Chapter 7

Residuals Management

This chapter describes management of concentrated waste streams (residuals) from both low-pressure (microfiltration–ultrafiltration [MF/UF]) and high-pressure (nanofiltration–reverse osmosis [NF/RO]) membranes. The quantity and quality of residuals produced by low- and high-pressure membranes vary and can limit disposal methods. Issues relevant to disposal of residuals from high-pressure membranes (also known as concentrate) as well as their disposal options are described. This chapter also presents regulatory issues that must be addressed when planning and designing membrane facilities and the impacts on the water reclamation processes that must be addressed to avoid water quality violations.

Membrane treatment systems generate significant volumes of waste streams that must be managed properly to ensure successful operation. Low-pressure membranes generate backwash streams that are up to 10 percent of the incoming flow. These streams contain solids removed by the membranes, including suspended solids, pathogens, and any coagulants added upstream of the membranes. As low-pressure membranes do not remove soluble constituents (unless precipitated first), these backwash wastes are typically returned ahead of the membrane treatment process. These wastes can be returned upstream of the membrane system for suspended solids removal or to intermediate treatment to remove solids. A periodic clean-in-place (CIP) membrane cleaning procedure that uses acids, chlorine, and caustic generates a waste stream that differs from the normal backwash residual stream and may require a different handling and disposal approach.

High-pressure membranes generate volumes of concentrate waste streams that are larger than those generated by low-pressure membranes; volumes range from 10 to 30 percent of the incoming flow. These systems remove dissolved constituents, and the residual streams contain the concentrated salts that were removed from the influent or feed along with removed organics and a small amount of suspended solids. Waste from membrane CIP procedures are also generated; these include cleaning chemicals and typically lower levels of salts compared to the concentrate streams. Depending on the reclaimed water source, concentrate may contain high concentrations of salinity, heavy metals, and other contaminants that may be toxic. Consequently, concentrate streams must be disposed of in compliance with the Clean Water Act and the Safe Drinking Water Act. In many cases, local regulations restrict the discharging of concentrate solutions to publicly owned treatment works.

RESIDUALS MANAGEMENT FOR LOW-PRESSURE MEMBRANES

This subsection presents the residuals generated by the various types of low-pressure membranes, residual water quality, disposal issues, and residual management techniques.

Types of Low-Pressure Membrane Residuals

Low-pressure membranes that are used for reuse applications include the following types of systems:

- Submerged MF or UF modules mounted in basins and
- Pressure vessel–enclosed membrane modules.

Submerged MF or UF modules mounted in basins. Submerged MF or UF modules are mounted in basins and used to treat secondary effluent. Submerged membranes are backwashed regularly, typically every 10 to 30 min for 1.5 to 2.5 min (WEF 2006). The membrane supplier generally provides the backwashing frequency and duration. Periodically, the entire basin is dumped to flush out the solids removed from the membranes. This flow is a spike of several thousand gallons per minute and is normally sent to an equalization basin. The volume of backflush water ranges from 5 to 10 percent of the feed flow. The equalized backwash waste can be sent to the head of the wastewater treatment plant (WWTP) (if possible) or to a separate treatment process for removal of the solids and organics prior to recycle to the membrane treatment system. Treatment methods are described under management techniques.

Maintenance cleans and recovery cleans are performed for submerged membranes. Similar chemicals and concentrations are used in the CIP recovery process. The frequency of maintenance cleans ranges from daily to weekly and recovery cleans range from 30 to 90 days. The frequency of maintenance and recovery cleans is highly dependent on the quality of the feedwater.

Pressure vessel–enclosed membrane modules. Pressure vessel membranes consist of hollow-fiber modules mounted in a pressure vessel. Membrane backflushing occurs at a rate of 1.5 to 2 times the normal flux during operation. Backflushing is normally performed every 10 to 30 min and lasts for 1 to 2 min (WEF 2006). The membrane supplier should be consulted for the frequency and duration of backflushing, which are based on the equipment and the quality of the water being treated.

Since the pressurized membrane system backflushes one unit (rack) at a time, the peak flow rate of the backflush water is less than that in a submerged system and therefore requires a smaller equalization basin. For systems larger than 10 mgd in capacity, the backflush flow is nearly continuous. The chemicals used for maintenance and recovery cleans are the same as those used for submerged membranes. The volume of spent solution is typically less because of smaller dead volume in the pressure vessels. The membrane supplier should be consulted for the actual CIP waste volumes.

RESIDUALS MANAGEMENT TECHNIQUES

Methods for handling different types of residuals from low-pressure membrane systems are discussed in this section.

Backwash Waste

Discharge to sewer. Discharge of backwash waste to a sewer system is successfully practiced at many locations. A reuse facility that is located at the WWTP sends the residual stream to the front of the plant or ahead of secondary treatment. For satellite treatment facilities, the residuals are discharged to the closest wastewater collection system. Discharge to a sewer is simple and convenient. However, with both approaches, there is an increase in hydraulic and solids loading of total suspended solids (TSS) and biological oxygen demand (BOD) to the local WWTP. The peak and average loadings should be determined to ensure that these loads do not impact the WWTP. Connection fees and user charges should also be calculated to determine the cost of this residuals management method.

Treatment and recycle. Treatment of backflush waste and recycling it to the head of the membrane system is often a cost-effective approach. The turbidity of the backflush wastewater can range from 30 to 150 ntu. The treatment system should use coagulation, flocculation, and some form of sedimentation to remove TSS, colloids, dissolved organic carbon, and bacteria and viruses. The residuals from the coagulation–flocculation–sedimentation (CFS) process can be sent directly to the solids handling system at the WWTP or dewatered separately with drying beds or mechanical dewatering. Examples of CFS systems used to treat membrane backflush waste include the following:

- Gravity thickener,
- Plate/tube settlers,
- Dissolved air flotation, and
- Ballasted flocculation.

Table 7-1 summarizes design considerations for each CFS process. Typical coagulants used to treat waste backflush water include alum, ferric chloride, and aluminum chlorohydrate and polymer. The plate settler and dissolved air flotation processes work best with flocculation, with at least 15 min of contact time. The ballasted flocculation systems typically have a built-in reaction/flocculation system, for example, the ACTIFLO system.

Another approach for handling waste backflush water is to use a second stage of membranes to concentrate the waste and produce a filtrate that can be combined with the treated flow from the first set of membranes. Secondary membranes must be operated at a flux that is lower than the flux for primary membranes and may require more frequent maintenance and recovery cleans. The residuals from secondary membranes can be handled with the same techniques used for primary membranes.

Table 7-1 Summary of coagulation–flocculation–sedimentation processes

System	Design Criteria	Effluent Quality	Solids Characteristics, %TSS
Gravity thickener	Hydraulic loading, 0.2 gpm/ft^2; TSS loading, 2.2 lb/ft^2/d	<2.0 ntu with coagulant and polymer	0.75–1.5
Plate settler	Hydraulic loading, 0.35 gpm/ft^2 on plate area	<2.0 ntu with coagulant and polymer	0.5–1.5
Dissolved air flotation	Hydraulic loading, 2–4 gpm/ft^2; TSS loading, 15–20 lb/ft^2/d	<2.0 ntu with coagulant and polymer	1.0–2.0
Ballasted flocculation	Hydraulic loading, 20 gpm/ft^2 on plate area	<1.5 ntu; requires coagulant and polymer to operate	0.05–0.1

Abbreviation: TSS, total suspended solids.

Maintenance Wash Waste and CIP Wastes

It is important to note that maintenance wash waste contains high concentrations of chlorine (up to 1,000 mg/L) and consequently needs to be neutralized with sodium bisulfite. In addition, the acid solution needs to be brought back to neutral pH prior to returning it to the upstream processes or disposing it to the sewer. The spent organic acids (citric or oxalic) have a very high BOD (5,000 to 10,000 mg/L) that should be considered in the WWTP design. Batch discharges of high-BOD maintenance wash waste can upset the biological process. Adding an equalization tank to the system and continuously discharging high-BOD wastes back to the WWTP at a low flow rate is a better approach for disposal. Equalization of the high-strength waste should be considered even for discharge into the WWTP collection system.

CIP wastes are more difficult to handle because they contain chlorine, metals, high concentrations of spent organic acids, ethylenediaminetetraacetic acid (EDTA), and organics removed from the membranes. After pH neutralization and dechlorination with sodium bisulfite or calcium thiosulfate, these wastes, if not discharging to the sewer, can be recycled along with the backflush waste or be treated separately to remove the acids. It is difficult to recycle the CIP waste because citric acid and EDTA are chelating agents that interfere with coagulation. Testing at the West Basin Water Recycling Plant, Carson, California showed that citric acid could be recycled only if the spent acid solution was separately collected and bled back into the recycled stream at a concentration of less than 10 mg/L. The best way to deal with citric acid and EDTA is biological treatment. If recycle or biological treatment is not possible, precipitation of citric acid with calcium chloride can be considered. The precipitated solids can be removed and handled with the other solids streams.

Membrane preservation and storage. Many membranes come shipped in special solutions such as glycerin to keep them wet and free from bacteria. The solutions are disposed of into a sanitary sewer; the BOD of the solution should be considered to prevent shock loading to the plant. An equalization tank for managing high-BOD waste streams will reduce the adverse impact on the WWTP biological process.

CONCENTRATE MANAGEMENT FOR HIGH-PRESSURE MEMBRANES

Membrane separation processes such as RO and NF are used in water reclamation to remove dissolved contaminants from treated wastewater. In addition to product water, these processes generate a by-product stream, referred to as concentrate, that contains all of the contaminants removed by the membrane process. The concentrate stream is typically 10 to 30 percent of the flow treated, and it has total dissolved solids (TDS) concentrations 3 to 10 times greater than those in treated wastewater. Managing the concentrate stream is often one of the greatest challenges at water reclamation facilities.

In pressure-driven membrane processes, the product water passes through the membrane, and contaminants are separated from treated water by rejection on the feed side of the membrane. The RO and NF membranes remove dissolved ions, organic contaminants, and pathogenic microorganisms that are collected in the concentrate at concentrations several times greater than those in the feedwater. Within the pressure-driven membrane category, RO membranes have higher rejection rates than NF membranes and therefore generate concentrate that contains higher levels of rejected contaminants.

Concentrate management is complicated by the volume of the concentrate stream, health and environmental issues, cost and energy issues, and the often complex interaction of federal, state, and local regulations that govern concentrate disposal.

ISSUES RELATED TO CONCENTRATE DISPOSAL

Concentrate Volume

The volume of the concentrate stream is determined by the recovery achieved by the membrane process. For reclaimed water, product water recovery ranges from 70 to 90 percent; therefore, the concentrate stream is 10 to 30 percent of the feed flow. The options for disposing of large concentrate streams are limited due to water quality, cost, and space requirements issues.

Blending concentrate with a WWTP influent or effluent is challenging because the ratio of concentrate to influent or effluent increases. When dilution is inadequate, the WWTP National Pretreatment Program may not allow the discharge of concentrate to the WWTP. The salinity is normally not toxic to microbial organisms in the WWTP until the chloride concentration is greater than 5,000 mg/L. Batch discharges of concentrate cause a sudden increase in TDS at the WWTP; however, the microbes can adjust to sudden increases in TDS with little process disruption. A sudden cessation of concentrate can cause a sudden drop in the TDS of the wastewater that can be fatal to the microbes. A sudden decrease in the wastewater TDS causes a large osmotic pressure differential across the microbial cell wall. This pressure differential causes the microbes to swell and, if high enough, will rupture the cell wall, killing the microbe. This sudden decrease in concentrate discharge may be unique to reclaim systems because reclaim water production could be stopped under certain conditions.

Direct discharge of concentrate to surface waters and too much concentrate discharged to the WWTP are both affected by effluent toxicity. Discharges to surface waters must meet acute or acute and chronic aquatic toxicity testing criteria. The total effluent flow to surface water or a receiving stream must meet the aquatic toxicity testing protocol. A TDS concentration greater than 1,500 mg/L exceeds a concentration threshold where aquatic toxicity can occur. As the effluent TDS concentration increases, the probability of effluent toxicity increases. While there is no absolute limit for toxicity, effluent with a TDS concentration of 2,500 mg/L is likely to fail the aquatic toxicity test.

One trigger for aquatic toxicity is the effluent's ionic composition. If the effluent has a high sodium or high chloride concentration (in relative terms, a higher proportion/molar concentration of sodium or chloride compared to the other ions present), toxicity is more likely to occur. The onset of toxicity is usually lessened (higher concentrations of TDS can be tolerated) as the effluent hardness or alkalinity is increased.

The ability to discharge to a specific receiving stream is based on the stream's volume of flow. If the summer low-flow periods produce a flow that is equal to or less than the proposed concentrate flow, it is likely that the discharge will no be allowed. The acceptance of a concentrate stream for discharge is also impacted by state rules pertaining to the aquatic toxicity test. Whole effluent toxicity (WET) testing is the most restrictive aquatic toxicity test. WET testing does not allow blending of the effluent with stream water. If allowed by a state, serial dilution is a better choice for surface discharges. For serial dilutions, the flow in the receiving stream dictates the amount of dilution allowed. Contact your state National Pollution Discharge Elimination System (NPDES) permitting authority for more information.

Many states have general permits for cooling tower blowdown discharge to surface waters. While cooling tower and membrane concentrates are not produced via the same mechanism, their characteristics are similar. To determine how a state might evaluate concentrate discharge to surface water, check the regulations regarding cooling tower discharges to see if surface water discharge is allowed.

Large concentrate volumes can make some treatment options too expensive or logistically impractical. For example, solar evaporation can be an effective option in arid regions; however, even in arid climates, the land area required for evaporation ponds can make this option impractical. A reclamation plant that treats a 10-mgd flow and achieves 70 percent RO recovery might require 1,000 to 1,500 acres of pond area to evaporate the concentrate in an arid climate (with loading rates between 1.4 gpm/acre and 2.0 gpm/acre). Land requirements of this magnitude can preclude pond construction in many situations.

HEALTH AND ENVIRONMENTAL ISSUES

State and federal regulations that relate to water reuse protect the public from pathogenic microorganisms. The water reclamation treatment process includes RO membranes and disinfection to provide barriers to these pathogens. However, concentrate is not treated by RO and is not disinfected; therefore, the public health protection barriers applied to reclaimed water do not exist for concentrate. Furthermore, all of the contaminants removed by RO and collected in the concentrate are at much higher concentrations than in reclaimed water. Consequently, standards for water reuse can restrict options for concentrate disposal where human exposure is likely.

Discharge of concentrate can also have detrimental environmental effects. TDS concentrations in reclamation plant concentrate typically range from 3,000 to 6,000 mg/L, levels that are toxic to many plants and animals. The high salinity levels in concentrate limit its disposal by surface water discharge or land application.

In addition to elevated salinity levels, concentrate can contain a variety of individual contaminants that adversely affect plants, fish, and wildlife. Domestic and industrial water uses add contaminants to wastewater that were not present in the natural water source. Examples include heavy metals, synthetic organic chemicals, pharmaceuticals and personal care products (PPCPs), and endocrine-disrupting compounds (EDCs).

EDCs are a large group of chemicals shown to interfere with the natural action of hormones in organisms and to induce adverse reproductive and developmental effects in wildlife. Examples of EDCs include natural and synthetic hormones such as estradiol and ethinylestradiol, degradation products of phenols and plasticizers, and pharmaceutical compounds such as hormones, lipid regulators, antibiotics, and analgesics. EDCs are not completely removed in wastewater treatment and have been found in wastewater plant effluents. Because many of these compounds are well rejected by NF and RO membranes, they end up in NF and RO concentrate at many times the concentrations found in wastewater effluent. When present in concentrate, environmental issues may arise if the concentrate directly or indirectly reaches surface water or groundwater.

COST AND ENERGY ISSUES

High concentrations of inorganic and organic compounds in concentrate make concentrate treatment more expensive (typically 10 times more expensive) and more energy intensive than treatment of water or wastewater. An example of this is treatment of concentrate with thermal desalination devices. Concentrate is treated and recovered as product water with a brine concentrator followed by a crystallizer. However, the capital cost and energy requirements are high. Seawater desalination with RO membranes is considered an expensive and energy-intensive process for generating drinking water. The cost and energy needed to treat concentrate with thermal technologies can be compared with RO seawater desalination. On a gallon-per-gallon basis, life-cycle costs for treatment with a brine concentrator is typically 4 times as expensive and consumes 8 times as much energy compared to an RO process. Crystallizer treatment is even more expensive and energy intensive. Compared to RO seawater desalination, the capital cost of using a crystallizer is approximately 125 times greater and energy consumption is 350 times greater.

CONCENTRATE DISPOSAL OPTIONS

The following methods have been used to manage concentrate:

- Discharge to surface water,
- Discharge to sewer,
- Inject underground,
- Use evaporation ponds,
- Use treatment, and
- Apply to land.

Discharge to Surface Water

Historically, discharge of concentrate to surface water has been the most widely used management method (Mickley 2006). Relative to other options, surface water discharge typically is low cost. However, there are high standards for environmental protection. Discharge of concentrate to surface water is regulated under the federal Clean Water Act (CWA) through the NPDES, which was created to establish minimum standards for surface water discharge. Any direct discharge to waters of the United States requires an NPDES permit. The permit specifies effluent limits, pretreatment requirements, and standards for inspection, monitoring, and reporting.

The effect of concentrate discharge on receiving waters depends on the water's dilution and mixing capacity. The amount of dilution and mixing required increases in proportion to the concentration of contaminants in the concentrate relative to the contaminant standard. Environmentally safe surface water discharge becomes more challenging as the volume of the concentrate stream increases and as the salinity and concentration of contaminants of concern increase.

Density of the concentrate relative to the receiving water also has an effect. If the concentrate has higher salinity than the receiving water, it will be denser and tend to sink. Conversely, if the concentrate has lower salinity, it will rise. Either condition could give rise to localized salinity gradients that are harmful to local plants and animals.

Surface water discharge systems include a pump, pipeline from the plant to the shore, pipeline from the shore to the outfall, and the outfall structure. Outfall structures frequently include a diffuser to promote dilution of the discharge. Diffuser design is complex and often conducted using software programs designed for this purpose. Design variables include the following:

- Discharge flow rate,
- Shape and hydraulics of the receiving body,
- Temperature of the effluent and receiving body,
- Density of the effluent relative to the receiving body, and
- Receiving stream flow rate, especially stream low flow.

While surface water discharge is often the least expensive concentrate management option, many factors affect its cost and feasibility. These include uses and quality of the receiving water, distance to the receiving water, environmental impacts, and outfall design.

Discharge to Sewer

Historically, discharge of concentrate to a sewer has been the second most widely used management method (Mickley 2006). An NPDES permit is not required for discharge to a sanitary sewer system. However, the publicly owned treatment works (POTW) that receives and treats the wastewater does have an NPDES discharge permit, and the ability of the receiving POTW to comply with its permit can be diminished if the concentrate is of extremely poor quality.

Concentrate discharge to a sewer system can have the following adverse effects:

- Corrosion of conveyance systems,
- Scaling of conveyance systems,
- Degradation of activated sludge settling,
- Salt inhibition of the activated sludge process,
- Toxicity in the WWTP effluent, and
- Contamination in the concentrate, for example, microconstituents, PPCPs, and EDCs.

Sulfate in concentrate can increase concrete corrosion within the collection system, including piping, manholes, and pumping stations. Sulfate can induce concrete corrosion directly (Lea 1998) or indirectly (Morton et al. 1991). In direct attack, sulfate reacts with calcium hydroxide in the cement to form calcium sulfate and with hydrated calcium aluminates to form calcium sulfoaluminate. In indirect attack, sulfate is converted to sulfides under the anaerobic conditions within the collection system; this leads to corrosion of concrete pipe and metal surfaces.

Concentrate can adversely affect the settling characteristics of biological floc in the secondary clarifier (Higgins & Novak 1996; Murthy et al. 1998; Bott & Anan 1999), and inhibition of methanization of volatile fatty acids in anaerobic digestion (Feijoo et al. 1995).

Furthermore, inorganic constituents such as chloride in the concentrate are not removed in biological treatment. As a result, discharge of concentrate to the sewer may cause the POTW to exceed its permit limits for inorganic contaminants. Contaminants in concentrate that are removed by biological treatment end up in the waste sludge and can affect its suitability for land application. POTWs must be willing to accept the concentrate, and they typically impose local limits on concentrate water quality to protect treatment efficiency and ensure compliance with NPDES permit limits.

The CWA also contains national water quality provisions for discharges to sanitary sewers under the National Pretreatment Program. These regulations are intended to protect POTWs from high concentrations of industrial pollutants. The standards are organized into two categories: categorical pretreatment standards and specific prohibitions. Categorical standards are applied to specific wastewater discharges of particular industrial categories. POTWs are not included in any industrial category and therefore are covered under the specific prohibitions. Specific prohibitions are intended to protect the receiving POTW from contaminants that could create a hazard, adversely affect treatment, cause corrosive damage, interfere with flow, or pose health risks to plant personnel. Authority to administer the Industrial Pretreatment Program is typically delegated to the POTW; however, several states have retained the authority to administer the program. In most states, any POTW with a design capacity that is greater than 5 mgd is required to develop and maintain an approved pretreatment program. All POTWs are required to develop a sewer use ordinance that gives them the legal authority to manage and regulate discharges into the collection system.

The requirement to control TDS in surface waters in the United States has been part of the CWA since its inception. However, in recent years states have begun to adopt water quality goals and are beginning to regulate TDS in general and to regulate specific ions. Many states have incorporated the secondary maximum contaminant levels (MCLs) for TDS, sulfate, and chloride into their water quality standards. Unlike secondary MCLs, water quality standards are not voluntary. Rather they are hard limits and, when incorporated into discharge permits, are limits that must be enforced and compliance determined.

Discharge to a sewer typically is not a sustainable option for reclaimed water because, in most cases, the sewer discharges back to the WWTP where the concentrate originated. Recycling the concentrate back to the WWTP would create a TDS sink at the WWTP, leading to increased TDS concentrations in the plant influent and effluent. If a large portion of the POTW-treated effluent is harvested as reclaimed water, it is likely to increase the TDS at the POTW to unacceptably high concentrations. This would limit the POTW ability to discharge to surface waters and possibly limit or increase the cost of producing reclaim water of acceptable quality.

Inject Underground

Underground injection is a disposal option in which waste streams are injected into porous subsurface formations for storage and confinement. Underground injection has been one of the most frequently used methods for disposal of hazardous wastes in the United States. Injection wells are also being widely used for concentrate disposal, particularly in Florida.

Underground injection is regulated by the Underground Injection Control (UIC) standards authorized under the Safe Drinking Water Act (SDWA). The UIC regulates injection of fluids into wells that are defined as follows:

- Can be bored, drilled, or driven and with a shaft that is not deeper than the largest surface dimension,
- A dug hole whose depth is greater that the largest surface dimension,
- An improved sinkhole, or
- A subsurface fluid distribution system.

The intent of the regulations is to protect underground sources of drinking water (USDW). The US Environmental Protection Agency (USEPA) established a classification system for injection wells based on location and the type of waste injected. Class I, nonhazardous, is the well classification pertinent to concentrate injection. Class I wells are used for the injection of nonhazardous industrial or municipal waste beneath the lowermost formation of any USDW within one-quarter mile of the well bore. A USDW is defined as having TDS less than 10,000 mg/L. Underground injection wells must be cased and cemented to protect USDW. UIC permits also include operating, monitoring, and reporting requirements.

There are several site requirements for class I nonhazardous underground injection. The injection zone must be below any USDW and separated from the USDW by a hydrologically impermeable formation that prevents migration of the injected fluid into the USDW. Any USDW must not be within one-quarter mile of the disposal well. The injection zone must meet water quality and hydrologic criteria. The water quality of the receiving formation must be physically, chemically, and bacteriologically compatible with the injected concentrate. The receiving zone must have adequate permeability and storage volume so that injection does not increase pressure in the receiving formation.

Underground injection is an isolation method for disposing of concentrate. The intent is that the injected waste remain immobilized in the isolation zone indefinitely, making site selection critical. Geologic and hydrologic evaluations are required to make certain the receiving formation has the capacity to hold and confine the waste volume. Porosity and permeability are two important hydrogeological characteristics that determine the suitability of subsurface formations for injection of wastes.

Porosity is the percentage of pore volume in the formation. The pores may be connected or discrete. Effective porosity is the percentage of interconnected pore volume. To be suitable for injection, a subsurface formation must have sufficient effective porosity to store large volumes of liquid. Sandstone is an example of a highly porous material; sandstone stratum generally is a good formation for underground injection.

Permeability describes the ability of water to move through the formation. Permeability is related to porosity by the interconnectedness of pores in the formation. A high degree of interconnectivity facilitates water movement through the formation and increases permeability. In addition to being porous enough to store concentrate, a suitable subsurface formation must be bound by impermeable strata that prevent the migration of injected concentrate. Shale is an example of an impermeable material.

UIC regulations specify construction requirements for class I injection wells. These wells must be cased and cemented to prevent leakage. A class I injection well is made up of casing, tubing, and packers. Casing is the outer pipe that is cemented in place. The casing is used to maintain the structural integrity of the bore hole and seal off intermediate aquifers from the injected concentrate. There may be several stages of casing comprising successively smaller pipe diameters with depth. The space between casing stages is filled with cement. Tubing is the innermost pipe that conveys the injected fluid to the injection zone. Packers are used to seal the annular space between the innermost casing and the tubing. The annulus between the casing and tubing is filled with a noncorrosive liquid that is maintained under positive pressure. Pressure in the annulus fluid is monitored to detect leaks.

Concentrate solutions are typically supersaturated with respect to sparingly soluble salts. Precipitation of salts after the concentrate is injected can reduce subsurface permeability and requires higher pumping pressures to maintain the design flow rate. Consequently, treatment with an antiscalant to inhibit precipitation may be necessary prior to injection.

Underground injection is an environmentally safe disposal method as long as there is no leakage of concentrate during injection or subsurface movement of concentrate after it reaches the injection zone. Strycker and Collins (1987) noted the following five ways in which an injected waste may contaminant adjacent underground water supplies:

- Leakage due to insufficient casing or corrosion of the casing;
- Escape vertically outside of the well casing;
- Escape vertically from the injection zone through confining strata that are inadequate due to high permeability, solution channels, joints, cracks, or induced fractures;
- Escape vertically from the injection zone through nearby wells that are improperly cased; and
- Lateral migration of concentrate to a region of freshwater.

Some regulatory agencies require monitoring wells for the detection of contaminants in nearby aquifers from the injection well. Samples are collected from the monitoring wells periodically and analyzed to ensure there has been no migration of concentrate into adjacent aquifers.