Basic disinfection will deactivate most of the viruses and pathogens (see treatment requirements, above), but will not deactivate protozoans such as *Cryptosporidium* or *Giardia*, which must be filtered out.

6.5.1.1 Nutrients and Eutrophication

Nutrients act as potential stressors when they stimulate primary production that results in eutrophication. In coastal waters such as those of southeast Florida, as in large areas of the world's oceans, coastal, and estuarine waters, primary production is usually limited by nitrogen (Dugdale, 1967; Ryther and Dunstan, 1971; Codispoti, 1989; Paerl, 1997). However, phosphorus can be limiting under some conditions, particularly in coastal waters where there may be varying salinities. On geologic time scales, phosphorus is believed to limit marine productivity (Howarth, 1988; Holland, 1978; Smith, 1984; Codispoti, 1989; Ruttenberg, 1993). Some marine cyanobacteria, Sargasso Sea phytoplankton, and some Caribbean macroalgae are phosphorus-limited (LaPointe, 1997; Sellner, 1997; Cotner et al., 1997).

A recent National Academy review of the causes of eutrophication of coastal waters found that nutrient overenrichment of coastal marine waters have resulted in the following adverse effects (National Research Council, 2000):

- Increased primary productivity
- Increased oxygen demand and hypoxia
- Shifts in community structure caused by anoxia and hypoxia
- Changes in phytoplankton community structure
- Harmful algal blooms
- Degradation of seagrass and algal beds and formation of nuisance algal mats
- Coral reef destruction.

The National Research Council review concluded that, while nitrogen is important in controlling primary production in coastal waters and phosphorus is important in fresh water systems, both need to be managed to avoid one or the other becoming the limiting nutrient (National Research Council, 2000). The differences in causes of eutrophication between fresh and marine ecosystems stem from a variety of ecological and biogeochemical factors, including the relative inputs of nitrogen versus phosphorus within the ecosystem and the extent to which nitrogen fixation can alleviate nitrogen shortages. In addition, eutrophication of coastal systems is often accompanied by decreased silica availability and increased iron availability, both of which may promote the formation of harmful algal blooms (National Research Council, 2000).

There are exceptions to the general principle that nitrogen is limiting in coastal ecosystems. For instance, the Apalachicola estuarine system on the Gulf coast of Florida appears to be phosphorus-limited (Myers and Iverson, 1981). Howarth (1988) and Billen et al. (1991) postulate that this is related to the relatively high ratio of nitrogen to phosphorus inputs. However, in this case, the ratio may also reflect the relatively small amount of human disturbance in the watershed and the relatively low nutrient inputs overall. Howarth et al. (1995) suggests that there is a tendency for estuaries to become more nitrogen-limited as they become more affected by humans and as nutrient inputs increase overall. This is because productivity is a function of the availability of nutrients to phytoplankton.

In nearshore tropical marine systems, phosphorus appears to be more limiting for primary production (Howarth et al., 1995), while the tropical open ocean is nitrogen-limited (Corredor et al., 1999). Nutrient limitation switches seasonally between nitrogen and phosphorus in some major estuaries such as the Chesapeake Bay (Malone et al., 1996) and in portions of the Gulf of Mexico, including the so-called "dead zone" (Rabalais et al., 1999).

There are approximately 300 species of algae known to produce "red tides," including flagellates, dinoflagellates, diatoms, silicoflagellates, prymnesiopytes, and raphidophytes. Of these 300 species, approximately 60 to 80 species are actually harmful or toxic as a result of their biotoxins, nutritional unsuitability, and ability to cause physical damage or anoxia, reduce irradiance, and so forth. (Smayda, 1997). In Florida, problematic harmful algae bloom (HAB) species include *Pfiesteria* species, *Cryptoperidiniopsoid*, *Alexandrium monilatum*, *Chattonella subsalsa*, *Dinophysis* spp., *Gambierdiscus toxicus*, *Gymnodinium pulchellum*, *Gyrodinium galatheanum*, *Gymnodinium breve*, *Karenia brevis* (said to be the most common cause of red tide on the Florida coast), *Karenia mikimotoi*, and the benthic genus *Prorocentrum* spp. The Gulf coast of Florida has been typically more affected by HABs, particularly of *Gymnodinium breve*, often during the summer and fall when seasonal changes in the wind and sea surface temperature occur (FFWCC, 2001).

Toxic symptoms of HABs can affect both humans and animals and include paralytic shellfish poisoning (PSP), diarrheic shellfish poisoning (DSP), amnesic shellfish poisoning (ASP), ciguatera fish poisoning (CFP), and neurotoxic shellfish poisoning (NSP). The effects range from discomfort to incapacitation to mortality (FFWCC, 2002a).

Environmental changes that may stimulate HABs include a variety of physical, chemical, and biological factors, such as climate change, increased pollution and nutrient inputs, habitat degradation through dredging, resource harvesting and regulation of water flows, and the failure of grazing organisms to control algal growth. The two primary algal groups that produce blooms in response to nutrient inputs are the cyanobacteria and macroalgae, as well as other species from different groups (NOAA, 2002b). Even nontoxic HABs can disrupt other organisms through biofouling, clogging of gills, or smothering of coral reefs and seagrass beds in South Florida (LaPointe, 1997).

HABs can also be caused by marine cyanobacteria, commonly called blue-green algae. Marine cyanobacterial species responsible for HABs include only a few taxa, such as *Trichodesmium*, *Richelia*, *Nodularia*, and *Aphanizomenon*. *Trichodesmium*, which is nitrogen-fixing, is found in low- and mid-latitude oceans and seas of the Atlantic, Pacific, and Indian oceans. Marine cyanobacterial blooms can occur in warm stratified areas in the ocean and in embayments and estuaries where nitrogen concentrations are often low, salinities are reduced, and where phosphorus becomes enriched through upwelling, eddies, mixing, or other sources. Phosphorus limitation appears to be more important than nitrogen limitation, since some of these species are nitrogen-fixing and inhabit nitrogen-poor waters (Sellner, 1997).

Human and animal health can be affected by ingestion of the toxins created by cyanobacteria such as *Trichodesmium*, *Nodularia* and *Aphanizomenon*, as documented by livestock, canine, and human cases (Sellner, 1997; Nehring, 1993; Edler et al., 1985). Other adverse effects of *Trichodesmium* blooms include mortality of mice, brine shrimp, and copepods; asphyxiation of fish, crabs, and bivalves; retreat of zooplankton to deeper waters free of the algae; and food-chain effects (reviewed in Sellner, 1997).

In Florida, extensive blooms of cyanobacteria, involving the cyanobacteria *Lyngbya majuscula*, a species that occurs worldwide, were documented in Tampa Bay in 1999 and from Sarasota Bay to Tampa Bay in 2000. Although this species is not toxic, it can produce large slimy brown floating mats and emit a foul odor (FFWCC, 1999). The causes of these blooms are unknown, although they are not believed to be related to sewage releases.

6.5.1.2 Pathogenic Microorganisms

Potential microbial stressors in treated wastewater include pathogenic enteric bacteria, protozoans, and viruses associated with human or animal wastes. Untreated raw sewage typically contains fecal indicator bacteria (such as fecal coliforms, total coliforms, and fecal streptococci) in concentrations ranging from several colonies to tens of millions of colonies per 100 mL (see Table 6-3). Other pathogens that are potentially present include other bacteria (*Campylobacteria jejuni*, *Legionella pneumophila*, *Salmonella typhi*, *Shigella*, or *Vibrio cholerae*), helminthes (such as hookworm, roundworm, or tapeworm), viruses (adenovirus, enteroviruses, hepatitis A, rotavirus, Norwalk agent, parvovirus, and others), and protozoa (*Cryptosporidium parvum*, *Giardia lamblia*, *Balantidium coli*, *Entamoeba histolytica*) (York et al., 2002).

Table 6-3. Typical Concentrations of Fecal Indicator Bacteria in Raw Untreated Sewage

Wastewater Source	Total Coliforms (colonies per 100 mL)	Fecal Coliforms (colonies per 100 mL)	Fecal Streptococci (colonies per 100 mL)
Raw sewage	22×10^6	8×10^6	1.6×10^6

Source: Wood et al., 1993, based on data from Geldreich, 1978, for communities in the United States.

For comparison, basic disinfection of secondary-treated wastewater must achieve the microbial standards of 200 and 2,000 colonies per 100 mL of wastewater for fecal coliforms and total coliforms, respectively, depending on the type of bacteria involved. Disinfection to these levels represents reductions of 10^4 or more.

Although secondary-treated wastewater destined for ocean outfalls is treated with chlorination, the minimal amount of chlorination needed to meet Class III water quality standards after dilution is generally used, in order to avoid the adverse effects of overchlorination. Pathogenic microorganisms that are not affected by secondary treatment or chlorination include the protozoans *Giardia* and *Cryptosporidium*, which are resistant because they form cysts that can remain dormant for periods of time and can be removed only through filtration. Filtration followed by disinfection is effective at removing viruses, while secondary treatment and chlorination is effective at removing helminthes (Rose and Carnahan, 1992).

Microbial contamination from enteric viruses, bacteria, and protozoans is a chronic problem in the Tampa Bay, Sarasota Bay, and Florida Keys coastal environments. This is probably because of high concentrations of onsite sewage disposal systems, porous sandy karst soils, and hydrologic connections between groundwater and coastal embayments and estuaries (Lipp et al., 2001; Paul et al., 1995). Survival of microorganisms in water is affected by a number of physical and biological factors, such as ultraviolet radiation and predation by grazers (Wood et al., 1993). Field measurements around the world provide a range of values of the time needed for reduction of enteric bacterial populations in seawater to 90 percent of their original concentrations (that is, t_{90}). These values for t_{90} range from 0.6 to 24 hours in daylight to 60 to 100 hours at night (reviewed in Wood et al., 1993). Enteric viruses tend to survive longer in seawater than do enteric bacteria: at 20 °C, if the t_{90} for bacteria was 0.6 to 8 hours, the t_{90} for enteric viruses was 16 to 24 hours (Feacham et al., 1983). Fecal streptococci tend to be more persistent than fecal coliforms in seawater (Wood et al., 1993).

The initial SEFLOE experiments involved the monitoring of plumes of unchlorinated treated effluent in the ocean to determine how dilution and natural attenuation processes would affect microbial concentrations of fecal coliforms, total coliforms, and enterococci. To provide guidance on the level of chlorination needed, these data were then used to calculate what the maximum bacterial concentrations in chlorinated effluent should be to achieve a given dilution at a given distance from the outfall. Southeast Florida wastewater treatment plants routinely provide secondary treatment and chlorination of wastewater to meet these standards (Hazen and Sawyer, 1994).

Because secondary effluent discharged through ocean outfalls is not filtered to remove protozoans such as *Giardia* or *Cryptosporidium*, these protozoans may pose potential human health risks that need to be evaluated.

6.5.1.3 Priority Pollutant Metals

Metals found in wastewater may constitute potential stressors because of potential human health risks and ecological risks. Metals are normally present in trace amounts in seawater (Bruland, 1984) and in higher amounts in sediments (Holland, 1978), but their concentrations are commonly elevated in wastewater because of the many anthropogenic uses of metals. As a consequence, metals are frequently used as tracers of wastewater in the ocean (Matthai and Birch, 2000; Flegal et al., 1995; Hershelman et al., 1981; Ravizza and Bothner, 1996; Morel et al., 1975). Marine disposal of untreated sewage or sewage sludge typically results in elevated concentrations of metals (typically chromium, copper, nickel, lead, silver, zinc, and iron) and other contaminants on the seafloor (Zdanowicz et al., 1991; Zdanowicz et al., 1995). Other sources of anthropogenic and natural metals to the ocean include stormwater runoff, inputs from surface water (rivers, streams) and groundwater, and atmospheric dust (Burnett and Schaeffer, 1980; Finney and Huh, 1989; Forstner and Wittman, 1979; Huh et al., 1992; Huntzicker et al., 1975; Klein and Goldberg, 1970).

Information on metal concentrations in marine organisms from this area includes the Mussel Watch Program, which is part of NOAA's National Status and Trends Program (NSTP). The NSTP found elevated concentrations of arsenic in oysters extending from the Florida panhandle in the eastern Gulf of Mexico, South Florida (Biscayne Bay and Miami River), and up the east coast of Florida to North Carolina. Potential sources of arsenic include both natural sources (phosphorite rocks) and anthropogenic sources (for example, anthropogenic inputs to Biscayne Bay from pesticides in agricultural runoff and phosphate mining). Oysters are a food source for humans, birds, and other organisms, thus there is a potential for secondary uptake of arsenic (Valette-Silver et al., 1999). Because oysters are typically found in nearshore environments and not in deeper shelf waters, it is probable that the arsenic found in these studies originates from more nearshore or terrestrial sources, whether anthropogenic or natural. This information indicates, however, that such bioaccumulation is common and needs to be taken into consideration when examining the potential effects of secondary effluent discharge into the ocean.

6.5.1.4 Organic Compounds

Potential organic stressors that may be present in secondary-treated wastewater include EPA priority pollutant organic compounds, including volatile organic compounds (VOCs), synthetic organic compounds (pesticides, herbicides), organochlorine compounds such as trihalomethanes, and a variety of other unregulated compounds, such as endocrine disruptors, surfactants, and organic matter.

6.5.2 Potential Receptors

Potential receptors of ocean outfall effluent constituents include any organism that may be exposed to seawater containing effluent constituents. Because seawater is not used for drinking water (unless it is treated through desalination), potential receptors mainly considered in this risk assessment are those that may be *directly* exposed to seawater containing effluent constituents. Such potential receptors in the South Florida marine environment include a wide variety of animals and plants living in or near brackish coastal waters or marine waters, including marine mammals, reptiles, fish, birds, marine invertebrates, and aquatic vegetation. Humans also use the ocean for recreation, fishing, and other activities and can be exposed by eating contaminated seafood.

6.5.2.1 Ecological Receptors

Marine mammals that may be found in the South Florida coastal and marine environment include Florida manatees, whales (right, Sei, finback, humpback, sperm), and dolphins. In coastal brackish and freshwater environments such as estuaries and rivers, river otters also occur. The U.S. Fish and Wildlife Services and NOAA list all of these marine mammals except dolphins as endangered species (FFWCC, 1997).

Reptiles known to occur in marine or brackish South Florida waters include the American crocodile (endangered), Atlantic salt marsh snake (threatened), gray salt marsh snake, Atlantic green turtle (endangered), Atlantic hawksbill turtle (endangered), Atlantic loggerhead turtle (threatened), Atlantic Ridley turtle (endangered), and the leatherback turtle (endangered) (Carmichael and Williams, 1991; FFWCC, 1997).

The South Florida shelf environment is host to a wide variety of subtropical marine invertebrates, including mollusks (clams, conchs, snails, octopi, squid), annelids (worms), arthropods (crabs, lobster, shrimp), coelenterates (corals, sea anemones, echinoderms, starfish, sea urchins), sponges, bryozoans, and many others (Alevizon, 1994; FFWCC, 1997). These marine organisms feed in a number of ways, including predation, scavenging, filter-feeding, grazing, and feeding on organic detritus. Predatory invertebrates include octopi, many snails such as conchs, starfish, and squid. Filter-feeding organisms include corals, sponges, bryozoans, and bivalves such as clams and mussels. Some filter-feeding organisms, like certain corals, have symbiotic algae that help the host animal to survive. Grazing organisms include sea urchins and mollusks. Detritus feeders and scavengers include many worms, crabs, lobsters, shrimp, and snails.

The most extensive reefs of South Florida are primarily associated with the Florida Keys, but reef-forming organisms such as corals, sponges, and bryozoans may be found along the South Florida coast. Associated with these reef-forming animals may be found coralline and encrusting algae, which require solid substrates for attachment. In the Florida Keys, coral reefs have declined from a combination of factors, not all of which may be manmade. An epidemic disease occurred in the early 1980s, affecting the longspined black sea urchins that graze on the macroalgae that compete with corals for space. The absence of urchins may account for increased growth of seaweed on the reefs. Groundwater nutrient inputs from onsite sewage disposal systems may also account for the growth of macroalgal blooms, such as *Codium isthmocladum* in southeast Florida and the Caribbean (LaPointe, 1997; NOAA 2002c).

Fish species found in Florida waters include yellowtail snapper, grouper, barracuda, stingray, parrotfish, porcupine fish, Key blenny (endangered), angelfish, butterflyfish, damselfish, goby, trumpetfish, and wrasse, among many others (FFWCC, 1997).

Birds that may be found in brackish and marine waters include the brown pelican, American oystercatcher, frigatebird, piping plover (threatened), roseate spoonbill, roseate tern (threatened), cormorant, least tern, and southeastern snowy plover (threatened). Many other birds found in more inland brackish to fresh waters include the flamingo, heron, kingfisher, little blue heron, osprey, reddish egret, snowy egret, tricolored heron, white ibis, whooping crane, bald eagle, and others (FFWCC, 1997; Williams, 1983).

6.5.2.2 Human Receptors

Potential human receptors who may be exposed to ocean outfall effluent include recreational and industrial fishermen, boaters, workers associated with ocean outfall operations or wastewater treatment and, if the exposure pathways exist, recreational swimmers.

6.5.3 Potential Exposure Pathways

For nonpotable water, the primary potential exposure pathways are related to direct exposure of humans to water containing stressors and ingestion of seafood with elevated levels of contaminants. There is also a possibility of airborne exposure if water droplets containing effluent constituents somehow are formed through turbulence or aerosolization. Potential primary human exposure pathways for waterborne stressors in discharged effluent include ingestion of stressors (followed by bioaccumulation or excretion), dermal contact with stressors, and inhalation of water vapor containing chemical or microbiological stressors. Recreational or fishing activities in or near the ocean outfall could bring humans into a situation where exposure could occur.

Potential exposure pathways for marine mammals, reptiles, and fish are similar to the above-named pathways (that is, ingestion, dermal contact, and inhalation). Predation or scavenging of other organisms feeding upon contaminated organisms or algae that contain elevated tissue concentrations of effluent constituents could also cause bioaccumulation of these constituents.

Potential exposure pathways for marine invertebrates include ingestion of particles or dissolved materials containing effluent constituents. Examples include filter-feeding or detrital-feeding organisms feeding on organic particles containing adsorbed metals or organic constituents or ingesting water containing dissolved effluent constituents. Such organisms may be feeding upon the fecal pellets of other marine organisms that may have ingested effluent constituents. Predators may feed on other organisms that have already ingested or bioaccumulated constituents such as metals or organic compounds.

Settling organic and inorganic particles in the ocean represent a significant mass transport mechanism for the cycling of particles from the surface of the ocean to the seafloor. Such settling particles can scavenge other materials in the water column by adsorption or other complexation processes (Honjo et al., 1982). Fecal pellets produced by zooplankton settle to the sea floor as organic detritus, thereby providing a conduit for the rapid removal of nutrients and other substances from the upper layers of the ocean to the deeper layers of the ocean (Pilskaln and Honjo, 1987). Much of the organic matter found on the seafloor ultimately derives from primary and secondary production in the photic zone, which is typically 10 m deep (Parsons et al., 1984).

Unlikely exposure pathways include direct exposure of shallow shelf or photic zone organisms to discharged effluent. Receptors could be exposed to stressors from the physical transport of stressors towards the coast. For example, if the Florida Current were to move nearshore or if an eddy of the Florida Current were to transport effluent constituents, then nearshore or onshore receptors could be exposed to effluent constituents.

The question of whether exposure and uptake pathways exist is crucial for risk assessment. The primary risk questions to be asked are these:

- Do these actual exposure pathways exist?
- If they do exist, is there actual uptake?
- If there is uptake, are there adverse effects upon humans or biota?

Unless seawater is used for desalination for a drinking-water source, the primary type of human risk that might occur would be related to recreational or occupational exposures to seawater and consumption of seafood.

6.5.4 Conceptual Model of Potential Risk for Ocean Outfalls

A conceptual risk model is a generic model of potential risks that may result from management of treated municipal wastewater using ocean outfalls. Such a model lists all potential exposure pathways and processes that control whether a receptor is actually exposed to a stressor or not. This conceptual model of potential risk represents the risk model to be tested using specific data. Section 6.6 describes the data and the testing of the model. It contains an evaluation of how realistic the potential risks are. A conceptual model for evaluating potential risks associated with ocean outfalls is shown in Figure 6-4.

The model components that control the fate and transport of wastewater discharged into the open ocean environment were adapted from a 1984 National Academy of Science study entitled "Disposal of Industrial and Domestic Wastes: Land and Sea Alternatives" and the Waquoit Bay National Estuarine Research Reserve Watershed risk assessment model that provides a method for identifying valued natural resources and evaluating the risk to those resources (Bowen et al., 2001).

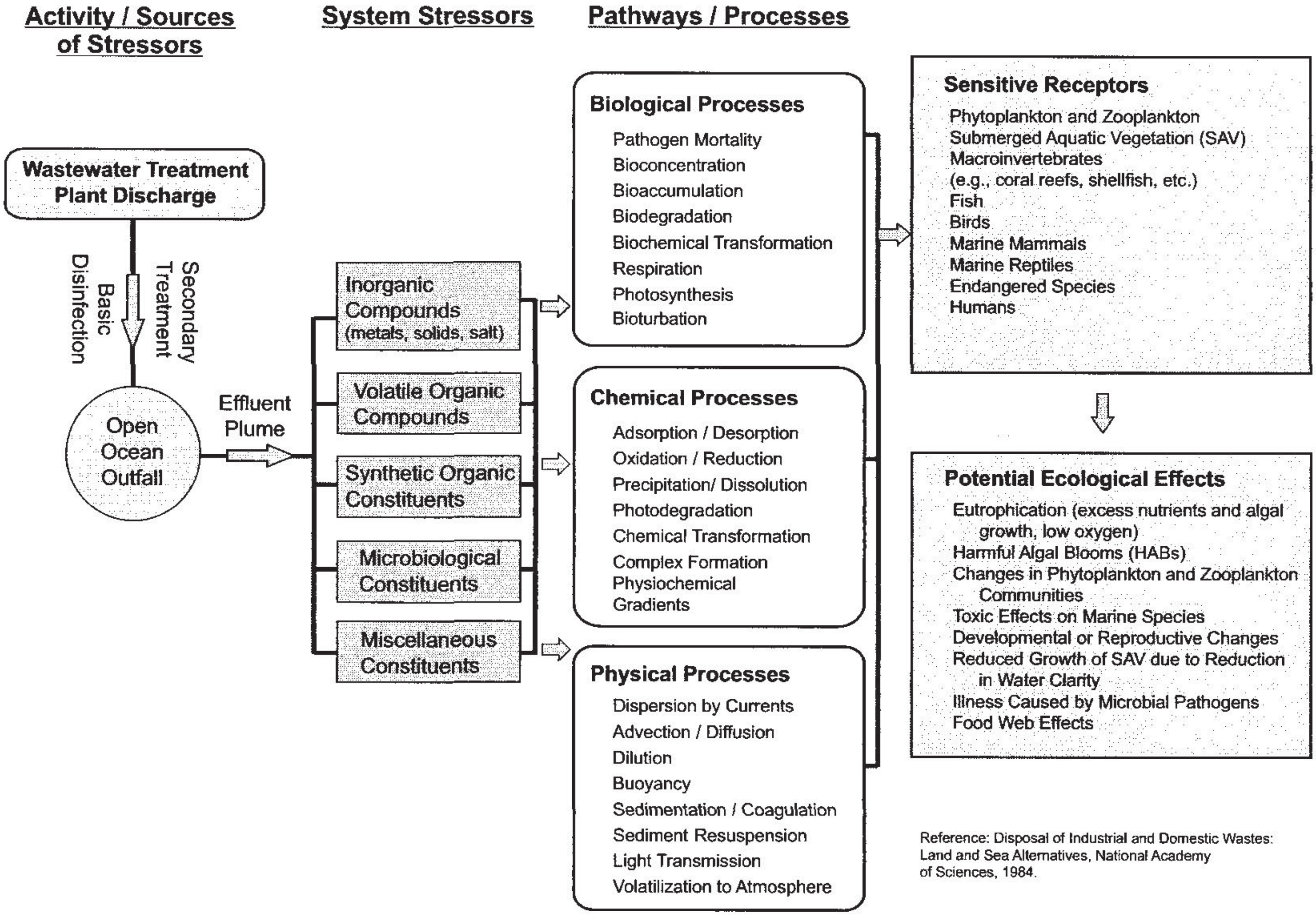
In this conceptual model, the source of stressors is the wastewater treatment plant providing secondary treatment and basic disinfection of municipal wastewater derived from industrial and domestic sources. The potential stressors are inorganic compounds (for example, metals, salts), organic compounds, nutrients, and pathogenic microorganisms.

The physical pathways and processes that occur when treated wastewater is discharged into any water body, either open ocean or surface water (such as rivers, lagoons, or estuaries), are extremely important in determining large-scale exposure pathways. In the vicinity of the outfall, the ways in which ocean currents affect dispersion and dilution of the effluent plume are extremely important. Farther away from the outfall, as dilution occurs, it is important to determine whether ocean circulation and mixing could vary enough to expose terrestrial or nearshore receptors.

Physical processes refers to the transport process that moves suspended or dissolved materials from one place to another (National Academy of Sciences, 1984). Examples include advection of a plume through current movement, dilution or dispersion of the plume through mixing with surrounding waters, density-driven advection, sedimentation of solids from the plume to the benthos, resuspension of sediment through turbulence or bioturbation, adsorption, and volatilization to the atmosphere.

Potential chemical processes are chemical reactions that wastewater constituents can undergo when discharged into the aquatic environment. These processes include adsorption and desorption, changes in oxidation state, precipitation and dissolution, photodegradation, transformation, and complex formation.

Potential biological processes affecting the fate and transport of stressors include uptake, bioconcentration and accumulation of stressors, inactivation of pathogenic microorganisms, biochemical transformation or degradation of stressors, photosynthesis, and the formation of organic marine particles such as zooplankton fecal pellets that transport stressors to benthic habitats. Both chemical and biological processes determine the fate and effect of a particular constituent.



Reference: Disposal of Industrial and Domestic Wastes: Land and Sea Alternatives, National Academy of Sciences, 1984.

Figure 6-4. Conceptual Model of Potential Risks for the Ocean Outfall Option

Potential receptors include submerged aquatic vegetation, plankton (phytoplankton, zooplankton), larger aquatic organisms (invertebrates, fish, marine mammals, and reptiles), birds, and humans. There are no drinking-water receptors in this conceptual model. If seawater were to be used for a drinking-water source through desalinization, which is being considered in South Florida, then this potential receptor would be added to the conceptual model. However, seawater in coastal areas would contain many of the same stressors derived from other sources on land.

6.6 Risk Analysis of Ocean Outfalls

In this section, the potential risk model expressed by the conceptual model is tested using actual data from existing ocean outfalls or the SEFLOE studies. As part of the risk analysis, the following questions will be answered:

- Do plausible exposure pathways exist for receptors to be exposed to stressors?
- Are concentrations of stressors high enough to potentially cause adverse effects?
- Is there evidence for adverse effects in receptors caused by exposure to stressors derived from treated wastewater effluent?

6.6.1 Evaluation of Physical Transport

In order to appreciate the large-scale risk setting, it is important to understand physical environmental risk factors. These are the physical features of the environment that play a significant role in the risk of a particular wastewater management option. A thorough understanding of physical oceanography, circulation, mixing, dispersion, and dilution of the discharged effluent plume at the ocean outfalls is necessary for evaluating the physical environmental risk factors associated with ocean outfalls.

The SEFLOE studies and other related studies provide much of the information needed to assess such risk factors. Intensive cruises were conducted to each outfall during winter and summer to detect and track, using acoustic measurements, the initial plume and to develop two-dimensional models of the effluent plumes. To map and model current velocities and water column structure, moored current monitors were deployed near outfall discharge sites for several periods between August 1991 and October 1992. An acoustic Doppler current profiler was deployed at the Miami-Central outfall diffuser in the summer of 1992 to obtain more information on current regimes and depth variations in currents. Dye and salinity tracking were also used to map the distribution and movements of water masses. Water-column characteristics (conductivity, temperature, and depth, or CTD) were measured using CTD water-column profiling on a semimonthly basis at each outfall from July 1991 to October 1992 (except months when intensive cruises were underway). Physical characteristics of the surfacing effluent plumes were monitored using towed CTDs. Initial and subsequent dilutions were estimated, using differences in salinity between the effluent and ambient seawater as a tracer.

The SEFLOE studies also collected water-quality information from the effluent plume and from ambient seawater. Parameters measured included bacteria (total coliforms, fecal coliforms, and *Enterococcus* bacteria), nutrients (ammonia, total Kjeldahl nitrogen (TKN), total phosphorus, nitrate, nitrite), oil and grease, 126 priority pollutants, and total suspended solids (TSS). Effluent samples from the six wastewater treatment facilities were also analyzed for salinity, bacteria, nutrients, priority pollutants, oil and grease, $CBOD_5$, and TSS.

6.6.1.1 Transport, Dispersion, and Dilution by Currents

Transport, dispersion, and dilution of effluent plumes by ocean currents and circulation are critical risk factors for evaluating potential risks of ocean outfalls. The direction and speed of current flow, which together determine current velocity, are critically important risk factors. The faster the current speed is at the outfall, the greater the rate at which the plume is dispersed and diluted by ambient seawater, and the lower the concentration of stressors. Conversely, the slower the current speed is at the outfall, the lower the rate at which the plume is dispersed and diluted by ambient seawater, and the higher the concentration of stressors remaining in the area. The direction of current flow, away from or towards human or ecological receptors, is also important to characterize. Current flow towards the coast will increase the likelihood that coastal receptors (human or ecological) will be exposed to effluent constituents, while current flow away from the coast will decrease the likelihood of exposure.

The SEFLOE II study provided an extensive set of current measurements and water-column density profiles, using a combination of acoustical backscatter and direct sampling methods. Information on water quality of the effluent plume and ambient seawater also was obtained. Analysis of the current data from the four outfall locations indicated that three major current regimes, characterized by different flow directions, were present at all outfall sites:

- *Current Regime i* = Northerly flows, thought to be associated with western meanders of the Florida Current
- *Current Regime ii* = Southerly flows, which are part of an extensive eddy current
- *Current Regime iii* = Rotary-like flow, which consists of groups of rotations interspersed between northerly and southerly flows. The rotations were irregular and temporally fleeting, with durations of 5 to 8 hours.

Current Regime *i* predominates, displaying rapid current flow in a northerly direction throughout the entire water column. The SEFLOE II study reports that this current flow occurs approximately 60% of the time. Current Regime *ii*, representing southerly flow, occurs approximately 30% of the time. Current Regime *iii*, representing flow in other directions (easterly, westerly) occurs irregularly and less than 10% of the time, and the duration of such flows is very short (5 to 8 hours).

To estimate the percentage of time that Current Regime *iii* flows to the west, data points reflecting current direction at a depth of 16.8 m at the Miami-Dade Central District wastewater treatment plant (Hazen and Sawyer, 1994) were visually analyzed. It was assumed that, as described in the SEFLOE II report, easterly and westerly flows occur a total of 10% of the time. This analysis indicates that westerly flows occur approximately 4% percent of the time, while easterly flows occur approximately 6% percent of the time. Data sets using an Aanderaa current meter and using an acoustic Doppler current profiler yielded equivalent results.

The Florida Current in the vicinity of the ocean outfalls can be characterized as a fast-flowing current, with speeds ranging from approximately less than 5 centimeters per second (cm/sec) to maximum speeds of over 60 to 70 cm/sec. In general, the mean current velocity observed during Regime *i* northerly current flow is greater than any other current regime, while the mean current velocity of Regime *iii* rotary-like flow is the lowest (Hazen and Sawyer, 1994). Because the dilution of the effluent plumes is a function of current velocity, the Regime *iii* rotary-like flow will result in the higher concentration of stressors.

For the purposes of evaluating plume dispersal, the SEFLOE II report used the lowest 4-day average current speeds and the lowest 10th-percentile average current speeds as conservative (that is, protective) estimates of average current speeds. These current speeds are shown in Table 6-4 (Hazen and Sawyer, 1994). The maximum current speeds recorded during the study are shown for comparison. In general, the average current speeds are highest at the Broward outfall.

Table 6-4. Average Current Speeds (cm/sec)

Outfall	Lowest 4-Day Average Current Speed	Lowest 10th-Percentile Average Current Speed	Maximum Current Speed
Broward	15.7	12.3	> 70
Hollywood	13.7	7.8	> 60
Miami-Dade North	13.2	7.7	> 70
Miami-Dade Central	13.6	11.6	> 70

Source: Hazen and Sawyer, 1994.

Irrespective of which current regime was predominant, current direction was generally the same at all depths, based on water column profiles. Slight variations in current speed occurred throughout the water column, with higher speeds occurring near the ocean surface.

6.6.1.2 Dilution of the Effluent Plume

The SEFLOE I study characterized dilution of the effluent plumes at all six of the ocean outfalls, using dye and salinity data and acoustic backscattering methods. Based on these studies, the effluent plume typically has three distinct phases:

1. The initial dilution phase commences when the effluent leaves the outfall pipe and lasts until the effluent reaches the surface of the ocean.
2. The near-field dilution phase commences when the plume reaches the surface and undergoes radial dispersion because of the momentum of the rising effluent

within the upper 3 m of the ocean surface. This phase is visible on the surface of the ocean as a feature that is often called a "boil."

3. The farfield dilution phase is characterized by an effluent plume that has undergone dilution during the initial and near-field dilution phases and is further dispersed by surface currents.

The characteristics of each of these dilution phases are discussed below.

Initial and Near-Field Dilution

Because the water samples are collected at or near the boil, within 1 m of the surface, the sampling actually is conducted within both the initial and near-field dilution phases, as defined above in the SEFLOE study. Therefore, these two dilution phases are discussed together in this section.

Initial dilution using tracer dye methods and chlorine was defined in the SEFLOE study as the ratio of measured concentrations of the dye in the effluent boil to the initial concentration of the dye in the effluent at the treatment facility. The initial dilution that occurs over a 4-day period at a conservative current speed (worst-case scenario with the lowest average current speed) is described in Table 6-5 below as the flux-averaged initial dilution factor. The greater this factor is, the higher the dilution.

Table 6-5. Flux-Averaged Initial Dilution of Effluent Plume.

Ocean Outfall	Lowest 4-day Average Current Speed (cm/s)	Flux-Averaged Initial Dilution Factor
Broward	15.7	43.3
Hollywood	13.7	28.4
Miami-Dade North	13.2	50.1
Miami-Dade Central	13.6	28.3

Source: Hazen and Sawyer, 1994, Table III-5.

The initial dilution factors from the SEFLOE studies indicate that initial dilutions were highest for the Miami-Dade North ocean outfall and lowest for the Miami-Dade Central and Hollywood outfalls. Yet, according to Table 6-5, Miami-Dade North outfall had the lowest 4-day average current speed. The high initial dilution at this outfall may explained by the use of multiport diffusers at the Miami-Dade North outfall. The use of multiport diffusers at the Miami-Dade North outfall appears to aid in dispersal of the effluent plume over a wider area, thereby decreasing potential risk. However, these effluent plumes were diluted at slower rates than the effluent plumes from the Hollywood and Broward outfall plumes, according to Englehardt et al. (2001).

The rate of initial dilution of the effluent also is largely dependent upon the current speed and the rate of discharge of effluent from the outfall. As current speed increases, dilution also increases. As the rate of effluent discharged from the outfall increases, the rate of dilution increases. These relationships are shown in Figure 6-5, which shows flux-averaged dilution vs. current speed for effluent discharged from the Miami-Dade Central ocean outfall (from Hazen and Sawyer, 1994).

At a lower current speed of 10 cm/sec at a 253 mgd discharge rate, the dilution factor is approximately 20; at a higher current speed of, say, 60 cm/sec, the dilution factor is over 40. Also, for a given current speed, at higher discharge rates (that is, 253 mgd), the dilution is lower than if effluent is discharged at a lower rate (that is, 115 mgd).

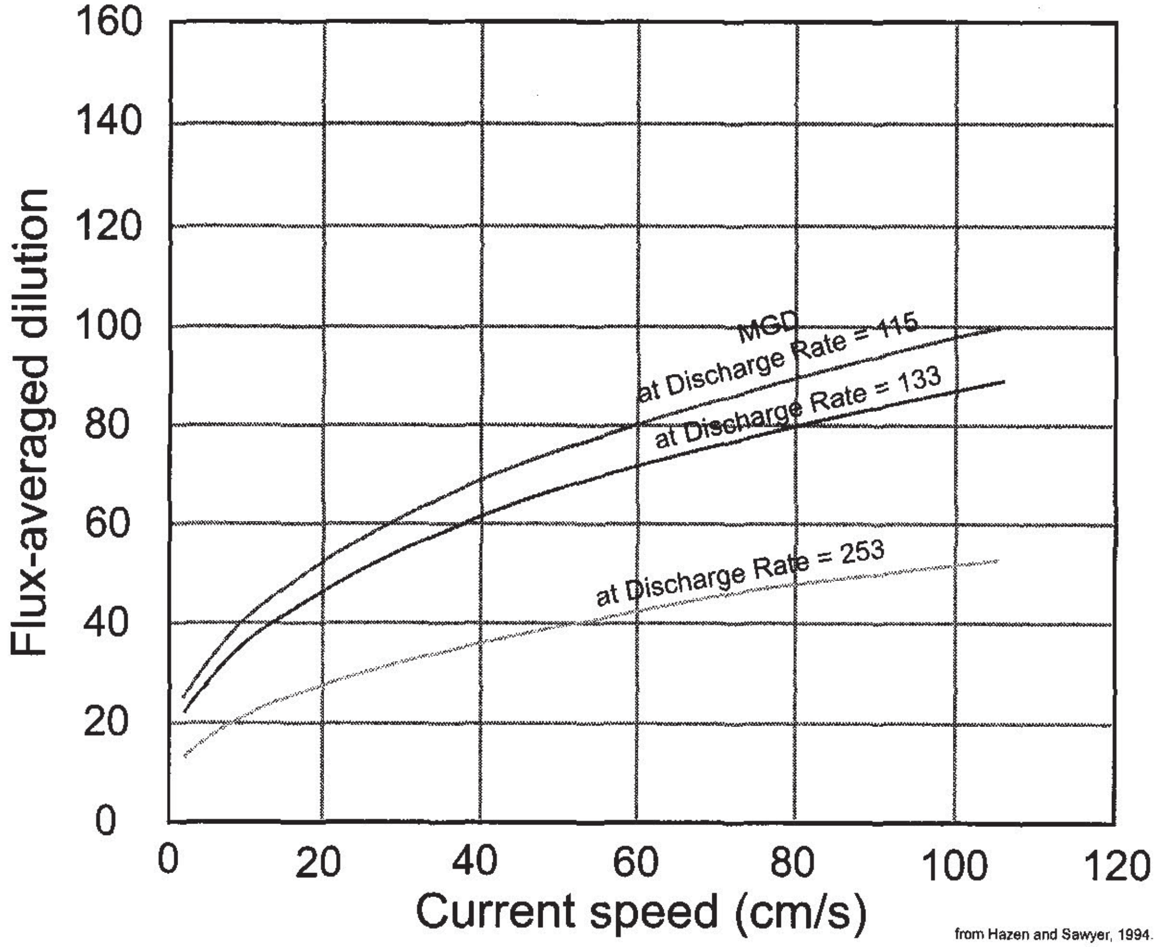
The SEFLOE study found that normally surfacing plumes were present at all outfalls throughout the year, even in summer months when density stratification of the water column was weak. It is noteworthy, however, that during several strong stratification events, portions of rising plumes were trapped and prevented from freely dispersing, based on acoustic profiling conducted by John Proni and colleagues (Proni et al., 1996, 1994; and Proni and Williams, 1997). In such areas of plume trapping, effluent constituents were present at relatively higher concentrations than in areas in which there was no such trapping and the effluent was freely dispersed. Concentrations of effluent constituents were, however, quite low, but their existence is quite significant. Definitive measurements of dilution in trapped plumes are planned for an upcoming SEFLOE III study (John Proni, personal communication). Plume trapping during strong stratification events therefore represents one potential risk factor.

Farfield Dilution

The SEFLOE II report indicates that measurements of farfield dilutions were the most difficult field measurements to obtain. Measurements of salinity, dye concentration, and acoustic backscatter intensity were used simultaneously for dilution calculations and to guide sampling for biological and chemical parameters for subsequent dilution determinations. Subsequent dilution is defined in the SEFLOE report as dilution that occurs as plume elements move away from the boil location, which represents the initial dilution and near-field dilution phases.

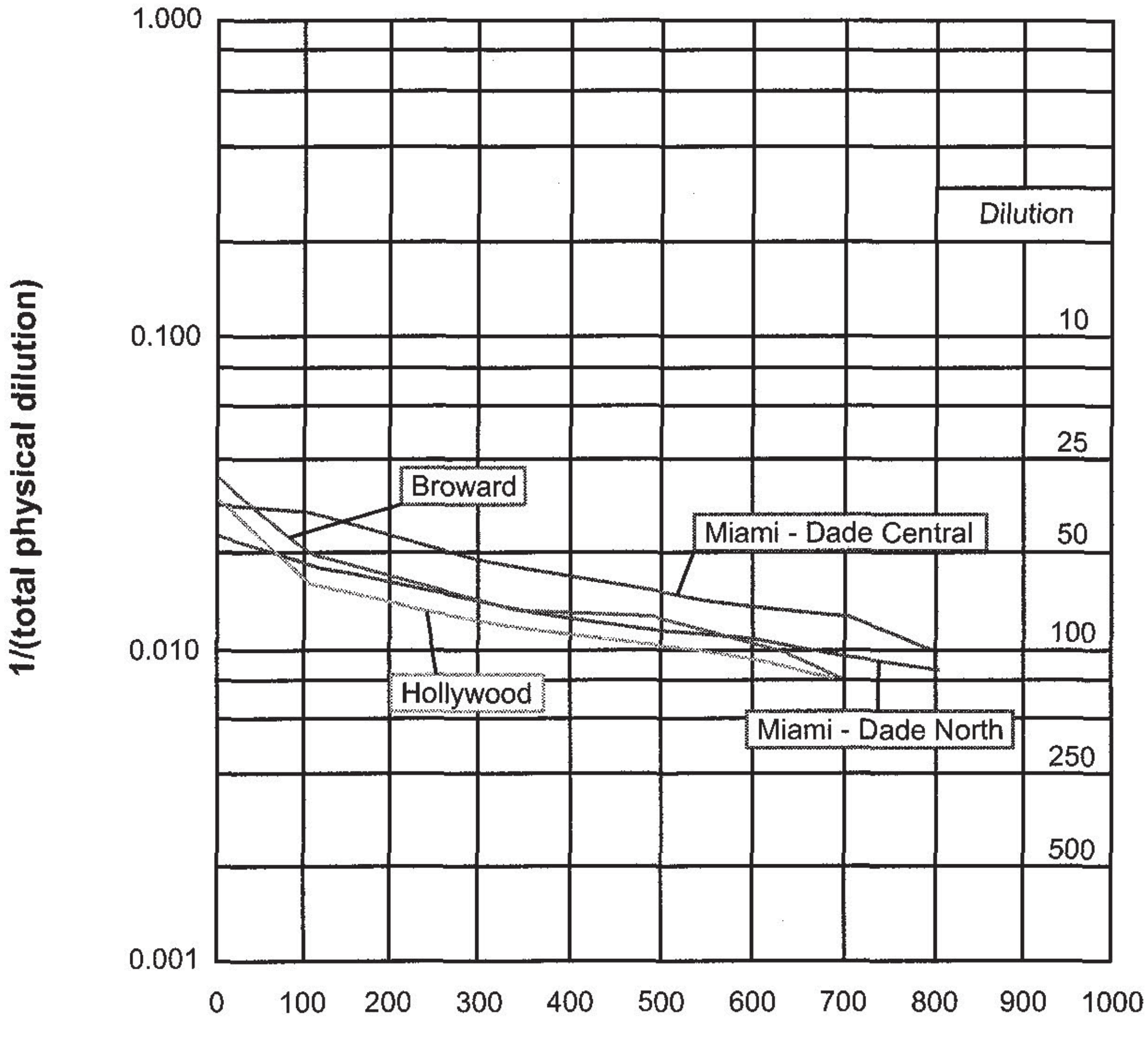
Average subsequent dilutions in the near-field and farfield for the four ocean outfalls are compared in Figure 6-6, which plots the inverse of total physical dilution (1/total physical dilution) of the plume on a logarithmic scale against the distance from the boil in meters (from Hazen and Sawyer, 1994, Figure III-77). On this plot, as one moves away from the boil, dilution increases. Figure 6-6 shows the following:

- Treated effluent discharged from the Broward and Hollywood outfalls experiences more rapid dilution in the 0- to 100-m range than the effluent discharged from the two Miami-Dade outfalls. These two outfalls have larger diameter ports than the other ocean outfalls (see Table 6-1).
- Between 100 and 200 m from the plume boil, there is a change in the rate of dilution, suggesting that buoyancy spreading and positive buoyancy of the plumes is still occurring at this distance from the outfall.



from Hazen and Sawyer, 1994.

Figure 6-□. Initial Dilution as a Function of Current Speed and Discharge Rate (Miami-Dade Central Outfall)



Source: Hazen and Sawyer, 1994

Figure 6-6. Total Physical Dilution as a Function of Distance from the Boil (Four Ocean Outfalls)

- Between 100 m and 400 m from the boil, total physical dilution with distance curves are approximately similar for both current Regimes *i* (northerly flow) and *ii* (southerly flow), with average dilutions ranging from approximately 60:1 to 90:1 at a distance of 400 m from the boil location.
- Dilution rate increases slightly at 500 m from the boil for Broward, 700 m from the boil for Miami-Dade Central, and 600 m from the boil for Hollywood outfalls. The effluent plume from the Miami-Dade North outfall shows steady dilution throughout nearly the entire distance sampled.

Note that the 400-m mixing zone equates to the 502,655 m^2 maximum mixing zone size for open ocean outfalls regulated by the state of Florida. Dilutions ranging from 60:1 to 90:1 were used to evaluate the concentrations of the measured constituents of concern in wastewater and were compared to the Class III standards.

The information from the SEFLOE studies indicates that overall dispersal and dilution of the discharged effluent occurs rapidly, within hours to days, and that the mixture of effluent and receiving water rapidly achieves background or near-background concentrations of tracer dyes and salinity within 400 to 600+ m of the outfall. Rapid dispersal results in dilution of the effluent and therefore reduces the risk of exposure to undiluted effluent.

6.6.2 Evaluation of Stressors, Exposure Pathways, and Receptors

In this section, information from the SEFLOE studies and other studies are used to evaluate the following risk questions posed by the conceptual model:

- Do concentrations of stressors exceed standards intended to protect human health or ecological systems?
- Is there evidence that human or ecological receptors are exposed to or take up stressors derived from the treated effluent or secondary stressors that are created by discharge of effluent?
- Is there evidence of adverse effects on human or ecological receptors in the vicinity of the outfalls?
- If there are adverse effects that can be attributed to the use of ocean outfalls, are these effects reversible?

6.6.2.1 Pathogenic Microorganisms

Pathogenic Microorganisms in Unchlorinated Effluent as a Worst-Case Scenario

The SEFLOE study measured three types of bacteria indicative of mammalian wastes: total coliforms, fecal coliforms and *Enterococcus*. Samples for microbiological analysis were taken from both secondary treated unchlorinated effluent and from within the effluent plume itself (Hazen and Sawyer, 1994). Based on these measurements and the effluent plume characteristics, SEFLOE provided recommendations to regulators concerning the width of the mixing zones that would have to be defined to allow dilution of the effluent to meet Florida water-quality criteria for bacteria.

Recommendations on the maximum allowable concentrations of bacteria in effluent were also provided to help guide treatment plant operators in determining the correct amount of chlorine to use in disinfecting effluent. Florida regulations require basic disinfection to meet a standard of 200 fecal coliforms per 100 mL of treated wastewater. However, because chlorine disinfection itself can create unwanted chlorinated byproducts (for example, trihalomehanes) and pose potential health or environmental risks, the regulations also allow for an effluent mixing zone range. This allows dilution of effluent, reducing the amount of chlorine used, while still meeting water-quality standards. SEFLOE's recommended widths of mixing zones of unchlorinated effluent to achieve Class III bacterial water quality standards are summarized in Table 6-6.

Table 6-6. Recommended Mixing Zone Ranges for Unchlorinated Effluent, Using Different Methods of Calculating Bacterial Concentrations

Facility	Radial Distance (m)			
	Maximum Single Requirement	**Percent Not Greater Than Requirement**	**Geometric Mean Requirement**	**Range of Controlling Criterion**
Broward County	900	900	400	900
Total coliform	800	800	400	800
Fecal coliform	800	800	400	800
Enterococci	900	900	400	900
City of Hollywood				
Total coliform	500	800	0	80
Fecal coliform	200	700	0	700
Enterococci	1,000	800	400	1,000
Miami-Dade North				
Total coliform	900	900	400	900
Fecal coliform	900	900	400	900
Enterococci	1,000	1,000	800+	1,000
Miami-Dade Central				
Total coliform	Uncertain	Uncertain	800	Uncertain
Fecal coliform	900	900	800+	900
Enterococci	Uncertain	Uncertain	800+	Uncertain

Note: Data from Miami-Dade Central are shown as uncertain because of suspected high background concentrations of indicator bacteria from the Miami River.
Source: Hazen and Sawyer, 1994.

Because these values represent distances that the unchlorinated effluent would have to travel before the concentration of bacteria became diluted to background levels, they provide information for an evaluation of one potential worst-case risk scenario, which is failure of chlorination to treat secondary effluent to meet Class III water-quality standards. In general, the results show that even if unchlorinated effluent were discharged, it would become dilute enough to meet Class III bacteriological water quality standards within 800 to 900 m of the outfall or, in some cases, much closer.

Disinfection To Achieve Microbial Standards

The Florida regulations require a mixing zone area of up to 502,655 m^2 to allow dilution of the effluent to Class III water-quality standards. Although the Florida regulations do not require that a circular mixing zone be established, and in fact do not specify a shape, the use of a circular mixing zone for evaluating whether dilution achieves the standards makes it easier to compare actual versus expected concentrations of effluent constituents. Such a circular mixing zone would have a radius of 400 m. It is worth noting, however, that a circular mixing zone would occur only in an environment where there is no current flow.

To assist facility operators in determining how to manage bacteria to meet Class III regulatory standards, SEFLOE provided calculations of the maximum allowable numbers of indicator bacteria in effluent within 400 m of the outfall. These calculated concentrations are shown in Table 6-7. They include assumptions concerning microbial attenuation processes that are not based solely on physical dilution alone (John Proni, personal communication). These bacterial numbers provide wastewater treatment facility operators with specific bacterial concentration goals to meet, using chlorination of effluent in order to meet Class III water-quality standards. The 800-m mixing zone is included because, as stated above, the mixing zone is not required to be a circular mixing zone but instead is an area, and the effluent plume may well extend outside of the 400-m-radius zone.

Table 6-7. Maximum Allowable Concentrations of Indicator Bacteria in Effluent within Different Mixing Zones

Facility	0 m Initial Dilution Zone	400 m Mixing Zone	800 m Mixing Zone
Broward County			
Total coliform	302	3,388	10,471
Fecal coliform	72.6	437.6	935
Enterococci	--	284	53
City of Hollywood			
Total coliform	575	2,884	3,631
Fecal coliform	296	324	1626
Enterococci	7.3	38.4	106
Miami-Dade North District			
Total coliform	3,715	14,454	28,840
Fecal coliform	1,517	20,465	7,962
Enterococci	153	840	879
Miami-Dade Central District			
Total coliform	186	417	11,000
Fecal coliform	68	252	1,910
Enterococci	2.4	29.0	334.0

Note: All bacterial numbers = 100 per 1000 mL
Source: Hazen and Sawyer, 1994, Table III-17.

Proximity of Effluent Plume to Coastal Receptors

One significant microbiological risk factor is the proximity of the ocean outfalls to land and to potential terrestrial and nearshore receptors. If one assumes that the required mixing zone area of 502,655 m^2 is translated into a circle of radius 400 m centered on the outfall, one can compare this with the actual distance of the outfall from land (Table 6-8). This table indicates that the highest risk outfalls, solely in terms of distance from shore, are the Del Ray Beach and Boca Raton outfalls, while the lowest risk outfall in terms of distance is the Miami-Dade Central outfall.

Table 6-8. Comparison of Circular Mixing Radii for Effluent and Outfall Distance from Shore (m)

Parameter	Miami-Dade Central District	Miami-Miami-Dade North District	City of Hollywood	Broward County	Delray Beach	Boca Raton
Distance offshore	5,730	3,350	3,050	2,130	1,600	1,515
Distance from 400 m circle to land	5,330	2,950	2,650	1,703	1,200	1,115
Distance from 800 m circle to land	4,930	2,550	2,250	1,330	800	715

Note: A 400-m mixing radius is required for chlorinated effluent to meet Class III bacteriological standards. If the effluent is unchlorinated, an 800-m mixing radius is required.
Source: Hazen and Sawyer, 1994.

It is important to note that in reality the effluent plumes do not disperse equally over a circular area, as implied by the circular mixing zone calculations used by the SEFLOE study, but are instead dispersed by the strong Florida Current to form an extended plume, whose longest dimension is aligned with the northerly flowing Florida Current. It is not known what would happen if the northerly current flow were to weaken or disappear. It is probable that, for such a major change in the Florida Current to occur, there would have to be major changes in ocean circulation elsewhere as well.

There are a number of gaps in information concerning human health and ecological risks from pathogenic microorganisms remaining in treated effluent. The SEFLOE studies of enteric microorganisms in effluent and the dilute effluent plume did not include measurements of *Cryptosporidium* or *Giardia.* Other enteric viruses and bacteria were not measured. Ecological risks posed by effluent microorganisms could not be evaluated in this report because of the lack of long-term monitoring studies of benthic organisms in the effluent plume track or adjacent waters.

Human health risks posed by effluent microorganisms also could not be evaluated directly because of the lack of information on pathogenic microorganisms in coastal waters adjacent to the outfalls and derived from the outfalls. Beach water-quality information would provide information on microbial concentrations, but would not distinguish between onshore versus offshore sources of pathogenic microorganisms. Many onshore sources of pathogenic microorganisms undoubtedly exist in southeast

Florida, from a combination of intensive urban and agricultural activities. To distinguish between these different sources, a tracer study involving microbial tracers or combined microbial/chemical/biochemical tracers would have to be conducted. However, it remains clear that there is a risk from pathogenic protozoans such as *Cryptosporidium*, which is not addressed by chlorination, and that the risk is highest during the westward-flowing current phase, which occurs approximately 4% of the time.

Nevertheless, the SEFLOE studies provide a significant body of knowledge for risk managers to understand the processes that affect microbiological risks to human health. They also provide specific recommendations concerning the level of dilution and disinfection of treated wastewater needed to achieve Class III water-quality standards for microbial indicators of wastewater (fecal coliforms, *Enterococcus*, total coliforms) at a hypothetical 400 –m-radius mixing zone. Although the SEFLOE studies do not provide follow-up monitoring to confirm that these standards are indeed met all of the time, monitoring of chlorinated treated wastewater at treatment facilities suggests that these microbial standards for regulated pathogens and indicator bacteria are nearly always met.

6.6.2.2 Nutrients

There are three questions that must be addressed in order to evaluate potential risks from nutrients in the secondary treated effluent:

- Are nutrient levels in the effluent higher than ambient water or applicable marine water-quality standards to protect ecological health?
- Is there evidence that nutrients from the treated effluent are taken up by phytoplankton and microalgae and then converted to biomass?
- Is there evidence of ecological effects from nutrient inputs from the effluent plume?

To evaluate ecological risks associated with nutrient discharge, information on effluent nutrient concentrations was compared with Florida water-quality standards designed to protect aquatic ecosystems. The Class III Florida water-quality standards state, "In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna." Therefore, it is also valuable to compare nutrient concentrations in secondary treated effluent with nutrient concentrations in ambient seawater at the site, because natural populations of organisms will be adapted to the ambient concentrations and may experience changes if nutrient concentrations change.

Table 6-9 compares the nutrient concentrations in secondary effluent, ambient seawater, and 400 m and 800 m mixing zones at three ocean outfalls (from Hazen and Sawyer, 1994, Tables III-18, III-19 and III-20). All values in the table are from Hazen and Sawyer (1994) unless otherwise noted as calculated for this report. The 800 m mixing zone is included as a conservative approach.

Table 6-9. Nutrient Concentrations in Secondary Treated Effluent, Ambient Water, and 400 m and 800 m Mixing Zones for Three Ocean Outfalls

Parameter	Ammonia (mg/L)				Nitrate (mg/L)				Total Phosphorus (mg/L)			
	Mean	Max.	No. of Samples	Other Values	Mean	Max.	No. of Samples	Other Values	Mean	Max.	No. of Samples	Other Values
						Broward						
Ambient water	0.09	0.5	28		0.16	0.16	1		0.08	0.16	17	
Effluent	12.48	20.0	42	8.7^{d}	0.42	1.08	7	0.64^{a}, 9.6^{b}, 0.28^{c}3.8^{d}	1.66	2.45	43	1.33^{d}
Boil	0.35	0.9	55		0.12	0.46	9		0.18	0.84	41	
400 m	0.13	0.35	32		0.02	0.02	1		0.10	0.3	25	
800 m	0.11	0.5	26		0.01	0.01	1		0.10	0.13	21	
Dilution at 400 m**	96x				21x				16.6x			
Dilution at 800 m**	113x				42x				16.6x			
						Hollywood						
Ambient water	0.09	0.14	8		0.11	0.11	9		0.09	0.11	6	
Effluent	5.96	14.00	31		1.70*	1.60*	31		0.97	1.60	32	
Boil	0.25	0.80	15		0.16	0.52	15		0.11	0.40	12	
400 m	0.09	0.12	4		0.12	0.30	4		0.10	0.10	2	
800 m	0.09	0.12	4		0.11	1.40	3		0.10	0.10	3	
Dilution at 400 m**	66x				14x				9.7x			
Dilution at 800 m**	66x				15.5x				9.7x			
Parameter	Ammonia (mg/L)				TKN (mg/L)							
	Mean	Max.	No. of Samples	Other Values	Mean	Max.	No. of Samples	Other Values				
						Miami-Dade North						
Ambient water	0.66	1.96	4		0.72	2.24	14		--	--	--	
Effluent	10.46	13.7	11		13.4	17.4	11		--	--	--	
Boil	0.56	2.24	10		0.6	3.64	28		--	--	--	
400 m	0.10	0.15	2		0.19	0.4	9		--	--	--	
800 m	0.38	0.84	4		0.61	1.96	13		--	--	--	
Dilution at 400 m**	105x				71x							
Dilution at 800 m**	28x				22x							

* These values are listed here as reported in the SEFLOE II report (Hazen and Sawyer, 1994).

** Calculated for this report using the ratio of observed concentration at the distance indicated to the initial concentration in effluent.

[a] = Miami-Dade North District, 1999. See Appendix Table 1-2.

[b] = Brevard County (South Beaches WWTF), 2000. See Appendix Table 1-2.

[c] = Albert Whitted WRF, St. Petersburg. See Appendix Table 1-2.

[d] = Mean value from Englehardt et al. (2001), compiled from several sources. See Appendix Table 1-2.

These data indicate that there are site-specific differences in whether or not the effluent nutrients become diluted to background levels by the time the effluent water reaches a distance of 800 m from the outfall. For example, at Broward, the average ammonia concentration in the plume did not reach ambient levels at 800 m. The average nitrate concentrations in the boil did not exceed background concentrations at the boil, although there are individual boil values which exceed background (John Proni, personal communication). Average total phosphorus in the plume did not reach background concentrations at 800 m.

There is also considerable variability in the concentrations and data as well; for example, the background value for nitrate is 0.16 mg/L based on 1 measurement, while the mean concentration of nitrate at the boil is 0.12 mg/L (9 measurements) and the concentration of nitrate at 400 m is 0.02 mg/L (1 measurement). Differences in time of sampling could account for these differences, as well as natural variability.

At the Hollywood outfall, average ammonia concentrations in the effluent plume reached background levels at 400 m, perhaps partly because the initial effluent concentration of ammonia was lower than at Broward. Nitrate concentrations in the plume did not reach background concentrations until 400 m out from the outfall. Total phosphorus did not reach background concentrations even at 800 m, similar to the Broward outfall.

At the Miami-Dade North outfall, ammonia at the boil did not exceed background concentrations. Concentrations of nitrate and phosphorus at this location were not reported in the SEFLOE study.

The calculated dilutions at 400 m and 800 m indicate that there are differences in dilution of ammonia, nitrate, and total phosphorus as the effluent plume becomes dispersed. Ammonia appears to dissipate most rapidly, nitrate may or may not become diluted to background concentrations at a distance of 400 m, and total phosphorus may not become diluted to background concentrations even at a distance of 800 m from the outfall. These differences in dilution may be from the differences in chemical behavior, natural variability in concentrations, differences in sampling time or location, or a combination of all of these factors.

The variability in dilution factors calculated using measurements of nutrient concentrations do provide an illustration of how the actual behavior of wastewater constituents (for example, nutrients) as measured *in situ* at a given time may deviate from the ideal modeled dilution factors, even if the modeled dilutions are based on the use of actual data on distributions of conservative tracers such as salinity, dyes, or density. To do a detailed analysis of nutrient dilution as the effluent plume moves further from the outfall, a specific study designed to track nutrient concentrations and composition would need to be conducted. Such a study should examine all inorganic and organic phases of nitrogen and phosphorus, as well as use stable isotope tracers to track effluent nitrogen and organic matter. The same is true for dissolved organic matter, which is not addressed in the SEFLOE study. The physical oceanographic conditions present during such a study would have to be documented as well, since it would be highly possible for dynamic changes in local current flow to disrupt an otherwise orderly plume tracking experiment. It should be noted that nutrient fate and transport was not a focus of the SEFLOE studies as reported in Hazen and Sawyer. A study of nutrient fate and transport, based on the use of stable isotope tracers, is described below (Hoch et al., 1995).

At the time of the SEFLOE II studies, there was concern that nutrients from the discharge of wastewater into the open ocean was causing enhanced growth of *Codium*, an algae observed in 1991 and 1992 on several southeast Florida coral reefs. The SEFLOE II reports gives several reasons as to why the nutrients discharged from the outfalls are not likely to cause increases in *Codium* (Hazen and Sawyer, 1994), as summarized below:

- *Codium* plants require attachment to a solid substrate in order to grow, while the outfall plume rises. Thus, *Codium* habitat is not exposed directly to the effluent plume.
- Attached *Codium* plants were not present near the outfall sites where nutrient levels are above background-seawater levels.
- *Codium* attaches to solid substrate in deeper waters, outside of the nutrient dispersal area associated with the outfalls. The effluent nutrient levels quickly reach background concentrations within a short distance of the outfall (typically several hundred meters).
- Natural cycles of *Codium* growth have been reported in the literature prior to the discharge of wastewater effluent to the open ocean.
- The sporadic occurrences of the algal blooms are not consistent with the uniform discharge of the effluent, indicating no significant relationship.

The SEFLOE summary states that, "While the introduction of nitrogen into the marine environment can have significant impacts on water quality and wildlife, in this case the impacts to the open ocean appear to be mitigated by the vast reservoir of water available for dilution, the speed with which dilution occurs due to the currents at the Floridian outfalls, and the uptake and removal of nitrate by phytoplankton which entrains the nitrogen into the food chain, thereby removing it from the area where it was first emitted. The rapid dilution and removal of nitrate from the area immediately surrounding the boil quickly decreases any measurable ecological risks associated with the discharge of nitrate into the open ocean at the point where the effluent meets the receiving waters."

The stable isotopic composition of nitrogen in organic matter, called $\delta^{15}N$, can be useful in distinguishing the sources of organic matter and nutrients and the trophic level of the organisms producing the organic matter (Hansson et al., 1997; Peterson, 1999). Wastewater nitrogen tends to be isotopically enriched in the heavier isotopes of nitrogen relative to the atmospheric nitrogen standard, which represents a pristine source of nitrogen. Sewage effluent nitrogen is often isotopically heavier (more positive numbers) because of isotopic fractionation along the food chain that results in higher trophic levels, producing isotopically heavier nitrogen in wastes (LaPointe, 1997; Densmore and Bohlke, 2000; Rau et al., 1981; Schroeder et al., 1993; Spies et al., 1981; Spies, 1984; Van Dover et al., 1992). Wastewater nitrogen has been implicated as a source of isotopically heavier nitrate in the Florida Keys (LaPointe, 1997). Carbon ($\delta^{13}C$) and sulfur

($\delta^{32}S$) also provide useful isotopic tracers for organic matter (Fry et al., 1998; Gearing, 1988; Gearing et al., 1991; Wainwright and Fry, 1994; Peterson et al., 1996; Peterson, 1999).

LaPointe et al. (1992) suggests that phosphorus may be of greater importance than nitrogen as a limiting nutrient in macroalgal growth in carbonate-rich tropical waters, while nitrogen is more important in siliciclastic systems. More recently, work by LaPointe (1997) found that, at four sites located between West Palm Beach and Hobe Sound approximately 2 to 3 kilometers offshore, waters enriched with dissolved inorganic nitrogen (DIN) increased the photosynthetic efficiency of *Codium isthmocladum* in southeast Florida waters. In addition, elevated $\delta^{15}N$ values of *C. isthmocladum* tissue indicated that wastewater dissolved in DIN was a source of nitrogen to blooms in southeast Florida. LaPointe found that increases in $\delta^{15}N$ values in *Codium* tissue of more than 10 parts per thousand (*o/oo*) occurred with the onset of the rainy season, suggesting that discharges during the rainy season provided a significant nitrogen source.

A different study of the fate of sewage effluent-derived nitrogen and carbon using stable isotope tracers was conducted by researchers from EPA and Texas A&M University (Hoch et al., 1995). This study examined suspended particulate organic matter, sediment organic matter, filter-feeding organisms (sponges, soft, or gorgonian corals), settling particle fluxes, and dissolved nutrients (ammonia, nitrate and nitrite, phosphorus, and organic carbon) in the vicinity of the six southeast Florida ocean outfalls and one small outfall located in the Florida Keys. The study hypothesized that pelagic suspended organic matter composed of phytoplankton is a source of organic matter to benthic ecosystems and sediments and that the isotopic composition of these phytoplankton sources (and the nutrients they utilize) would be reflected in the isotopic composition of organic matter in sediments.

Hoch et al. (1995) found that sewage effluent ammonia from the southeast Florida outfalls had $\delta^{15}Ns$ ranging from 4.4*o/oo* at the Central Miami-Dade outfall, to 8.6*o/oo* at Broward and 15.4*o/oo* at Key West. Sewage effluent DIN ranged from 4.3*o/oo* to 8.1*o/oo* to 12.7*o/oo*, respectively. Nitrate and nitrite together had $\delta^{15}Ns$ ranging from –1.6*o/oo* to – 5.7*o/oo* to 10.5*o/oo*, respectively. In comparison, suspended particulate organic matter (including phytoplankton that take up nutrients) had $\delta^{15}Ns$ that were more negative than effluent DIN and more similar to ambient marine organic matter (2*o/oo* to 4*o/oo*). This suggests that the effluent plume nitrogen was being diluted with ambient marine suspended particulate organic matter. In general, the nitrogen isotopic composition of ammonia and DIN at the Central Miami-Dade outfall was not very different from that of ambient marine organic matter and DIN, while ammonia and DIN from the Broward plant had isotopic signatures significantly different from that of ambient marine organic matter.

The results for the six southeast Florida ocean outfalls indicated that phytoplankton uptake of effluent-derived nitrogen into biota was not clearly demonstrated at any of the southeast Florida outfalls, including the largest outfalls (Broward and Central Miami-

Dade). At these outfalls, there appears to be little coupling between the pelagic and benthic ecosystems, even though loading of sewage effluent-derived nitrogen to coastal environments was significant (about 6 x 10^6 kg of total N per year, of which more than 97 percent is derived from the six southeast Florida outfalls). Furthermore, the measured rates of primary production were less than production estimated from the nitrogen load. Hoch and colleagues concluded that the strong currents and rapid dilution at the southeast Florida outfalls may have caused rapid dilution of sewage effluent nitrogen prior to uptake by plankton. An alternate explanation for the observed isotopic values of organic matter is that phytoplankton may have taken up a form of nitrogen not measured isotopically (for example, organic nitrogen) (Hoch et al., 1995).

In contrast, the same study found that, at the Key West outfall, a conservative estimate of the amount of effluent particulate carbon contributing to the diet of soft corals immediately adjacent to the outfall is about 40%, based on the use of both carbon and nitrogen stable isotopes. These different results suggest strongly that the physical dispersion and dilution of effluent along the southeast Florida coast plays a major role in reducing the ecological significance of effluent nitrogen. However, it also suggests that the use of stable isotopes may not be an extremely sensitive tracer if the sewage effluent isotopic composition is not significantly different from ambient marine organic matter to begin with (Hoch et al., 1995).

6.6.2.3 Metals and Organic Compounds

As with nutrients, there are three basic questions concerning potential effects of metals and organic priority pollutants remaining in effluent following secondary treatment:

- Are concentrations of priority pollutants in effluent or diluted effluent higher than water-quality standards for protection of ecological health?
- Can biological uptake of priority pollutants be demonstrated for any ecological component?
- Is there evidence of adverse effects because of exposure to or uptake of priority pollutants?

Metals

To address the question of whether metals in undiluted and diluted effluent meet water-quality standards, the SEFLOE studies measured priority pollutant metals and detected several (copper, arsenic, silver, lead) and cyanide in undiluted effluent. Concentrations sometimes exceeded Class III marine water-quality standards (Table 6-10). None of the metals tested in undiluted effluent exceeded the Florida Maximum Allowable Effluent Levels (Hazen and Sawyer, 1994).

Table 6-10. Priority Pollutant Metals Detected in Treated Wastewater Effluent Exceeding Class III Marine Water-Quality Standards

Metal	Concentration in Treated Effluent (µg/L)	Background Concentration in Oceans[a] (µg/L)	Florida Maximum Allowable Effluent Level (µg/L)	Florida Class III Marine Water Standards (µg/L)	EPA Saltwater Criteria (µg/L)	Dilution To Meet Most Stringent Criteria
Broward						
Arsenic, total	BDL, **124**, <1.70, 2.3	1.77	N/A	≤ 50	36	3.6
Copper, total	2.1, 20, **111.3**, 14.4	0.261	N/A	≤ 2.9	2.9	42.1
Lead, total	BDL, 5.0, 4.8, **6.7**	0.0021	≤ 500	≤ 5.6	8.5	1.2
Silver, total	BDL, 0.5, **0.9**, 0.5	0.0028	N/A	≤ 0.05	N/A	19.0
Miami-Dade North						
Arsenic, total	**0.83**, BDL, <10.0[c]	1.77	N/A	≤ 50	36	N/A
Copper, total	**19.0**, 16.0, <10.0[c]	0.261	N/A	≤ 2.9	2.9	7.1
Lead, total	**20.2**, BDL, <5.0[c]	0.0021	≤ 500	≤ 5.6	8.5	3.6
Cyanide	**8.41**, 8.0, <4.0[c]	N/A	N/A	≤ 1	1	8.41
Miami-Dade Central						
Copper, total	**35**, 10	0.261	N/A	≤ 2.9	2.9	13.2
Lead, total	**40**, BDL	0.0021	≤ 500	≤ 5.6	8.5	7.2
Silver, total	**14**[d], BDL	0.0028	N/A	≤ 0.05	N/A	296.6
Cyanide	9.6, BDL	N/A	N/A	≤ 1	1	9.6

Note: Data are from Hazen and Sawyer, 1994, unless indicated otherwise by superscripts.

[a] From Bruland, 1983.

[b] Values shown in boldface represent the highest sample values. The dilutions to meet most stringent criteria are calculated in this report based on these highest sample values.

[c] Miami-Dade North District, 1999. See Appendix Table 1-2.

[d] Questionable value, according to Hazen and Sawyer, 1994.

BDL Below detection limits.

N/A Not available.

Note that with the possible exception of silver at the Miami-Dade Central plant (where the value may be incorrect), the dilution required to meet the most stringent water quality standard varies from 1.2 to 42, depending on the metal and the effluent concentration. The 400 m to 800 m mixing zones required under the Florida regulations are intended to provide dilutions ranging from 60:1 to 90:1 or more, based on modeling of the effluent plume. Also, the concentrations of metals in effluent are measured in the parts per billion range, which is low for industrial effluent.

Both the regulatory criteria for Class III marine water and the effluent studies of South Florida ocean outfalls address total metals concentrations rather than dissolved metals. Since dissolved metals are the most bioavailable, they have the most potential to cause ecosystem toxicity effects. Therefore, the values in Table 6-10 can only be used for a general estimate of risks.

The SEFLOE studies did not specifically report on biota in the vicinity of the outfalls, although Hazen and Sawyer (1994) report that a healthy ecosystem appeared to be present. Thus, there is no information concerning potential effects of metals or other stressors on benthic populations of organisms in the outfall areas.

It is therefore not possible to answer the third question concerning evidence of adverse effects of priority pollutants on marine ecosystems in the area, but it is also not possible to rule out adverse effects. No long-term ecological monitoring studies of possible ecological effects were done following the conclusion of the SEFLOE studies in 1994.

Volatile Organic Compounds

Monitoring data were very limited for volatile organic compounds (VOCs); the only detected compound originates from the Miami-Dade Water Sewer North District, which reported a one-time measurement of tetrachloroethene of 4.66 ug/L on March 19, 1999. The Florida Class III marine water-quality standard for tetrachloroethene is $\leq$8.85 ug/L on an annual average. Although the SEFLOE report sampled for 126 EPA priority pollutants, including tetrachloroethene and many other organic compounds, there were no other reported detections of tetrachloroethene.

The one data point for VOC concentration in effluent is less than the regulatory standard for VOCs in Class III marine waters, and it is less than the reported literature toxicity values (see Section II). VOCs are highly volatile and would be expected to volatilize as the effluent rises to the upper ocean layer. There is little or no evidence concerning VOCs in ecological receptors. Unfortunately, there are not enough data available to offer firm conclusions on this point. Again, while the effluent toxicity testing suggests that there is no short-term acute toxicity, there are no long-term ecological monitoring studies to examine long-term or cumulative ecological changes that might occur as a result of the discharge of effluent containing trace amounts of VOCs. Thus, for VOCs, the small amount of data available from the SEFLOE report suggests that the amounts of VOCs present in treated discharged effluent are very low and becomes even lower when rapid dilution by currents occurs. The toxicity testing indicates no toxic effects for chronic short-term testing or acute toxicity testing.

Synthetic Organic Compounds

Very little data were available concerning linear alkylbenzenesulfonates (a detergent component used as a representative detergent compound in this study) in Florida wastewater effluent. Effluent data from the Miami-Dade North District detected a concentration of methylene blue anionic surfactant (MBAS) surfactant of 0.063 mg/L in the effluent prior to discharge (Table 6-11 from Hazen and Sawyer, 1999). This concentration is lower than the regulated Class III standard of ≤0.5 mg/L for detergents. More information on occurrence and levels of surfactants in treated effluent and in receiving waters and their biological effects is needed to adequately evaluate ecological risks posed by this category of compound.

Table 6-11. MBAS Concentrations in Effluent and Calculated Dilution Concentration at 400 m from the Boil

	MBAS in Effluent (mg/L)	MBAS in Effluent (mg/L), 60:1 Dilution	MBAS in Effluent (mg/L), 90:1 Dilution	Background Seawater (mg/L)	Class III Standard for Detergents (mg/L)
MBAS surfactant	0.063[1]	0.001	0.0007	0	≤0.5

[1] Data from Miami-Dade Water/Sewer, North District. 1999. Submission #9903001041, pp. 47-52. Screen effluent collected 3/19/99.

No information is available on monitoring of detergents or other synthetic organic compounds in ecological receptors at or near the effluent outfall.

Hormonally Active Agents

Estrogen equivalences were measured from two grab samples at the Gulfgate and Southgate treatment plants in Sarasota, Florida. Both of these plants treat to advanced wastewater treatment levels and discharge to surface-water creeks. The average concentration of estrogen substances in the treated wastewater effluent was 3.253 nanograms per liter (Frederic Bloettscher, Consulting Professional Engineer, personal communication). At this point, this information only indicates that these substances may be present in treated wastewater effluent intended for discharge into surface water. The literature suggests that, while these concentrations may not induce toxic effects in aquatic organisms, more study is needed concerning the concentrations at which endocrine disruption may occur because of biodegradation byproducts.

No information is available concerning concentrations of estrogen-like compounds in ambient seawater at the southeast Florida ocean outfall sites, nor in ecological receptors at or near the ocean outfall sites. Ongoing and future research should provide a better framework for discussing these compounds and evaluating their risks. Having monitoring data for these constituents in effluent would allow risk to be better evaluated.

6.6.2.4 Toxicity Testing of Effluent

One way to address the question of whether there could be adverse effects from effluent is to conduct toxicity testing of effluent using marine organisms. In order to comply with Florida standards, biological toxicity testing of the diluted and undiluted treated effluent was conducted as part of the SEFLOE studies (Commons et al., 1994a, 1994b) and is summarized in the Hazen and Sawyer (1994) report. A total of 1,727 acute bioassay toxicity tests and 109 short-term chronic bioassays were performed, using diluted effluent water from four ocean outfall wastewater treatment plants and effluent plume samples. Acute toxicity was assessed using the mysid shrimp *Mysidopsis bahia* and the estuarine fish *Menidia beryllina*. Short-term chronic toxicity testing was assessed using those organisms, the sea urchin *Arbacia punctulata*, and the macroalga *Champia parvula*. The bioassay results were compared with current velocities to determine initial and farfield dilutions and to calculate actual exposure times. This allowed researchers to determine potential toxicity of the undiluted effluent, initial dilution, and mixing-zone effluent/seawater mixture.

In all ocean bioassay tests, no potential acute toxicity of effluent or diluted effluent was demonstrated. The bioassays are believed to be conservative: during the tests using diluted effluent, organisms are exposed to the effluent longer and at concentrations that greatly exceed actual measured concentrations of effluent constituents in the ocean outfall area (Commons et al., 1994a, 1994b; Hazen and Sawyer, 1994).

While toxicity testing indicates that there are no acute toxic effects to biological organisms, long-term low-dose chronic toxicity testing was not conducted. Toxicity testing also does not address effects of nutrient enrichment on ecological processes of production, organic cycling, or microhabitats where nutrients may remain more concentrated. Ecological processes that are not addressed by toxicity testing include nutrient-stimulated primary production and respiration, production of organic matter for consumers and detrital feeders, decomposition of organic matter, and the effects of these processes on water quality and biological communities.

6.6.3 Final Conceptual Model of Probable Risk for Ocean Outfalls

The SEFLOE studies provide a risk assessment and a prediction that there should not be any adverse effects resulting from ocean discharge of secondary-treated effluent. This prediction is based largely on the rapid dispersal and dilution of the effluent plumes by the Florida Current and that the treated effluent has relatively low concentrations of stressors to begin with. Prevailing current directions and fast current speeds of the Florida Current are major factors that decrease risk for the six ocean outfalls that discharge into the Florida Current. Current speeds can be more than 60 or 70 cm/sec for the Florida Current, while speeds of 20 to 40 cm/sec commonly occur. Northerly flow with the fastest speeds occurs approximately 60% of time. Southerly flow with similar or lesser speeds occurs about 30% of time. Flow in other directions (easterly, westerly) exhibits the lowest current speeds and occurs less than 10% of the time. Westerly flow towards the east coast of Florida, which represents the highest risk, is estimated to occur less than approximately 4% of the time, while easterly flow is estimated to occur less than approximately 6% of the time.

Other factors that decrease risk are the distance of the outfalls from land. The lowest risk outfalls are farthest from land (Miami-Dade Central outfall), while the highest risk outfalls are closest to land (Boca Raton, Del Ray Beach). The use of multiport diffusers, compared to the use of single-port diffusers, appears to aid in dispersal of the effluent plume over a wider area, decreasing potential risk. Discharging the effluent at a faster initial speed also appears to increase the rate of dispersal and dilution of the effluent plume.

Based on toxicity testing of marine organisms, there is no evidence that the diluted effluent causes acute toxic effects or short-term chronic effects.

Based on nitrogen isotope studies of organic matter in sediments and nutrients in the water column, it does not appear that the nitrogen in outfall effluent is taken up in significant amounts by phytoplankton in the area. This may be because of the rapid dilution of the effluent nitrogen by the Florida Current.

The state of Florida requires that Class III water quality standards be met outside a mixing zone of 502,655 m^2 around the outfall. This mixing zone allows for dispersal, mixing, and dilution of the effluent plume. A mixing zone with a circular radius of 400 m measured from the outfall was used by the utilities in the SEFLOE study. This circle would cover an area equivalent to 502,655 m^2. The use of a circular mixing zone is not required by Florida, but is used for ease of defining an area to monitor.

Concentrations of pathogens are controlled at the treatment plant through chlorination to meet water-quality standards within the required mixing zone; viruses and most bacteria are expected to be adequately inactivated by chlorine. However, there is no filtration to remove *Cryptosporidium* and *Giardia.* Lack of treatment to remove pathogenic protozoans probably constitutes the greatest human health risk posed by this wastewater management option.

Pathogenic protozoans may also pose significant ecological risks related to infections of marine mammals. The effects of pathogenic protozoans on aquatic organisms need to be further investigated.

Concentrations of priority pollutant metals in undiluted effluent may exceed marine water-quality standards (but meet effluent standards), but there is no information on actual receptors or exposure pathways because there were no benthic tissue monitoring studies, benthic ecology studies, or studies of trace metals in the water column as part of the SEFLOE studies. The results of the SEFLOE study for metals monitoring indicates that, in general, water-quality standards are met at 400 m or 800 m.

In coastal areas from North Carolina south to Florida, oysters, other shellfish, and sediments have elevated concentrations of arsenic, although not at levels that would pose a threat to humans or to marine life, according to a NOAA National Status and Trends Program report (Valette-Silver et al., 1999). Postulated sources of arsenic include pesticides, mining of arsenic-containing phosphate rocks, atmospheric dust, river and groundwater inputs, and ocean upwelling. The NOAA study did not examine ocean outfalls as potential sources of metals. Since oysters are a nearshore intertidal species, it is most likely that the arsenic is derived from terrestrial and coastal sources close at hand, rather than the ocean outfalls.

Concentrations of priority pollutant organic compounds in treated wastewater are generally very low. Monitoring data were very limited for volatile organic compounds; the only data available originates from the Miami-Dade Water Sewer North District, which reported a one time measurement of tetrachloroethene of 4.66 μg/L, which meets the Florida Class III annual average marine water-quality standard for tetrachloroethene of ≤8.85 μg/L. There were no reported detections of tetrachloroethene in the SEFLOE study.

Concentration of a surfactant, MBAS, of 0.063 mg/L in the effluent is lower than the regulated Class III standard for detergents of ≤0.5 mg/L. The effects of low concentrations of surfactants on aquatic organisms in natural settings are not well understood or documented. The lack of knowledge concerning effects of surfactants on the tissues and physiologic functions of aquatic organisms is not cause to eliminate this as a potential stressor. Surfactants act to decrease surface tension and reduce adhesion, which may affect microorganisms or for other functions in higher organisms.

Despite the lack of information on effects of endocrine disruptors in South Florida marine waters, effluent discharged to marine waters typically contains such compounds. Endocrine disruptors may pose a concern because they can cause effects in aquatic organisms at very low concentrations and because they are typically present in wastewater and not removed by existing wastewater treatment technology. However, better information on the concentrations of these substances in Florida wastewater, coastal waters, and in aquatic organisms is needed. A better understanding of their effects is also needed.

In summary, the chlorinated discharged effluent largely meets Class III water-quality standards for all regulated wastewater constituents within 400 m of the outfalls, with exceptions as noted.

The lack of long-term ecological, microbial pathogen, and chemical monitoring studies makes it difficult to evaluate whether the conclusions of the SEFLOE studies will continue to hold true in the future. It is not possible to evaluate whether long-term, cumulative, chronic risks exist or not. There are no ongoing monitoring studies downcurrent of any of the effluent plumes or within the footprint of the effluent plume. An initial project to formulate a long-term study to address issues concerning nutrients, growth of nuisance macroalgae (*Codium*), productivity, and the benthic community had begun in the early 1990s, but this project did not go forward at that time. A long-term extensive program is now being contemplated that will examine long-term monitoring of the outfalls and adjacent areas and examine sources of nutrient loading (personal communication, John Proni).

Potential long-term ecological risks may exist, particularly within the 400-m mixing zone, but also outside it. Nutrients, including both nitrogen and phosphorus, may constitute the most important ecological stressors resulting from ocean outfalls. Nutrient dispersal poses concerns because coastal water quality throughout Florida is already impacted by a variety of human activities on land, such as agriculture, septic systems, urbanization, and channelization of wetlands. The cumulative ecological risks associated with continually discharging nutrients into the Florida Current, and ultimately the Gulf Stream, are not known. The same is true of other effluent constituents, such as metals and organic compounds.

Information needed to assess whether or not there is a long-term, chronic, or cumulative adverse effect on marine organisms would include the following:

- Monitoring of benthic communities in the plume track and adjacent areas
- Tissue studies of bioaccumulation in the food chain
- Monitoring of primary production and nutrient uptake and cycling
- Tracer studies of the sources of nitrogen and phosphorus being utilized by phytoplankton
- Marine particle fluxes of metals in the plume track and adjacent areas to determine whether metals discharged in the effluent adsorb onto marine snow particles or precipitate as solid particles or not
- Related studies of the ecology and chemistry of the ocean within the plume footprint and adjacent to it.

Human health risks are of some concern, both within the 400-m mixing zone and outside of it, primarily because treatment of effluent prior to discharge via ocean outfalls does not include filtration to remove *Cryptosporidium* and *Giardia*. The most probable human exposure pathways include fishermen, swimmers, and boaters who venture out into the Florida Current and experience direct contact, accidental ingestion of water, or ingest fish or shellfish exposed to effluent. Otherwise, there is a very small, but not nonzero, chance for onshore or nearshore recreational or occupational users to be exposed to effluent constituents, since there is a small (10%) chance that currents will change direction to east or west.

Finally, there is the question of whether any adverse effects, if they exist, are reversible. Monitoring studies of Tampa Bay, where tertiary treatment of effluent is now required instead of secondary treatment (see Chapter 7, Surface Water Discharge) indicates that water quality and benthic ecological conditions will improve upon upgrading treatment (Lipp et al., 2001). Even at highly affected marine disposal sites where sewage sludge has been disposed of, cessation of disposal has resulted in improvement of the benthic communities and water and sediment quality (Studholme et al., 1995, 1989). Because the existing southeast Florida ocean outfalls discharge to the Florida Current, recovery from any adverse effects, if they exist, would probably be rapid because of the rapid flushing by the Florida Current.

6.7 Potential Effects of Data Gaps

Because of the relatively short term of the SEFLOE studies (several years), the long term or cumulative ecological risks of nutrient loading and loading of other effluent constituents cannot be evaluated. Some of the specific questions that cannot be answered at this time include:

- Effects of adding nitrogen and phosphorus to the Gulf Stream nutrient budget and its potential to affect primary productivity in the open ocean
- Effects on productivity and marine organisms within the plume where nutrient concentrations are higher than background concentrations
- Potential changes in the ratio of nitrogen to phosphorus and effects on phytoplankton diversity
- Frequency of harmful algal blooms in the vicinity of the outfalls
- Bioaccumulation of effluent constituents by marine organisms in the vicinity of the outfall and its plume footprint
- Changes in trophic structure and potential food-web effects
- Effect of global climate change or other factors on the Florida Current that would cause changes in current speed, direction, or position and affect dilution of the effluent plume, affecting risk
- Long-term, chronic effects of exposure of benthic or nektonic marine organisms to effluent constituents in the vicinity of the effluent plume.

Regarding potential human health risk issues, there are also significant data gaps. Some examples of questions that remain unanswered include the following:

- Are *Cryptosporidium* and *Giardia* present in nearshore waters that are used by humans, are their concentrations within safe limits, and if not, can their sources be determined (for example, onshore sources versus ocean outfalls)?
- Are pathogenic *E. coli*, enteric viruses, and other enteric pathogens present in the treated effluent in numbers high enough to be of concern for human health?
- What is the relative contribution of enteric pathogens and other stressors from existing onsite septic disposal systems and other sources versus ocean outfalls to water quality near the outfalls?

These are just a few of the issues that remain to be addressed if long-term risk from ocean outfalls is to be fully assessed.

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7.0 DISCHARGE TO SURFACE WATERS

In this chapter, the potential risks associated with discharge of treated municipal wastewater into surface-water bodies are evaluated for South Florida.

7.1 Definition of Discharge to Surface Waters

In South Florida, treated wastewater managed by this option is discharged into canals, creeks, and estuaries. At a minimum, wastewater discharged to surface waters must receive secondary treatment with basic disinfection. However, wastewater discharged to some water bodies (for example, Tampa Bay, Indian River Lagoon) must first receive advanced treatment, including nutrient removal.

Florida's Anti-Degradation Policy, which prohibits surface-water resources from being degraded, discourages discharge to surface waters because of the high cost of treatment and the ecological risks, which are generally perceived as high. Even treatment plants that use this option generally do so infrequently, as a backup when other options (for example, reuse) are not available.

7.2 Use of Discharge-to-Surface-Waters Option in South Florida

The discharge-to-surface-waters option is used to varying degrees throughout South Florida. As described in Chapter 2, Figure 2-2, facilities in Brevard, Hillsborough, and Sarasota counties make significant use of this option. Facilities in Hillsborough County rely on this option (roughly 75% of total design capacity) to a greater extent than do facilities in most other counties in South Florida. In Pinellas and Collier counties, treatment facilities use a combination of options, including discharge to surface waters. In Collier County, discharge to surface waters accounts for an insignificant portion (1%) of the total design capacity. Facilities in Broward, Palm Beach, and Dade counties rely primarily upon ocean outfalls and underground injection and do not discharge to surface-water bodies (see Figure 2-2).

The treatment facilities reviewed in this study that discharge to surface waters either discharge directly to estuaries with brackish water, coastal embayments, or to freshwater creeks or canals that eventually discharge to embayments. In Brevard County, the South Beaches and Cape Canaveral wastewater treatment facilities discharge to the Indian River Lagoon only when no other practical alternative exists. The Indian River Lagoon System and Basin Act of 1990, contained in Chapter 90-262, Laws of Florida, "prohibits new discharges or increased loadings from domestic wastewater treatment facilities into surface waters…." (FDEP, 2002a). Exceptions are made if the applicant can meet the following conditions:

- The permit applicant conclusively demonstrates that no other practical alternative exists and that the discharge will be treated to advanced treatment levels or higher

- The applicant conclusively demonstrates that the discharge will not cause or contribute to water-quality violations and will not hinder efforts to restore water quality in the Indian River Lagoon System
- The discharge is an intermittent discharge to surface waters occurring during wet weather conditions, subject to the requirements of applicable Florida Department of Environmental Protection (DEP) rules.

The Act also requires facilities to investigate the feasibility of using reclaimed water to promote reuse and reduce nutrient loadings. Based on these requirements, the Cape Canaveral treatment plant was upgraded in the mid-1990s to provide advanced wastewater treatment (AWT). The new AWT plant is part of a reclaimed water system that supplements the City of Cocoa Beach's reclaimed water supply. Discharge to the Banana River, a segment of the Indian River Lagoon, is allowed during periods of wet weather or when demand for reclaimed water is low (FDEP, 20021; Cape Canaveral Wastewater Treatment facility, personal communication).

In Hillsborough County, the Howard F. Curren AWT plant serves the city of Tampa. In 2000, the plant managed 48.5 million gallons per day (mgd) using a combination of discharges to Hillsborough Bay (a portion of Tampa Bay) and reuse of reclaimed water for cooling and irrigation (City of Tampa, Florida, 2001). In Sarasota County, the Gulfgate and Southgate treatment plants discharge into two freshwater creeks, Phillippi Creek and Methany Creek. These eventually drain to Roberts Bay (Marella, 1999). Gulfgate has a permit capacity of 1.80 mgd and no reuse capacity. Southgate has a permit capacity of 1.36 mgd and very limited reuse capacity. Both facilities discharge approximately 70% to 80% of their permitted capacity, and each is planning for expanded reuse (Joseph Squitieri, Florida Southwest DEP, personal communication).

7.3 Environment Into Which Treated Wastewater Is Discharged

7.3.1 Estuarine Environments

An estuary is defined as "a semi-enclosed coastal body of water that is connected to the sea and within which seawater is measurably diluted with fresh water from land drainage" (Pritchard, 1967). Estuaries are some of the most productive, diverse, and complex ecosystems on earth. They exhibit tremendous temporal and spatial variability in their physical, chemical, and biological characteristics.

Lagoons are considered a type of estuary. They are produced by wave action and are typically found behind a barrier beach or spit. Lagoons are characterized as being less well drained and are uniformly shallow, often less than 2 meters deep. Physical processes of mixing and circulation in lagoons are mostly wind-dominated, whereas freshwater inflow (from surface water and groundwater) tends to drive mixing and circulation in salt-marsh estuaries.

The Tampa, Sarasota, and Florida bays are representative of estuarine coastal embayments in South Florida. The Indian River Lagoon is an example of a lagoon system. Tampa Bay, Sarasota Bay, and Indian River Lagoon each receive effluent discharges treated to AWT standards. Although Florida Bay does not receive known or permitted discharges of treated wastewater, there are a number of relevant concerns regarding its water quality and aquatic habitat. These concerns establish a useful context in which to consider risks associated with the discharge-to-surface-waters option.

Potential human health and ecological risks associated with discharges to these environments would be greatly influenced by site-specific flushing rates and the depths of water bodies.

7.3.1.1 Tampa Bay

Tampa Bay is located on the west coast of the Florida peninsula and is part of the Gulf of Mexico. This extremely shallow bay (average depth of 4 meters) is the largest open-water estuary in Florida, encompassing over 400 square miles and with over 100 freshwater tributaries (Pribble et al., 1999). Dominant habitats in the Tampa Bay estuary include seagrass beds, mangrove forests, salt marshes, and oyster bars. Wildlife is abundant; over 40,000 breeding pairs of birds, such as the brown pelican and roseate spoonbill, nest in Tampa Bay every year. The bay is also home to dolphins, sea turtles, and manatees.

Tampa Bay was heavily polluted before 1979. This pollution largely resulted from discharges of primary-treated wastewater from the Hooker's Point Wastewater Treatment Facility (now the Howard F. Curren Plant) into Hillsborough Bay, a subembayment of Tampa Bay. Since the state of Florida began requiring advanced treatment to remove nitrogen, the bay has been recovering. Water clarity and the health of benthic communities have improved, and sea grasses have reappeared (City of Tampa Bay Study Group, 2001a, 2001b). While the adverse effects of discharged wastewater have been reduced, the bay is still suffering from other pollution sources, particularly atmospheric and nonpoint source loading of nutrients. Sediment quality in Hillsborough Bay remains impaired; 33% of sediments are of marginal quality with respect to metals, and 8% of sediments are of poorer quality (Pribble et al., 1999).

7.3.1.2 Sarasota Bay

Sarasota Bay, located on the Gulf of Mexico in southwest Florida, is another coastal embayment that receives discharges of treated municipal wastewater. The bay is composed of two major embayments, Sarasota Bay and Little Sarasota Bay, and many smaller embayments. The bay is 56 miles long and ranges in width from 300 feet to 4.5 miles. Average depth throughout much of the bay ranges from 8 to 10 feet (Roat and Alderson, 1990). Sarasota Bay exhibits wildlife and habitat that are very similar to Tampa Bay, including mangroves, sea grasses, marine mammals, and waterfowl.

Since 1990, nitrogen discharges from wastewater treatment plants have been reduced by 80% because of the implementation of AWT and reuse programs (Sarasota Bay National Estuary Program, 1993). As a result, water quality and habitat quality have improved.

Sea-grass coverage in the bay has increased by 18% since 1988 (Sarasota Bay National Estuary Program, 2000).

7.3.1.3 Indian River Lagoon

The Indian River Lagoon is located on the east coast of Florida, stretching 156 miles from Ponce de Leon Inlet, south of Daytona Beach, to Jupiter Inlet near West Palm Beach (Adams et al., 1996). The Indian River Lagoon is a lagoonal estuary composed of several water bodies, including the Indian River, the Banana River, and Mosquito Lagoon. The lagoon system receives inputs of salt water via inlets from the ocean. Fresh water is received in the form of direct precipitation, groundwater seepage, surface runoff (discharges from creeks, streams, and drainage systems), and point sources such as wastewater treatment plants. The long narrow shape and shallow waters of the lagoon result in sluggish circulation patterns in many places. Circulation is primarily wind-driven, and tidal exchange is limited to six widely separated inlets with restricted tidal flushing (Adams et al., 1996).

In some areas, habitat loss and alteration have been significant. Portions of the Banana, North Indian, and South Indian rivers have experienced the greatest long-term declines in sea-grass cover within the lagoon system (Adams et al., 1996). Approximately 27% of the mangrove acreage in the Fort Pierce area was lost between 1940 and 1987 (Hoffman and Haddad, 1998). Many salt marshes and mangrove swamps were impounded and flooded to control mosquito breeding.

7.3.1.4 Florida Bay

Florida Bay is located at the southernmost tip of Florida, bounded by the mainland and the Keys. It is a semi-enclosed, shallow, oligotrophic bay, with depths ranging from 6 to 30 feet. The watershed, which discharges to the bay, includes all of the freshwater wetlands south of Lake Okeechobee. This vast area slopes gently and drains towards Florida Bay and the Gulf of Mexico (NOAA, 1999).

Although there are no known discharges to surface waters of municipal wastewater into Florida Bay, conditions in Florida Bay provide examples of many of the natural resource issues confronting wastewater and water managers in South Florida. The Florida Bay hydrologic system has been highly altered, largely through the construction of a complex canal and levee system to control flooding and provide fresh water for agriculture. The U.S. Geological Service (USGS) has been investigating environmental changes that have occurred over the past 150 years within Florida Bay and the surrounding South Florida ecosystem (McPherson et al., 2000; McPherson and Halley, 1996). Recent studies (Boyer et al., 1997, Brewster-Wingard and Ishman, 1999; Brewster-Wingard et al., 1996) have focused on describing temporal and spatial variability within the bay ecosystem. These studies show the following:

- Salinity in the bay has increased since the 1950s

- Before 1940, fluctuations in salinity and sea-grass distribution matched a natural cycle; since 1940, fluctuations have been greater and no longer match a natural cycle
- Sea grass and macrobenthic algae were much less abundant in the 1800s (and early 1900s) and have increased in the last half of the 20th century
- Invasive plants (for example, cattails) have increased in number and are slowly displacing the native saw grass communities along the canals that form part of the drainage system to Florida Bay
- Regional ecosystem disturbances occurring in the late 20th century have been accelerated by human activities
- Between 1991 and 1994, in the central region, nitrate, ammonia, and chlorophyll *a* increased
- Over the past 7 years, concentrations of phosphate and total phosphorus decreased dramatically throughout the bay
- The bay is becoming more phosphorus-limited from west to east.

In recent times, the bay has experienced sea grass die-offs, algal blooms, and declines in the populations of shellfish and sponges (USGS, 1996a). In western Florida Bay, a massive sea grass die-off began in 1987. Since then, some recovery of sea grasses has occurred, while other areas have been slow to revegetate. Algal blooms have been reported in the last few years across western Florida Bay, extending to the Florida Keys (NOAA, 1999).

7.3.2 *Freshwater Environments*

Much of the information that informs this analysis of the discharge-to-surface-waters option was obtained from treatment facilities located in Brevard, Hillsborough, and Sarasota counties. These facilities discharge directly to estuaries or to creeks or canals that discharge to an estuarine environment. This study did not reveal any effluent discharges to freshwater lakes or ponds in South Florida.

Florida's surface-water features include extensive wetlands and numerous lakes, streams, and canals. Streams and wetlands in South Florida have direct hydrologic connections to the surficial aquifer (Randazzo and Jones, 1997). Much of South Florida was originally covered with wetlands. Canals, which are a prominent surface-water feature in South Florida, were dug to drain these wetlands and make the land useable. Canals are the major surface-water drainage feature in South Florida outside of the Everglades (Englehardt et al., 2001). Many canals that receive effluent discharges subsequently empty into saltwater bodies.

Canals are generally man-made waterways or artificially improved rivers; they serve various uses such as irrigation, shipping, recreation, and flood control (Kapadia and Swain, 1996). They vary in size from a few feet wide and deep, to several hundred feet wide and 12 to 15 feet deep. Some canal banks are earthen, while others are encased in concrete.

Surface-water quality throughout large areas of South Florida has already been degraded by human activities, as summarized in two USGS reports on the National Water Quality Assessment (NAWQA) Program Study of South Florida. The USGS made several major findings concerning surface-water quality in South Florida (McPherson et al., 2000; McPherson and Halley, 1996):

- Concentrations of total phosphorus at NAWQA sites in South Florida exceeded the Environmental Protection Agency's (EPA's) Everglades water-quality standard of 0.01 milligram per liter (mg/L) and were above Everglades background levels. A major source of the phosphorus is fertilizer from agriculture.
- Dissolved organic carbon (DOC) concentrations were relatively high when compared with those in other waters of the United States. High DOC concentrations provide food for microorganisms to grow, reduce light penetration in water, and enhance transport and cycling of pesticides and trace elements, such as mercury.
- Pesticides were detected in almost all South Florida NAWQA samples. Most concentrations were below aquatic-life criteria, but the criteria do not address cumulative effects of mixtures of pesticides or their degradation products, which were common in the samples. Organochlorine pesticides, such as DDT and its degradation products, are still prevalent in bottom sediment and fish tissue at South Florida NAWQA sites, even though use of these pesticides has been discontinued in recent decades.
- Exotic plants and animals pose a threat to native biota, and herbicides that were used to control exotic plants were detected in surface water at NAWQA sites.
- Of 21 NAWQA areas nationwide, the Everglades has the second highest enrichment of methylmercury relative to mercury in sediments; methylmercury is highly biologically active and can be taken up by biota.
- The frequency of external anomalies (lesions, ulcers, and tumors) on fish collected at two NAWQA sites in South Florida places these sites among the top 25% of 144 NAWQA sites sampled nationwide. Such anomalies may indicate that fish are stressed by contamination.

The NAWQA study found that major causes for degradation of surface-water quality include modification of drainage patterns, wetland destruction, runoff from agricultural and urban areas, high concentrations of DOC and its effects on mercury transport and light transmission, and release of exotic species.

The USGS also collected water-quality samples between 1996 and 1997 within selected southeast canals that show increases in nutrient concentration corresponding to patterns of land use. For example, nitrate concentrations were highest in agricultural areas; ammonia and total and inorganic phosphorus concentrations were highest in urban areas; total organic nitrogen was highest in wetlands (Lietz, 2000).

In summary, surface-water quality in South Florida shows significant degradation as an apparent result of urban and agricultural activities. Canals in areas of urban and agricultural land use commonly contain water with high concentrations of nutrients, coliform bacteria, metals, and organic compounds when compared to water taken from areas that are remote from these canals. Wildlife has been stressed by human alteration of the hydrologic regime and by the addition of nutrients, sediment, and other pollutants to surface-water bodies (McPherson et al., 2000; McPherson and Halley, 1996).

7.4 Option-Specific Regulations and Requirements

This section describes regulations concerning treatment and discharge of wastewater to surface-water environments.

7.4.1 Treatment and Disinfection Requirements

At a minimum, treatment prior to discharge to surface water must include secondary treatment with basic disinfection (Florida Administrative Code [FAC] 62-600.510(1)). When discharges to surface waters is used as a backup to reuse systems, wastewater is frequently treated to reclaimed-water standards before being discharged. Discharge to Class I drinking waters requires principal treatment, which consists of secondary treatment and high-level disinfection (see Chapter 2). Discharge to waters contiguous to Class I waters requires review of the travel time of effluent to the drinking-water intake; the discharge must also meet Technology Based Effluent Limits (TBEL) or Water Quality Based Effluent Limits (WBEL), as established by the permit. The Florida DEP may require that a facility meet additional water-quality-based effluent limits; these provide and enforce more stringent requirements for effluent quality. TBELs and WBELs are based on the characteristics of the discharge, the receiving-water characteristics, and the criteria and standards of FAC 62-302.

Effluent discharge must not exceed 10 mg/L total nitrogen (FAC 62-600.420(2)(a)(2)), and effluent must contain maximum pollutant levels less than those specified for community water systems in FAC 62-550. These facilities must be designed to reduce total suspended solids to 5.0 mg/L or less before the application of disinfectant (FAC 62-600.540(5)(e)).

In order to be permitted to discharge to either Tampa Bay or the Indian River Lagoon, wastewater treatment plants must treat using AWT. Typically, AWT includes secondary treatment, basic disinfection, nutrient removal (nitrification, denitrification, and phosphorus removal), additional removal of metals and organic compounds, and filtration. Dechlorination is also required (see Appendix Table 1-1). AWT standards must be met on an average annual basis. AWT standards are summarized as follows:

- Carbonaceous biological oxygen demand ($CBOD_5$) must be less than 5 mg/L
- Total suspended solids must be less than 5 mg/L
- Total nitrogen (as N) must be less than 3 mg/L
- Total phosphorus (as P) must be less than 1 mg/L
- Discharge to a treatment or receiving wetland may not exceed 2 mg/L total ammonia (as N) on a monthly average.

Some treatment plants utilize wetland treatment before discharge into surface-water bodies; this provides further reductions in nutrient concentrations prior to discharge.

Basic disinfection (no more than 200 fecal coliform colonies per 100 milliliters (mL)) is a minimum requirement for all discharges to surface waters in Florida. High-level disinfection (fecal coliform removal below detectable limits per 100 mL) is required of all facilities discharging to Class I surface waters. Intermediate-level disinfection may be allowed, if discharge is to wetlands with restricted public access (FAC 62-600.440(5)g) or to surface waters that serve as backup to a reuse system and provided that there is no discharge to Class I waters or their tributaries (FAC 62-600.440(5)(h)). Dechlorination of chlorinated wastewater before discharge to surface waters is also required (see Tables 2-4 and 2-5).

Currently, there are no federal or state limits for concentrations of the pathogens *Giardia lamblia* or *Cryptosporidium* in treated wastewater. However, on January 1, 2002, the EPA did establish drinking-water treatment requirements for these pathogenic microorganisms. The EPA mandated drinking-water treatment to remove 99.9% of *Giardia lamblia* and 99% of *Cryptosporidium* from raw water sources (National Primary Drinking Water Standards, CFR 141). Florida DEP applies a numerical standard (no more than 5.8 cysts or oocysts per 100 L, which corresponds to a 1 in 10^{-4} human illness risk) for *Cryptosporidium* and no more than 1.4 cysts per 100 L for *Giardia* in reclaimed water (York et al., 2002). These recommended limits address the significant human health risks that may be associated with ingestion of viable pathogenic protozoans present in unfiltered or inadequately filtered treated wastewater.

7.4.2 Standards for Surface-Water Quality

In addition to discharge standards, Florida has use and classification standards for surface-water bodies (FAC 62-302.530). The standards are meant to protect the designated use of the water bodies. Table 7-1 summarizes the uses and criteria for some of the relevant stressors reviewed in this study (FAC 62-302.530).

Table 7-1. Criteria for Surface-Water Quality Classifications

Parameter	**Units**	**Class I: Potable-Water Supply**	**Class II: Shellfish *Propagation* or Harvesting**	**Class III: Recreation, Propagation, and Maintenance of a Healthy Well-*Balanced Population of Fish and* Wildlife**	
				Fresh	***Marine***
Fecal coliform bacteria	Numbers per 100 mL	MPN or MF counts cannot exceed monthly average of 200, nor exceed 400 in 10% of samples, nor exceed 800 on any day. Monthly averages must be based on minimum of 5 samples taken over a 30-day period.	MPN shall not exceed a median value of 14, with not more than 10% of the samples exceeding 43, nor exceed 800 on any day.	MPN or MF cannot exceed monthly average of 200, nor exceed 400 in 10% of samples, nor exceed 800 on any day. Monthly averages must be based on minimum of 5 samples taken over a 30-day period	MPN or MF counts shall not exceed monthly average of 200, nor exceed 400 in 10% of samples, nor exceed 800 on any day. Monthly averages must be based on minimum of 5 samples taken over a 30-day period
*Copper	µg/L	Cu ($_e$(0.8545[lnH]-1.465)	2.9	Cu ($_e$(0.8545[lnH]-1.465)	0.9
Nitrate	mg/L	10, or concentration that exceeds nutrient criteria.			
Nutrients		Discharge of nutrients is limited as needed to prevent violations of other standards. Man-induced nutrient enrichment (total nitrogen or total phosphorus) is considered degradation (Section 62-302.300, 62-302.700, and 62-4.242 FAC). Nutrient concentrations in a body of water cannot be altered so as to cause an imbalance in natural populations of aquatic flora and fauna.			
Phosphorus	µg/L		0.1		0.1

*Florida surface-water quality standards for metals were used as assessment endpoints. The standard for copper in Class I and Class III freshwater bodies takes into account water hardness ($CaCO_3$) and provides a range from 0.00361 mg/L to 0.036 mg/L (corresponding to a range in $CaCO_3$ from 25 to 400 mg/L).
MPN = most probable number
MF = membrane filter

In addition to the above classes of water bodies, Florida has a category for Outstanding Florida Waters and Outstanding National Resource Waters. This generally refers to waters of exceptional recreational or ecological significance that are found within national and state parks and wildlife preserves. A complete listing is available under 62-302 and includes the waters of the Everglades National Park. These waters fall under Florida's Antidegradation Policy and are afforded the highest protection.

In December 2000, the EPA published recommendations for ambient freshwater quality criteria for different regions around the country. These water-quality goals or recommendations are intended to assist states and tribes in establishing nutrient limits for water bodies that are consistent with Section 303(c) of the Clean Water Act. These criteria are recommended, not required.

Using historical data and reference sites, the EPA determined that the unimpacted lakes and reservoirs of South Florida (Ecoregion XIII) had a mean background predevelopment total nitrogen concentration of 1.27 mg/L (US EPA, 2000a). The 3 mg/L standard for treating nitrogen before discharge represents a concentration that is 2.4 times higher than this background.

Similar mean background predevelopment nitrogen concentrations for rivers and streams in South Florida are not currently available. In Ecoregion XII, which includes central and northern Florida (as well as portions of Alabama, Georgia, and Mississippi), the EPA recommends a background total nitrogen concentration of 0.9 mg/L in streams and rivers (US EPA, 2000b). The 3 mg/L standard for treatment before discharge represents a concentration that is approximately 3.3 times higher than this background level.

Total phosphorus includes all forms of phosphorus, both inorganic and organic. For streams and rivers in nearby Ecoregion XII, the EPA recommends a total background phosphorus water-quality criterion of 40.0 μg/L, or 0.040 mg/L (US EPA, 2000b). This is two orders of magnitude lower than the AWT treatment standard. Florida regulations require that plants that discharge to surface-water bodies treat wastewater so that the final concentration of total phosphorus in the discharged effluent is 1 mg/L. The EPA has determined that the unimpacted lakes and reservoirs of South Florida (Ecoregion XIII) had a mean background predevelopment total phosphorus concentration of 17.50 μg/L, or 0.0175 mg/L (US EPA, 2000a). The standard for AWT-treated wastewater, 1 mg/L, represents a concentration 57 times larger than this recommended background level for lakes and reservoirs.

7.5 Problem Formulation

Human health and ecological risks that may be associated with the discharge-to-surface-waters option are expected to be highly site-specific. There may be substantial differences of scale in important physical processes and variations in the assimilative capacity of individual water bodies. Therefore, this option-specific risk analysis focuses on whether surface-water quality standards are likely to be exceeded by actual discharges. This is coupled with a review of the types of adverse effects that might be anticipated where surface-water quality standards are exceeded. Implicit in this approach is an assumption that surface-water quality standards are adequately protective of human and ecological health. For one area where this assumption may be suspect (standards for nutrient discharges), a set of surface-water quality recommendations serve to expand this analysis to include additional considerations.

7.5.1 Potential Stressors

Potential stressors entrained or dissolved in treated wastewater are discharged to surface-water outfalls located in canals, creeks, or estuaries. Wastewater constituents that may act as stressors to human or ecological health include nutrients (nitrogen and phosphorus), certain metals, organic compounds, pathogenic microorganisms, and hormonally active agents. A group of potential "secondary stressors" (for example, shifts in community structure and productivity) may at the same time be caused by the presence of wastewater constituents and, in turn, be the cause for additional adverse effects. Secondary stressors include such things as changes to plant, invertebrate, and fish community structure; growth of invasive species; reduction in oxygen levels; and harmful algal bloom.

7.5.1.1 Nutrient Stressors

Because most, if not all, of the permitted discharges to surface waters eventually reach coastal embayments, the risk assessment of these discharges resembles the risk assessment of the ocean outfall option in many ways. Nutrient stressors are an example. Nutrients act as ecological stressors when present in surface waters at sufficient concentration to overstimulate primary production (leading to eutrophic conditions) or otherwise cause adverse changes in ecosystem health or structure (for example, loss of native species, growth of invasive species).

Nitrogen limitation in coastal and ocean waters was reviewed in Chapter 6 (see Paerl, 1997; Dugdale, 1967; Ryther and Dunstan, 1971; Codispoti, 1989; Eppley, et. al., 1979). Freshwater ecosystems are typically characterized by phosphorus limitation (Schindler, 1977, 1978; Smith, 1982). Phosphorus limitation is generally stems from low levels of naturally occurring dissolved inorganic phosphorus. However, ecosystem responses to additions of phosphorus will depend on both the levels of additional phosphorus made available and the levels of nitrogen that are latent in the ecosystem, often as a result of human activity (such as agricultural inputs). In Florida, natural ambient levels of phosphorus may be higher than in other areas of the country because of high phosphorus content in the regional geology (Valette-Silver et. al., 1999).

The National Research Council concluded that, while nitrogen is important in controlling primary production in coastal waters and phosphorus is important in freshwater systems, both need to be managed to avoid overproduction (National Research Council, 2000). The causes of eutrophication in fresh and marine ecosystems are not identical but do reflect ecological and biogeochemical processes. In either case, the relative inputs of nitrogen and phosphorus and the extent to which nitrogen fixation can alleviate limitation play a crucial role in determining the limiting nutrient to production in aquatic ecosystems. The limiting nutrient is the nutrient in shortest supply in a natural system. In marine waters, nitrogen is generally present in low concentrations, while in fresh water, phosphorus is present in low concentrations.

While phosphorus limitation in fresh water seems universal, there are exceptions to the general principle that nitrogen is limiting in coastal ecosystems. For example, the Apalachicola estuarine system on the Gulf coast of Florida appears to be phosphorus-limited (Myers and Iverson, 1981). Howarth (1988) and Billen et al. (1991) suggest that this is related to the relatively high ratio of nitrogen to phosphorus inputs. Howarth et al. (1995) suggests that there is a tendency for estuaries to become more nitrogen-limited as they become more affected by humans and as nutrient inputs increase overall.

In nearshore tropical marine systems, phosphorus tends to be more limiting for primary production (Howarth et al., 1995). In some major estuaries, nutrient limitation switches seasonally between nitrogen and phosphorus. Examples of such seasonally varying nutrient limitation include the Chesapeake Bay (Malone et al., 1996) and portions of the Gulf of Mexico, including the so-called "dead zone" (Rabalais et al., 1999). Tampa Bay has become a nitrogen-limited system instead of a phosphorus-limited system because of the long-term mining of phosphorus. In contrast, Florida Bay is phosphorus-limited (Bianchi et al., 1999).

7.5.1.2 Metals

Trace metals in wastewater are potential stressors because they may cause adverse human health and ecological effects at high concentrations. Trace metals are frequently elevated in wastewater as a result of common industrial usage. Levels in treated wastewater are, in general, greatly reduced, but trace metals are still frequently used as tracers of wastewater in the aquatic environment (Matthai and Birch, 2000; Flegal et al., 1995; Hershelman et al., 1981; Ravizza and Bothner, 1996; Morel et al., 1975). Additional sources of metals that may contribute to levels present in surface-water bodies include combustion of fossil fuels, mining activities, stormwater runoff, atmospheric deposition, and other surface-water and groundwater sources (Burnett et al., 1980; Finney and Huh, 1989; Forstner and Wittman, 1979; Huh et al., 1992; Huntzicker et al., 1975; Klein and Goldberg, 1970).

Metals can bioaccumulate in the food chain, thus having adverse secondary impacts on an ecosystem. For example, arsenic may bioaccumulate in aquatic organisms. However, there is considerable variability in aquatic food-web bioaccumulation (Penrose et al., 1977; Woolson, 1977). See Chapter 3, Methodology, for further description of metals as a potential stressor in the environment.

7.5.1.3 Organic Compounds

Potential organic stressors that may be present in treated wastewater include volatile organic compounds (VOCs), synthetic organic compounds (such as pesticides, herbicides, surfactants), trihalomethanes, and some hormonally active agents (endocrine disruptors). See Chapter 3, Methodology, for a further description of organic compounds as potential stressors in the environment.

Hormonally active agents may have potentially adverse effects on aquatic organisms, based on the scientific literature. A study conducted in the United Kingdom found that wastewater induced vitellogenin synthesis in caged and wild fish several kilometers downstream of points of discharge (Rodgers-Gray et al., 2000); vitellogenin is a protein important to yolk production. These effects were induced at dilutions of treated wastewater ranging from 9.4% to 37.9%. Similar studies were conducted in the United States. However, there was no apparent vitellogenin induction in fathead minnow (*Pimephales promelas*) in response to exposure to treated wastewater (Nichols et al., 1998).

Studies in Florida have documented potential adverse effects from exposure to hormonally active agents in upland and freshwater organisms, including the Florida panther (Facemire, et al., 1995) and American alligator (Guillette, 1994, Semenza, 1997). However, these studies do not document the sources of these agents.

These studies indicate that hormonally active agents may be capable of causing potentially adverse health effects in aquatic organisms. However, more information is needed to determine how these compounds cause adverse reactions.

7.5.1.4 Pathogenic Microorganisms

Pathogenic stressors that may be present in treated wastewater include enteric bacteria, protozoans, and viruses associated with human or animal wastes. Secondary treatment, chlorination, and filtration generally remove all viruses, helminthes, and pathogenic bacteria. However, the protozoans *Giardia* and *Cryptosporidium* form cysts that are resistant to chlorination and that can only be removed through careful filtration. The Florida DEP has evaluated monitoring data from reclaimed-water treatment facilities that treat wastewater intended for reuse or discharge to surface waters. Wastewater treated at some facilities still contains levels of *Cryptosporidium* and *Giardia* that may pose human health risks, despite chlorination and filtration (York et al., 2002).

Much of the information concerning survival and transport of pathogenic protozoans discussed in Chapter 4 applies to discharges to surface waters. *Cryptosporidium* oocysts, for example, have a T_{90} (that is, the time needed to inactivate 90% of the population) of approximately 200 days (Robertson et al., 1992). This time frame is long enough that discharged effluent traveling over short distances and short travel times may still contain some pathogenic protozoans.

Contamination of Florida's coastal environments with enteric viruses, bacteria, or protozoans is a widespread and chronic problem. This is notably the case for Tampa Bay, Sarasota Bay, and the marine environment surrounding the Florida Keys. There are a number of potential causes for this. They include the prevalence and high density of onsite sewage-disposal systems (such as septic systems), the presence of predominantly porous and sandy soils, and karst topography and the hydrologic connection between groundwater and coastal embayments and estuaries (Lipp et al., 2001; Paul et al., 1995).

7.5.1.5 Secondary Stressors

Secondary stressors are the result of exposure to the potential stressors discussed above and include the following:

- Increased primary productivity
- Increased oxygen demand and hypoxia
- Shifts in community structure caused by anoxia and hypoxia
- Changes in phytoplankton community structure
- Harmful algal blooms

- Marine mammals and human impacts from harmful algal blooms
- Degradation of sea-grass and algal beds and formation of nuisance algal mats
- Coral reef destruction
- Trophic impacts.

Sea-grass degradation in Tampa Bay, Sarasota Bay, and Indian River Lagoon has been attributed to nutrient loading, from both point and nonpoint sources. Sea grass serves as a valuable habit for juvenile fish, some marine mammals, and shellfish as it provides food, oxygen, and refuge. In addition, sea grass stabilizes the bottom substrate, keeping sediment out of the water column. The loss of sea grass can also cause secondary effects by adversely affecting other species that utilize this habitat. Nutrient loading that increases phytoplankton populations can damage sea grass; this in turn decreases light transmission to the substrate.

The increase in production can also result in increased organic loading that, upon decomposition, utilizes oxygen, thus creating hypoxic or anoxic conditions. These conditions can result in fish kills or a decrease in available fish habitat.

Changes in nutrient concentrations in the water column can alter the phytoplankton community structure. This may result in increased nuisance or harmful algal blooms. In addition, the availability of silica and iron appears to play a role in coastal eutrophication and may promote the formation of harmful algal blooms (National Research Council, 2000).

Harmful algal blooms (HABs) pose particular concerns in brackish, coastal, and estuarine environments. Harmful algal blooms taxa and associated problems in coastal or estuarine environments are described in the Chapter 6. The causes of harmful algal blooms are still controversial. They include a variety of physical, chemical and biological changes, such as climate change, increased pollution and nutrient inputs, habitat degradation through dredging, resource harvesting and regulation of water flows, failure of grazers to control algal growth, and better monitoring. It is uncertain whether higher numbers of harmful algal bloom reports in recent years are a result of an actual increase in harmful algal blooms or better water-quality monitoring.

Harmful cyanobacterial ("blue-green") algal blooms can occur in warm stratified areas in embayments and estuaries, where nitrogen concentrations are low, salinities are reduced, and phosphorus is enriched through upwelling, eddies, or mixing. Phosphorus limitation is generally more important than nitrogen limitation (Sellner, 1997). In Florida, extensive blooms of the cyanobacterium *Lyngbya majuscula* were documented in Tampa Bay in 1999 and from Sarasota Bay to Tampa Bay in 2000. Although this species is not toxic, it is a nuisance alga because it produces large, slimy, brown odorous floating mats (Florida Fish and Wildlife Conservation Commission, 1999). The causes for this bloom are unknown; it is not believed that discharges of treated effluent played a significant role.

Harmful algal blooms of *Gymnodinium breve* occur frequently off the southwest coast of Florida, especially from Clearwater to Sanibel Island, occurring in 21 of the last 22 years

(Boesch, et al., 1997). Blooms move inshore and can have impacts on the health of humans or wildlife. In 1996, more than 150 manatees died from exposure to brevetoxin during prolonged red tides along the southwest coast of Florida (Steidinger et al., 1996). There is some evidence that dense blooms of *Gymnodinium* rely on new nutrient inputs; human impacts to watersheds may be responsible for extending the duration and adverse effects of red tides once they enter nearshore areas (Boesch et al., 1997).

Effects of secondary stressors also include changes in trophic processing of organic matter, uptake and bioaccumulation, biodiversity and populations, and growth of invasive species displacing native species.

7.5.2 Potential Receptors and Assessment Endpoints

Assessment endpoints represent discrete natural resource values or functions deemed important to local ecology or natural communities. Water-quality standards are set based upon such endpoints. For example, maintenance and protection of aquatic life might be one such endpoint. Other endpoints might be fishable and swimmable waters. Water-quality criteria then would be set, based on reaching that goal. As discussed in section 7.4.2, Florida uses a class system to designate uses of water bodies and applies water-quality standards to meet those uses.

The water-quality standards are set based upon the best science available and are conservative. Still, there are many unknowns and uncertainties, particularly when setting standards related to protecting complex ecosystems. For example, many times numerical standards are not set for nutrients in water bodies because the ecoystem effects are very site-specific.

Canals, which are a frequent receptor for discharge of treated wastewater into surface-water bodies, are often hydrologicly connected to groundwater and are recharged by groundwater. Adams (1991) examined water in the surficial aquifer and canals in Martin and Northern Palm Beach counties and concluded that groundwater quality did not seem to be affected by canal water, probably because the aquifer is discharging to the canal rather than the canal recharging the aquifer. However, water from canals may enter the surficial aquifer when canals are used as an irrigation source. Drinking-water receptors (underground sources of drinking water (USDWs) or water-supply wells) may be exposed where surface waters have a direct hydrologic connection to the groundwater resource

7.5.3 Potential Exposure Pathways

When human health or ecological receptors are exposed to wastewater constituents in sufficient concentration, these receptors may be at risk for potentially adverse health effects. Complex processes and interactions govern how wastewater discharged to surface waters will move and behave. These processes and interactions define the pathways that may expose receptors to stressors present in treated wastewater.

Potential transport processes include advective transport in stream and nearshore currents, and estuarine and tidally driven circulation. The action of these transport processes varies substantially over time and space. Patterns and mechanisms of transport are often quite different in water bodies of different sizes, shapes, and orientations. Transport processes can also vary substantially within water bodies, over the course of time, and in response to localized changes in depth, currents, temperature, and many other factors.

The capacity of water bodies to dilute or assimilate wastewater constituents is fundamentally important to the fate of potential stressors in surface-water ecosystems and to the risks that may be posed by such stressors. In this respect, the rate of flow through a canal or creek and the rate of flushing for an embayment or lagoon are key parameters that influence both fate and risk. In general, adverse effects are expected to be greater in smaller surface-water bodies that flush slowly than in larger water bodies that are well flushed.

Sedimentation and flocculation are important physical and chemical processes that can act to take wastewater constituents out of the water column. Turbulent mixing and resuspension frequently act to counteract these processes, setting up a dynamic equilibrium in which materials are exchanged (over time and space) between the water column and sediment layer. Where conditions are conducive to sedimentation or flocculation, the sediment layer can become a sink, potentially affecting local flora and fauna at the sediment interface.

Potential exposure pathways for ecological receptors include direct ingestion of water or sediments, dermal contact and other forms of uptake (for example, diffusion into submerged plants and soft-bodied invertebrates), and bioaccumulation or food-chain bioconcentration. Ecological receptors are exposed to secondary stressors, such as the disappearance of favorite prey items or reduced levels of available oxygen, through their trophic relationships and position within the larger biological community.

Potential human exposure pathways include direct ingestion or dermal contact with surface water and ingestion of contaminated fish, shellfish, or other plants and animals exposed to treated wastewater. Drinking-water receptors may be exposed where surface waters have a direct hydrologic connection to the groundwater resource.

7.5.4 Conceptual Model of Potential Risk for the Discharge-to-Surface Waters Option

Figure 7-1 presents a generic conceptual model for the discharge-to-surface-waters wastewater management option. The primary source of potential stressors is defined as the wastewater treatment plant from which treated effluent is routed to one or more surface-water outfalls. The rate of discharge may vary, depending on the size and operational status of the facility. but is generally measured in millions of gallons per day.

Treated wastewater is discharged directly to surface-water bodies. These are predominantly small, flowing, fresh-to-brackish bodies of water (canals, creeks, and estuaries). According to the Florida DEP, discharge to closed bodies (ponds and lakes) is no longer practiced in South Florida. Wastewater is typically treated to a higher level than effluent discharged through ocean outfalls. Treatment includes secondary treatment and basic disinfection, followed by filtration and, in some cases, nutrient reduction and dechlorination to remove harmful chlorination by-products. In the model, nutrient limitation varies, depending on whether disposal into freshwater, estuarine, or coastal marine waters is conducted.

Potential ecological receptors include the wildlife, waterfowl, fish, and invertebrates that are dependent on canals, estuaries, and other surface-water ecosystems for food and habitat.

Potential human receptors include recreational fishermen, swimmers, agricultural workers, and others whose work or recreation brings them into close proximity or contact with surface-water bodies that receive effluent discharges. Waters classified as fishable and swimmable are assessment endpoints meant to protect these ecological receptors.

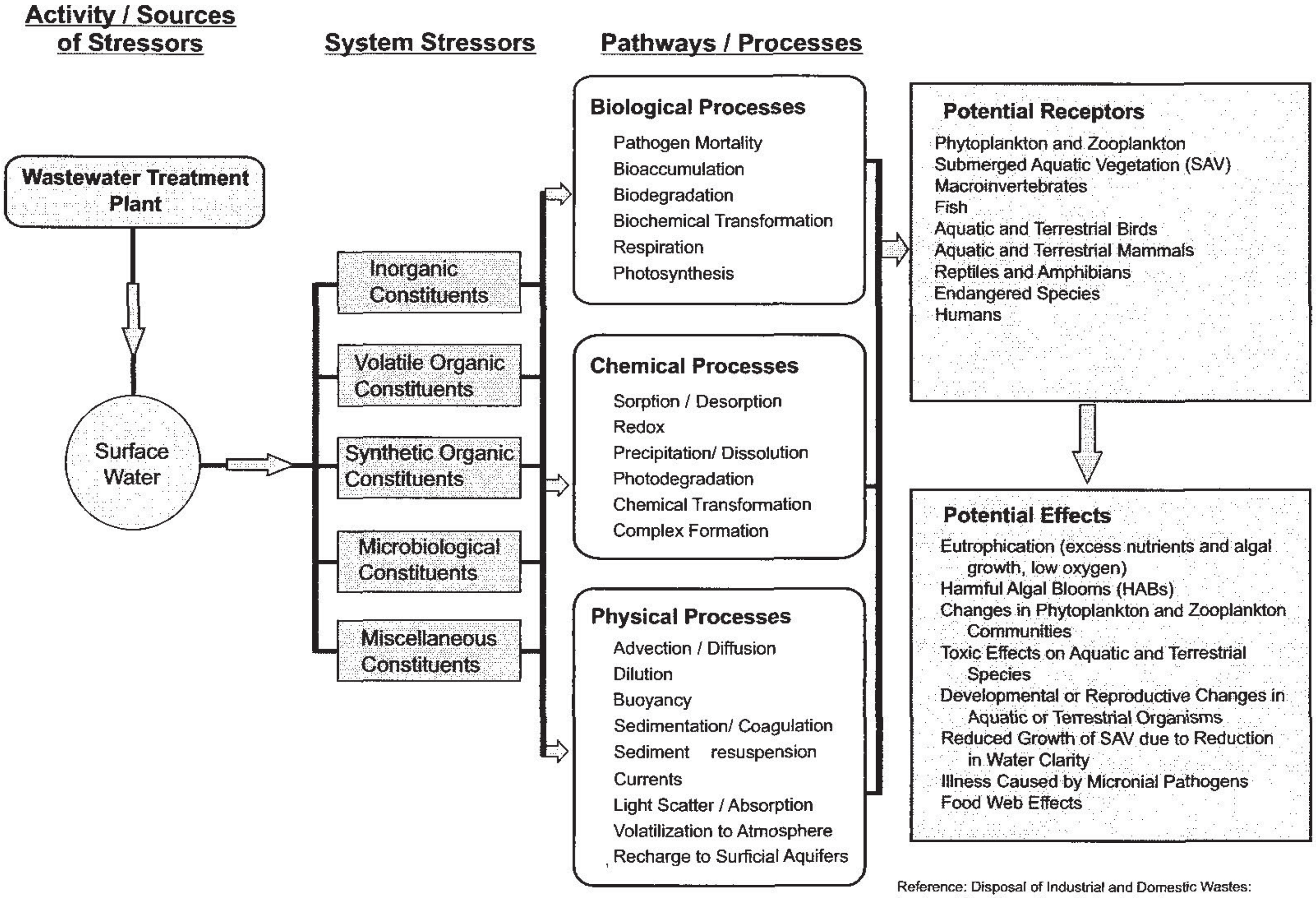
Drinking-water receptors may be exposed to wastewater when surface waters have direct hydrologic connection to the groundwater resource. While this study did not find any evidence of wastewater discharging to surface waters in direct connection to groundwater wells in South Florida, it is a consideration when analyzing potential receptors.

7.6 Risk Analysis of the Discharge-to-Surface-Waters Option

In this section, data are integrated into the conceptual model for the discharge-to-surface-waters option. Actual data on stressors, receptors, and exposure pathways are used to examine potential risks.

Discharge monitoring data from several public treatment facilities, as well as a database provided by the Florida DEP (2002b), were used to examine where (and to what extent) the discharge-to-surface-waters option is used in South Florida. Staff from Florida DEP assisted in determining which options are utilized by specific treatment facilities (personal communication, Kathryn Muldoon, February, 2002).

Information to describe the volume and quality of treated wastewater discharged to surface waters was limited. In order to characterize potential stressors and stressor concentrations, data were obtained from three AWT plants that discharge to surface waters (the City of Cape Canaveral and South Beaches treatment facilities in Brevard County and the Howard F. Curren treatment plant in Hillsborough County). In addition, information on AWT effluent managed at two wastewater treatment plants in Sarasota County (Gulfgate and Southgate Wastewater Treatment Plants) was obtained from the report by Englehardt et al. (2001) (Appendix Table 1-1). No data were available to characterize discharges to surface waters treated to less-than-AWT standards.



Reference: Disposal of Industrial and Domestic Wastes: Land and Sea Alternatives, National Academy of Sciences, 1984.

Figure 7-1. Conceptual Model of Potential Risks for the Surface Water Option

To describe the proximity and vulnerability of receptors, information was obtained regarding biological communities present in the receiving water bodies, particularly sensitive or vulnerable populations. A review of the scientific literature provided information about potential exposure pathways, adverse impacts, and risks. Wherever available, previous studies and investigations were used to appropriately expand the scope of this analysis.

7.6.1 Evaluation of Stressors and Assessment Endpoints

7.6.1.1 Nutrients

Annual average concentrations of total nitrogen in treated wastewater for 1999 and 2001 were calculated from monthly monitoring report averages for the City of Cape Canaveral's AWT wastewater treatment plant (Appendix Table 1-1). The annual average concentration of total nitrogen during this period ranged from 0.752 to 0.970 mg/L; the maximum monthly average was 1.353 mg/L, and the minimum monthly average was 0.321 mg/L of total nitrogen. These values are well below the 3 mg/L AWT standard for treatment. Background concentrations of nitrate (a component of total nitrogen) at two ocean locations off the east coast of Florida reported in Hazen and Sawyer (1994) were 0.11 mg/L and 0.16 mg/L. One monitoring result for nitrate for the City of Cape Canaveral's wastewater treatment plant revealed a nitrate concentration in treated effluent of 0.062 mg/L. This is an order of magnitude lower than background concentrations of nitrate reported for the SEFLOE studies in an open ocean environment (summarized in Hazen and Sawyer, 1994).

Annual average concentrations of total phosphorus for 1999 and 2001 were calculated from monthly monitoring report averages for the City of Cape Canaveral's AWT wastewater treatment plant (Appendix Table 1-1). The annual average concentration of total phosphorus during this period ranged from 0.119 to 0.152 mg/L; the maximum monthly average was 0.273 mg/L, and the minimum monthly average was 0.064 mg/L total phosphorus. The annual average concentrations of total phosphorus are higher than recommended background levels for total phosphorus in fresh water. Thus, the excess phosphorus may pose some ecological risks.

Permitted concentrations of nitrogen and phosphorus (3 and 1 mg/L, respectively) in AWT-treated effluent discharged to surface waters are often greater than background concentrations in unimpacted water bodies. Phosphorus concentrations in AWT effluent were generally significantly higher than recommended background concentrations for fresh waters. However, as indicated above, actual nitrate concentrations in AWT effluent can be lower than background oceanic nitrate concentrations.

Long-term water-quality and biological monitoring in Hillsborough Bay indicates that water quality and clarity have improved and shoal grass (*Halodule wrightii*) has recovered since AWT was implemented at the Howard F. Curren Wastewater Treatment Plant (City of Tampa Bay Study Group, 2001b).

Given the limited use of this disposal option and limited data on actual discharged effluent, it is difficult to estimate risk for this option except in these more general terms relating to water-quality standards. Nevertheless, nutrient loading is one of the top reasons for impairment of surface-water bodies in Florida. It is likely that point sources are part of this larger problem. Rivers, streams, and canals typically empty into other water bodies that can be impacted by nutrient enrichment. In some instances, treatment plants discharge to a wetland before ultimately discharging to surface waters; when this occurs, the nutrient load decreases and thus the risk from this type of disposal may be diminished.

7.6.1.2 Metals

Concentrations of all inorganic and secondary analysis metals in AWT effluent reviewed for this study were below standards for drinking water quality (Appendix Table 1-1). Copper concentrations in AWT effluent were similar to concentrations found in secondary-treated effluent (Englehardt et al., 2001). Total copper in advanced treated wastewater was 0.003 mg/L. This is below copper water-quality standards in Florida. Because the concentrations of copper in wastewater effluent reported by utilities in this study were below water-quality standards, it is unlikely that this constituent poses significant risks to human or ecological health. For the Cape Canaveral plant, copper concentrations were below detection limits (<0.0005 mg/L).

7.6.1.3 Organic Compounds

Concentrations of trihalomethanes, synthetic organics, and volatile organics were below drinking-water standards (Appendix Table 1-1). Compared to the Florida standards for surface water quality, all trihalomethanes in AWT wastewater were below Class II and Class III standards for fresh and marine surface-water quality. Class I standards, which apply to surface waters used as drinking-water supplies, were not met by the AWT effluent monitoring results reviewed for this study. However, none of the AWT plants surveyed in this report discharge treated effluent to Class I surface-water drinking supplies.

All synthetic and VOCs that were analyzed from one monitoring sample of treated effluent by the City of Cape Canaveral wastewater treatment facility were below detection limits (Appendix Table 1-1).

The representative contaminant chosen to evaluate potential risk include a number of estrogenic and estrogen-like substances. Estrogen equivalence is a measure of the response of breast cancer cells to exposure to strongly estrogenic substances, such as hormone replacement and birth-control pills (Frederic Bloettscher, personal communication). Estrogen equivalence was measured from two grab samples at the Gulfgate and Southgate treatment plants in Sarasota, Florida. Both of these plants treat to AWT levels and discharge to surface-water creeks. The average concentration of estrogen-equivalence substances in the treated wastewater effluent was 3.253 nanograms per liter (ng/L) (Frederic Bloettscher, personal communication).

At this point, this information only indicates that these substances may be present in treated wastewater intended for disposal into surface water. Recent literature suggests that concentrations below 1 ng/L can cause vitellogenin levels to increase in aquatic organisms (Sadik and Witt, 1999; Larsson, et al., 1999). The literature suggests that more study is needed concerning the concentrations at which endocrine disruption may occur from biodegradation byproducts.

No information is available concerning concentrations of estrogen-like compounds in ambient surface waters near the outfall sites, nor in ecological receptors at or near the outfall sites. Ongoing and future research should provide a better framework for discussing these compounds and evaluating their risks.

7.6.1.4 Pathogenic Microorganisms

Monitoring data reported by the city of Cape Canaveral to the Florida DEP for its National Pollutant Discharge Elimination System permit indicate that, between 1999 and 2001, the maximum concentration of fecal coliforms in treated effluent (measured monthly) ranged from 0 to 8 colonies per 100 mL (Cape Canaveral NPDES Database, 1999–2001). As noted above, a certain number of fecal coliforms are permitted, up to a limit of 200 fecal coliforms per 100 mL of effluent, for all but Class I surface waters. These concentrations do not meet drinking-water standards.

The Howard F. Curren Wastewater Treatment Plant in Tampa Bay reported annual sampling results in 2000 and 2001 for *Giardia lamblia* and *Cryptosporidium*, pathogenic protozoans that can cause gastrointestinal illness in humans when ingested (David York, pers. comm.). In 2000, the concentration of *Giardia lamblia* and *Cryptosporidium* were each less than 0.7 cysts per 100 L of effluent. In 2001, the concentration of *Giardia lamblia* was less than 0.29 cysts per 100 L of effluent, and the concentration of *Cryptosporidium* was 2.33 oocysts per 100 L of effluent. These numbers are below the DEP's recommended limit of 5.8 per 100 L for both *Cryptosporidium* and *Giardia*. Monitoring of other wastewater treatment facilities in Florida indicates that a few facilities do not meet the informal standard of 5.8 per 100 L, despite the fact that the effluent is filtered (York et al., 2002).

7.6.2 Evaluation of Receptors and Exposure Pathways

Some potential ecological receptors in water bodies in Florida that receive treated wastewater are described below. Water-quality problems that have arisen or been corrected through the implementation of improved wastewater treatment are noted.

- **Submerged aquatic vegetation** (such as sea grasses) populations are abundant in the nearshore areas surrounding South Florida. In recent years, there have been documented changes in the abundance of sea grass in the nearshore environment. For example, in Tampa Bay, there have been recent declines in sea-grass populations, but this has occurred after several years of sea-grass expansion throughout the bay. In the late 1980s and early 1990s, sea grasses were returning at the rate of 500 acres a year as Tampa Bay responded to improvements in water quality resulting from improvements in wastewater treatment. The sea-grass expansion rate slowed to about 350 acres in the mid-1990s. The latest figures show an overall cumulative loss of sea grass to pre-1990 levels (Coastlines, Issue 11.4).

- **Bordering habitats** (such as mangroves and salt marshes) are located throughout the nearshore estuarine environment in South Florida. Like sea-grass habitats, these areas offer food and refuge to many aquatic species and are affected by increased nutrients.

- The Indian River Lagoon supports one of the most diverse **bird populations** in the United States, with 125 breeding species and 172 species that over-winter in the area (Adams et al., 1996). Many bird species in the region are impacted by human activities, especially activities that contribute to habitat loss and fragmentation. In 1987, the dusky seaside sparrow became extinct in the Indian River Lagoon because of alterations to coastal marsh habitat (marsh impoundment). Avian communities are also susceptible to overexploitation (primarily hunting) and to the adverse effects of widespread use of chemicals (especially DDT).

- **Marine mammals,** such as the West Indian manatee and the Atlantic bottlenose dolphin, inhabit lagoons and estuaries along the Florida coast. One-third of the endangered Floridian population of West Indian manatee (*Trichechus manatus*) resides in the Indian River lagoon. Collisions with boats pose the most significant threat to these populations, at least from human activities. However, *Cryptosporidium* and *Microsporidium* infections have been implicated in recent manatee deaths along the Gulf Coast of Florida, according to biologists at Tampa's Lowry Park Zoo (Grossfield, 2002). Dolphin (*Tursiops truncatus*) populations are believed to be stable. Approximately 20 dolphin fatalities are reported annually; 8% to 12% of these fatalities are believed to be related to boat accidents or fishnet entanglement. A fungal skin disease that affects approximately 12% of the dolphin population may be linked to water quality, as documented by the Treasure Coastal Dolphin Project conducted in 1994 (Adams et al., 1996).

- Both **green and loggerhead turtles** are on the U.S. Fish and Wildlife Service list of threatened and endangered species (Adams et al., 1996; Gilmore, 1995; Gilmore et al., 1981). The green turtle (*Chelonia mydas mydas*), a state and federally endangered species, inhabits the Indian River Lagoon. Boat collisions and fishing line entanglement are believed to be the principal causes of sea turtle mortality. However, 40% to 60% of green turtles surveyed in the Indian River Lagoon were found to be infected with fibropapillomatosis; this disease may be linked to water quality (Ehrhart and Redfoot, 1995).

- As of January 1994, 782 **fish species** were documented in the east-central Florida region. At least half of these species use estuaries and lagoons, such as the Indian

River Lagoon, at some point in their life histories (Gilmore, 1995; Gilmore et al., 1981).

Toxicity testing results from the city of Cape Canaveral AWT Wastewater Treatment Plant in June 2001 (City of Cape Canaveral, 2001) revealed that the survival rate of *Ceriodaphnia dubia* ranged from 85% to 95% for undiluted treated wastewater. The survival rate for *C. leedsi* was 100% for all tests. While the data were limited, this indicates that the AWT-treated wastewater is not acutely toxic.

There is no direct evidence (such as the use of tracer studies) that indicates that constituents in AWT-treated wastewater are taken up by aquatic biota or human receptors in the coastal embayments or canals reviewed. However, although there is no direct evidence, indirect evidence indicates that discharges of treated wastewater do affect water quality on a regional scale. Zhou and Rose (1995) and City of Tampa Bay Study Group (2000b) reported that water quality in Sarasota Bay and Hillsborough Bay (Tampa Bay) improved after wastewater treatment plants that discharged to rivers or the bay itself upgraded their wastewater treatment to meet tertiary or advanced standards. This suggests that the high nutrient levels previously measured in the bay were at least partly the result of discharges of secondary-treated effluent.

Some potential ecological receptors, such as endangered species, may be more susceptible to harm and may be at risk from concentrations less than the applicable standards. Additionally, eutrophication is site-specific as it is greatly influenced by physical and biological processes. Addition of nutrients and, indeed, any constituents that may be present in treated effluent needs to be examined in a site-specific context to truly evaluate risk.

Little information was found on ecological receptors in canals that may be receiving wastewater effluent. However, estuaries examined in this study that are receiving treated wastewater contain marine mammals, fish, and birds that are known to be at risk from other effects of human development.

In terms of the applicable water-quality standards, surface waters receiving discharges of treated wastewater reviewed in this report were designated as Class III waters. Class III water-quality standards are meant to protect a healthy population of fish and wildlife and provide recreational uses. Compared to these standards, the quality of AWT effluent was often well below the required minimum concentrations.

Physical mixing and dilution are important large-scale processes that will act to decrease concentrations of stressors in a water body. This is especially true for streams, rivers, estuaries, and coastal embayments that are well mixed. Such dispersion and dilution will decrease the risks to human and ecological receptors.

There is a strong coupling of groundwater and surface water in South Florida. At present, there are few estimates of the hydrologic fluxes between groundwater and surface water in south Florida. However, in recent studies in the Everglades, it was found that extensive human manipulation of the natural drainage system in southern Florida has altered hydrology that has led to increased recharge and discharge in the north-central Everglades (USGS, 2002). Additional evidence of interaction between groundwater and surface waters in the Everglades was provided when mercury was found to be recharged from surface water to groundwater and stored in the surficial aquifer. Indeed two-way exchange of surface water and groundwater may be a localized phenomenon, as was found in Taylor Slough (USGS, 2002).

Canals, which are a frequent receptor for discharge of treated wastewater into surface-water bodies, are often hydrologicly connected to groundwater and are recharged by groundwater. Adams (1991) examined water in the surficial aquifer and canals in Martin and Palm Beach counties and concluded that groundwater quality did not seem to be affected by canal water. This suggested that the aquifer is discharging to the canal rather than the canal recharging the aquifer. However, water from canals may enter the surficial aquifer when canals are used as an irrigation source. Drinking-water receptors may be exposed where surface waters have a direct hydrologic connection to the groundwater resource.

7.7 Final Conceptual Model of the Discharge-to-Surface-Waters Option

This disposal option presents limited risks, because the volumes of treated effluent discharged to surface water are much smaller than volumes discharged via ocean outfalls or Class I injection wells and because the discharges are typically discharged intermittently.

- The degree and kind of treatment of wastewater is an important factor determining effluent quality and therefore risk. To discharge to surface waters in the state of Florida, wastewater treatment plants are likely to treat using AWT. AWT treats wastewater to a higher standard than secondary treatment, removing additional nutrients, organic compounds, and total suspended solids from the effluent.
- Several of the AWT standards (for example, nutrients) are elevated when compared to natural background levels of these compounds in unimpacted surface waters and when compared to the EPA's recommended standards for unimpacted surface waters, which are based on monitoring of more pristine water bodies. Nutrients, both nitrogen and phosphorus, pose ecological risks for the aquatic environment as they may increase primary production, alter phytoplankton communities, and encourage or exacerbate the growth of harmful algal blooms. The data available reveal that wastewater treatment facilities often have the ability to remove nitrogen to well below the standard required, which would reduce risk. While phosphorus met treatment standards, the concentrations that remain in treated wastewater are often higher than recommended water-quality standards, based on unimpaired waters.
- There is a lack of water-quality monitoring data and tracer studies that would show whether effluent constituents are taken up by receptors.

- There are no effluent or surface-water quality standards for *Cryptosporidium* and *Giardia*, although the Florida DEP has recommended that numerical standards corresponding to a 1 in 10^{-4} human illness risk be adopted for *Cryptosporidium* and *Giardia* in reclaimed water (York et al., 2002). These recommendations are 5.8 oocysts per 100 L and 1.4 cysts per 100 L for *Cryptosporidium* and *Giardia*, respectively. For comparison, background concentrations of *Cryptosporidium* oocysts in North American water bodies, such as lakes, rivers, springs, and groundwater, averaged 44, 43, 4, and 0.3 oocysts per 100 L, respectively (York et al., 2002).
- Concentrations of pathogenic microorganisms in treated wastewater from the Howard F. Curren facility were well below the standards for discharges to surface waters for Class III waters. Concentrations of the pathogenic protozoans *Giardia* and *Cryptosporidium* in effluent from the Howard F. Curren AWT plant were very low.
- Monitoring of pathogenic protozoans at other wastewater treatment facilities in Florida indicates that a few facilities do not meet the recommended limit of 5.8 per 100 L, despite the fact that filtration is done (York et al., 2002). While human health risks from pathogenic protozoans are generally very low, they are not zero.
- Facilities that nitrify appear to be better at removing *Giardia* than facilities that do not nitrify (York et al., 2002).
- All inorganic compounds, including nutrients and metals, measured in AWT effluent were below drinking-water-quality standards. Copper was used as a surrogate because of its known toxicity in the aquatic environment. Copper concentrations in treated wastewater met Florida water-quality standards.
- Measured organic compounds, which include trihalomethanes, synthetic organics, and volatile organics, were below drinking-water standards. All synthetic and VOCs were below detection limits for the data reviewed in this study. Two grab samples for estrogen equivalence (hormonally active agents) revealed that these constituents are present in the effluent in relatively small concentrations (on the order of ng/L). Despite the lack of information on *in situ* concentrations, hormonally active agents pose ecological risks for aquatic ecosystems because of information from studies of their effects on other aquatic organisms elsewhere and because the effects are observed at very low concentrations.
- Toxicity testing of AWT effluent revealed no toxicity to aquatic organisms. The limited data available suggests that AWT effluent poses little or no ecological or human health risks.
- The relative risk of AWT-treated wastewater is lower than the risks posed by lesser-treated wastewater, based on improvement of water quality in Tampa Bay after AWT was required.
- Despite the relative lack of monitoring information from surface-water disposal outfalls and lack of evidence of adverse effects, it is reasonable to assume that, given the already-impacted nature of many surface-water bodies in South Florida, further discharge of nutrients in treated wastewater poses some ecological risks. The potential effects of nutrients on surface-water bodies will vary, depending on site-specific characteristics and the existing nitrogen loading from other sources. Preferably, a water-quality-based effluent limit (such as total maximum daily

loading) would be established that takes into account these site-specific characteristics and the carrying capacity of an individual surface-water body.
- In some areas, depending on existing impairment of water quality, it may be worthwhile to consider whether discharge of treated wastewater could help restore hydrology or water quality.

7.8 Gaps in Knowledge

Possible gaps in knowledge and their possible effects on this risk analysis are summarized below.

- The benefits or detriments of discharging AWT-treated wastewater into natural systems have yet to be proven.
- One of the most important gaps in knowledge concerns the numbers and significance of unpermitted, inadvertent, or occasional unplanned discharges of untreated or secondary-treated wastewater to surface-water bodies. Such discharges may occur at treatment facilities when storms or other causes combine to produce wastewater volumes that cannot be treated rapidly enough to keep up with incoming volumes. Rapid infiltration basins receiving untreated or secondary treated wastewater that overflow to nearby surface-water bodies, such as canals or creeks, provide examples of such untreated or minimally treated discharges. Such discharges are believed to occur at a number of South Florida facilities, including those at Miami-Dade South Treatment Facility. Although such discharges are outside the scope of this study because they are not a permitted form of wastewater management, they nonetheless pose high risks.
- The potential and actual human health and ecological health effects of exposure to AWT-treated effluent that has not been filtered to remove pathogenic protozoans to the levels recommended by the Florida DEP have yet to be determined. The ecological effects of pathogenic protozoans are only beginning to be documented; the latest example involves the implication of *Crytosporidium* and *Microsporidium* in mortality of manatees along the Gulf coast of Florida.
- Distinguishing between other sources of wastewater stressors and those derived directly from AWT-treated wastewater will be difficult unless specific tracers are utilized in studies designed specifically to distinguish different sources. Many other sources of stressors already have adversely affected Florida's surface waters and coastal waters.
- The effects of discharging wastewater treated to AWT standards into water bodies that are already adversely affected have not been explored or documented, according to available information. Comparing AWT-treated wastewater with water-quality recommendations based on pristine or unaffected ambient Florida waters also raises water-management questions that can only be answered through a combination of public process and scientific studies of the fate of these stressors and the capacity of the watershed or embayment to assimilate stressors without experiencing adverse effects.

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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