8.0 RELATIVE RISK ASSESSMENT

This chapter presents the findings of EPA's relative risk assessment for the South Florida municipal wastewater management options: deep-well injection, aquifer recharge, discharge to ocean outfalls, and discharge to surface-water bodies. The preceding chapters outlined the overall framework for the risk assessment and the application of that framework to the individual assessments of the South Florida municipal wastewater treatment options. The main issues that were considered when assessing the risk are summarized in this chapter, followed by an examination of the human health risks and the ecological health risks.

Although the term *option,* used to describe the wastewater treatment methods, suggests any of these are available for use by the wastewater treatment plants in South Florida, in fact most facilities are limited by local conditions as to possible treatment methods. However, most wastewater treatment facilities do not rely solely on one method but combine management options to meet the current demands and local conditions.

8.1 Identified Risk Issues

Although all four disposal options deal with municipal wastewater, they differ from each other in almost every aspect. The option used depends on geographic location, the underlying geology, final injection point, type of treatment, disinfection level, site-specific conditions, local needs and constraints, the opportunities for water reuse, and, in some instances, weather conditions. Because of this variation, each disposal option has its own specific stressors (hazards), exposure pathways, receptors, and effects. Also, parameters that are relevant to one particular disposal option are not necessarily relevant to the remaining three. As a result, it is not feasible to present strictly quantitative data for all parameters associated with all options.

Table 8-1 identifies the major issues relevant to assessing risk associated with each of the four options. This information and data is a summary of the findings from the option-specific risk assessments that were discussed in detail in Chapters 4 through 7. Although overall quantitative comparisons are not feasible, the information in the table identifies key issues and allows the reader to relate these issues between the four wastewater treatment options. The issues are central to managing wastewater treatment in a way that limits risk to people and the environment.

Table 8-1. Relevant Risk Assessment Issues for the Four Wastewater Management Options

Issue	Deep-Well Injection	Aquifer Recharge (RIBs)	Discharge to the Ocean	Discharge to Surface Waters
Type of Treatment and Level of Disinfection	Secondary treatment; treatment plants must maintain basic disinfection capability. (Exceptions such as Pinellas County use secondary treatment, high-level disinfection and filtration.)	Secondary treatment, including high-level disinfection. Meets Florida's reclaimed-water standards.	Secondary treatment, including basic disinfection.	Secondary treatment, including basic disinfection. Discharge to Class I waters requires high-level disinfection. Discharge to sensitive waters (such as Tampa Bay) requires advanced wastewater treatment (AWT) with nitrogen removal.
Wastewater Constituents Remaining After Treatment (Stressors)	Moderate levels of nutrients (phosphorus, nitrogen); concentrations typically meet maximum contaminant levels (MCLs), but may exceed surface-water quality standards (for example, AWT standards). Small amounts of metals and organic compounds; concentrations typically meet MCLs (trihalomethanes may occasionally exceed the MCL). Pathogenic protozoans are not removed; infective bacteria and viruses remain.	Low levels of nutrients (phosphorus, nitrogen); concentrations frequently exceed AWT standards and EPA recommendations for ambient surface-water quality. Trace amounts of metals and organic compounds; concentrations typically meet MCLs. Low mean numbers of pathogenic protozoans (occasional instances of higher numbers); bacteria and viruses are effectively inactivated.	Moderate levels of nutrients (phosphorus, nitrogen). Trace amounts of metals and organic compounds; concentrations typically meet MCLs. Metals frequently exceed ambient seawater concentrations. Pathogenic protozoans are not removed; small numbers of infective bacteria and viruses may remain.	Low levels of nutrients. Nutrient concentrations typically meet standards specific to water bodies, but may exceed EPA recommendations for ambient surface-water quality. Trace amounts of metals and organic compounds; concentrations typically meet MCLs. Low numbers of pathogenic protozoans; bacteria and viruses are effectively inactivated.

Table 8-1. Relevant Risk Assessment Issues for the Four Wastewater Management Options

Issue	Deep-Well Injection	Aquifer Recharge (RIBs)	Discharge to the Ocean	Discharge to Surface Waters
Large-Scale Transport Mechanisms	Simultaneous upward and horizontal migration. Vertical transport occurs as a result of injection pressure and fluid buoyancy. Horizontal transport in the direction of groundwater flow.	Initial downward migration (infiltration, percolation). Horizontal transport in the direction of groundwater flow. Potential for recharge to surface waters.	Initial upward migration into the ocean water column. Horizontal transport within the Florida Current (northward). Occasional transport towards the coast.	Downstream (horizontal) transport in canals. Turbulent mixing in estuaries and bays. Potential for recharge where water body is hydrologically connected to groundwater.
Distance Between Point of Discharge and Potential Receptors *(Note: Depending on the particular option, receptors may be USDWs and drinking-water supplies, or they may be human or ecological.)*	Injection occurs between 1,000 and 3,000 feet below ground surface. Vertical distance to the nearest overlying USDW varies geographically: • Dade Co.: approx. 1,000 ft. • Brevard Co.: approx. 950 ft. • Pinellas Co.: approx. 570 ft. Thousands of feet to water-supply wells or potential ecological receptors.	The distances range from tens of feet to hundreds of feet.	Discharge occurs between roughly 1 and 3.5 miles offshore. No drinking-water receptors exist at the ocean outfall discharge points. Tens of feet (or more) to ecological receptors in the vicinity of outfalls.	Tens of feet to receptors at discharge point; hundreds of feet to other receptors.

Table 8-1. Relevant Risk Assessment Issues for the Four Wastewater Management Options

Issue	Deep-Well Injection	Aquifer Recharge (RIBs)	Discharge to the Ocean	Discharge to Surface Waters
Time of Travel to Potential Receptors *(Note: Depending on the particular option, receptors may be USDWs and drinking-water supplies, or they may be human or ecological.)*	Potential receptors are deep USDWs and current drinking-water supplies. Vertical times of travel to these receptors vary geographically: • Dade Co.: Between 14 and 420 years to deep USDWs; 30 to >1,100 years to the depth of current water supplies • Brevard Co.: Between 86 and 340 years to deep USDWs; 136 to >1,100 years to the depth of current water supplies • Pinellas Co.: Between 170 days and 2 years to deep USDWs; 6 to 23 years to the depth of current water supplies. Fluid movement into deep USDWs confirmed at 3 facilities; probable movement into USDWs at an additional 6 facilities.	Horizontal times of travel within the surficial aquifers vary with site-specific characteristics and with mandatory setback distances: • Dade Co.: Approx. 40 days to travel 200 feet; 1.5 years to travel ½ mile • Brevard Co.: Approx. 3 years to travel 200 feet; 40 years to travel ½ mile • Pinellas Co.: Approx. 6 years to travel 200 feet; 75 years to travel ½ mile.	There are no drinking-water receptors. Immediate transport (minutes) to receptors that may occur around the discharge points. Rapid transport to downstream ecological receptors (hours to days); however, there is rapid attenuation by dilution in the ocean.	Immediate transport to receptors around surface-water outfalls. Rapid transport to downstream human and ecological receptors (hours to days). Delayed and variable recharge to surficial USDWs.

Table 8-1. Relevant Risk Assessment Issues for the Four Wastewater Management Options

Issue	Deep-Well Injection	Aquifer Recharge (RIBs)	Discharge to the Ocean	Discharge to Surface Waters
Attenuation Processes	Dilution; filtration by porous geologic media; sorption onto media; other chemical degradation processes.	Filtration by soils and by porous geologic media; sorption onto soils and media; dilution; microbial degradation; other chemical degradation processes.	Dilution; settling; sorption onto sediments; biological uptake and degradation; photo-oxidation; other processes.	Dilution; settling; sorption onto sediments; biological uptake and degradation; photo-oxidation; other processes.
Anticipated Reduction in Stressor Concentration *(Note: Depending on the particular option, receptors may be USDWs and drinking-water supplies, or they may be human or ecological.)*	Minimally to substantially reduced before reaching deep USDWs. Minimal reduction where estimated times of travel are short (for example, Pinellas Co.) or where groundwater monitoring indicates rapid vertical fluid movement (for example, Miami-Dade, South District). Moderate to substantial reduction where estimated times of travel to USDWs are long. Substantially reduced before reaching the depth of current water supplies or potential ecological receptors.	Minimally reduced before reaching USDWs. Moderately to substantially reduced before reaching other potential receptors.	Minimally to moderately reduced before reaching receptors that may occur or be near points of discharge; mean dilutions between 60:1 and 90:1 are achieved within 400 meters of the discharge point. Substantially reduced before reaching receptors that may occur or be at greater distances from points of discharge.	Minimally reduced before reaching receptors near outfalls. Moderately to substantially reduced before reaching receptors at further distances from outfalls.

Table 8-1. Relevant Risk Assessment Issues for the Four Wastewater Management Options

Issue	Deep-Well Injection	Aquifer Recharge (RIBs)	Discharge to the Ocean	Discharge to Surface Waters
Factors That May Increase Risk	The potential for long-term impacts to USDWs. Long time frames for recovery. The difficulty in performing remediation in the deep subsurface. The lack of attenuation where conduit flow is a major fluid movement mechanism. Instances where there is little natural straining or filtering of particulates or microorganisms.	The potential for long-term impacts to USDWs and current water supplies. The proximity to drinking-water and ecological receptors.	The proximity to ecological receptors. The potential for shifts in current toward shore and human receptors. This is currently estimated to occur approximately 4% of the time. The lack of natural straining (filtration) of particulates or microorganisms.	The potential for recharge to surficial USDWs. The proximity to ecological receptors. The potential for long-term impacts to surface-water quality. The lack of natural straining (filtration) of particulates or microorganisms.
Factors That May Decrease Risk	Appropriate siting, construction, and operation of wastewater treatment plants and outfalls.	Use of a high level of wastewater treatment and disinfection (results in high-quality wastewater).	The absence of drinking-water receptors (resulting from off-shore location for discharge points). Rapid, significant dilution achieved by siting in fast-moving currents and perhaps by the use of multiport diffusers.	Use of a high level of wastewater treatment and disinfection. The absence of drinking-water receptors (resulting from little reliance on surface-water bodies as sources of drinking water).

Table 8-1. Relevant Risk Assessment Issues for the Four Wastewater Management Options

Issue	Deep-Well Injection	Aquifer Recharge (RIBs)	Discharge to the Ocean	Discharge to Surface Waters
Data and Knowledge Gaps	Site-specific mechanisms of transport (for example, porous media flow vs. conduit flow); locations and connectivity of natural conduits such as solution channels. The fate and transport of pathogenic microorganisms; rates of die-off and natural attenuation. The extent of, if any, reduction in inorganic stressor concentration resulting from local geochemical conditions (for example, rate of biologically mediated transformation of ammonia). Groundwater monitoring data to describe transport to (or within) the Biscayne and surficial aquifers.	Site-specific hydrologic data (for example, horizontal hydraulic conductivities); site-specific estimates of horizontal time-of-travel. Groundwater monitoring data to describe transport within the Biscayne and surficial aquifers. Geospatial data to describe proximity to water-supply wells (especially private wells). Fate and transport of pathogenic micro-organisms still present after disinfection; rates and die-off.	The potential for adverse ecological effects near outfalls. The potential for bioaccumulation (such as metals, persistent organic compounds) through food chains. Water-quality and ecological monitoring downcurrent of outfalls (beyond mixing zones). The potential for changes in ocean currents, sea level, or climate that might affect changes in circulation and transportation patterns or exposure.	The potential for adverse ecological effects near points of discharge. The potential for bioaccumulation (such as metals, persistent organic compounds) through food chains. Water-quality and ecological monitoring data for specific potentially impacted water bodies. The nature and extent of recharge to surficial USDWs.

8.1.1 Wastewater Treatment and Disinfection

The four disposal options are generally associated with four different types of treatment and disinfection levels (Table 8-1). The type of treatment and level of disinfection given the wastewater before disposal, discharge, or recharge are the most important issues that affect risk. The treatment and disinfection determine the constituents that remain after treatment and therefore the potential stressors in the wastewater to be discharged.

The type of treatment and level of disinfection are factors that can be prescribed and controlled through management. This is in contrast to factors that are related to physical setting and natural processes and that are largely beyond the control of plant operators and risk managers. State and Federal laws require different minimum types of treatment, depending on the final disposal method. Although plant operators can opt to provide treatment beyond the minimum required, it is not usually practical.

Advanced wastewater treatment (AWT) is the highest level of wastewater treatment conducted in South Florida and poses the fewest risks to human health or ecological values. It combines several treatments and results in water that meets water-quality standards for receiving water bodies and also, for the most part, meets drinking-water standards. AWT includes secondary treatment, basic disinfection, filtration, high-level disinfection, nutrient removal, and removal of toxic compounds. Wastewater discharged to Tampa Bay, Sarasota Bay, and other already-impaired surface-water bodies must be treated to AWT levels (Table 8-1).

Treated wastewater bound for aquifer recharge and for discharge to Class I surface waters undergoes **secondary treatment and high-level disinfection**. This reclaimed water may contain small amounts of nitrogen and phosphorus and trace amounts of other inorganic and organic constituents.

Secondary treatment with basic disinfection represents a third and lower level of treatment (Table 8-1). This type of treatment and level of disinfection represent the minimum standard required of most wastewater treatment facilities in South Florida. Secondary treatment generally results in water of a quality that may often meet drinking-water standards in terms of chemical constituents but that still contains moderate amounts of nutrients (nitrogen and phosphorus) and small amounts of inorganic and organic compounds. However, basic disinfection may not achieve drinking-water standards for fecal coliform bacteria (nondetection). Because filtration is not provided, pathogenic protozoans, such as *Cryptosporidium*, *Giardia,* and other chlorine-resistant microorganisms may remain in the treated wastewater. Secondary treatment with basic disinfection is provided for wastewater destined for ocean outfalls.

In Florida, **secondary treatment without disinfection** is used when wastewater is discharged to deep-injection wells. This lowest level of treatment poses the highest potential risks (Table 8-1). Moderate amounts of nutrients and microorganisms may remain in this treated wastewater.

8.1.2 Large-scale Transport Processes

Large-scale transport processes represent another important factor in assessing risk. They include the physical processes of advection (large-scale mixing) and of dispersion and diffusion (small-scale movements of water and diluted constituents). Dilution occurs as a result of dispersion, advection, and diffusion. Concentrations of wastewater constituents decrease as dispersion and dilution occur in the receiving water body. The receiving water may be groundwater (deep-well injection and aquifer recharge), the ocean (discharge to the ocean), or surface-water bodies (discharge to surface waters) (Table 8-1). The relative effects of large-scale transport are likely more significant for discharges to the ocean, where there is rapid dilution in the Florida Current, than to deep-well injection and aquifer recharge, where transport is through porous rock media. However, regardless of the medium, large-scale transport processes have a role in the level of risk associated with each of the four wastewater treatment processes.

8.1.3 Distance and Time Separating Discharge Points and Potential Receptors

The physical separation (distance between the point at which effluent is discharged into the environment and the potential human or ecological receptors or drinking-water receptors) is another important factor when assessing risk. Like the type of treatment and level of disinfection used, the physical separation of discharge points from the potential receptors is under the control of risk managers and can be adjusted through careful planning and siting of treatment plants and of the associated discharge points. However, in many cases, it is not feasible for the risk manager to manipulate the factors affecting time and distance to reduce risk. For example, increasing the distance to potential receptors may be difficult or impossible for existing treatment facilities.

The time of travel needed for effluent water and effluent constituents to reach possible drinking-water, human, or ecological receptors is related to the distance, the nature of the environment through which the effluent must travel, and the nature of the stressors remaining in the effluent. In general, the longer the time of travel and the greater the distance the effluent must migrate, the lower the risk. However, if problems are identified in a given situation, long times of travel may mean that the benefits of corrective actions will not be realized for some time.

In general, higher relative risks are related to fast times of travel because of the potentially rapid exposure of receptors and the limited attenuation that may achieved by filtering or straining. However, in the case of ocean disposal, where the time of travel may be almost instantaneous, attenuation by dilution can greatly reduce potential risk.

Direct comparisons between the distances and times of travel for the four wastewater treatments options provide no useful assessment of risk because the four options involve very different processes. As an example, there is virtually immediate transport between the discharge point and potential receptors for discharge to the ocean or to a surface-water body, whereas contact between a stressor and a receptor for some deep-well injection can be on the order of hundreds of years (Table 8–1).

8.1.4 Attenuation Processes

Attenuation results in a decrease in concentration of wastewater constituents. Depending on the disposal option being used, attenuation can have a significant role in reducing the concentrations of effluent constituents, including potential stressors. The attenuation processes and the degree to which they are effective in reducing concentrations depends on the media through which the effluent moves and how the constituents interact with those media.

In the ocean and in surface-water bodies, attenuation processes may include dilution, microbial and biological processes, photo-oxidation (by natural sunlight) of organic compounds, inactivation of viruses and bacteria by ultraviolet rays (in sunlight), adsorption onto sediment or organic particles, and settling of particles containing adsorbed wastewater constituents (Table 8-1).

In the subsurface, attenuation processes include dilution, adsorption to geologic material, entrapment or filtration of microorganisms and other constituents, oxidation, reduction, or other chemical processes that affect the mobility of constituents, and biological degradation of organic compounds (Table 8-1). There may be some microbial transformation (denitrification) of nutrients nearer to the surface, but overall microbial decomposition or other microbial activities is not expected to be significant.

The highest potential risks are associated with the least attenuation of stressors. Although all four management options provide attenuation, the least attenuation is probably associated with deep-well injection. In the absence of information to the contrary, the subsurface environment may have low rates of biological and chemical degradation, compared to surface-water bodies and soils. However, for deep injection wells, all constituents except nitrate and metals typically decrease to lower levels by the time the effluent water reaches the USDWs. This is because of the long travel times associated with deep-well injection.

For deep injection wells in Dade and Brevard counties, the concentrations of all constituents except nitrate and metals decrease to lower levels by the time the effluent water reaches the drinking-water receptors. Nitrate and metals may remain at the same concentration as the discharge point unless local geochemical conditions facilitate attenuation. In Pinellas County, effluent water may reach drinking-water receptors because of the short overall vertical travel time. However Pinellas County uses a higher level of treatment, and so the initial effluent may have low concentrations of stressors, which are further reduced by the time the effluent water reaches receptors.

Microbial survival in the deep subsurface and in groundwater is also an important issue, because wastewater injected into deep-injection wells is not disinfected or filtered. The processes involved in microbial survival are not well understood and constitute an information gap. Inactivation rates for fecal coliforms range up to tens of days for 90% inactivation (Bitton et al., 1983; Medema et al., 1997). As a result, the microorganisms likely cannot survive the months, decades, or years of transport before reaching drinking-

water receptors. However, there are no studies that examine long-term survival and transport of microorganisms in the context of deep-well injection. Inactivation times for pathogenic protozoans, such as *Cryptosporidium,* may be in a range that would pose a human health risk if significant numbers of *Cryptosporidium* were present initially in the discharged effluent (Table 8-1).

For aquifer recharge, travel times are shorter than for deep-well injection, but the effluent must travel through soils and, in some cases, surface vegetation. Uptake of potential stressors by soils and vegetation may constitute an important attenuation process for disposal by aquifer recharge. Also, reclaimed water for aquifer recharge does not pose the same degree of microbial risk as deep-well injection or ocean outfalls because the level of treatment and disinfection is higher.

Ocean outfalls have designated mixing zones associated with each outfall. Water-quality standards are usually met for ocean disposal because of the rapid attenuation within the mixing zone from dilution. Within the mixing zone, the level of stressors may temporarily exceed standards; however, by the time the effluent reaches the boundary of the mixing zone, dilution has reduced the levels of stressors.

Treated wastewater discharged to surface waters generally meets surface-water quality standards (for Class III waters). In some cases, monitoring data indicate that the discharged water is of higher quality than the receiving water. Treated wastewater still contains small amounts of nutrients and other constituents. This is especially significant for phosphorus, which can stimulate algal blooms in nearshore or brackish environments. Since high-level disinfection and filtration are provided, risks from pathogenic microorganisms are very low.

8.1.5 Factors That Contribute To or Diminish Risk

In general, factors that when present contribute to risk are the same factors that when eliminated diminish risk. For example, proximity to human or ecological or drinking water receptors will increase risk, whereas increasing the distances to or travel times for these receptors will diminish the risk (Table 8-1). Also, the factors that may contribute to risk for one particular disposal option may have no effect on other disposal methods. For example, a lack of natural straining and filtering by geologic media will increase risk for deep-well injection when flow is preferentially through cracks, fissures, and cavernous openings. However, for ocean disposal, this lack of attenuation by natural straining or filtering may be insignificant as far as human and ecological health effects because of the dilution of effluent by the ocean.

The major factors that decrease risk are use of a higher degree of treatment, a high degree of dilution in receiving water, long travel times to receptors, and the ability of the system to recover quickly if input of wastewater constituents were to decrease or cease. Aquifer recharge and surface-water discharge are characterized by higher degrees of treatment and by rapid potential recovery rates. Ocean outfalls and surface-water discharge are characterized by rapid dilution, more so for ocean outfalls than for surface water discharges. Class I injection wells are characterized by very long travel times for effluent

to reach drinking-water receptors in Dade and Brevard Counties (but short travel times in Pinellas County).

8.1.6 Data and Knowledge Gaps

For all four wastewater disposal options, there is limited site-specific information concerning potential ecological effects, bioaccumulation of wastewater constituents, survival and transport of pathogenic microorganisms, and of specific evidence (such as tracers) that link stressors from disposal options to ecological or biological or human health effects. The potential effects of local geochemical conditions on fate and transport of nitrate and metals cannot be assessed with available information.

Table 8–1 lists the major areas where information and data are lacking. Key general areas where information is needed to better design, manage, and control wastewater treatment and disposal include the following:

- Microbial survival, inactivation, and transportation rates in groundwater
- Rates for microbial straining or filtration by geologic media under different flow scenarios
- Extent of hydrologic connection between groundwater, surface water, and the ocean
- Definitive tracer studies to conclusively prove that monitored stressors are derived from discharged treated wastewater and to conclusively demonstrate the most likely transportation pathways
- Monitoring ecological or human health effects
- Monitoring effects of climate change on large-scale transportation processes.

8.2 Risk Issues Relevant to Human Health

The potential human health risks associated with each wastewater disposal option differ, but overall they can be considered low (Table 8–2). Just as for the general risk-related issues discussed above, quantitative comparisons between the four disposal options are not feasible. However, the information in Table 8–2 identifies key issues for human health and allows the reader to relate these issues between the four wastewater treatment options. Of the various human health stressors identified, pathogenic protozoans (*Cryptosporidium*, *Giardia*) are the most important for all but the surface water option where high level disinfection is provided. The deep-well injection process is dominated by porous media flow, long travel times and fine pore spaces may attenuate and retain microorganisms including protozoans. When wastewater treatment includes filtration, the risk posed by pathogenic protozoans decreases significantly but does not disappear, partly because filtration must be maintained at a high level in order to remove protozoans. When wastewater treatment does not include high-level disinfection or basic disinfection, the risks posed by viruses and bacteria are significantly higher.

Table 8-2. Relevant Issues for Human Health

Issues	Deep-Well Injection	Aquifer Recharge (using RIBs)	Discharge to the Ocean	Discharge to Surface Waters
Human Health Stressors Remaining After Treatment	Infective bacteria or viruses and pathogenic protozoans. Nitrates and ammonia.	Bacteria and viruses are effectively inactivated; there may remain low mean numbers of pathogenic protozoans with occasional instances of higher numbers. Disinfection byproducts, such as trihalomethanes, may remain.	Small numbers of infective bacteria or viruses may remain, as well as pathogenic protozoans (those that can survive basic disinfection). Remaining nitrogen and phosphorus, in excess, can cause harmful algal blooms, which are secondary stressors. Metals or organic compounds; these may bioaccumulate in fish or shellfish consumed by humans.	Infective bacteria and viruses are effectively inactivated; low numbers of pathogenic protozoans may remain. Remaining nitrogen and phosphorus, in excess, can cause harmful algal blooms, which are secondary stressors. Metals or organic compounds; these may bioaccumulate in fish or shellfish consumed by humans.

Table 8-2. Relevant Issues for Human Health

Issues	Deep-Well Injection	Aquifer Recharge (using RIBs)	Discharge to the Ocean	Discharge to Surface Waters
Treatment Adequacy	Disinfection is not conducted and so pathogenic bacteria and viruses are not inactivated. Levels of *Cryptosporidium* and *Giardia* are uncertain. This wastewater is usually not filtered and likely exceeds the State health-based limits (reuse limits) for pathogenic protozoans. Levels of disinfection byproducts may rarely exceed health standards. Levels of nitrate occasionally exceed the drinking-water standard (MCL). Levels of ammonia meet the EPA lifetime health-advisory limit; exceed stringent risk-based criteria that account for indoor air exposure. Levels of regulated metals and organic compounds typically meet drinking-water MCLs.	High-level disinfection inactivates pathogenic bacteria and viruses. Filtration is generally adequate to remove *Cryptosporidium* and *Giardia*; levels occasionally exceed health-based limits. Levels of disinfection by-products (for example, total trihalomethanes) or ammonia may rarely exceed health-based standards. Levels of nitrate, regulated metals, and organic compounds typically meet drinking-water MCLs.	Pathogenic bacteria and viruses are inactivated by basic disinfection. However, the levels of bacteria may occasionally exceed the fecal coliform limit for recreational waters (14 per 100 milliliters). Levels of the pathogenic protozoans *Cryptosporidium* and *Giardia* are uncertain. This wastewater is usually not filtered, and so it may exceed the State health-based limits (reuse limits). Levels of nitrate, regulated metals, and organic compounds typically meet drinking-water MCLs. Nutrient levels (nitrogen, phosphorus) typically exceed ambient concentrations. These nutrients can cause localized harmful algal blooms.	AWT inactivates pathogenic bacteria and viruses. Filtration is generally adequate to remove *Cryptosporidium* and *Giardia*; levels are typically below ambient concentrations in surface waters. Levels of disinfection byproducts (for example, total trihalomethanes) may rarely exceed health-based standards. Levels of nitrate, regulated metals, and organic compounds typically meet drinking-water MCLs.

Table 8-2. Relevant Issues for Human Health

Issues	Deep-Well Injection	Aquifer Recharge (using RIBs)	Discharge to the Ocean	Discharge to Surface Waters
Known Significant Exposure Pathways	Transport of stressors to deep USDWs.	Transport of stressors to shallow USDWs.	No known significant exposure pathways.	Dermal contact or accidental ingestion associated with recreational use of water bodies.
Potential Exposure Pathways	Transport of stressors to shallow USDWs and to public or private water-supply wells. Exposure to significant stressor concentrations is unlikely, but depends upon proximity and site-specific vertical times of travel.	Transport of stressors to public or private water-supply wells. Exposure to significant stressor concentrations is unlikely, but depends upon drinking water well proximity and highly variable horizontal times of travel. Additional pathways are associated with other forms of reuse not discussed here (such as inhalation exposure to aerosols created by spray irrigation).	Dermal contact or accidental ingestion associated with recreational use. Ingestion of contaminated fish or shellfish. Possible stimulation of harmful algal blooms (that is, "red tide"); these can increase algal toxins in marine water and air.	Recharge to shallow USDWs and subsequent transport; exposure to significant stressor concentrations is unlikely (pathogens are a possible exception). Ingestion of contaminated fish or shellfish.

Table 8-2. Relevant Issues for Human Health

Issues	Deep-Well Injection	Aquifer Recharge (using RIBs)	Discharge to the Ocean	Discharge to Surface Waters
Data and Knowledge Gaps	Survival and transport of pathogenic microorganisms in the deep subsurface. Exact means of transport at specific locations (for example, porous media flow versus bulk flow through conduits). Rates of biogeochemical transformation for conservative compounds (such as nitrate and ammonia). This is of particular relevance in relatively shallow aquifers.	There is incomplete information regarding the presence and numbers of pathogens in reclaimed water. Little is known about the survival and transport of pathogenic microorganisms in the shallow subsurface and surficial aquifers. Extent of surface-water recharge to surficial USDWs.	Downstream monitoring information from outside of the mixing zones is not available. The potential for changes in the circulation of ocean currents is unknown, as is the subsequent effect changes may have on transport within the effluent plume. Potential for bioaccumulation or bioconcentration of metals and persistent organic compounds is not known or understood.	Survival and transport of pathogenic microorganisms in surface-water bodies and coastal embayments. Extent of surface-water recharge to surficial USDWs. Potential for bioaccumulation or bioconcentration of metals and persistent organic compounds.

Table 8-2. Relevant Issues for Human Health

Issues	Deep-Well Injection	Aquifer Recharge (using RIBs)	Discharge to the Ocean	Discharge to Surface Waters
Overall Estimate of Human Health Risk	Low where proper siting, construction, and operation result in physical isolation of stressors, with no fluid movement. Low where there have been impacts to deep USDWs; however, exposure of current water supplies is unlikely. Increased risk where short times of travel prevail and where exposure of current water supplies is more likely. In all cases, the risk would be further reduced when injected wastewater is treated to reclaimed water standards.	Low when treated with high-level disinfection, filtration, and treatment to reclaimed-water standards. Increased risk where filtration is not adequate to meet health-based recommendations for *Giardia* or *Cryptosporidium*. Increased risk where chlorination results in high levels of disinfection byproducts (that is, failure to dechlorinate).	Low because of rapid dilution and an absence of drinking-water receptors. The low probability (less than 4%) that current flow is towards the coast means that human exposure along coastal beaches is reduced. Increased risk where recreational use is near the discharge. Increased risk where discharges contribute to stimulation of harmful algal blooms.	Low when treated with high-level disinfection and treatment to AWT standards. Increased risk where filtration is not provided or is inadequate to meet health-based recommendations for *Giardia* or *Cryptosporidium*. Increased risk where surface-water discharges are near recreational use of water bodies. Increased risk where discharges contribute to stimulation of harmful algal blooms.

Other lower-priority human health stressors included nitrate and ammonia associated with deep-well injection and nitrogen and phosphorus associated with ocean outfalls (because of the potential for causing harmful algal blooms). Persistent organic compounds may pose some risks in the deep-well injection option when shorter travel times occur and when treatment is not adequate to reduce concentrations below the MCL (Table 8-2).

For aquifer recharge, disinfection byproducts, such as trihalomethanes, also may be of concern in reclaimed water that is not dechlorinated (Table 8-2).

Other human health stressors, including metals and organic compounds, are associated with all options. For aquifer recharge and surface-water discharge, nutrients are lower-priority human health stressors, because treatment of wastewater for these options removes significant amounts of nutrients.

Wastewater treatment is adequate for metals and most organic compounds to meet existing regulatory standards and drinking-water MCLs (Table 8-2). However, there are no quantitative standards for unregulated substances, such as endocrine disruptors and detergents, or for *Cryptosporidium* and other pathogenic protozoans.

8.3 Risk Issues Relevant to Ecological Health

Just as for human health risks, the potential ecological health risks differ, depending on the option. However, there is somewhat more of a gradation between the different disposal options (Table 8-3). The overall risk is likely very low (but probably not zero) for aquifer recharge, discharge to surface waters, and deep injection wells in Dade and Brevard counties; low for discharges to the ocean; and moderate for deep injection wells in Pinellas County.

Nutrients are the major ecological stressors for all four disposal options. Nutrients can potentially stimulate primary production, and this can lead to eutrophication or other adverse changes in community structure. Because of its mobility in groundwater, nitrogen is the primary nutrient of concern for deep injection wells and aquifer recharge. Phosphorus is not a concern for these disposal options because phosphorus tends to adsorb quickly to sediment or soil. Nitrogen is also the primary nutrient of concern for ocean outfalls because it is generally the limiting nutrient for primary production in the ocean. For discharges to fresh-to-brackish surface water, phosphorus poses the greatest concern because it is generally limiting in such systems and is not as quickly immobilized as it is in soil.

Table 8-3. Relevant Issues for Ecological Health

Issue	Deep-Well Injection	Aquifer Recharge (RIBs)	Discharge to the Ocean	Discharge to Surface Waters
Ecological Health Stressors Remaining After Treatment	Nitrogen. Metals, organic compounds, phosphorus, pathogenic micro-organisms.	Nitrogen. Disinfection by-products. Metals, organic compounds, phosphorus, pathogenic micro-organisms.	Nitrogen and phosphorus. Metals, organic compounds, pathogenic micro-organisms.	Nitrogen and phosphorus. Metals, organic compounds, pathogenic micro-organisms.
Treatment Adequacy	Post-treatment nutrient levels are high enough to pose potential ecological risks for surface-water bodies. However, no off-site ground water monitoring is conducted and so actual subsurface levels are not known. The presence of subsurface receptors is also not known.	Post-treatment nutrient levels may exceed recommended levels for unimpacted water bodies, but are lower than concentrations in secondary-treated wastewater and also lower than some ambient levels in surface-water bodies.	Nutrient levels are high enough to pose potential ecological risks if dilution does not occur or if there are cumulative effects over time. However, no ecological monitoring is conducted, and so individual or cumulative effects are not understood or identified.	Nutrient levels may exceed recommended levels for unimpacted water bodies. Discharges to sensitive water bodies (such as Tampa Bay) must meet a 3-milligram-per-liter limit on total nitrogen (a 70% reduction).

Table 8-3. Relevant Issues for Ecological Health

Issue	Deep-Well Injection	Aquifer Recharge (RIBs)	Discharge to the Ocean	Discharge to Surface Waters
Known and Potential Exposure Pathways	Transport of stressors to surface-water bodies is feasible, but would occur over long time frames. Pinellas County has shorter times of travel but a higher level of treatment is used and so risk is reduced.	Pathways include contact, ingestion and inhalation. Exposure of ecological receptors may occur in areas where there is significant surface water or groundwater interaction or exchange. Exposure is most likely where surface-water bodies are near RIBs or under direct influence from groundwater.	Pathways include contact, ingestion and inhalation. Fish and other marine organisms within the mixing zone are exposed to potential stressors. The effects of cumulative or chronic exposure to elevated concentrations of some potential stressors (such as metals) are not known.	Pathways include contact, ingestion and inhalation. Ecological receptors near the discharge points are exposed to potential stressors. Discharges may contribute to cumulative effects such as nutrient loading and bioaccumulation. Discharges may aggravate conditions in some surface-water ecosystems already under stress.
Recommended Water Quality for Ecological Protection	If injectate reaches surface waters, the nitrate level may exceed recommended surface-water levels in the absence of denitrification in the subsurface.	Reclaimed water standards do not meet ecological protection recommended standards, but does meet Florida standards for receiving waters.	Exceeds the recommended levels within the allowed mixing zone (502,655 square meters). Effluent plume may occasionally exceed Class III marine water-quality standards outside the mixing zone.	AWT may not be sufficient for ecological health water-quality standards, but otherwise meets Florida Class III standards for receiving waters.

Table 8-3. Relevant Issues for Ecological Health

Issue	Deep-Well Injection	Aquifer Recharge (RIBs)	Discharge to the Ocean	Discharge to Surface Waters
Data and Knowledge Gaps	Survival and transport of microorganisms in the deep subsurface; microbial transformation processes in deep subsurface; cumulative impacts of long-term disposal.	Impact of aquifer recharge on groundwater movement and the transport of existing groundwater contaminants; ecological impacts on nearby wetlands; cumulative and long-term impacts.	Cumulative impacts of long-term disposal of nutrients; ecological impacts or bioaccumulation of metals or other compounds in the biota at or near discharge points; impact of global climate change on ocean currents and effluent dispersal.	Ecological impacts of nutrient phosphorus or bioaccumulation of metals or other compounds in the biota; cumulative effects.
Overall Ecological Health Risk	The risks from chemical constituents are low, but not zero, because of possible hydrologic connectivity. Risks related to pathogenic microorganisms are low to moderate for Dade and Brevard counties because of lack of disinfection and filtration. Microbial risk is very low in Pinellas County because of use of disinfection and filtration.	Low because of possibility of hydrologic connectivity between wetlands and surficial aquifer. Cumulative and long-term effects are not known.	Low because of the concentrations of nutrients in the discharged effluent. No ecological monitoring is currently conducted. Cumulative and long-term effects are not known.	Low because of the concentration of nutrients in the discharged effluent.

Metals and organic compounds are also ecological stressors for all options. However, they are considered a lower stressor than nutrients because the information reviewed did not identify toxic effects over the short-term at either acute or chronic exposure levels. Pathogenic microorganisms are also considered a lower-priority ecological stressor, although there is evidence to suggest that aquatic organisms suffer from high concentrations of enteric microorganisms, just as humans do. The low concentrations of microorganisms associated with aquifer recharge and discharge to surface water implies that there probably are few, if any, ecological effects.

8.4 Conclusion

This relative risk assessment analyzed and characterized potential human health and ecological risks associated with four wastewater management options currently in use in South Florida. The relative risk assessment emphasized analysis and characterization of the processes involved in each option and, in particular, of the processes that affect fate and transport of disposed wastewater effluent. There are many physical, chemical, and biological factors that affect risk. Their degree of influence varies widely, depending on the particular disposal option. Some factors can be readily manipulated and managed to control or reduce risk.

Each of the four wastewater management options is associated with existing State programs that have been operating over a period of years and that have levels of control focused on the risks posed by that management option. As demonstrated by the range of information and data presented in the four chapters dealing with the individual options, each management option for treatment and disposal is extremely complex and can vary, depending on site-specific conditions and constraints. This makes the task of interpreting the data and presenting the relative risk assessment very difficult. In spite of this, for all options, there is either low or no risk.

There is a decrease in the level of confidence concerning deep-well injection. In some cases, a lack of confinement of the injected effluent has been confirmed, and the areal extent of the fluid is unknown. This migration of effluent seems to be associated with very few site-specific cases but warrants attention. Also, although risks to ecological health are also considered low, there are considerable data gaps concerning the biota and natural systems. Additional or new information and data could provide additional insight into the actual risks.

For all four wastewater disposal options, the type of wastewater treatment used may be the most simple factor for comparing the concentrations of stressors that may come in contact with a receptor. Treatment type and the resulting concentration of stressors is a risk factor that can be managed. However, the feasibility of using a particular type of treatment is not equal across the four disposal options.

Another significant issue for both human and ecological health is the distance that must be traveled by discharged effluent in order to reach a receptor. The longer the distance

traveled to a receptor (and the greater the time of travel), the lower the risk. Distance and the associated travel time is also a risk factor that can be manipulated by risk managers.

Natural attenuation processes can significantly reduce risks in all of the options. The type and opportunity for attenuation is very specific to the particular disposal option and the local conditions under which it is used. Natural attenuation processes include filtration by geologic media, dispersion by groundwater or ocean currents, biological degradation, adsorption, and photo-oxidation. The distance between the receptors and stressors and the resulting travel times are important factors that can further enhance attenuation.

Depending on the geographic location, there are significant differences in hydrogeology, coastal hydrology, and water quality in South Florida. These site-specific and regional characteristics can determine whether there is a very low risk or a significant risk. For example, deep-well disposal in Dade and Brevard counties have long travel times in comparison to Pinellas County. However, this potential increased risk for Pinellas County is ameliorated by providing a higher level of wastewater treatment in Pinellas County. As another example, the coastal conditions off southeast Florida are favorable for ocean disposal because the local currents result in rapid dispersion and dilution, whereas the circulation and water-quality conditions along Florida's Gulf Coast would probably preclude placement of outfalls.

The relative risk assessment identified major data and knowledge gaps for all of the disposal options. This is particularly the case for how natural processes may influence attenuation in deep-well injection and in the extent and nature of ecological impacts. The relative risk assessment relied on existing information and data and some modeling of that data. It is clear that for deep-well injection, many issues have never been addressed because of the belief that there would be no movement of the effluent into USDWs once the fluid was injected. The confirmation of fluid movement, even in the few cases reported, reveals that there is much about the pathways, flow, attenuation, and so forth that is little understood, given the fact that injected fluid can reach USDWs in some cases.

For all options, there is very limited information concerning ecological health effects. Water-quality standards do not exist for this area, and in many cases, the numbers and types of receptors may not be known. Also, compared to human health effects, there is little information on the impacts of specific stressors on specific populations (such as zooplankton, fisheries, marine mammals, birds).

Definitive studies are needed to track stressors back to their origins or sources because there are many potential sources other than wastewater disposal for the same stressors. It is important to identify and recognize the contributions of various sources of stressors. Cumulative effects are not well understood for either human or ecological receptors and may go unrecognized. As more demand develops for additional wastewater treatment capacity in South Florida, these data and information gaps will likely need to be addressed so that new facilities can be designed, constructed, operated and maintained with full confidence that public health and the environment are protected.

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