

similar to those used with the vacuum assisted beds described in Section 6.4. The typical sludge depth for a single application ranges from 10 to 25 cm (4-10 in). The optimum for a particular system will be determined with operational experience. In some cases, as also described in Section 6.4, it may be possible to apply multiple sequential layers with decantation of the supernatant prior to starting the drainage phase.

There have been reports of damage to the plastic surfaces when front-end loaders have been improperly used to remove the sludge cake. The proper procedure requires driving straight in and backing straight out. Sharp, skidding turns can cause structural damage to the molded polyurethane surfaces.

It is important for the operator to carefully manage the initial controlled drainage rate to insure maximum water flow during this phase. If the rate is too slow the total cycle time will have to be increased, and if the rate is too high, complete drainage may not occur. The manufacturer's drainage recommendations can be used initially and then modified as necessary with operational experience.

6.5.5 Costs

Land is not usually a significant factor in the capital costs of wedgewire systems, unless additional land area is needed for further drying of the sludge cake. The other construction costs will depend on whether existing sand beds can be retrofitted instead of constructing entirely new basins. Construction costs in the latter case might range from \$1,000 to \$1,900/m² (\$93 to \$177/ft²). Operating costs may be slightly less than the vacuum assisted systems described in Section 6.4, but will still fall in the same range. The comparisons in Section 6.4.5 to sand beds should also be approximately applicable to wedgewire systems.

6.6 Sludge Lagoons

A distinction must be made between sludge drying lagoons and sludge lagoons primarily intended for storage. Some drying occurs in storage lagoons but the primary intent is to provide temporary or semi-permanent storage.

Drying lagoons are operated on a regular cycle to dewater sludges. A typical operational cycle includes the following activities:

- Well stabilized liquid sludge is pumped into the lagoon, over a period of several months or more.
- Supernatant is decanted, either continuously or intermittently, from the lagoon surface and returned to the treatment plant.

- Filling and decanting operations are continued until the design depth of sludge is reached.
- The surface crust is repeatedly broken up and/or removed during the drying period.
- Dewatered sludge is removed with some type of mechanical removal equipment.
- Maintenance and repair is performed while the lagoon is empty and then the filling cycle is repeated.

The complete cycle for a single lagoon typically takes from less than 1 to 3 years, depending on the final solids concentration required, local climate, the depth of sludge applied, and management practices (17). All sludge should be stabilized prior to addition to the lagoon to minimize odor problems. Occasional odors, flies and mosquitos may still be a problem, so a remote site is essential.

6.6.1 Design Considerations

Until recently, sludge lagoons were often located in soils with at least moderate permeability to take advantage of subsurface drainage and percolation. That practice is now the exception rather than the rule in most of the United States due to more stringent environmental and groundwater protection regulations. If a groundwater aquifer with drinking water potential exists beneath the site, it may be necessary to line the lagoon or otherwise restrict significant percolation. Unless a sand bottom and underdrains are then installed, the only sludge dewatering mechanisms left are decanting supernatant and evaporation.

In effect, the sludge drying lagoon is similar in concept to a deep sand drying bed with restricted drainage. The depth of sludge in the lagoon might be 0.7 to 1.4 m (24 to 48 in) as compared to 0.3 m (12 in) for the sand bed. The recommended solids loading for the drying lagoons is 36 to 39 kg/yr/m³ of lagoon capacity (2.2 to 2.4 lb/ft³/yr). A minimum of two cells is essential, even at very small systems, to insure availability of storage space during cleaning, maintenance or emergency conditions.

Evaporation and decantation are usually the dominant pathways for water even if an underdrainage network exists. The required lagoon surface area depends on the temperature, precipitation, and evaporation rates for the local area. Equations 6-8 to 6-12 in Section 6.7 can be used to estimate surface area requirements, or assuming that standing water is routinely decanted, the design calculations for evaporation are similar to Equations 6-1 to 6-4. The evaporation procedures in Reference 18 to complete retention ponds can also be used. The water to be removed from the sludge lagoons is the required portion of the sludge moisture content plus

that portion of precipitation that will infiltrate the sludge mass rather than be removed as supernatant.

The dependence on evaporation tends to favor arid and semi-arid climates for this dewatering process. However, the Metropolitan Sanitary District of Greater Chicago, the Milwaukee Metro Sewerage Authority, and the City of Philadelphia have all successfully operated large scale sludge drying lagoons in cool humid climates (19).

It is possible to facilitate drying with a device that consists of a tractor with a helical screw in front to push sludge aside and mix it. This helps to open up the dried top layer and expose the wet material below.

6.6.2 Structural Elements

The retaining walls for drying lagoons are typically earthen dikes 0.7 to 1.4 m (2 to 4 ft) high with a side slope of 1:3. The lagoon is typically rectangular in shape to facilitate sludge removal. Required equipment includes: sludge feed lines and pumps, supernatant decant lines, and sludge removal equipment. The last can include trucks, front-end loaders, bulldozers, or draglines, depending on the size of the operation.

6.6.3 Performance Expectations

Solids concentrations in the range of 15 to 40 percent are expected in the sludge removed from the lagoon; concentrations can be higher in arid climates. These lagoons share a common problem with other air drying processes in that a surface crust forms early in the evaporative stage, which then restricts further evaporative water losses. This problem is minimized with the paved drying beds described in Section 6.8 that use mechanical equipment to move around the bed to turn and mix the sludge. Similar equipment and procedures can be used in drying lagoons if the depth of sludge permits. Floating devices can also be used. Larger scale facilities have used a cable and scraper system as shown in Figure 6-11.

6.6.4 Operation and Maintenance

The routine operational activities consist of sequential sludge applications and decantations until the lagoon contains the design volume of sludge. The periodic break-up or removal of the surface crust then insures continued evaporation. Sludge removal is labor intensive but occurs infrequently. Maintenance activities include care of equipment and dikes and control of dike vegetation. Some sludge drying lagoons may require insect and odor control. The labor requirements for sludge drying lagoons are shown in Figure 6-12.

6.6.5 Costs

The capital cost for drying lagoons is significantly influenced by the cost of land at the project site. Other major factors include construction of the dikes,

sealing the bottom (if required), underdrainage (if used), and the other structural elements described in Section 6.6.2. The construction costs for the lagoon (with earthen dikes) are similar to the costs for sludge storage lagoons, or wastewater treatment ponds. Appendix A-32 in Reference 8 can be used to estimate these costs. The other capital costs depend on the intended methods for sludge loading and removal, and should be determined on a case-by-case basis. The major O & M costs are for labor, fuel, and maintenance of sludge removal equipment. Figure 6-12 (20) can be used with prevailing wage rates to estimate labor costs. The remaining O & M costs will depend on the equipment and procedures used and must also be determined on a case-by-case basis.

6.7 Paved Beds

Until recently, paved beds used an asphalt or concrete pavement on top of a porous gravel subbase. Unpaved areas, constructed as sand drains, were placed around the perimeter or along the center of the bed to collect and convey drainage water. The main advantage of this approach was the ability to use relatively heavy equipment for sludge removal. Experience showed that the pavement inhibited drainage, so the total bed area had to be greater than that of conventional sand beds to achieve the same results in the same time period.

Recent improvements to the paved bed process utilize a tractor-mounted horizontal auger, or other device, to regularly mix and aerate the sludge (21). This mixing and aeration breaks up the surface crust that inhibits evaporation, allowing more rapid dewatering than conventional sand beds. Some of the equipment was originally developed for composting operations but serves equally well for paved bed dewatering. Underdrained beds are still used in some locations, but the most cost effective approach in suitable climates is to construct a low cost impermeable paved bed and depend on decantation of supernatant and auger/aeration mixing for evaporation to reach the necessary dewatering level. Figure 6-13 shows a bed of this type.

6.7.1 Design Considerations

The critical design parameter for paved beds, as with sand beds and drying lagoons, is the surface area required to dewater the sludge to the specified solids level in the specified time. Since drainage is not a factor in many modern paved bed designs, the only ways water can be removed is through decantation and evaporation. These water losses will depend on the same factors described in Section 6.2, but with paved beds the use of the mechanical auger/aerator sustains evaporation near the maximum potential for sludge. Paved beds can be used in any location, but since evaporation provides the major pathway for water loss, they work best in warm, arid and semi-

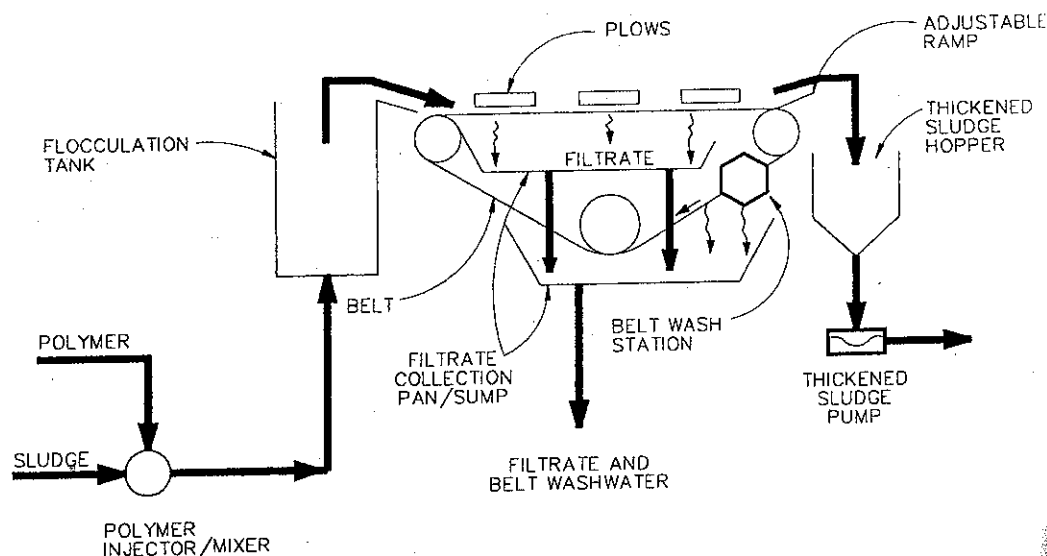


FIGURE 17.6 Gravity belt thickener schematic. (Source: WEF Manual of Practice No. 8, Design of Wastewater Treatment Plants.)

Other Mechanical Thickening Processes. Gravity belt thickening is the most common type of mechanical thickening. However, other mechanical devices have been used or studied for sludge thickening at water treatment plants, and these processes are discussed later in this chapter.

Natural Dewatering Processes. The division between concentrating (or thickening) and dewatering has traditionally been vague. Concentrating has generally been defined as increasing the solids concentration of a liquid stream, and dewatering has been defined as the separation of liquid from a solid.

Natural dewatering refers to those methods of sludge dewatering that remove moisture either by natural evaporation, gravity, or induced drainage. Most air-drying systems were originally developed for dewatering wastewater treatment sludge.

Air-drying processes are less complex, are easier to operate, and require less energy to operate than mechanical systems. However, they are not often used because they require a large land area, the operation depends on climatic conditions, and they are labor intensive. The effectiveness of air-drying processes is directly related to weather conditions, type of sludge, conditioning chemicals, and materials of construction for the drying bed. Loading requirements for a natural dewatering process are shown in Figure 17.7.

These processes may include evaporation and percolation for unlined lagoons and beds or underflow for drying beds with underdrain or vacuum systems. Understanding the mechanisms is important in sizing the process.

Typical loading criteria for lagoons and drying beds are not well documented but agulant sludges are typically applied to sand drying beds at between 2 and 5 lb/ft^2 (2.4 to 2.4 g/m^2). The loading rate is a function of both the application depth and the applied solids concentration as shown in the following equation:

$$\text{SLR} = D_i / 12 \times 62.4 \times DS_i / 100$$

where SLR = solids loading rate
 D_i = the applied depth in inches
 DS_i = the applied solids concentration in %

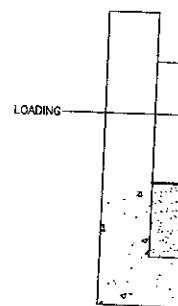


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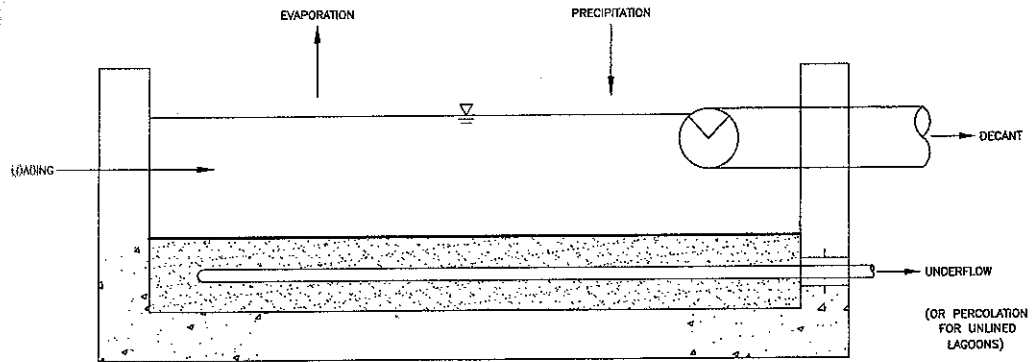
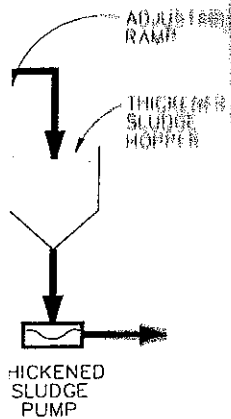


FIGURE 17.7 Natural dewatering sizing parameters.

The required time to achieve a desired solids concentration on the bed can be obtained from the following equation:

$$T = \frac{[D_i - (D_i \times VU) - (D_i \times VD)] - (D_i \times DS_f/DS_f)}{E}$$

where T = evaporation time in months
 VU = % volume reduction through underflow/100
 VD = % volume reduction through decanting/100
 DS_f = finished solids concentration in %
 E = seasonal net pan evaporation rate in in./month

One study has shown that this equation is a conservative estimate of the drying time (Vandermeiden, 1993). Design involves setting up a monthly balance of the loadings on each drying bed. This balance will show the anticipated cycling of the beds in and out of service.

One factor impacting the design of dewatering basins is local groundwater protection regulations. The regulations may require lining of a dewatering basin to protect an underlying aquifer. The state of Arizona, for instance, requires that a liner with a minimum equivalent permeability of 10^{-6} cm^{-1} be provided beneath waste lagoons. Lining increases the cost of the waste basin by both the liner installation cost and also additional area and volume required due to the loss of the percolation function.

Drying Beds. Drying beds usually consist of a sand underdrain with gravel and perforated pipe. In dry climates, shaped, shallow, earthen basins without underdrains are used that rely only on evaporation to separate solids from water. With either type of drying bed, sludge storage facilities must also be provided for periods when climatic conditions prevent effective dewatering.

Some designs incorporate additional drying beds that hold sludge until the right season. The size of drying beds should be based on the effective number of uses that may be made of each bed and the depth of sludge that can be applied to the bed. The required area can be estimated using the formula

$$A = \frac{V}{N \times D \times 7.5}$$

where A = drying bed area, ft^2
 N = number of uses of beds each year
 D = depth of sludge to be applied, ft
 V = annual volume of sludge for disposal, gal

The number of times that the beds may be used depends on the drying time and the time required to remove solids and prepare the bed for the next application. The bed is usually considered dewatered when sludge can be removed by earth-moving equipment (such as a front-end loader) and does not retain large quantities of sand. Alum sludges generally attain solids concentrations of 15% to 30%, and lime-softening sludges attain 50% to 70% solids content.

Alum sludges require from 3 to 4 days to drain, but polymers may accelerate this to 1.5 to 3 days. These are optimal times and do not reflect realistic field conditions. Both field tests and a detailed study of climatic variations are required to apply this option. Bed uses usually range from 1 to 20 per year, depending on climate. In northern locations, drying beds are sometimes designed for one use per year, partially to take full advantage of the natural freezing.

The depth at which sludge may be applied ranges from 8 to 30 in. (20 to 75 cm) for coagulant sludge and from 12 to 48 in. (30 to 122 cm) for lime sludge. Greater sludge depths require proportionally longer drying times. For example, alum sludge at Kirksville, Missouri, required 20 h per percent solids concentration for an 8 in. (20 cm) application, and 60 h per percent solids concentration for a 16 in. (40 cm) application. To obtain a dewatered cake on the bed with a finished thickness suitable for removal with a front-end loader, at least 16 to 24 in. (40 to 60 cm) of sludge should be applied. For example, for a 1 mgd (44 L/s) average treated water quantity, 2,000 lb (900 kg) of sludge per million gallons (3.8 ML) treated, and 20 bed uses per year, a 2% concentration sludge applied at a 16 in. (40 cm) depth requires:

$$A = \frac{4,357,000}{20 \times 1.33 \times 7.5} = 22,000 \text{ ft}^2 (2,044 \text{ m}^2)$$

Freeze-Assisted Sand Beds. Alum residuals have a jellylike consistency that makes them extremely difficult to dewater. By freezing and then thawing the sludge, the bound water is released from the cells, changing the consistency to a more easily dewatered granular type of material. Freezing alum residuals changes both the structure of the residuals slurry and the characteristics of the solids themselves. In effect, solids tend to be compressed into large discrete conglomerates surrounded by frozen water. When they thaw, drainage occurs instantaneously through the large pores and channels created by the frozen water. Cracks in the frozen mass also act as conduits to carry off the melt water.

Freezing can be done mechanically or naturally. Because of the high cost associated with mechanical systems, natural systems are most common. The optimum effects of both the freezing and thawing portions of the cycle can be obtained by exposing solids on uncovered beds. Water may drain during thawing at a faster rate and produce a greater volume when compared with applying the same unconditioned solids to a conventional sand bed.

The critical operational requirement is to ensure complete freezing of the solids layer before the next layer is applied. Hand probing with a small pick or axe usually helps make this determination.

Solar Drying Beds. Until recently, paved drying beds were constructed with an asphalt or concrete pavement on top of a porous gravel subbase. Unpaved areas, constructed as sand drains, were placed around the perimeter or along the center of the bed to collect drainage water. The main advantage of this approach was the ability to use relatively heavy equipment for solids removal. However, experience has shown that pavement inhibits drainage, so the total bed area must be greater than that of conventional sand beds to achieve the same results in the same period.

Recent improvements to the paved bed process include a tractor-mounted horizontal auger or other device to regularly mix and aerate the sludge. Mixing and aeration break the surface crust that inhibits evaporation, allowing more rapid dewatering than conventional sand beds. Although underdrain beds are still used in some locations, the most

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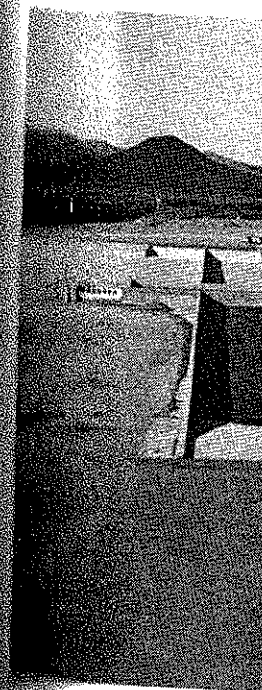


FIGURE 17.8 Solar drying

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effective approach in suitable climates is to construct a low-cost, impermeable paved bed and depend on decantation of supernatant and auger/aeration mixing for evaporation to reach the necessary dewatering level. A solar drying bed is pictured in Figure 17.8.

Vacuum-Assisted Drying Beds. In vacuum-assisted drying, a vacuum is applied to the underside of rigid, porous media plates on which chemically conditioned sludge has been placed. The vacuum draws free water through the plates and essentially all sludge solids are retained on top, forming a cake of fairly uniform thickness. Solids can be concentrated to between 11% and 17%, depending on the type of solids and the kind and amount of conditioning agents used.

One problem encountered with this system involves improper conditioning of the sludge. The wrong type of polymer, ineffective mixing of polymer and solids slurry, and incorrect dosage result in poor performance of the bed. In addition, overdosing polymer may lead to progressive plate clogging and the need for special cleaning procedures to regain plate permeability.

Plate cleaning is critically important. If not performed regularly and properly, media plates will clog and the beds will not perform as expected. The special cleaning measures then required are costly and time consuming.

Wedgewire Beds. The wedgewire, or wedgewater, process is physically similar to the vacuum-assisted drying beds. The medium in this case consists of a septum with wedge-shaped slots about 0.01 in. (0.25 mm) wide. This septum supports the sludge cake and allows drainage through the slots. Through a controlled drainage process, a small hydrostatic suction is exerted on the bed, removing water from the sludge.

Lagoons. Lagoons are one of the oldest processes used to handle water treatment residuals. Lagoons can be used for storage, thickening, dewatering, or drying. In some instances, lagoons have been used for final disposal of residuals.

The lagoon process involves discharging residuals into a large hole in the ground, with the anticipation that the solids will be retained there for a long period of time. Solids eventually settle to the bottom, and liquid can be decanted from various points and levels

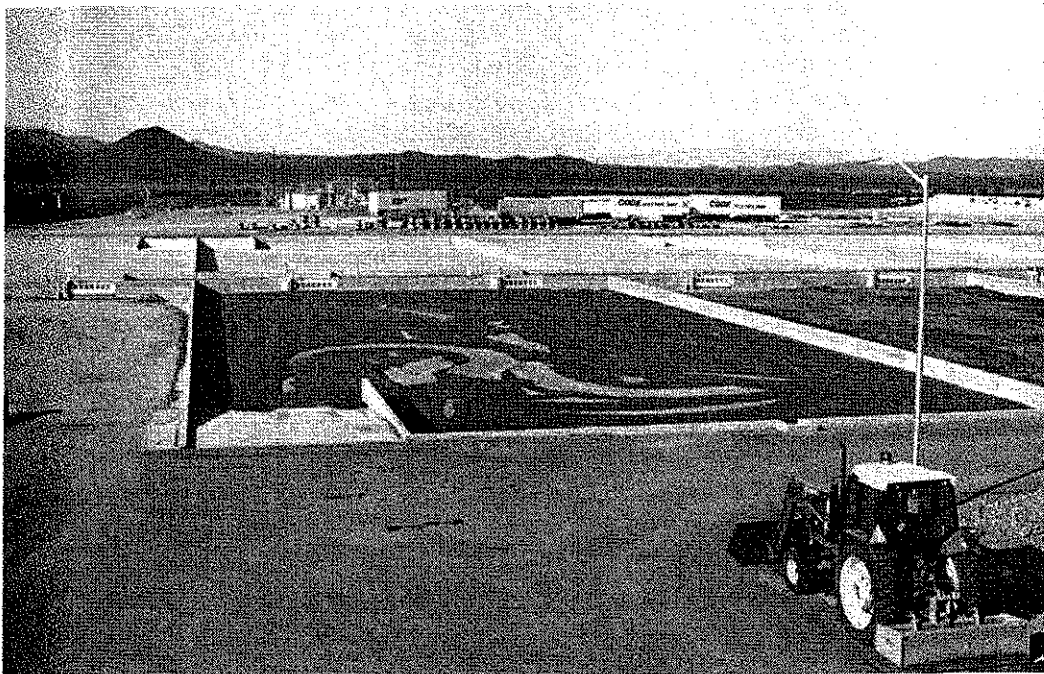


FIGURE 17.8 Solar drying bed.

in the lagoon. Evaporation may also be used in the separation process if the residuals are to be retained in the lagoon for a long period of time.

The traditional lagoon consists of either an earthen berm built on the ground surface or a large basin excavated in the ground. Various types of systems are installed into lagoons to decant the supernatant and ultimately drain the lagoon. State and local regulations have become more stringent with regard to preventing pollution of groundwater and may affect the design of water treatment residual lagoons. Liners using materials such as high-density polyethylene (HDPE), leachate collection systems, and monitoring wells are becoming common features of lagoon designs. Lagoon depth typically varies from 4 to 20 ft. The surface area of lagoons ranges from 0.5 to 15 acres (AWWARF, 1987). A typical section for a lined lagoon is shown in Figure 17.9.

The effectiveness of lagoons in concentrating solids typically depends on the method of operation. Operating lagoons at full water depth without further air drying of solids typically results in a solids concentration of 6% to 10% for metal hydroxide solids when solids are retained in the lagoon for one to three months. Solids concentrations of 20% to 30% may be achieved for lime sludges under the same conditions. Some facilities achieve solids concentrations above 50% by stopping influent to the lagoon and allowing drying through evaporation. This process may require over a year of holding solids in the dewatering lagoon.

The lagoon process may incorporate certain modifications similar to sand or solar drying bed systems. Using a freeze-thaw process for lagoons is a common approach in northern climates.

Mechanical Dewatering. Mechanical equipment used for dewatering water treatment plant sludge includes filter presses, belt presses, centrifuges, and vacuum filtration.

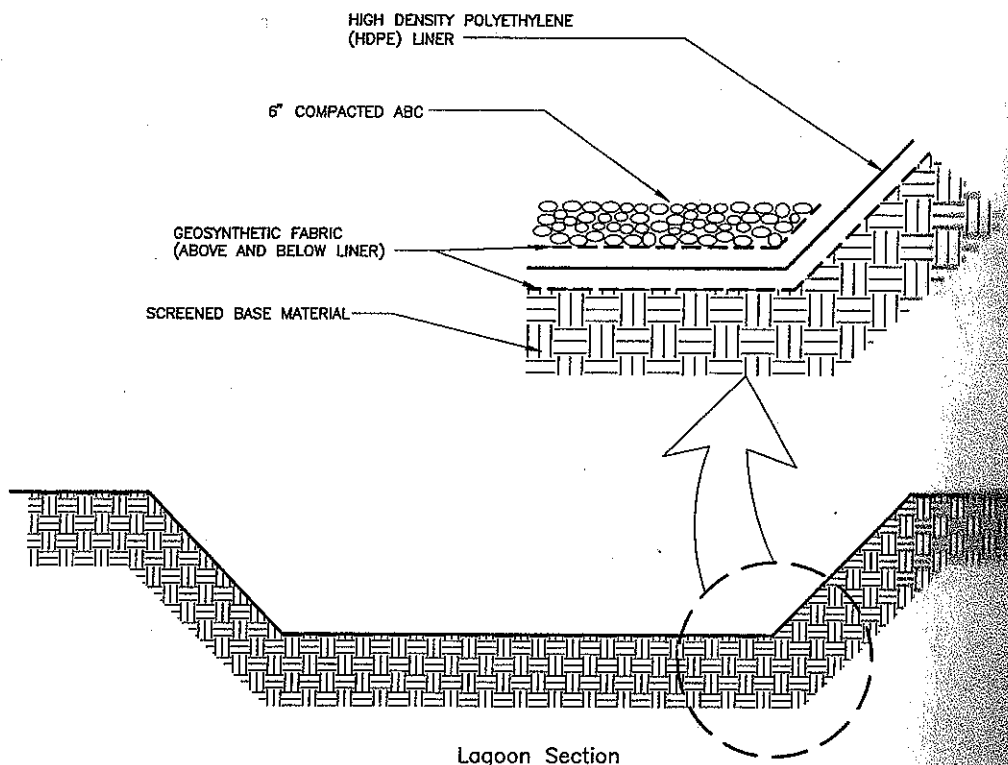


FIGURE 17.9 Lagoon lining profile.

Filter Presses

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Diaphragm filter volume presses is a additional plate and diaphragms along the solids in each chamber provide higher filter plate and frame press units for drainage

Chemicals used and polymers. Precipitation of the filter media the sole conditioning

The primary operation media after each most models as a recommended periodic wash press is shown in Figure

Although the filter is primarily used for metal sludges because of periods of time until their polymer conditioning required. Fly ash may pressing cycle times is usually about 12 to

Filters can be preselected material should be selected. Selection is usually streams.

Layout and profile recommended clearances are a lifting bridge crane is a device.

Advantages of pre

- Generally highest capacity
- High-quality filtrate
- Good mechanical strength
- Adaptable to varying