. The feed system shown in Figure G-l should be used, since the selected polymer is a liquid of low viscosity requiring a 50-fold dilution. The average polymer flow rate is

$$\text{Avg. Dredge Flow Rate} = 15 \text{ fps} \times \pi/4 \times (14 \text{ in.} \div 12 \text{ in./ft})^2 = 16.04 \text{ cfs}$$

$$\text{Avg. Polymer Flow Rate} = 16.04 \text{ fps} \times 10 \text{ mg}/\ell \times 28.31 \ \ell/\text{ft}^3 \div 1.10 \text{ g/ml} \div 1{,}000 \text{ mg/g} = 4.13 \text{ ml/set} = 0.065 \text{ gpm or } 94.2 \text{ gpd}$$

The polymer pump capacity should be about four times the average rate or 0.25 gallon per minute. The pump should be able to pump as low a flow as 0.4 millilitre per second or 0.0065 gallon per minute.

e. Polymer feed tank. The polymer feed tank should be sized to hold a 2-day supply of polymer. The tank should be kept in a heated shelter with the pumping equipment.

Tank Volume = 94.2 gpd x 2 days
x (0.8, the production efficiency)
= 150 gal

f. Dilution Water Pump. To reduce the polymer feed concentration below 20 grams per litre, the dilution factor must be 55. At average polymer flow rate, the required dilution water flow rate would be 3.6 gallons per minute. The dilution water pump capacity should be twice this rate to dilute higher polymer flow adequately. Therefore, the dilution water flow rate should be

Dilution Water Pump Rate = [(1.1 x 1,000 g/ℓ) ÷ 20 g/ℓ]
x 2 x 0.0654 gpm = 7.20 gpm

The pump must deliver this flow rate and produce high pressure (60 pounds per square inch) to force the viscous polymer solution through the eductor, feed lines, and injector.

g. Feed Lines. The size of the feed lines should be determined by head loss analysis for pipe flow. This subject is discussed in any fluid mechanics textbook or hydraulics handbook. The pipe diameter is dependent on the viscosity, flow rate, length of line, minor losses, and losses through the eductor and injector. One-inch inside diameter (ID) rubber hose or PVC pipe should be used for this example. The head loss would be less than 30 pounds per square inch.

G-3. Example Culvert Design. Given an l&inch-diameter dredge pipeline, a minimum head difference of 3 feet between the primary and secondary cells, and a range of culvert lengths between 50 and 100 feet based on the containment area design, the culvert design would proceed as follows:

a.
$$Q_{max} = 15 \text{ fps} \times \pi(18 \text{ in.}/12 \text{ in./ft})^2 \div 4 = 26.5 \text{ cfs}$$

$$Q_{ave} = 26.5 \text{ cfs} \times (\text{Production ratio, } 0.75) = 19.9 \text{ cfs}$$

b.
$$\Delta h = 3 \text{ ft}$$
$$H = 3 \text{ ft} - 0.5 \text{ ft} = 2.5 \text{ ft}$$

c. Using equation G-11, the calculated minimum diameters for the following lengths and numbers of culverts are:

N	L, ft	D, ft	D, in.
1	50	2.23	26.8
1	100	2.44	29.3

2	50	1.67	20.0
2	100	1.85	22.2
3	50	1.42	17.0
3	100	1.57	18.8
4	50	1.26	15.1
4	100	1.41	16.9
5	50	1.15	13.8
5	100	1.29	15.5

d. Using Equation G-12, the selected commercial sizes and calculated lengths are:

N	D, in.	L, ft
1	27	54.1
2	21	69.3
3	18	73.3
4	18	100.0
5	15	83.0

e. Using Equation G-13, the friction factor and velocity at average flow are:

N	D, in.	$\bar{v}$, fps	ft
1	27	5.00	0.0882
2	21	4.14	0.0959
3	18	3.75	0.1010
4	18	2.82	0.1010
5	15	3.24	0.1073

f. Using Equation G-14, mixing at average flow:

N	D, in.	L, ft	G (sec^{-1})	t (sec)	Gt
1	27	54.1	449	10.8	4,855
2	21	69.3	400	16.7	6,690
3	18	73.3	382	19.5	7,470
4	18	100.0	249	35.5	8,830
5	15	83.0	346	25.6	8,870

g. Head loss at average flow:

$$H = 1.41 \text{ feet}$$

h. Flow through a completely submerged weir:

$$Q = 29.0 \text{ cubic feet per second}$$

1. Generally, a Gt of about 8,000 provides adequate mixing for chemical treatment. In this example, either three la-inch-diameter, 73-foot-long culverts; four 18-inch-diameter, 100-foot-long culverts; or five 15-inch-diameter, 83-foot-long culverts could be used. However, four la-inch-diameter culverts would be the best design, since it would provide considerably more mixing than three culverts and about the same mixing as five culverts. Also, this design would provide better mixing at lower flow rates.

G-4. Design Example. Given the following project information, the settling basin size would be determined as follows:

a. Project Information.

Primary effluent solids conc.	2 grams per litre
Secondary effluent solids conc.	50 milligrams per litre
Volume to be treated (as determined in the polymer feed system design)	5×10^8 litres
Depth of basin	6 feet
Average flow rate	16 cubic feet per second

b. Volume of Settled Treated Material. Assuming a ponded depth of 3 feet,

From Equation G-15, mass of settled material = (2 - 0.05) g/ℓ x 5 x 10^8 ℓ
= 9.75 x 10^8 g

From Equation G-16, avg. conc. of settled material
= [(2 x 50 g/ℓ) + (25 g/ℓ-ft x 3 ft)] ÷ 2
= 88 g/ℓ

From Equation G-17, volume of settled material
= 9.75 x 10^8 g ÷ 88 g/ℓ
= 1.11 x 10^7
= 3.91 x 10^5 ft^3 or 9.0 acre-ft

c. Required Area Based on Storage.

From Equation G-18,
Area = 9.0 acre-ft ÷ 3 ft
= 3.0 acres

d. Volume of Ponding.

From Equation G-19,
Ponded volume = 16 cfs x 9,000 sec
= 1.44 x 10^5 ft^3 or 3.3 acre-ft

e. Required Area Based on Ponding.

From Equation G-20,
Area = 3.3 acre-ft ÷ 3 ft
= 1.1 acres

f. Second Trial. The areas based on storage and ponding are quite different. Therefore, the ponded depth should be decreased to reduce the area required for storage.

Using a ponded depth of 2 feet and, therefore a storage depth of 4 feet,
From Equation G-15,
Avg. conc. of settled material
= [(2 x 50 g/ℓ) + (25 g/ℓ-ft x 4 ft)] ÷ 2 = 100 g/ℓ

From Equation G-17,
Volume of settled material = 9.75 × 10^8 g ÷ 100
= 9.75 × 10^6 ℓ
= 3.45 × 10^5 ft^3
= 7.9 acre-ft

From Equation G-17b
Area for storage = 7.9 acre-ft ÷ 4 ft
= 1.98 acres

From Equation G-18,
Ponded volume = 16 cfs x 9,000 sec
= 1.44×10^5 ft^3
= 3.3 acre-ft

From Equation G-19,
Area for ponding = 3.3 acre-ft ÷ 2 ft
= 1.65 acres

g. Final Design. The two areas in the second trial are similar, indicating a better design. Therefore, the secondary cell should have the following characteristics:

Volume	12 acre-ft or 5.2×10^5 ft^3
Area	2 acres
Depth	6 feet
Storage depth	4 feet
Ponded depth	2 feet

G-5. Mud Pumping.

a. The area and depth of the basin can be reduced further if the basin is not used for storage, that is, if the settled material is pumped out regularly. The size could be reduced to about an area of 1.0 acre and a depth of 5 feet. With a shallow storage depth, the solids concentration of the settled material would be about 60 grams per litre.

b. The mud pumping rate, assuming 16 hours of production per day would be:

From Equation G-20,
Solids Pumping Rate = (2.0 - 0.05) g/ℓ
x 28.31 ℓ/ft^3 x 16 cfs
x 16 hr/day x 3,600 sec/hr
= 5.09×10^7 g/day

From Equation G-21,
Volumetric Pumping Rate = 5.09×10^7 g/day ÷ 60 g/ℓ
= 8.5×10^5 ℓ/day
= 0.347 cfs or 156 gpm