Brevard County Near Shore Ocean Nutrification Analysis

Provided by the

Near Shore Nutrification Brevard County Science Panel

(T.P. Carsey, R. Ferry, K.D. Goodwin, P.B. Ortner, J.R. Proni, P.K. Swart, J.-Z. Zhang)

to

Brevard County, Florida

Dr. John R. Proni, Project Director

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Atlantic Oceanographic and Meteorological Laboratory
Ocean Chemistry Division
4301 Rickenbacker Causeway
Miami, Florida 33149

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Executive Summary

Coastal zones can receive nutrients from a number of sources, and elevated nutrients can lead to ecological changes in near shore environments. In order to respond to the possibility that nutrients were elevated in the Brevard County surf zone, Brevard County contracted the National Oceanic and Atmospheric Administration (NOAA)/Atlantic Oceanographic and Meteorological Laboratory (AOML) to assemble an expert panel to conduct a review of available data and literature. They were charged with answering the following nine questions:

(1) Are there elevated nutrient levels in the surf zone along Brevard County beaches? If adequate data are not available, what methods can accurately make this determination?

(2) What impacts might there be from elevated nutrients to near shore ecology?

(3) What impacts might there be from elevated nutrients in the surf zone to human health?

(4) Would elevated nutrient concentrations be expected to affect the occurrence or duration of red tide (*Karenia brevis*) blooms?

(5) Can nitrogen isotope ratios be reliably used to detect whether sewage or treated wastewater effluent are sources of elevated nutrients to the surf zone?

(6) Are there alternate methods that can be reliably used to detect whether sewage or treated wastewater effluent are sources of elevated nutrients to the surf zone?

(7) If sewage or treated effluent were to be identified as a source of elevated nutrients, are there reliable methods to determine whether the nutrients are from local or remote sources?

(8) Is it likely that shipping activities contribute to the observed nutrient levels?

(9) If nutrient levels are elevated, what future research is recommended to determine near shore nutrient sources?

These questions were answered using a variety of sources including peer-reviewed literature, reports, data provided by counties and the State of Florida, and communication with a variety of environmental professionals.

Q1. Nutrients in the Brevard County surf zone (pg. 10)

Available coastal water nutrient data were analyzed in a variety of ways. Data from Florida Department of Environmental Protection (FDEP) statewide sampling sites were partitioned into six segments to allow for sub-regional analysis of coastal nutrient data. Brevard County was included in the east central area. Statewide data from the FDEP and data specifically for Brevard County from Barile (2004) were averaged, and coastal zone nutrient concentrations in Brevard County were compared to the east central area as a whole and to other regions (northeast, south, west central, northwest, and the panhandle). Further analysis was performed looking at individual data points within the east central and northeast regions versus latitude and day of year. This analysis did not show elevated nutrient concentrations in the Brevard County surf zone. Phosphate and ammonium concentrations were among the lowest in the State, and nitrite+nitrate concentrations were within the range reported for the other coastal regions.

Although the data analysis performed did not show elevated nutrient concentrations in the near shore waters off of Brevard County, the data set was limited. There was little data in terms of the number of analytes, geographic extent, and temporal coverage for Brevard County. To verify the analysis given here and to establish baseline measurements that could provide a powerful tool to assess the impact of urbanization on the coastal zone would require initiation of a water-quality monitoring program that would include measurements of at least nitrate, nitrite, ammonium, and silicate. Such a program would include sampling of all the major potential sources of nutrients to the coastal zone, for which there is presently no data at all. The information available suggests that passage of remineralized nutrients from the Indian River Lagoon into adjacent coastal waters is possible, and if a sampling program was warranted, this would be a potential source worthy of study. Fixed time point sampling would not suffice; synoptic samples would also be needed (e.g., after strong rain/water discharge "events"). A limited baseline survey of sediment conditions (e.g., biologically and/or chemically active heavy metals and total phosphorus) might also be useful. Initial studies to determine the degree of spatial and temporal concentration variability within the region would be required to provide more detailed recommendations as to an adequate sampling strategy (e.g., sample frequency, sample distribution, and number of replicates). Coordination with other ongoing and planned programs would facilitate implementation of such a program.

Q2. Nutrients and near shore ecology (pg. 30)

A question posed by the Environmental Protection Agency (EPA) (EPA, 2003) used to evaluate potential ecological risks from nutrients in treated wastewater states "are the nutrient levels in the effluent higher than ambient water or applicable marine water-quality standards to protect ecological health?" The analysis presented in Question 1 suggests that the Brevard County area does not show elevated nutrient concentrations. Another question posed by the EPA states "is there evidence that nutrients from the treated effluent are taken up by phytoplankton and microalgae and then converted to biomass?" Reports of macroalgal overgrowth raise concern, but quantitative surveys of macroalgal cover and species distributions in the Brevard County littoral zone are lacking. Such data for appropriate control regions and areas suspected of nutrient stress are needed to properly address this issue.

In general, ecosystem status reflects the balance between a complex set of natural biological, physical, oceanographic, meteorological, and geochemical conditions. Human interaction with natural systems often affects multiple stressors simultaneously, making it difficult to discern "the" cause for ecological decline, if a single cause even exists. Therefore, even if elevated nutrients had been measured in the Brevard County coastal zone, it would be difficult to predict the ecological consequences of this elevation without considerable additional information. An ecosystem management approach requires interdisciplinary efforts leading to quantifiable results that allow sources, sinks, and relative impacts to be ranked. In addition, the combined commitment of local people, industries, and governments is needed to reduce cumulative coastal environmental impacts.

Q3. Near shore nutrients and human health (pg. 33)

Nutrients at the concentrations found in any of the coastal water samples considered (see Question 1) do not themselves pose a threat to human health. However, if elevated nutrients were observed and if they were associated with sewage contamination, there would be a risk of water-borne illness. Concentrations of fecal-indicating bacteria are routinely monitored in the Brevard County surf zone as part of the Florida Healthy Beaches Program, and an extensive data set was available for review. Samples were collected after rain events; however, no specific synoptic studies were performed. There was no bacteriological evidence of sewage contamination in the sampled areas and, therefore, no indication of bacteriologically-related human health risks.

Concerns have been expressed that eutrophication[1] might increase the occurrence of algae that pose a risk to human health. The primary concern for the high-energy coastal zone of Brevard County would be the induction of *Karenia brevis* ("red tides"). Aerosols derived from *K. brevis* blooms are known to cause respiratory irritation. However, there is neither strong evidence of a relationship between coastal nutrient inputs and *K. brevis* blooms nor of increased local red tide incidence (see Question 4).

Q4. Nutrients and red tide (*Karenia brevis)* (pg. 36)

Presently, the published scientific literature indicates that initiation of *K. brevis* blooms is not related to near shore coastal nutrient concentrations. *K. brevis* blooms appear to initiate well off shore of the Florida coast in the low nutrient waters of the Gulf of Mexico and are then transported by coastal currents into the near shore. Documented occurrences of *K. brevis* on the east coast of Florida have been due to transport from the west coast and around the tip of Florida. *K. brevis* bloom distributions do not appear to be correlated to measured near shore nutrient concentrations. Although coastal nutrient inputs have increased, *K. brevis* blooms in the western Gulf of Mexico do not appear to be more frequent or longer in duration than in the historical record; data re-analysis for the eastern Gulf of Mexico is ongoing. Another line of evidence against a *K. brevis*/nutrient link is that other planktonic organisms are better adapted to high nutrient environments and should out compete *K. brevis* under such conditions. However, the

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[1] Eutrophication: "the enrichment of water by nutrients causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned, and therefore refers to the undesirable effects resulting from anthropogenic enrichment by nutrients…" (OSPAR, 2003; http://www.ospar.org)

exact factors that sustain (and terminate) *K. brevis* blooms remain unresolved, and work continues to understand what does control Florida's red tides. For example, it is possible that future studies may find a link between *K. brevis* blooms and dissolved organic nutrients that are contributed directly or indirectly by anthropogenic[2] sources.

Q5. Nitrogen isotope ratios as a means of identifying sewage-contaminated coastal waters (pg. 38)

While the nitrogen isotope method may be used to help identify sources of pollution, it cannot be utilized alone to indicate sewage pollution. Positive $\delta^{15}N$ values can be present in benthic[3] organisms for a number of reasons both natural and/or anthropogenic. Changes in the abundance of nitrogen isotopes occur during practically every transformation involving nitrogen compounds. A variety of factors influence the extent of nitrogen enrichment. Isotopic fractionation during assimilation by plants and algae is known to be species-specific and dependent on growth conditions. Although isotopic enrichment (high $\delta^{15}N$ values) is often seen in response to sewage nutrients, macroalgal tissues have also been observed to become more negative in response to sewage inputs. Therefore, it is simply not possible to assign a precise value for $\delta^{15}N$ as "sewage." Furthermore, based on information from numerous peer-reviewed sources, the panel concluded that $\delta^{15}N$ values as low as +4‰ do not necessarily indicate sewage. Interpreting $\delta^{15}N$ values requires an understanding of the nitrogen cycle and the fractionation processes occurring in that particular system. It also requires $\delta^{15}N$ analysis of a variety of sources and organisms. Simultaneous analysis of additional isotopes can aid the interpretation of $\delta^{15}N$ studies. Overall, the entire issue of whether specific isotopically positive $\delta^{15}N$ values reflect sewage needs to be critically re-examined.

Q6. Other means of identifying sewage contaminated-coastal waters (pg. 51)

The analysis presented in Question 1 did not indicate the presence of elevated nutrients in Brevard County coastal waters. Furthermore, the extensive data set regarding bacteriological water quality did not indicate a problem with sewage contamination in the Brevard County surf zone. Had they done so, appropriate scientific methods do exist that would definitively determine if and to what degree the Brevard County coastal waters are contaminated with sewage or sewage-derived nutrients. Quantifying the relative contribution of nutrients from a number of possible sewage sources is, however, complex. A great deal of information regarding the sewage sources in question and the ambient environment must be gathered and considered. Nutrients from both natural and anthropogenic sources exist in the marine environment in a variety of forms of varying biological and ecological significance. A comprehensive effort to quantify sewage contributions to ambient waters would require several chemical and biological markers in addition to stable isotope studies (Question 5), hydrodynamic studies (Question 9), and modeling efforts, as well as a comprehensive water quality monitoring program (Question 1) specifically incorporating synoptic sampling of rain events and coupled to continued bacteriological sampling.

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[2] Anthropogenic: Effects or processes that are derived from human activities, as opposed to natural effects or processes that occur in the environment without human influences.

[3] Benthic: The environment at the bottom of a waterbody.

Q7. Tracking the source (local or remote) of sewage-derived nutrients (pg. 57)

In the Brevard County area, local sources of sewage-derived nutrients could include contaminated groundwater or surface discharges, whereas remote sources of sewage-derived nutrients could include sewage outfalls from counties to the south. As detailed in Question 6 and Question 9, a combination of chemical and biological markers, tracer studies, hydrodynamic studies, and modeling efforts would be required to rigorously determine sources and their relative impacts.

Q8. Nutrients and shipping (p. 58)

The extent of risk posed by ship discharges depends upon the nutrient load of these discharges relative to other sources and to the overall system loading. In addition, the level of risk depends on the fate of these discharges, and the physical oceanography of the area is an important controlling factor. Presently, the total nutrient load of ship discharges, the fate of these discharges, and how the input compares to other nutrient loads in the area (e.g., waste water, septic tanks, storm water) have not been fully evaluated. Preliminary analysis of the available data indicate that discharge to the area from gaming vessels is significantly smaller than from cruise ships (on the order of 10-40X for black water and gray water[4], respectively); however, the cruise ships generally claim to discharge farther offshore and to use a higher level of treatment. Comparison of vessel discharge to other near shore nutrient sources was not performed. Comprehensive assessment of nutrient loading by ship discharges also requires verifying industry claims of present practice, which appear to be consistent with the Florida Cruise Ship Memoranda of Understanding (MOU) stipulation of discharges at least 4 nautical miles from shore. Some vessels also claim to discharge at a distance of at least 12 nautical miles from shore. Although the preliminary nutrient data does not indicate a problem, if further analysis of coastal nutrients was to show elevated concentrations, our suggestion would be to request a port-specific amendment to the Florida Cruise Ship MOU such that cruise ship discharges begin not at 4 nautical miles but at least 12 nautical miles for both gray water and treated black water in order to avoid interaction with the Southeast Shoal. Gaming vessel discharges could be made into pumpout facilities. Assuming such an agreement was enforceable and compliance was monitored, this could give legal protection to Brevard County coastal waters.

Q9. Recommendations for future research if nutrients are elevated (p. 64)

Additional data are needed to determine the degree to which further efforts are warranted. At a minimum, this involves additional water quality sampling and scientific investigation of possible macroalgal overgrowth on Brevard County near shore rock ledges. As discussed above, scientifically rigorous answers to the underlying questions posed would require a comprehensive interdisciplinary program that would include nutrient and microbiological water quality monitoring (also encompassing likely sources in local sediments, at least initially), physical circulation studies, and mass-balance analysis. In addition, use of biochemical sewage markers, deliberate tracers, synoptic studies, stable isotope studies (e.g., N, C, and S), and numeric modeling would be necessary to provide complete characterization, if needed. The scope and

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[4] Gray water is derived from lavatories, bathtubs, showers, and other fixtures discharging dilute non-fecal wastes or of fully treated sewage effluent. Black water is water that has come in contact with toilet wastes.

expense of such a program implies it would be feasible only with substantial leveraging. This leveraging may be obtainable through close cooperation and coordination with ongoing (e.g., bacteriological sampling) and planned federal, state, and county programs.

Introduction

Motivation for Study

Brevard County is committed to programs that protect, conserve, and enhance the natural resources of Brevard County, Florida, that are vital to the health, quality of life, and economic well being of its residents.

In response to a study that concluded that nutrient levels in Brevard County's coastal waters were abnormally elevated and that their sources were local in nature and might be related to septic systems or wastewater disposal processes (Barile, 2004), the County engaged the National Oceanic and Atmospheric Administration (NOAA) to help determine: (1) if nutrient levels were elevated in Brevard County near shore coastal waters above normal background levels; (2) if existing nutrient levels were elevated, whether they represented a risk to human health and the near shore ecology; and (3) if nutrient levels were elevated, what were the potential or actual local or remote source(s).

NOAA was asked to carry out this study because it has the expertise, capabilities, and resources necessary to provide an objective evaluation of existing research and assist in an evaluation of near shore nutrient levels, as well as assess their impact on near shore ecology and provide recommendations associated with further analysis or action.

NOAA routinely monitors contaminants in coastal resources nationwide to understand the relationship of those contaminants to pollutant discharge and to understand their sources and predict potential habitat impacts. Many of these projects are undertaken through partnerships with states, local governments, academic institutions, and non-governmental organizations to identify national coastal problems and issues and provide management funds and assistance.

This study directly supports the first mission goal of NOAA's Strategic Plan, namely, to protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management. To achieve this goal, NOAA works with many partners to provide a balance between use and protection of coastal resources to ensure their sustainability, health, and vitality for the benefit of current and future generations.

NOAA was asked to select and coordinate an integrated response from a team of respected scientists including, but not necessarily limited to, conducting scientific literature searches, assessing existing relevant information and/or water quality data, and utilizing the resultant information and best available methodology (or combination of methodologies) to answer the questions posed by Brevard County.

Background

Brevard County, on Florida's east coast, has over 72 miles of Atlantic coastline. The population has grown by approximately 90,000 people per decade since 1950 (data from the Brevard Property Appraiser, www.brevardpropertyappraiser.com). The major cities include Melbourne, Palm Bay, and Titusville. According to the 1995 *Florida Land Use Cover and Forms Classification System* (FLUCCS), approximately 26% of Brevard County was classified as wetlands. A map of Brevard County with details of significance to this study is given in Figure 1.

Brevard County contains the Mosquito, Indian River (northern section), and Banana River Lagoons, as well as the southern part of the St. Johns River. However, the lagoon system has only two openings to the coastal ocean in Brevard County: Port Canaveral Inlet and Sebastian Inlet. The former inlet is controlled by a lock, resulting in minimum exchange of water with the Ocean.

Panel Members

Dr. Thomas P. Carsey	NOAA-AOML	Miami, Florida
Dr. Roland Ferry	U.S. EPA	Atlanta, Georgia
Dr. Kelly D. Goodwin	NOAA-AOML	Miami, Florida
Dr. Peter B. Ortner	NOAA-AOML	Miami, Florida
Dr. John R. Proni	NOAA-AOML	Miami, Florida
Dr. Peter K. Swart	University Miami (RSMAS)	Miami, Florida
Dr. Jia-Zhong Zhang	NOAA-AOML	Miami, Florida

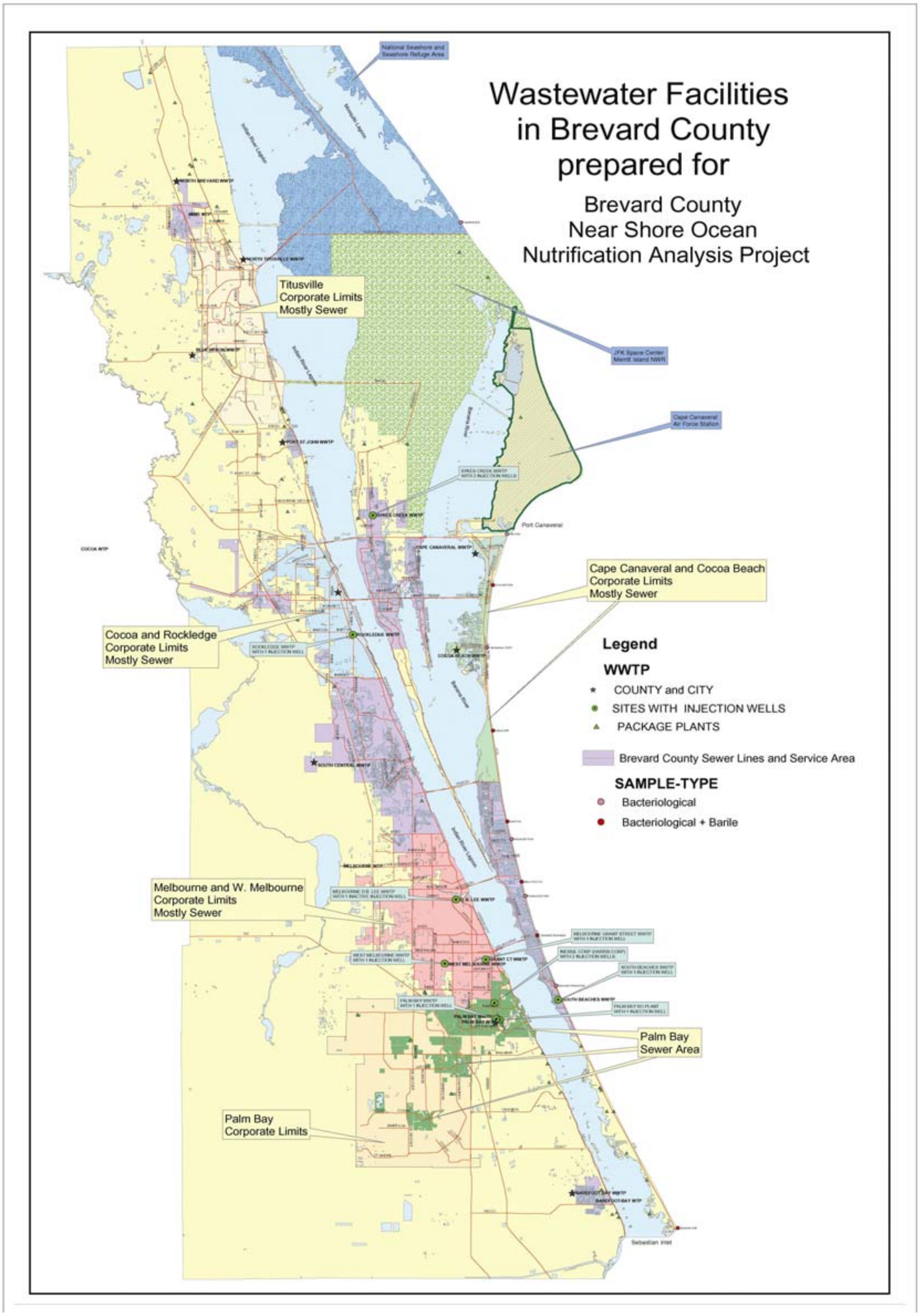

Figure 1. Map of Brevard County, Florida. Map courtesy of the Regional Stormwater Utility Department, Brevard County

Question 1

Are nutrient levels in the surf zone along Brevard County beaches elevated? If adequate nutrient data are not available, what methodology should Brevard County utilize to accurately make this determination?

Introduction

Nitrogen and phosphorus are essential nutrients required by all organisms. These nutrients are present in water, not only as dissolved molecules, but also in organisms, particles of detritus, and both suspended and bottom sediments. Dissolved nitrogen occurs in natural waters as organic nitrogen, ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^{-2}). Among these, nitrate is the most stable in oxygenated waters. Nitrite and ammonium are intermediate products of biological processes and are usually present in small quantities in aerobic[5] waters. In oxygen-saturated surface water, ammonium and nitrite are oxidized to nitrate. Plants take up nitrate, nitrite, or ammonium and convert them to organic nitrogen. A combination of chemical oxidation and biological uptake typically maintains low concentrations of dissolved inorganic nitrogen species (i.e., nitrate, nitrite, and ammonium) and relatively high concentrations (particulate and dissolved) of organic nitrogen in sun-lit surface waters. Dissolved phosphorus occurs in natural water in the forms of organic phosphorus and phosphate (PO_4^{-3}). Because of its strong surface reactivity, particulate phosphorus is often the major phosphorus reservoir in aquatic systems. In general, nutrient concentrations in oceanic surface waters are low because of biological uptake within the euphotic[6] zone. Sinking particulate organic matter is remineralized at depth and associated nutrients are released to deep water; thus, upwelled ocean water is relatively rich in nutrients.

The different forms of nutrients are inter-converted depending on physical, chemical, and biological conditions. They may undergo a variety of chemical reactions, including oxidation, reduction, dissolution, and precipitation. For example, ammonium originally discharged in wastewater or groundwater can be oxidized to nitrite and then to nitrate as the source water mixes with oxygenated surface waters. Although some organic nitrogen and phosphorus compounds might not be immediately available for biological uptake, biogeochemical processes can transform them to bioavailable forms on a longer time scale. For example, microbial activity plays a key role in breaking down large organic nitrogen- and phosphorus-containing compounds into small inorganic nutrients readily available for biological uptake.

The availability of nutrients is a major control upon the overall productivity of most aquatic environments. As discussed above, although organic nitrogen and phosphorus can dominate the dissolved nitrogen and phosphorus pools, they have limited direct bioavailability. On the other hand, inorganic forms of nitrogen (nitrate, nitrite, and ammonium) and phosphorus (phosphate) are readily available for biological utilization and are typically of greater concern with regards to eutrophication (Gilbert *et al.*, 2005). Except in sluggish waters where long residence time permits microbial oxidation of organic compounds, the introduction of exogenous inorganic nutrients into coastal waters is the usual cause of eutrophication (over-stimulation of primary

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[5] Aerobic: oxygen-containing.

[6] Euphotic zone: The uppermost layer of a body of water that receives sufficient light for photosynthesis and the growth of plants.

production and a shift in trophic status[7]). Population growth, food production, and energy production and consumption are predominant forces leading to eutrophication. Both nitrogen and phosphorous are a concern, but nitrogen is the primary focus in estuarine and coastal waters because it is often the nutrient that limits plant and algal growth in these waters. In addition, the application of nitrogen from synthetic fertilizers is far greater than that of phosphorus (NRC, 2000; Gilbert *et al.*, 2005). Elevated concentrations of nitrogen and phosphorus in coastal regions are often attributed to municipal wastewater, industrial wastewater, and agricultural run-off. In municipal wastewater, ammonium is typically the dominant form of nitrogen (~10 mg/L), followed by nitrate (~6 mg/L) and organic nitrogen (~4 mg/L). The inorganic phosphorus concentration (~4 mg/L) is typically twice as high as organic phosphorus (~2 mg/L) (EPA, 2003).

Surf Zone Nutrient Analysis

Since the Brevard coastal system is open and water residence times are short, it is reasonable to put primary emphasis upon the following inorganic nutrients: ammonium, nitrite, nitrate, and phosphate. Because of analytical exigencies, nitrite and nitrate are often reported as a sum (nitrite+nitrate). Also, analytical procedures are sometimes employed which distinguish partitions within the nutrients, e.g., sometimes the total value (e.g., total ammonium) is distinguished from dissolved ammonium (which would not include ammonium derived from particulates).

Although nutrient measurements have been made in the adjoining lagoon system (Indian River Lagoon, Mosquito Lagoon, and Banana River Lagoon), there have been fewer measurements made of nutrients in the Atlantic coastal ocean region of Brevard County. The FDEP (www.dep.state.fl.us/water/monitoring/data.htm) has been monitoring the coastline of Florida from a large number of sites around the state (Figure 2). These data were made available to us by the FDEP (courtesy of J. Hand, FDEP). The analytes reported by FDEP are given in Table 1.

For the purpose of this analysis, we have subjectively grouped the FDEP sample sites into six regions (Figure 2). They are designated as PH (panhandle), NW (northwest), WC (west central), S (south), EC (east central), and NE (northeast), located in Figure 2 counterclockwise from upper left. The latitude/longitude limits are given in Table 2.

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[7] Trophic status: In water, an indication of the level of nutrient enrichment. Oligotrophic is lowest, mesotrophic is medium, and eutrophic is high, as measured by concentrations of chlorophyll-a, total phosphorus, total nitrogen, and water clarity. *Trophic* refers to the feeding habits or food relationship of different organisms in an ecosystem.

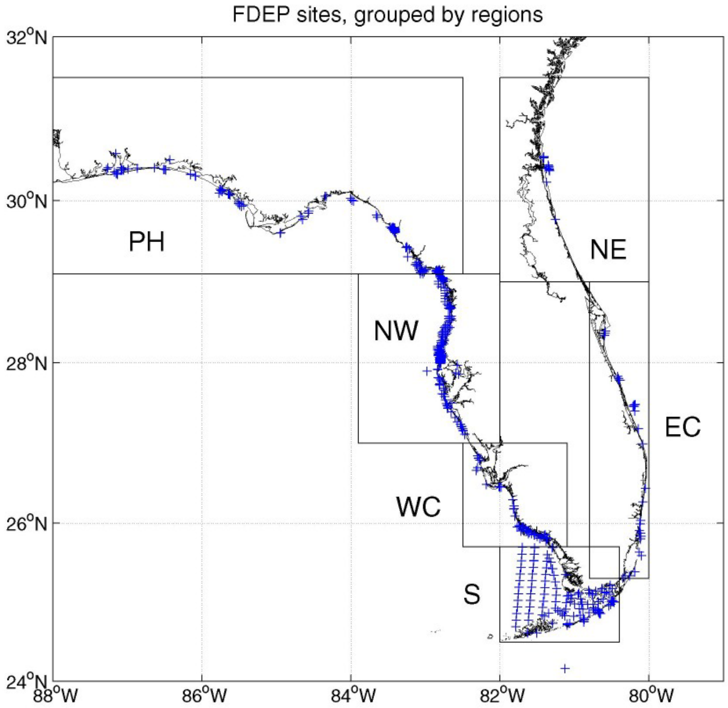

Figure 2. Map of FDEP water quality monitoring sites in Florida, partitioned into six segments.

Table 1. Water quality measurements for coastal Florida (FDEP).

Number of Measurements	Analyte
5004	Color (platinum-cobalt units)
66	Color, apparent (unfiltered sample) platinum-cobalt units
5697	Nitrite nitrogen, total (mg/L as N)
128	Nitrite plus nitrate, dissolved (mg/L as N)
6492	Nitrite plus nitrate, total (mg/L as N)
5752	Nitrogen, ammonia, dissolved (mg/L as N)
1240	Nitrogen, ammonia, total (mg/L as N)
31	Nitrogen, inorganic, total (mg/L as N)
1874	Nitrogen, Kjeldahl, total (mg/L as N)[8]
622	Nitrogen, organic, total (mg/L as N)
4765	Nitrogen, total (mg/L as N)
11481	Phosphorus, total (mg/L as P)

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[8] Total Kjeldahl Nitrogen (TKN) is organic nitrogen + ammonia. High measurements of TKN typically result from sewage and manure discharge into water bodies. See www.epa.gov/region09/qa/pdfs/dqi/nktotal.pdf.

Table 2. Boundaries (minimum and maximum) of regions for FDEP sample sites.

Panhandle (PH)		Northwest (NW)		West central (WC)		South (S)		East central (EC)		Northeast (NE)	
Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon
31.5	-82.5	29.1	-82.0	27.0	-81.1	25.7	-80.4	29.0	-80.0	31.5	-80.0
29.1	-88.0	27.0	-83.9	25.7	-82.5	24.5	-82.0	25.3	-80.6	29.0	-82.0

The density of data points across the six regions is uneven. Brevard County (located in the EC region, with a coastline range of latitude ~27.86°N to 28.80°N) had only three FDEP sample sites; clearly these areas were not as well sampled as those for which there had been greater concern about water quality (e.g., Florida Bay). In addition, sampling across the State was performed without specific consideration and controls for ambient conditions such as time of day, tides, season, near shore physical oceanography, meteorology, etc. Since such factors can affect nutrient concentrations, these would need to be carefully considered in a more rigorous assessment. Furthermore, at any given site not all of the analytes listed in Table 1 were measured; only total nitrogen and total phosphorus were measured in Brevard. An additional set of data has been provided in Barile (2004) from seven sampling sites in Brevard and Indian River Counties, obtained at five separate times during 2003 (Table 3).

Table 3. Nutrients in the surf zone of Brevard and Indian River Counties in 2003 (Barile, 2004).

Location	Nutrient	MAR	JUN	AUG	OCT	DEC	Nutrient	MAR	JUN	AUG	OCT	DEC
Cocoa Beach	NH_4	0.0385	0.0013	0.0126	0.0259	0.0084	DIN[a]	0.0585	0.0207	0.0205	0.0399	0.0126
Patrick AFB	NH_4	0.0154	0.0056	0.0070	0.0203	0.0070	DIN	0.0244	0.0097	0.0132	0.0205	0.0126
Satellite Beach	NH_4	0.0077	0.0140	0.0077	0.0357	0.0126	DIN	0.0210	0.0202	0.0154	0.0639	0.0168
Indialantic	NH_4	0.0483	0.0147	0.0147	0.0140	0.0140	DIN	0.1136	0.0226	0.0223	0.0240	0.0179
Sebastian Inlet	NH_4	0.0056	0.0070	0.0189	0.0112	0.0126	DIN	0.0116	0.0119	0.0262	0.0171	0.0266
Wabasso Beach	NH_4	0.0154	0.0105	0.0112	0.0287	0.0182	DIN	0.0336	0.0200	0.0176	0.0457	0.0756
Vero Beach	NH_4	0.0063	0.0112	0.0063	0.0189	0.0182	DIN	0.0261	0.0168	0.0126	0.0548	0.0643
Cocoa Beach	NO_2+NO_3	0.0200	0.0081	0.0078	0.0140	0.0055	SRP[b]	0.0112	0.0087	0.0099	0.0105	0.0084
Patrick AFB	NO_2+NO_3	0.0090	0.0041	0.0062	0.0057	0.0055	SRP	0.0071	0.0056	0.0056	0.0056	0.0077
Satellite Beach	NO_2+NO_3	0.0133	0.0062	0.0077	0.0282	0.0045	SRP	0.0084	0.0087	0.0065	0.0090	0.0071
Indialantic	NO_2+NO_3	0.0653	0.0078	0.0076	0.0099	0.0039	SRP	0.0074	0.0099	0.0102	0.0065	0.0068
Sebastian Inlet	NO_2+NO_3	0.0060	0.0049	0.0073	0.0059	0.0140	SRP	0.0090	0.0062	0.0040	0.0046	0.0056
Wabasso Beach	NO_2+NO_3	0.0182	0.0095	0.0064	0.0169	0.0574	SRP	0.0155	0.0090	0.0068	0.0059	0.0130
Vero Beach	NO_2+NO_3	0.0197	0.0056	0.0063	0.0359	0.0461	SRP	0.0093	0.0062	0.0068	0.0059	0.0062

[a] DIN = Dissolved inorganic nitrogen = $[NO_2+NO_3] + [NH_4]$.

[b] SRP = Soluble reactive phosphorus ("orthophosphate").

At each site, duplicate samples were analyzed for ammonium, nitrite+nitrate, soluble reactive phosphorus (SRP), and nitrogen stable isotopes (see Question 5). Because the raw data were not available to us, the mean (average) results from that paper were employed in this report (Table 3) as if they were single data points. The first four sites are located in Brevard County, the remaining three are in Indian River County.

Examination of the state-wide FDEP data and the Barile (2004) data provides a meaningful basis by which we can respond to Question 1. This analysis is presented in Table 4 and Figure 3. As discussed above, the Brevard County data set was extremely limited. The FDEP data for Brevard County contained only six measurements of total nitrogen and six measurements of total phosphorus at three sites. Nutrient concentration statistics are presented in Table 4. The data in Table 4 and Figure 3 show that the limited nutrient measurements presently available for Brevard County (indeed for the EC region as a whole) do not show significantly elevated concentrations. The phosphate and ammonium concentrations were among the lowest in the state. The NO_2+NO_3 concentrations are well within the range reported for the other coastal regions. **Overall, these data do not suggest that nutrient levels in the surf zone along Brevard County beaches are elevated.**

Table 4. Nutrient concentration statistics for coastal Florida (units in mg/L). Brevard (Brv) is within the EC region, and the Brevard FDEP data are included in the EC sample subset. Bar refers to the Barile (2004) data found in Table 3; other abbreviations are given in Table 2.

	Average								**Standard Deviation**							
Nutrient	**PH**	**NW**	**WC**	**S**	**EC**	**NE**	**Brv**	**Bar**	**PH**	**NW**	**WC**	**S**	**EC**	**NE**	**Brv**	**Bar**
TP	0.027	0.042	0.049	0.014	0.019	0.057	0.012		0.037	0.106	0.072	0.010	0.032	0.040	0.006	
NH_4	0.029	0.040	0.022	0.044	0.029	0.076		0.015	0.033	0.078	0.058	0.085	0.039	0.106		0.010
DIN		0.058	0.026	0.074	0.023			0.029		0.108	0.024	0.852	0.028			0.023
TN	0.269	0.450	0.417	0.439	0.159	0.253	0.102		0.210	0.241	0.208	0.293	0.070	0.051	0.020	
NO_2		0.020	0.065	0.043	0.034					0.004	0.708	0.568	0.509			
NO_2+NO_3	0.049	0.021	0.013	0.010	0.028	0.048		0.014	0.085	0.059	0.037	0.016	0.048	0.052		0.015

	Maximum								**Number of Measurements**							
Nutrient	**PH**	**NW**	**WC**	**S**	**EC**	**NE**	**Brv**	**Bar**	**PH**	**NW**	**WC**	**S**	**EC**	**NE**	**Brv**	**Bar**
TP	0.625	3.500	1.140	0.190	0.339	0.212	0.021		860	4635	1136	4393	372	57	6	
NH_4	0.290	1.000	1.390	0.703	0.206	0.460		0.048	372	952	1074	4139	397	29	0	35
DIN		1.210	0.165	45.01	0.171			0.114	0	138	671	2818	151	0	0	35
TN	4.020	6.600	1.300	1.500	0.330	0.380	0.130		464	3743	69	427	35	27	6	
NO_2		0.040	8.000	8.000	8.000				0	141	1140	4139	247	0	0	
NO_2+NO_3	0.665	1.400	1.110	0.161	0.443	0.130		0.065	376	626	999	4017	417	30	0	35

TP = total phosphorus (as P); NH_4 = total ammonia (as N); DIN = dissolved inorganic nitrogen (as N); TN = total nitrogen (as N); NO_2 = nitrite (as N); NO_2+NO_3 = nitrite plus nitrate (as N).

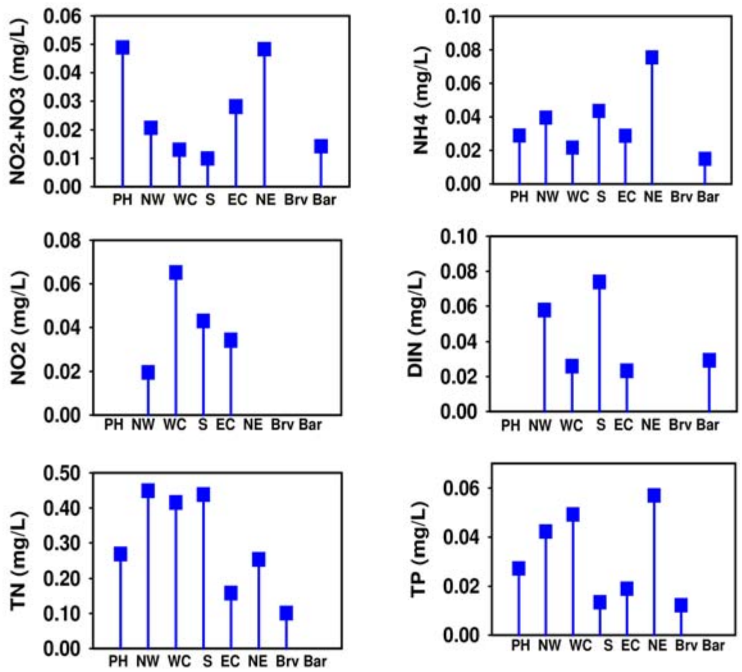

Figure 3. Nutrient concentrations (average, mg/L) reported by the FDEP for six Florida regions, for Brevard County alone ("Brv"), and by Barile (2004) ("Bar"). The Brevard data are also included within the EC region data set.

An argument could be made that the inhomogeneity of oceanographic and ecological characteristics across the State make such comparisons problematic. A more appropriate subset of the FDEP data would be those from the eastern coastline of Florida. We examined the variation in nutrient concentrations along the latitudinal extent of the eastern Florida coastline (EC and NE regions). The analysis included both FDEP and Barile (2004) data. In Figure 4, data for five nutrients are plotted versus latitude. This analysis does not suggest that the Brevard region of the coastline is elevated in nutrients. There are areas of the eastern coastline with relatively elevated nutrients in the data set, but they appear to be associated with the six sewage outfalls at Delray Beach, Boca Raton, Broward, Hollywood, Miami North, and Miami Central (EPA, 2003), and from the highly developed Jacksonville and St. Augustine areas. Another site with relatively high nutrients appears to be the Jupiter Inlet (26.95°N, 80.07°W). The same data set was plotted in Figure 5, this time with latitude limits (x-axis) to remove the outfalls and with the vertical axes changed (where appropriate) to reflect the lower values. The data for Brevard County (27.86°N-28.8°N) are clearly not elevated, with the exception of some Barile (2004) data points (Indialantic Boardwalk) identified as being a possible outlier.

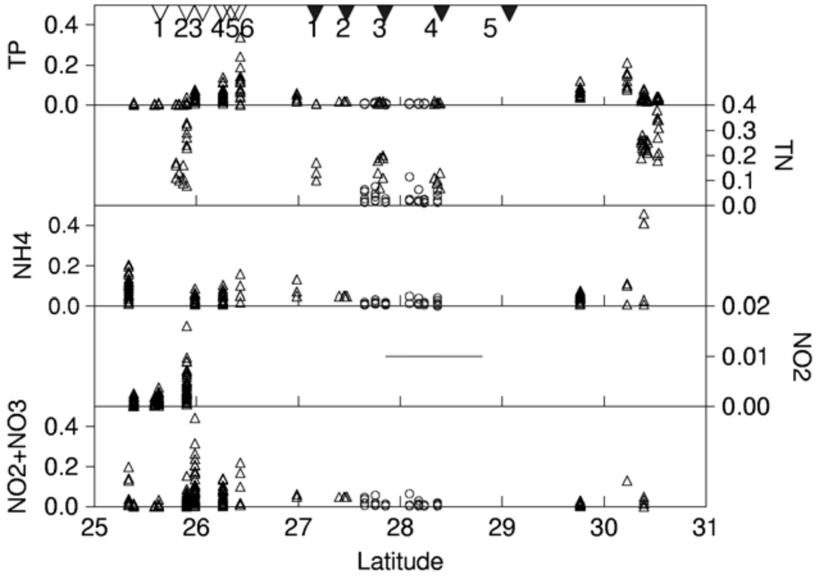

Figure 4. Nutrient concentrations (mg/L) from the Florida east coast versus latitude. FDEP data from the EC and NE regions are denoted by open up triangles (△) and data from Barile (2004) by circles (○). Six sewage outfalls are located from approximately 25.6°N-26.5°N, denoted by open down triangles (▽) in the topmost panel: (1) Miami Central; (2) Miami North; (3) Hollywood; (4) Broward; (5) Boca Raton; (6) Delray Beach (locations from EPA, 2003). Outlets to the Indian River Lagoon system (Table 5) are denoted by filled down triangles (▼) in topmost panel. The Brevard coastline is approximately from 27.86°N-28.8°N latitude (the horizontal bar in NO_2 plot).

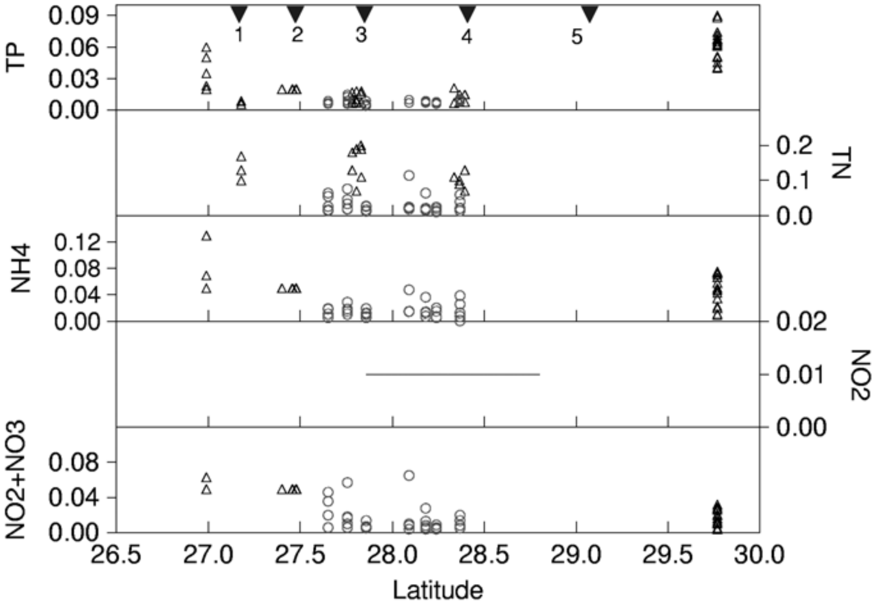

Figure 5. Data as shown in Figure 4 but with the vertical axes for NH_4, PO_4 and NO_2+NO_3 and the horizontal axes for all plots truncated to remove high values from sewage outfalls. Symbols are the same as in Figure 4. Approximate latitude extent of the Brevard coastline is indicated by the horizontal bar in the NO_2 plot, which had no measurements in the plotted region.

Finally, we examined the annual distribution of data to assess whether seasonal inputs from storm water run-off and lagoon outflow contribute a discernible signal to the coastal zone nutrient profile. The FDEP data set contained measurements from the EC and NE regions from 1994 to 2001. The rainfall in Brevard County is seasonal (Figure 6a), with rainfall maxima during the months June through September. This is also when canal discharge into the lagoon is expected to be maximal. If the lagoon outflow generates elevated nutrient concentrations, we might expect a seasonal pattern in coastal nutrient concentrations. Given its length, the Indian River Lagoon system has remarkably few inlets to the ocean (Port Canaveral and Sebastian Inlets). The locations of these inlets and others in the area are listed in Table 5.

Table 5. Location of inlets to the Indian River Lagoon system and vicinity.

	Name	Latitude (N)	Longitude (W)
1	St. Lucie Inlet	27°10.0′	80°09.7′
2	Fort Pierce Inlet	27°28.3′	80°17.5′
3	Sebastian Inlet	27°51.6′	80°26.9′
4	Port Canaveral	28°24.6′	80°35.4′
5	Ponce Inlet	29°04.4′	80°55.1′

We now examine the nutrient concentrations in the coastal waters of the EC and NE regions, but only from latitudes 26.5°N-30.0°N in order to avoid the elevated measurement signals from the ocean outfalls described above. These results are shown in Figure 6b. These data do not indicate a systematic seasonal variation in nutrient concentrations. However, stormwater and lagoon inputs would be quickly diluted in the high-energy near shore coastal system. It is possible that sampling location and timing did not adequately capture the signal. In addition, the available data did not allow an analysis of nutrient concentrations versus tide. The data did not permit a more detailed analysis of inlet impact to the coastal zone or analysis of the impact of tidal pumping through the sediments (Li *et al*., 1999; Martin *et al*., 2002). Moreover, as discussed in respect to Question 9, there is a relationship between lagoon tidal exchange and lagoon salinity such that mixing can be inhibited by density differences between lagoon and coastal waters.

The forgoing analysis employed the available nutrient measurements from the Atlantic coastal regions of Florida. On the other hand, observation of *Caulerpa* overgrowth on some Brevard County rock ledges (see Question 2) could implicate locally-elevated nutrients. The paucity of the data on which our conclusions are based, in terms of the number of analytes, geographic extent, and time (day, season, oceanographic events), cannot be overemphasized. There is no question that a more complete and confident answer to the question of whether nutrients are significantly elevated over natural levels would require a much more complete data set. Nonetheless, **the data presently available do not support the view that the Brevard County portion of this coast has elevated concentrations of nutrients**.

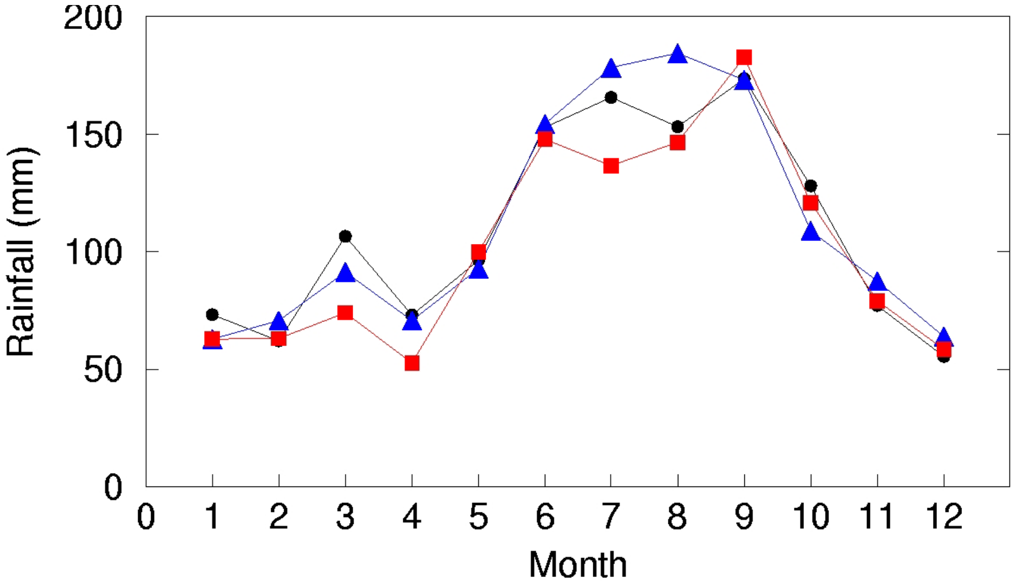

Figure 6a. Rainfall data for three localities within Brevard County (from www.weather.com): Titusville (triangles), Sebastian (circles), and Melbourne (squares).

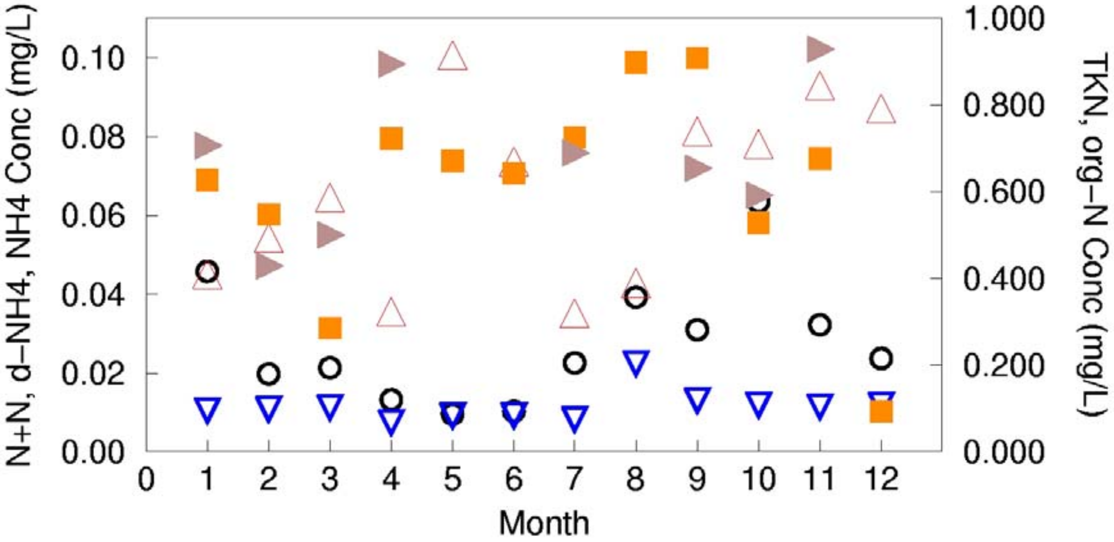

Figure 6b. Monthly averaged nutrient concentrations (in mg/L) for the years 1994-2001 for FDEP sites in the EC and NE regions (latitudes 26.5°N through 30°N) versus month of the year. Legend: NO_2+NO_3 — circles (○); dissolved NH_4 — down triangles (▽); total NH_4 — up triangles (△); TKN — squares (■); organic-N — right triangles (▶). The open symbols correspond to the left vertical axis; the solid symbols use the right axis.

Other Nutrient Information

Groundwater

Hydrologic Overview. A relatively shallow (110 feet thick) surficial aquifer underlies Brevard County. It yields only small amounts of water and is thus not a major source for public water supply, although it is used for private water supplies. Along the Atlantic coastal ridge of Brevard County, the surficial aquifer supplies water for lawn irrigation and heat pump/air conditioning (Toth, 1988). Under the surficial aquifer is the Floridan aquifer. The Floridan aquifer is extensive, underlying all of Florida, parts of Alabama, southeastern Georgia, and southern South Carolina. It is the main source of water supply in central Florida. The surficial aquifer is separated from the Floridan aquifer by an approximately 200-foot thick intermediate confining unit in central and southern Brevard County. This confining unit is thin or absent in northern Brevard County (Toth, 1998), with Floridan aquifer springs occurring in Seminole, Volusia, and Lake Counties (McGurk and Presley, 2002). The Floridan aquifer is divided by a middle confining unit which separates it into the Upper Floridan and Lower Floridan aquifers (EPA, 2003).

Groundwater Nutrient Concentrations. Nitrate concentrations in the surficial and Floridan aquifers of the Georgia-Florida coastal plain have been compiled by the U.S. Geological Survey (USGS) (Berndt, 1994). The Coastal Flatwoods land resource area includes the coastlines of Georgia and Florida. Median nitrate concentrations for water samples taken from the surficial aquifer between 1972-1992 were relatively low. Concentrations were 0.05 mg/L for urban areas, 0.02 mg/L for agricultural/rangeland areas, and less than or near detection limits in barren and forest areas. The nitrate concentrations in water from the Upper Floridan aquifer were generally low (less than 0.50 mg/L), with median concentrations ranging from 0.02 to 0.43 mg/L. Confined areas of the Upper Floridan (as is the case for central and southern Brevard County) demonstrated the lowest concentrations, with median concentrations at or near detection limits. Unconfined areas (as is the case for northern Brevard County) had higher values. The highest median values in the Upper Floridan were for unconfined agricultural/rangeland areas (0.43 mg/L) and unconfined urban areas (0.26 mg/L). The USGS data (Berndt, 1994) are consistent with a scattering of data available from individual samples taken from the Floridan and surficial aquifers in the Brevard County area (Duncan *et al*., 1994; St. Johns River Water Management District (SJRWMD) database, personal communication). In comparison, uncontaminated groundwater of the Biscayne Aquifer has ammonium plus organic nitrogen concentrations of ~0.6 mg/L (USGS, 1996).

Reported nitrate concentrations in the pore water and in seep water of the Indian River Lagoon are also low, with concentrations less than 0.01 mg/L (Martin *et al*., 2002). Concentrations of other nutrient species in pore and seep water are also available in that report.

Groundwater Input to Marine Systems. Groundwater can supply nutrients to the overlying waters through a number of processes, which vary in their significance. In normal marine sediments unaffected by significant advection of fluid, the pore fluids in the sediments rapidly become anoxic as the decomposition of organic material utilizes all the available oxygen, releasing ammonium and phosphate. If the sediment has a high permeability or is bio-irrigated by organisms, these products of decomposition can escape to the overlying waters easily and, therefore, the increase in nutrient concentration and reduction in oxygen is minimized. With decreasing permeability the products of decomposition can build up, leaving the pore fluids with a significantly higher nutrient concentration and lower oxygen content. Under such circumstances, nutrients enter the marine waters through a relatively slow process of diffusion along concentration gradients (Li *et al*., 1999; Burnett *et al*., 2003). Such transported nutrients would be modified during travel by biological processes and perhaps by anthropogenic inputs. Although phosphate and ammonia are released during the processes of organic material decay, ammonia eventually is oxidized to nitrate as it is exposed to oxygen in sandy soils, and phosphate is rapidly adsorbed onto carbonate particles. Hence, after flowing through the local carbonate bedrock, the fluids which eventually emerge should contain little phosphate and a mixture of nitrate and ammonia. Analysis of the pore water profile of a nutrient can provide an indication of whether there is active transport of nutrients through the sediments, resulting in non-steady state concentrations with respect to depth, or whether there is a steady state condition. However, nutrient flux measurements from groundwater to the littoral zone do not appear to have been measured in the Brevard County area. Such measurements are needed in order to provide a basic estimate of the groundwater nutrient load to the littoral zone. Studies could then be refined to estimate the relative contributions of inputs to the nutrient signal.

A source of groundwater to the local marine environment is the local unconfined surficial aquifer system that outcrops offshore, with potential inputs to littoral zone macroalgal communities. The water that emerges at the beach is oceanic water that has been flushed through the surficial aquifer by tidal and wave pumping (Li *et al*., 1999; Boehm and Paytan, 2005). The velocity of cross shore flow is important to the fate of groundwater discharge, with weak cross shore flow acting to keep nutrient concentrations near the beach (Boehm *et al*., 2005). Transport to the marine environment can take a substantial amount of time. Even in the highly transmissible Biscayne aquifer of southern Florida, groundwater takes 50 to 75 years to reach the submerged coast (Finkl and Charlier, 2003), and transmissivities in south Brevard County are less than in Palm Beach County (Toth, 1988). Estimates for the Melbourne Beach barrier island surficial aquifer are 25,000-26,000 gal/day/ft (D. Toth, personal communication). For rapid infiltration basins discharging into the surficial aquifer in Brevard County, horizontal time of travel has been estimated to be three years to travel 200 feet and 40 years to travel a half mile (EPA, 2003). Although nutrients will be modified during transport, as described above, groundwater is expected to be a source of nutrients to the surf zone. Nutrient flux measurements from shallow groundwater to the littoral zone do not appear to have been measured in this area. Such measurements are needed to estimate the fate of groundwater nutrient loads to the littoral zone.

A potential source of groundwater to the marine environment is the deep Floridan aquifer, which should outcrop at considerable depth off the continental shelf. In contrast with the surficial aquifer system, the Floridan aquifer is a confined artesian system separated from the surficial aquifer by a thick confining unit. As a result of this thickness, leakage from the Floridan to the surficial system is unlikely. It is considered unlikely that any water discharged from this unit contributes significantly to the geochemical budget of water influencing the beaches. Rarely is the flux of water from the land to the marine environment sufficient to allow undiluted water to emerge in the oceans as “springs” (Finkl and Charlier, 2003). Instead, the water becomes mixed with seawater in the aquifer as a result of saltwater intrusion. Freshwater springs have been documented at a few places off the east coast of Florida, but not in areas where there is an extensive lagoon system; it is likely that groundwater discharges into these lagoons rather than into the marine environment. The U.S. Geological Survey has not documented, nor do potentiometric head maps indicate, marine freshwater springs in central and southern Brevard County (D. Toth, personal communication).

Potential Inputs from the Indian River Lagoon. In the case of the Indian River Lagoon, sediment remineralization appears to be a major contributor to nutrient loading in the Indian River Lagoon (Martin *et al*., 2002). Studies have revealed that in spite of a high rate of flushing, the pore waters are anoxic the majority of the time (Martin, personal communication). This means that there must be a sufficiently high rate of supply and remineralization of organic carbon in order to maintain the anoxic condition of the pore water in spite of rapid turnover of water. Such questions remain a matter of speculation, as there have been no studies to examine the flux of organic carbon into the area. Passage of remineralized nutrients from the Indian River Lagoon onto the adjacent seaward beaches may be possible since the water level in the lagoon is generally higher than that of the adjacent oceans. When the total hydraulic head is high enough to overcome the density difference caused by the groundwater being less salty than the seawater flowing toward the surf zone, enough hydrodynamic energy may be available to disturb nutrient-rich pore waters underneath the barrier islands and transport them into the surf zone; however, measurements that would allow confirmation of this hypothesis have not been made to date. It is interesting to note that within the Indian River Lagoon the contribution of the surficial and the Floridan aquifers to nutrient loading has been estimated to be minor (Martin *et al*., 2002). Instead, 95-99% of the groundwater appears to discharge from the shallow sediments ("seep" or "recycled" water). In comparison, seepage water at a southern California beach front was found to be ocean water that had been pumped through the surficial aquifer with only minor contributions from a local marsh (Boehm and Paytan, 2005). Overall, whether nutrient-rich Indian River Lagoon water can communicate with the beach front and the extent of nutrient modification during groundwater transit remains an open question.

Package Plant Percolation Ponds. Some wastewater treatment facilities utilize percolation ponds to dispose of treated wastewater. In Brevard County, there are nine active package plants[9] on the barrier island adjacent to the coast (FDEP, 2003) (two of the package plants depicted in Figure 1 are no longer active according to personal communication with FDEP). These have a permitted capacity of 1.1 MGD with a combined actual annual average daily flow (AADF) of 0.62 MGD (Tables 6 and 7). All of the facilities treat the water with some type of extended aeration which nitrifies all of the ammonia (i.e., the ammonia is converted to nitrate, leaving an ammonia concentration that is essentially zero) and may allow for some denitrification (i.e., conversion to nitrogen gas, and thus removal from the system) (D. Martens, Brevard County, personal communication). The package plant effluent is released into percolation ponds or drainfields. Such "rapid infiltration basins" have an effluent limit of 12 mg/L for nitrate nitrogen or a groundwater limit of 10 mg/L nitrate at the 100-foot zone of discharge (Florida Rules 62-610.510 and 62-522.400). Water quality data were obtained for monitoring wells of nine of the facilities (Table 6), and nitrogen loading based on this data was calculated to be 0.0023 metric tons of nitrogen per day or 0.83 metric tons per year (Table 7).

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[9] Package plants: "Small wastewater treatment systems, known as package plants, are designed to treat limited sewage flow from suburban residential developments, hotels, schools, and other relatively isolated wastewater sources. These package plants use prefabricated steel tanks and hold the wastewater for a longer duration as part of their wastewater treatment process" (www.epa.gov/safewater/uic/cl5oper/ cesspools.html).

Table 6. Information on package plant treatment facilities utilizing percolation ponds on the barrier island adjacent to the coastline in Brevard County.

Location	Permit Capacity (MGD)	Annual Average Daily Flow (MGD)	Measured Nitrate (mg/L)[a]	Treatment	Name
Melbourne Beach	0.005	0.0015	3.6	Extended aeration sewage treatment plant with effluent to a 7,000 square foot drainfield.	Treetop Villas
Melbourne Beach	0.015	0.0032	4.2	Extended aeration sewage treatment plant with surge tank and dual screen filter. Effluent to one (1) drainfield.	Sterling House Condo
Melbourne Beach	0.075	0.028	2.1	Extended aeration sewage treatment plant with effluent to drainfields via carbon filter.	South Shores Utility
Melbourne Beach	0.024	0.015	1	Extended aeration sewage treatment plant with effluent to one (1) drainfield.	Lighthouse Cove WWTF
Melbourne Beach	0.012	0.008	NA	Extended aeration sewage treatment plant with effluent to a percolation pond.	Long Point Recreational Park
Melbourne Beach	0.01	0.006	7	Extended aeration sewage treatment plant with effluent to a drainfield.	Cove at South Beaches Condo Association
Melbourne Beach	0.099	0.0532	2.8	0.3 MGD capacity activated sludge Schreiber process with tertiary filtration and a 1.2 MGD holding tank discharging to a subsurface drainfield 0.075 MGD capacity.	Aquarina Beach Community
Cape Canaveral Air Force Station	0.8	0.504	4.7	Oxidation ditch with effluent to six (6) percolation ponds.	CCAFS/Regional
Kennedy Space Center	0.01	0.0021	5.4	Extended aeration sewage treatment plant with effluent to two (2) percolation ponds.	CCAFS/TEL-IV, WWTF #3

[a] The plants denitrify, thus effluent NH_4 concentrations are essentially zero.

Table 7. Calculated nitrogen load from package plant treatment facilities utilizing percolation ponds on the barrier island adjacent to the coastline in Brevard County, based on the data given in Table 5.

Permit Capacity (MGD)	Annual Average Daily Flow (MGD)	Annual Average Daily Flow (million liters per day)	Nitrogen Load (metric tons per day)
1.1	0.62	2.35	0.0023

Septic Tanks. Septic tanks or "on-site disposal systems" (OSDS) are a probable source of nutrients to the coastal zone. Of particular concern are older systems (>18 years) that may no longer function properly. In addition, systems installed prior to current setback regulations (Chapter 10D-6, Standards for Onsite Sewage Treatment and Disposal Systems, Florida Administrative Code) have the potential to directly impact surficial aquifer waters. Area geology is another important factor in determining the fate of septic system waste. Deliberate tracer studies have shown that discharge into septic systems in the Florida Keys can quickly reach coastal waters (Paul *et al*., 1995b).

The USGS reported that 50 of 421 water samples from the surficial aquifer in the Georgia-Florida coastal plane exceeded the maximum contaminant level (MCL) for nitrate; 18 of those samples were in the Coastal Flatwood area and many were associated with sewage-effluent disposal sites (Berndt, 1994). Nutrient concentrations in septic tanks are estimated to be 36-45 mg/L total N and 6-10 mg/L total P. A functioning septic system should reduce these values to 15-25 mg/L total nitrogen and <5 mg/L total phosphorous (personal communication, V. Buchanan, Environmental Health Services, Brevard County Health Department). Septic effluent nitrogen is primarily in the form of NH_4^+, but is quickly oxidized to nitrate in sandy aquifers. Phosphate is also high in the septic effluent, and precipitation and sorbtion are important processes involved in lowering concentrations of this nutrient (Harman *et al*., 1996).

Denitrification in the groundwater can further reduce nitrogen concentrations. For example, a study of septic systems in the Indian River Lagoon area reported a strong correlation between soil organic content and denitrification rates. This study found elevated nutrient concentrations in the septic tank area, but a return to background levels within 15 m downgradient of the septic systems (Anderson, 1998). For use in loading calculations, volumes of effluent can be estimated as 50 gallons per day per bedroom (Brevard County Health Department). For homes on the average of three to four bedrooms, this translates to approximately 662 L per day per septic tank. Accurate estimates of loading to the coastal zone would require information regarding the function of the septic systems and the influence of denitrification. Using an estimate of 20 mg/L (the average of 36, 25, and 0) translates to a loading of 13.5 g N per septic tank per day. These rough approximations yield a loading estimate that is in the range of values estimated by Horsley *et al.* (1996) for septic system loading to the Indian River Lagoon (20-25 pounds N per septic tank per day with 50% loss from denitrification, which translates to 12-16 g N per septic tank per day). The panel did not obtain a value for the number of septic tanks on the barrier island adjacent to the ocean coast in Brevard; however, 3,000 septic tanks are estimated to be present in the barrier island region both east and west of the lagoon (Barile, 2004). This number of septic tanks multiplied by the loading parameter given here yields a value similar to the load estimated in Barile (2004). Failed septic systems will have the greatest impact in a localized area. The panel did not acquire location, age, and setback distance data on septic systems adjacent to the coastal ocean in Brevard County.

Deep Well Injection. Treated wastewater in Brevard County is injected within the Lower Floridan aquifer at about 2,700 feet of depth, and the zone of injection goes up to a depth of about 1,500 feet. The intermediate confining unit acts to separate and confine the Lower Floridan from the Upper Floridan aquifer (EPA, 2003). The deep Floridan aquifer is thus thought to communicate with the marine environment well offshore near the continental shelf break because of the depth of injection into the aquifer and because there appears to be no springs in the area (see above). Transport time would be on the order of hundreds to thousands of years.

Deep well injection systems operating as designed are thus thought to pose little human health or ecological risk (EPA, 2003). For this reason, the popularity of deep well injection has been growing as a strategy to deal with the nutrient loads of treated wastewater (Table 8). However, fractures and faults are known to occur in the Floridan aquifer system, particularly in the Boulder Zone (EPA, 2003), and this can raise concern over where to place wells to properly monitor deep-well injection programs (Duncan *et al.*, 1994). The EPA has provided a risk analysis of Florida deep well injection (EPA, 2003).

Table 8. Deep well injectate nutrient loads in 2004. Data provided by Brevard County Water/ Wastewater Operations.

	Metric Tons Per Day				
	TKN	**NH_3**	**Total N**	**NO_3**	**TP**
South Beaches	0.014	0.003	0.107	0.090	0.034
Rockledge	0.008	0.000	0.009	0.001	0.003
MI Sykes	0.034	0.028	0.042	0.011	0.018

Potential stressors to ecological health from deep-well injection are generally limited to nitrate and phosphate nutrients if unintended vertical migration were to occur, although there is little data available on which to base risk (EPA, 2003). However, nutrient concentrations in a Brevard County monitoring well known to be impacted by deep-well injectate are near background levels (Figure 7). The South Beaches Water Treatment Facility is the only deep well injection plant in Brevard County located on the barrier island adjacent to the coastline. South Beaches provides advanced wastewater treatment[10] (EPA, 2003), which includes some denitrification (D. Martens, personal communication). Water taken from South Beaches monitoring well #2 in the Lower Floridan aquifer (Figure 7) has been impacted by deep well

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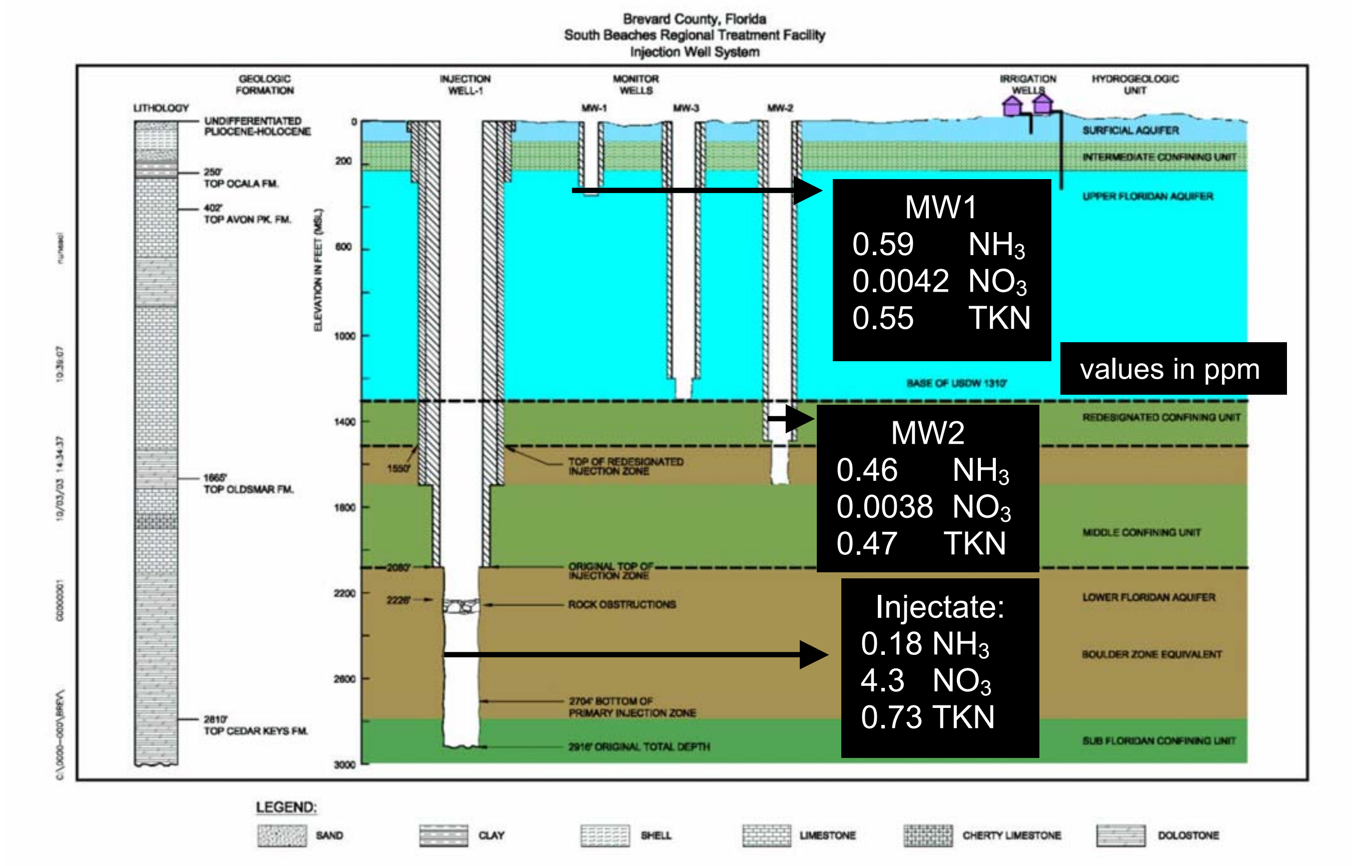
[10] "advanced (or tertiary) wastewater treatment is a term of art that simply means wastewater treatment beyond secondary treatment such as processes that are used if there are requirements to remove specific components, such as nitrogen and phosphorus which are not removed by the secondary treatment" (EPA, 2003).

injectate, as can be seen by the freshwater signature in Figure 8. However, nutrient concentrations were not elevated (Figures 7 and 9). Average nutrient concentrations measured in monitoring well #2 between January 2002 through January 2005 are as follows (average ± STDEV, n=37): 0.038 ± 0.030 mg/L NO_3^- (23 of the samples were below the limit of detection); 0.42 ± 0.05 mg/L NH_3; and 0.44 ± 0.21 mg/L TKN (total Kjeldahl nitrogen). Measured fecal coliform levels in monitoring well #2 were <1 fecal coliform/100 ml. The average nitrate concentration for the 2002-2005 period was close to that measured in the aquifer prior to injection (0.03 mg/L) (Duncan *et al.*, 1994). Measured nitrate concentrations for January 2004 through January 2005 were mainly below the limit of detection (Figure 7). Background TKN measurements at monitoring well #2 also appear to be at or below the levels measured in the aquifer prior to the start of injection. TKN measurements were not taken at the South Beaches site but were taken at the Merritt Island site, and background TKN concentrations there were 0.69 mg/L (Duncan *et al.*, 1994).



MW1
0.59 NH_3
0.0042 NO_3
0.55 TKN

values in ppm

MW2
0.46 NH_3
0.0038 NO_3
0.47 TKN

Injectate:
0.18 NH_3
4.3 NO_3
0.73 TKN

Figure 7. Diagram of the South Beaches Regional Treatment Facility injection and monitoring wells. Values (ppm) are averaged measured nutrient concentrations from January 2004 through January 2005. Data and diagram courtesy of Brevard County.

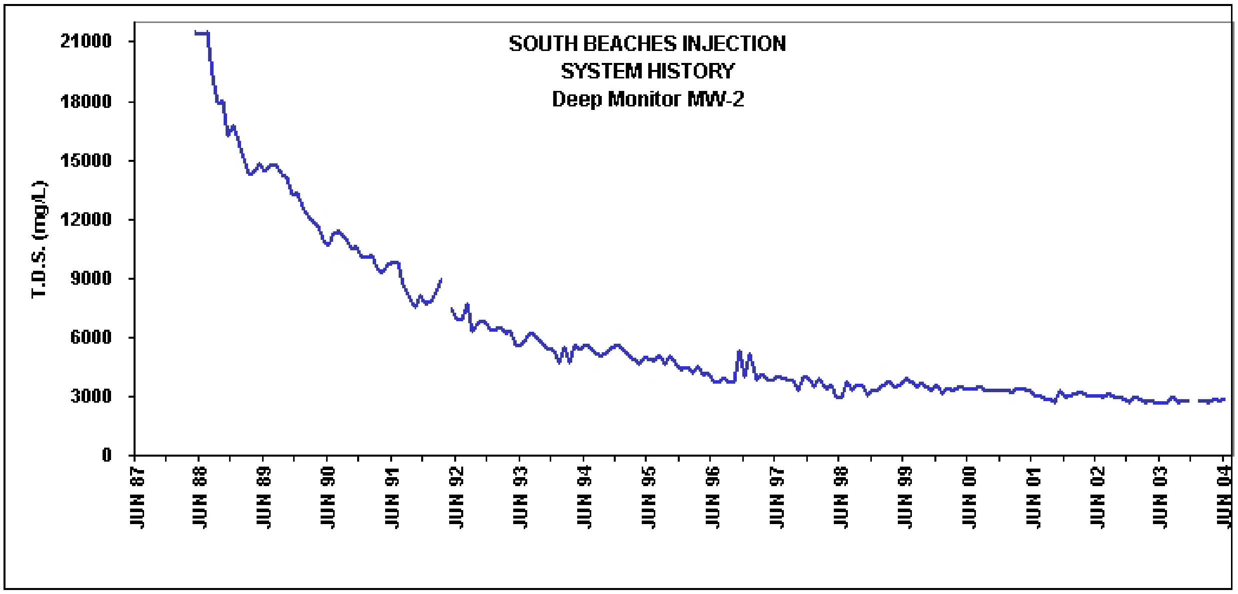


Figure 8. Total dissolved solid concentrations (mg/L) in the South Beaches Regional Treatment Facility monitoring well #2. Graph courtesy of Brevard County.

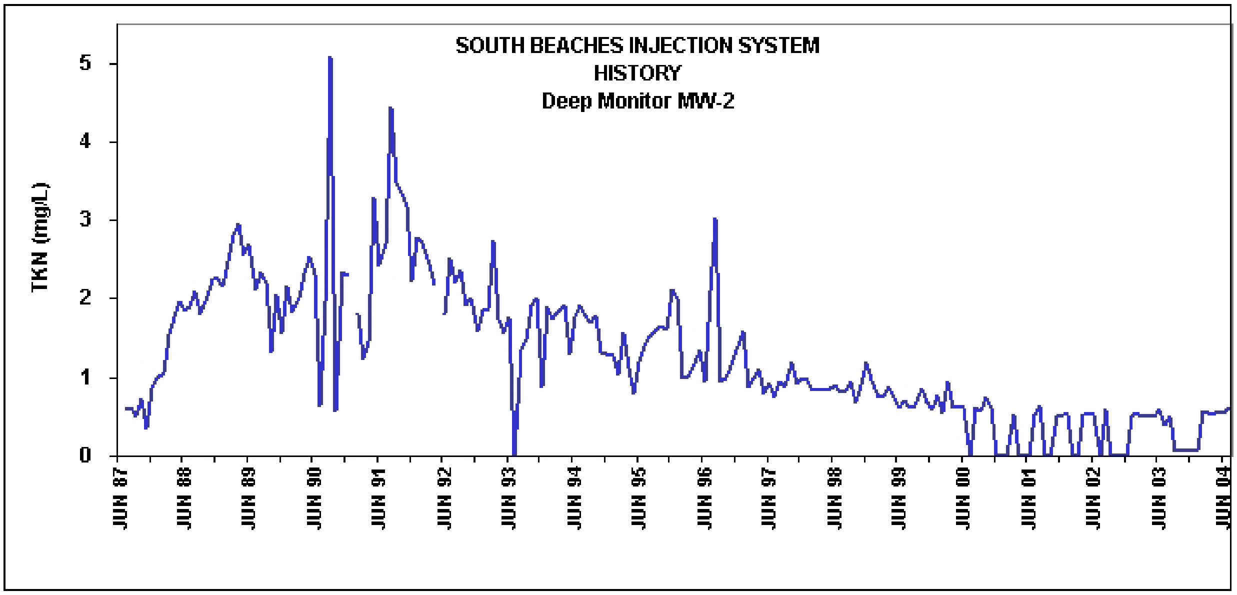


Figure 9. Total Kjeldahl nitrogen (mg/L) in the South Beaches Regional Treatment Facility monitoring well #2. Graph courtesy of Brevard County.

Atmospheric Deposition

Atmospheric deposition can be an important contributor of nitrogen to coastal ecosystems (Paerl, 1997). Analysis of nitrogen loading in the Brevard area has been performed (Dreschel *et al.*, 1990). Loading calculations were performed for the Banana River, Mosquito, and Indian River Lagoons using areas of 179, 153, and 582 km^2, respectively. Nitrogen deposition was estimated to be on the order of 200-300 metric tons per year to the surface waters of the lagoons. These values translate to a loading parameter of 749 g N/km^2 per year. Atmospheric deposition was estimated to be one-third of that contributed by sewage effluent compared to 1985 estimates of discharge into the Indian River Lagoon basin (38.7 million gallons per day).

Other Nutrient Inputs

Run-off and Leaking Sewers. Urban drainage can also be a source of nutrients to the coastal region, and impervious cover is known to negatively impact the health of coastal streams. In addition, urban drainage appears to adversely affect the safety of recreational waters (Dwight *et al.*, 2004). It has been estimated that street surface run-off contains a weighted mean of 312 g phosphate and 27 g nitrate per km of curb (EPA, 1972). In addition, leaks from sewer mains can contribute nitrogen to urban aquifers (Wakida and Lerner, 2005).

Coastal Upwelling. In some near shore regions, upwelling of nutrient-rich ocean waters may naturally contribute to nutrient enrichment, with inputs that can be larger than wastewater and storm water run-off (Leichter *et al.*, 2003). A loading estimate given by Leichter *et al.* (2003) (1.68×10^3 kg N/bore for 200 km of coral reef tract) translates to 8.4×10^3 g N per upwelling event per kilometer longshore.

Indian River Lagoon Coastal Exchange. The exchange of water between the Indian River Lagoon and the Atlantic Ocean is complex. Most estuaries and lagoons have large water exchanges with adjacent ocean waters, but this is not the case with the Indian River Lagoon. In particular, water exchange becomes quite limited north of the Sebastian Inlet. Water exchange of the Indian River Lagoon with the ocean has been considered negligible in some analyses, but may be more important than previously believed. In particular, it is possible that the 972 million m^3 per year net outflow from the St. Lucie Inlet into the Atlantic may impact near-shore bottom ecosystems (Woodward-Clyde Consultants, 1994). In the area between the Melbourne Causeway and the Sebastian Inlet, input from streams and other drainage ditches is greater than inputs from precipitation and run-off. The magnitude of drainage and the poor connection to the ocean has impacted water quality. These factors also imply that salinities should be lower in these segments than measured, suggesting that some ocean exchange is occurring (Woodward-Clyde Consultants, 1994). Thorough calculations of nutrient loads from Indian River inlets into the Brevard County coastal zone appear to be lacking.

Future Work

There are many sources of nutrients to coastal waters. Many of these have not been characterized in the Brevard County region; therefore, it is unknown which sources pose the most threat to the continued quality of Brevard County surf zone waters. Although the data analysis performed here does not show elevated nutrient concentrations, the data set is extremely limited. In addition, baseline data provide a powerful, but often lacking, tool for assessing the impact of population growth and land-use practices on the coastal zone. **In order to provide a more scientifically grounded basis for answering Question 1, a comprehensive water-quality monitoring program would need to be initiated that included measurement of at least nitrate, nitrite, ammonium, and silicate.** The sampling program in near shore waters would have to be designed to encompass the spatial and temporal variation in nutrient distributions in coastal waters. Initial studies would be needed to determine spatial and temporal variability before an exact sampling protocol could be recommended. However, a general outline for sampling is presented here. Measurements would be made approximately monthly, with careful documentation of meteorological and physical oceanographic conditions. Samples would have to be taken along the coast and near inlets at a number of transects perpendicular to the coastline extending sufficiently offshore to cover relevant biological habitats. At each station, water samples would be taken at various depths, from surface to sea floor. Sampling, analysis, and quality control protocols should follow the EPA's standard estuarine/marine water methodologies (www.epa.gov/nerlcwww/ordmeth.htm; EPA, 1997).

With regard to details of surf zone monitoring and the impact of terrestrial pollution on the surf zone, in general, Brevard County would benefit by contacting the Broward County Department of Planning and Environmental Protection (Broward DPEP, 954-519-1499). Personnel at Broward DPEP (Nancy Craig, Ken Banks) are currently planning a sampling program to monitor nutrient concentrations in Broward County coastal waters. A lack of consistent measurements presented difficulties for our analysis, and coordination among the counties could help overcome this problem. Coordination might also result in savings and substantial gains in efficiency and reduced costs.

It is envisioned that a comprehensive sampling program would also include nutrient measurements in potential source waters such as inlets, harbors, canals, and the Indian River Lagoon. A decade long (1990-1999) monitoring of Indian River Lagoon provided total nitrogen concentrations of 0.5-1.4 mg/L with an average of 1 mg/L and total phosphorus of 0.02-0.13 mg/L with an average of 0.07 mg/L. However, concentrations of critical nutrient compounds, such as ammonium, nitrate, nitrite, and phosphate, have not been measured. Interfacing with and expanding upon present monitoring efforts in the Indian River Lagoon, Port of Canaveral, and the FDEP would be mutually beneficial.

In an effort to characterize nutrient inputs to the coastal zone, a sampling program would have to incorporate synoptic adaptive sampling. Studies could be designed to focus on specific episodic sources of concern. For instance, a synoptic study focused on rain events could be constructed to estimate inputs from storm water run-off and/or septic tanks. Measurements at and around pipe outfalls before, during, and after rain events should be considered. An appropriate control region having less anthropogenic impact must also be included (e.g., Playa Linda area). Adequate knowledge of the physical oceanography of the region would be essential (see Question 9) so that a simple box model could be constructed to estimate nutrient loading from different sources.

A variety of pollutants can impact the coastal zone. A one-time survey of environmental pollution in the sediments could be conducted in the Indian River Lagoon, harbor, and surf sites to establish a baseline and determine the need for ongoing sediment sampling in critical areas.

Parameters measured in the sediment survey should include phosphorus and biologically-significant (and often toxic) metals. Pesticides or other persistent organic pollutants used in the region would also be good candidates for inclusion in this one-time baseline survey. Coordination with NOAA's National Status and Trends Program (O'Connor, 2002), which has sampled in the region, would be suggested for such an effort.

Nutrients are the primary cause of eutrophication, but there are many other factors that determine the ultimate level and type of atrophic symptoms in coastal waters, including tidal change, long shore currents, etc. Over the past few decades, it has been recognized that using nutrient concentrations alone is not a sufficient indicator of eutrophication risk. For example, nutrient concentrations are usually low during and after a phytoplankton bloom as a result of biological uptake. Exposure of biological communities to elevated nutrients cannot be determined by spot measurements of concentration. More indicative are the symptoms from nutrient enrichment, such as chlorophyll-a, turbidity, algal dominance changes, low dissolved oxygen content, harmful algae, etc. NOAA's National Ocean Service has developed a comprehensive model to assess eutrophication in the nation's estuaries (http://spo.nos.noaa.gov/projects/cads/nees/Eutro_Report.pdf). In their model, the index of eutrophication was defined by three primary and three secondary symptoms. Nutrient concentrations in the water column were not included as symptoms in the model. Although the model was developed for estuaries rather than for high energy coastal zones, the information may be of value for those designing sampling protocols for the surf zone. OSPAR (Convention for the Protection of the Marine Environment of the North East Atlantic) and JAMP (Joint Assessment and Monitoring Program) also give eutrophication monitoring guidelines (http://www.ospar.org/).

A comprehensive measurement of physical oceanographic, biological, and chemical characteristics of the coastal region, linked to appropriate ecosystem or biological indicator models, would be needed to assess the current status and predict the effects of future growth and development within Brevard County. The costs of such a study is likely to be prohibitive at the county level; thus, coordination with and leverage upon existing and planned federal and state programs is critical.

Even with such coordination and leveraging, resources are likely to be limiting. Therefore, efforts should be focused where the needs are the most critical. For example, this analysis suggests that the limited data available for the Brevard County coastal zone does not show elevated nutrients. It also suggests that water quality in the Indian River Lagoon has the potential to impact the near shore surf zone. If the coastal zone nutrient analysis presented here is verified, a comprehensive program monitoring the surf zone may not be warranted at this time.

Question 2

What inferences can be made, if any, from the known nutrient data of impacts of same to the near shore ecology?

Overview of the Brevard Near-Shore Environment

Climatologically, Brevard County is located in a transition area between the subtropical environment of southern Florida and the temperate region of the Georgia coast (Phlips *et al*., 2002). It is a high-energy shoreline (Livingston, 1990) characterized by shifting sands, which creates an unstable environment for near shore organisms trying to survive in the benthos. Shifting sand covers habitat, scours surfaces, reduces light visibility, and interferes with the ability of many organisms to filter feed. Where available, hard substrate is a critical habitat providing anchorage against wave action. There is not a clear definition of "near shore," but "shallow-water" live-bottom habitats are described as occurring in <6 m by Jaap and Hallock (1990), and the South Atlantic Fishery Management Council (1998) described the "near shore" worm reef area in Brevard as 0-4 m (0-12 ft). This area is basically the intertidal zone, roughly encompassing the extreme high and low water marks. In general, "near shore" tends to include both the littoral (intertidal) and sublittoral (subtidal) zones of the continental shelf which holds major coastal communities such as those of shorelines, marshes, mangroves, seagrass meadows, intertidal zones, and rock and coral reefs (Burchett, 1996).

In 1995, the near shore ecology of 24 miles of Brevard County coast was studied as part of an environmental impact study for beach renourishment. The study area included the cities of Cape Canaveral, Cocoa Beach, Satellite Beach, Indian Harbor, Indialantic, and Melbourne Beach (Army Corp of Engineers, 1996). The report states that organisms inhabiting the intertidal beach zone include the mole crab (*Emerita talpoida*), coquina clams (*Donax variabilis*, *D. parvula*), and species of polychaetes, amphipods, gastropods, isopods, crustaceans, and bivalves. Foraging shorebirds include a variety of tern species, black skimmer, and snowy plover. The surf zone area (from MLT [mean low tide] level to 80 cm in elevation below MLT) includes organisms similar to those in the intertidal zone, as well as portunid crabs and sand dollars. Fish species are seasonal with few year-round residents. Fish observed in the surf zone include catfish, lizardfish, croaker, kingfish, and pompano. Jacks, mackerals, ladyfish, bluefish, anchovies, and herrings can be periodically found (Army Corp of Engineers, 1996).

In the Brevard County area, outcrops of lithified coquina rock provide hard substrate. Broken coquina rock provides a variety of crevices and ledges that are thought to be particularly valuable to organisms (Olsen Associates, 2003). Although these hard-bottom habitats are not as well known as Florida's coral reefs, they are ecologically important (Jaap and Hallock, 1990). Brevard County has relatively little of this hard substrate. Along approximately 70 miles of coast, most of the near shore bottom is quartz sand, shell hash, and rock rubble with only about 9 miles of coast having exposed hardground (Army Corp of Engineers, 1996; Olsen Associates, 2003). The rock outcrops are concentrated north of Indialantic Beach to north of the Patrick Air Force Base (the "mid-reach" area). Approximately 32 acres of rock outcrop was estimated to exist in 1995 (Army Corp of Engineers, 1996). In 2001, 60.8 acres of exposed hardground was cataloged, with approximately 32 acres of this estimated to be the ecologically valuable broken coquina rock. Local field experience suggested that the 2001 estimates were at or near their greatest levels of exposure, and much of the rock observed during the 2001 study was buried by sand in subsequent months (Olsen Associates, 2003).

The rock outcrops are vulnerable to coastal activities such as beach renourishment, which has prompted studies to characterize it and efforts to preserve it, including designation by the National Marine Fisheries Service as an Essential Fish Habitat-Habitat Area of Particular Concern (EFH-HAPC) (Olsen Associates, 2003; South Atlantic Fishery Management Council, 1998). The ecological community on rock outcrops includes macroalgae and invertebrate grazers that provide important foraging for juvenile turtles and fish (V. Kosmyin, FDEP, personal communication). In some near shore rock outcrop areas, the sabellariid polychaete worm, *Phragmatopoma lapidosa*, can be found. Several crab species are also observed (*Pachycheles monilifer*, *Menippe nodifrons*, *Pachygrapsus transversus*), as well as a variety of fish, including blennies (*Labrisomus nuchipinnis*, *Blennius cristatus*), spottail pinfish (*Diplodus holbrooki*), porkfish (*Anisotermus virginicus*), sailors choice (*Haemulon parrai*), and sergeant majors (*Abudefduf saxatilis*). The orange sponge (*Cliona lampa*) is also found. A variety of macroalgae exists on the outcrops. Species identified include *Dictyota cervicornis*, *Padina* spp., *Ulva* spp., *Caulerpa prolifera*, *Codium decorticatum*, *Gracillaria* spp., and *Luarencia* spp. The presence of *Padina* and *Caulerpa* were reported to indicate “reef stability” (Army Corp of Engineers, 1996).

Overview of Possible Ecological Effects of Nutrification

In brief, elevated nutrients in near shore environments, if they occur, can result in shifts in algal (phytoplankton and/or macroalgal) abundance and community structure (Paerl, 1997; Paerl, 1988; Gobler and Boneillo, 2003; Valiela *et al.*, 2004). Perturbations at the basis of the food web, especially changes that result in loss of species diversity, can then resonate up trophic levels. In restricted estuaries, problems with hypoxia, toxins, and changes in the structure of biological communities have been observed (Paerl, 1988). In contrast, high-energy coasts are less vulnerable to these problems (Laws *et al.*, 1999), in part because short water residence times prevent anthropogenic inputs and phytoplankton from accumulating (Valiela *et al.*, 2004) and dilute the effects of anthropogenic sources. Potential receptors of treated wastewater in the marine environment include submerged aquatic vegetation, plankton, invertebrates, fish, reptiles, birds, and marine mammals (EPA, 2003). An extensive set of surface-water quality regulations (Chapter 62-302, Florida Administrative Code) are designed to protect ecological receptors and human recreation.

The specific impact of elevated nutrients on ecosystems is difficult to predict. For example, patterns of algal abundance in the Indian River Lagoon demonstrate that a variety of factors, in addition to nutrients, affect phytoplankton abundance (Phlips *et al.*, 2002). In Hawaii, groundwater impacted by golf course fertilization was found not to affect benthic organisms in the surf zone not only because of dilution occurring on the exposed coastline, but also because the groundwater plume was buoyant; thus, nutrient concentrations did not actually reach the benthos (Dollar and Atkinson, 1992).

Overall, the exact role of nutrients in coastal ecosystems, even those that have undergone evident degradation, has been debated (Miller, 1996; Lapointe, 1997; Hughes *et al.*, 1999; Lapointe, 1999; Miller *et al.*, 1999; Szmant, 2002; Lapointe *et al.*, 2004b). The reason for debate appears to be that many complex forces control ecosystem balance, and populated coastal areas perturb multiple forces simultaneously. Examples of coastal zone perturbations that often occur in addition to nutrient loading include changes in salinity, sedimentation, heavy metal concentrations, chemical pollutants (including hormones), atmospheric pollution, microbiological inputs, over-fishing, removal of top predators, habitat destruction, and introduction of invasive species. In addition, a complex set of natural (but variable) factors exerts an influence on algal abundance (Bledsoe and Phlips, 2000) and nutrient concentrations (Leichter *et al.*, 2003).

The Issue as Related to Brevard County

A fundamental question posed by the EPA (2003) when assessing the potential risks to ecosystems from nutrients in treated wastewater was “are the nutrient levels in the effluent higher than ambient water or applicable marine water-quality standards to protect ecological health?” **The area in question does not appear to show elevated nutrient concentrations (see Question 1).**

Another question posed by the EPA (2003) in order to evaluate potential ecological risk from nutrients in treated wastewater was “is there evidence that nutrients from the treated effluent are taken up by phytoplankton and microalgae and then converted to biomass?” Although a formal survey was not conducted, V. Kosmyin of the FDEP stated that he observed *Caulerpa* “overgrowth” on some Brevard County near shore rock ledges, but the species was not identified (V. Kosmyin, personal communication). In addition, Barile (2004) reports that nutrient-loving species such as *Ulva lactuca*, *Caulerpa prolifera*, and *Gracilaria tikvihae* have populated Brevard County littoral reefs. In contrast, *Caulerpa* overgrowth has not been observed in near shore regions of northern Indian River County (I. Irlandi, Florida Institute of Technology, personal communication). The species of *Caulerpa* primarily found in this location was *C. prolifera*, and *Caulerpa brachypus* was not observed. There is particular concern over *C. brachypus* because it may be an exotic species (Florida Fish and Wildlife Conservation Commission, 2003). Overgrowth by *C. brachypus* has been observed on coral reefs in Broward and Palm Beach Counties (Lapointe and Barile, 2001). However, overgrowth of any *Caulerpa* species is of concern because it could indicate nutrient impacts (Paul Carlson, Florida Fish and Wildlife Conservation Commission, personal communication). Although data sets exist for the Indian River Lagoon, detailed biological surveys of macroalgal cover and species distributions in the Brevard County littoral zone appear to be lacking. **Quantitative surveys providing a time-series of macroalgal cover and species distributions for appropriate control regions, as well as regions suspected of experiencing nutrient stress, could address this issue.**

Overall, ecosystems are balanced by biological, physical, meteorological, and geochemical forces. Human interaction with ecological systems usually affects multiple forces simultaneously. Therefore, a variety of factors contribute to ecological decline, making it difficult to fulfill the desire to identify one factor that can then be “fixed.” **Even if “elevated” nutrients had been found, the response of near shore ecology depends on a complex set factors that would need to be considered in an integrated fashion.** Such an ecosystem approach requires interdisciplinary efforts leading to quantifiable results that allow coastal managers to rank impacts based on sound science. Because multiple factors are usually important, including a variety of land-use practices, ecosystem preservation is likely to require the commitment of local people, industries, and governments to reduce cumulative coastal environmental impacts.

Question 3

What inferences can be made, if any, from the known nutrient data relating to the health of humans involved in activities in the near shore region?

Drinking water nitrate is regulated at 10 mg/L and nitrite at 1 mg/L because of potential human health risks, primarily to infants, from ingesting water at concentrations above that level (http://www.epa.gov/safewater/mcl.html#mcls). Nutrients in the coastal zone are not regulated in this manner because salt water is generally not ingested. Moreover, coastal waters typically have concentrations well below what is allowed in drinking water, as is the case in Brevard County (see Question 1). **Therefore, nutrients in the coastal zone are not thought to pose a direct risk to human health.**

An indirect threat to human health could occur if "elevated" nutrients in coastal waters were derived from sewage, because the sewage can contain infectious organisms. Therefore, it is coastal microbiological data, rather than nutrient data, that are most relevant from a human health perspective. A nutrient signal may be decoupled from a microbiological signal if the treated wastewater has been adequately treated to remove the microbiological load but not specifically treated to remove the nutrient load. Oceanic upwelling and internal waves are natural sources of nutrients to the coastal zone (Menge *et al.*, 1999; Leichter *et al.*, 2003) that are not a source of human pathogens.

Coastal waters can become contaminated with nutrients and fecal bacteria from sewage outfalls, septic tanks, leaking sewer mains, run-off, boat discharges, animal deposits, and from contaminated groundwater (Howington *et al.*, 1992; Paul *et al.*, 1995a; Scarlatos, 2001; Paytan *et al.*, 2004; Boehm *et al.*, 2004). Viral contamination of coastal areas from urbanized groundwater is a growing concern (Paul *et al.*, 1997; Paul *et al.*, 1995b; Lipp *et al.*, 2001; Nicosia *et al.*, 2001; Griffin *et al.*, 2003). Bacteria are thought to be preferentially adsorbed to sandy sediments, but bacterial contamination of beach fronts from groundwater has been reported (Boehm *et al.*, 2004; Paytan *et al.*, 2004). Human sewage is thought to pose the greatest risk to human health because it has the greatest potential to carry human pathogens; however, animal sewage (e.g., dairy, pig, dog, and bird) is also unsanitary. The health risk of animal fecal contamination is not clearly understood, although some studies suggest there may be some risk from non-human fecal contamination (EPA, 2004a).

Epidemiological studies indicate that swimming in waters contaminated with fecal bacteria pose a health risk (Cabelli *et al.*, 1979; Dufour, 1984; Cheung *et al.*, 1990; Kueh *et al.*, 1995). The main route of exposure to illness-causing organisms during recreational water use is through accidental ingestion of fecally-contaminated water. The EPA guidelines for marine recreational water quality are risk-based, meaning that the standards are based on epidemiological studies, which associated the risk of illness from exposure to marine recreational waters to the presence of bacterial indicators of water quality. Enterococci are the recommended indicator for marine waters because it was found to be the best indicator of illness (EPA, 2004a). The methods of monitoring and the allowable concentrations of fecal-indicating microbes in marine recreational waters are given in EPA guidelines (EPA, 1986, 2000, 2002, 2004a) and other standard methods (Greenberg *et al.*, 1992).

There has been much research effort to verify and improve upon the indicators used to regulate recreational water quality. In particular, there is concern that indicators may give false negative results, especially with regard to viruses (Lipp *et al.*, 2001; Griffin *et al.*, 2003; Harwood *et al.*, 2005) and protozoans such as *Giardia* and *Cryptosporidium*. Concerns over protozoans has lead to required monitoring of these organisms in treated wastewater slated for reuse in Florida (Chapter 62-610, Florida Administrative Code). Alternatively, false positive results are also possible due to regrowth of the indicators (Solo-Gabriele *et al*., 2000; Desmarais *et al*., 2002), and false positive results can have significant economic consequences (Rabinovici *et al.*, 2004). However, most of the research that raises concern over the possibility of false positive or false negative results has not been linked to epidemiological data, the standard on which EPA regulations are set. From an epidemiological perspective, the overall literature to date supports the use of enterococci in marine waters as predictors of gastro-intestinal illness in marine environments and supports the guideline levels developed by the EPA (Wade *et al*., 2005).

The EPA guidelines for Class 3 marine recreational waters are as follows: For enterococci bacteria, the geometric mean of the enterococci densities shall not exceed 35 per 100 ml, based on a statistically sufficient number of samples (generally not less than 5 samples equally spaced over a 30-day period). For a designated bathing beach, no single sample should exceed 104 enterococci/100 ml of water (one sided 75% confidence limit). The limits are less stringent for moderate, light, and infrequently used coastal recreational waters. The most probable number (MPN) or membrane filtration (MF) counts for fecal coliform bacteria shall not exceed a monthly average of 200 CFU/100 ml, nor exceed 400 CFU/100 ml in 10% of the samples, nor exceed 800 CFU/100 ml for any one sample. MPN or MF counts for total coliform bacteria shall not exceed a monthly average of 1,000 CFU/100 ml nor exceed 1,000 CFU/100 ml in 10% of the samples, nor exceed 800 CFU/100 ml for any one sample. Monthly averages shall be expressed as geometric means based on a minimum of 10 samples taken over a 30-day period.

With regard to microbiological data, the Florida Department of Health (FDOH) collects data for recreational coastal water quality (FDOH, 2004a, 2004b), including data for 10 sites in Brevard County (Canaveral National Seashore #4, Jetty Park, Cocoa Beach Pier, Cocoa Beach Minuteman Causeway, Patrick Air Force Base North, Pelican Beach Park, Paradise Beach Park, Indialantic Boardwalk, Spessard Holland North, and Sebastian Inlet North). Surveys of seawater conducted between August 2000 and April 2004 yielded 1,423 data points for enterococci and fecal coliforms. For enterococci, 1,348 samples were "good" as classified by the Florida Healthy Beaches Program (0-34 enterococci per 100 ml of marine water) and 49 samples were "moderate" (35-103 per 100 ml). Out of the 49 "moderate" samples, there was sufficient data for 36 to calculate a reasonable monthly geometric mean, and the geometric mean for all was "good" (0-34 enterococci per 100 ml). For fecal coliform, 1,422 samples were good (0-199 fecal coliform per 100 ml) and 1 was moderate (200-399 per 100 ml). No samples were "poor" (≥104 enterococci or ≥ 400 fecal coliform per 100 ml), no advisories were posted, and no beaches were closed (FDOH). Therefore, there was no evidence of contamination with fecal bacteria at these Brevard County sites. Some Brevard beaches were highlighted in a National Research Defense Council (NRDC) report as not being monitored (NRDC, 2003). These sites, located in the Indian River Lagoon system, are not designated as bathing beaches, and are thus not monitored under the Florida Healthy Beaches Program, nor are they considered in this report.

In addition to FDOH monitoring, water quality is monitored monthly in the Port Canaveral Harbor and includes measurements of fecal and total coliform concentrations. Records for fecal and total coliform densities from 1999-2004 (Sheffield Engineering and Associates, 1999, 2000, 2001; Safety and Environmental Assessment Services, 2003) generally show good microbiological water quality, particularly at station 4. Station 4, located at the mouth of the harbor, is essentially oceanic water and is thus more similar to samples collected at beach sites. In 2003, seven monitoring stations within the harbor were monitored. The concentrations were "good" to "moderate" even well within the harbor. At station 4, monthly fecal coliform counts ranged from 2 to 4 CFU/100 ml and total coliform from 2 to 22 CFU/100 ml. In 2002, measured densities of fecal coliform at station 4 were ≤2 CFU/100 ml and ≤13 CFU/100 ml for total coliform. During 2001*, station 4 fecal coliform counts ranged from <2 to 30 CFU/100 ml and total coliform from <2 to 170 CFU/100 ml. During 2000*, station 4 fecal coliform counts ranged from <2 to 23 CFU/100 ml and total coliform from <2 to 240 CFU/100 ml. During 1999*, station 4 fecal coliform counts ranged from <2 to 30 CFU/100 ml and total coliform from <2 to 110 CFU/100 ml. Therefore, there was no evidence of contamination with fecal bacteria at the mouth of the Port Canaveral Harbor. (*units not adequately documented in reports, but it is reasonable to assume that CFU/100 ml was meant).

Concentrations of fecal bacteria in surface waters are well known to increase after rain (Boehm *et al.*, 2002). Bacterial sources include run-off, septic tanks, sewage discharges, and storm water discharge. FDOH data include samples taken after rain, and the amount of rainfall is routinely recorded; however, synoptic studies to look at the concentrations immediately after rain events are not conducted as part of the program. Furthermore, there are presently no end-of-pipe guidelines for County storm water discharge and thus little data available. The Brevard County Stormwater Utility has collected a few bacteriological measurements. Water samples were collected from the end of three storm water pipes on August 23, 2003. The samples were processed after the six-hour holding time required by the EPA protocol, but the extent that the hold time was exceeded was not noted. Fecal coliform counts in these samples were high (600, 55,000, and 70,000 CFU/100 ml for Grant Avenue, Indialantic, and Indialantic-D sites, respectively). *E. coli* ribotyping was performed on the samples, and the analysis indicated that the source of feces was from animals rather than humans (the source and status of the *E. coli* library was not provided). Although there are no end-of-pipe regulations, the receiving waters are regulated under EPA guidelines. Unfortunately, data was not available from the same day, but FDOH collected samples at the Indialantic Boardwalk on August 25, 2003 and concentrations of enterococci and fecal coliform were "good" (1 enterococci and 1 fecal coliform per 100 ml). It is well known that degradation of beach water quality follows rain; however, other factors can contribute to problems, including bird populations. It is interesting to note that in three out of the six cases in which bacterial water quality was "moderate" at Indialantic Boardwalk, there had been no significant rain in the last three days. **Overall, elevated levels of fecal-indicating bacteria can indicate a risk to human health; however, there was no evidence of this in numerous samples taken within the Brevard County surf zone**.

Eutrophied estuaries with restricted circulation may have problems with toxic algal blooms, and toxins may accumulate in fish and shellfish, which pose a human health risk (Paerl, 1988; Viviani, 1992; Townsend *et al.*, 2003; Phlips *et al.*, 2004). In a high energy coastal zone such as Brevard County, the primary concern is red tide caused by *Karenia brevis*. Blooms coming ashore are known to cause respiratory irritation (Backer *et al.*, 2003; Kirkpatrick *et al.*, 2004). For a discussion of the relationship between coastal nutrient inputs and *K. brevis* blooms see Question 4.

Question 4

What effects could be expected from the nutrient concentration levels on the occurrence or duration of red tide (Karenia brevis) blooms above expected background or historic levels?

The occurrence of *Karenia brevis*, Florida's red tide causing organism, has been routinely documented and intensively studied (Tester *et al*., 1991; Walsh and Steidinger, 2001; Walsh *et al*., 2002; Magaña *et al*., 2003; Backer *et al*., 2003; Kirkpatrick *et al*., 2004; Stump *et al*., 2000; Vargo *et al*., 2004). The factors that initiate and terminate a bloom are still under investigation. However, there is consensus that the occurrence of *K. brevis* on the east coast of Florida is due to oceanographic conditions that advect the bloom around the tip of Florida from its typical residence on the west coast. In other words, *K. brevis* blooms do not appear to initiate on the east coast, but are transported there. The first documented Florida east coast bloom occurred in 1972. At that time it was noted that this occurrence of red tide on the east coast was the result of unusual oceanographic conditions that lead to concentration and transport of *K. brevis* (Murphy *et al*., 1975).

Some blooms of harmful algae have been associated with nutrient increases in conjunction with appropriate environmental conditions (Paerl, 1988; Smayda and White, 1990; Paerl, 1997; Hallegraeff, 1993; Tada *et al*., 2001; Anderson *et al*., 2002; Yang and Hodgkiss, 2004). Coastal waters in China, Hong Kong, and Japan provide convincing examples of the relationship between nutrient loading or changes in nutrient ratios and harmful algal blooms (HABs), and a relationship between population growth and HABs is found in Puget Sound, Washington (Gilbert *et al*., 2005). However, a nutrient-caused effect is not always evident (Hallegraeff, 1993; Smayda and White, 1990). Although some types of harmful algal blooms have become more frequent and longer in duration, other types of blooms "have always occurred and are entirely natural" (NRC, 2000). ***K. brevis*, the red-tide causing organism in Florida, appears to fall into this category. The majority of published scientific evidence does not link initiation of *K. brevis* blooms to near shore coastal nutrients.** The lack of evidence for a link includes no correlation of *K. brevis* to measured nutrients, the fact that blooms initiate well off-shore and then are transported by wind and sea to the near shore, and the experimental evidence that other phytoplankton are better adapted to take advantage of high nutrient concentrations (Smayda, 1997; Walsh and Steidinger, 2001; Vargo *et al*., 2004) and should out compete *K. brevis* if nutrients were elevated. Finally, there is the report that *K. brevis* blooms do not appear to be more frequent or in longer duration than that recorded historically (Magaña *et al*., 2003). The historical evidence includes detailed records since the 1950s, as well as compelling accounts that go back at least 350 years. However, a re-analysis of data for the eastern Gulf of Mexico is ongoing, and preliminary results indicate a possible increase in bloom duration, intensity, and extent. At the time of this report, this preliminary data were not available for review. This analysis does not include data for the east coast of Florida (L. Brand, personal communication).

Overall, the complex combination of nutrient sources, timing of inputs, uptake abilities and limitations, and competitive interactions among the microbial community make it difficult to differentiate the role of eutrophication from other forces that control algal community structure in Florida. **It should be noted that although there appears to be much progress in ruling out**

causative associations, the factors regulating sustenance and termination of *K. brevis* blooms remain largely unresolved. For example, the scientific community is just beginning to recognize the import of dissolved organic matter (DOM; includes carbon as well as nitrogen), dissolved organic nitrogen (DON), and dissolved organic nutrients to HAB populations (Gilbert *et al*., 2005). *K. brevis* can uptake DON as well as the nitrogen-containing compounds glutamate ($C_5H_9NO_4$) and urea ($CO(NH_2)_2$) (Bronk *et al*., 2004). It is plausible that future studies will find a link between loadings of dissolved organic nutrients to *K. brevis* blooms, perhaps directly from anthropogenic sources or indirectly from prior algal blooms that had been stimulated by "traditional" nutrients.

Question 5

Is evaluation of nitrogen isotope ratios in a near shore oceanic environment a reliable method to identify sewage or treated wastewater effluent as the source of elevated nutrients?

The Nitrogen Cycle

The nitrogen cycle is particularly complex. Biological processes play a major role in cycling nitrogen through its various forms. The process of incorporating inorganic nitrogen into living matter is termed assimilation (NH_4^+ or $NO_3^- \rightarrow$organic-N). The reverse is ammonification or mineralization (organic-N$\rightarrow NH_4^+$). Other critical processes are nitrification ($NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$), denitrification ($NO_3^- \rightarrow \rightarrow N_{2gas}$), and nitrogen fixation (e.g., $N_{2gas} \rightarrow NH_3$). These processes are critical because not all forms of nitrogen are equally bioavailable. For example, N_2 gas is relatively inert. Few organisms can use it because of the strength required to break the triple bond of the N_2 molecule. However, N_2 in the atmosphere is the largest source of nitrogen; therefore, nitrogen fixation, which transforms the nitrogen into a biologically utilizable form, is of great ecological importance. Many organisms can take up ammonia or ammonium, but it is toxic in high quantities. Nitrate is the preferred form of nitrogen for many plants and algae, resulting in competition for this nitrogen species. The nitrogen cycle is further complicated by the fact that some processes require anaerobic conditions to occur and that pH and soil type affect nitrogen availability. The result is a complex web of tightly coupled, and often competing, reactions.

Stable Isotopes

All elements possess both stable and unstable isotopes. Isotopes are forms of an element that possess the same number of protons, but differing numbers of neutrons. Unstable isotopes can occur either naturally or be produced through anthropogenic processes such as nuclear reactions, whereas the overall inventory of stable isotopes in the Earth system has remained more or less the same since the Earth's formation.

Nitrogen has two stable isotopes, ^{15}N and ^{14}N. The atmospheric ratio of these isotopes is generally considered to be constant and their abundance is measured relative to the composition of the atmosphere and is expressed in parts per thousand relative to air (per mille, or ‰) (equation 1).

$$\delta^{15}N(‰) = \frac{^{15}N/^{14}N_{sample}}{^{15}N/^{14}N_{s\tan dard}} - 1 * 1000 \tag{1}$$

This notation is used to express the abundance of all stable isotopes, although the standard used varies according to the element and isotope system under consideration. Atmospheric nitrogen is the standard for the nitrogen isotopic system, and is thus defined as having an isotopic composition of 0‰. Substances that contain more ^{15}N are said to be isotopically heavy or enriched. Substances that contain less ^{15}N are isotopically depleted, light, or more negative. This is the only notation scheme commonly used to express the abundance of stable isotopes at natural abundances. In some studies, the heavier isotope of nitrogen (^{15}N) is used as a tracer, meaning that it is added to a system under study. In these experiments, the measured changes are usually very large and the concentrations of ^{15}N are sometimes expressed as atom %, or the number of ^{15}N atoms in 100 atoms of total ($^{14}N + ^{15}N$). However, the per mille (‰) notation is the proper notation to describe the isotopic composition of natural samples because the absolute differences between samples and standard are quite small at natural abundance levels and might appear only in the third or fourth decimal place if atom % were reported.

Isotope Fractionation

The relative abundance of stable isotopes can change as a compound undergoes physical and chemical processes. One of the most obvious examples of a process influencing the stable isotopic composition of an element is that which affects oxygen during evaporation. During this process, the heavier isotope of oxygen (^{18}O) is preferentially left behind in the water, while the water vapor contains more of the more abundant and lighter isotope (^{16}O). As a result, rainwater possesses a fundamentally different ratio of ^{18}O to ^{16}O than seawater, or it is “lighter” than seawater. This type of change is called fractionation and occurs during many transformation processes involving stable isotopes.

Fractionation processes are described by a fractionation factor (α), which relates the ratio in the product to that in the reactants according to equation 2. A value of unity means that the $^{15}N/^{14}N$ ratio in the products is identical to that in the reactants.

$$\alpha = \frac{^{15}N / ^{14}N_{products}}{^{15}N / ^{14}N_{reac\tan ts}} \qquad (2)$$

Processes involving the nitrogen cycle can be enzyme-mediated or proceed without biological intervention. Regardless, such reactions often result in isotope fractionation, with the lighter isotope being reacted first, leaving behind the heavier one. This can cause large changes in the nitrogen isotopic system. For example, fractionation occurs during the first step of nitrification, the transformation of ammonium to nitrite ($NH_4^+ \rightarrow NO_2^-$). The fractionation factor (α) for this process is 1.02 (Miyake and Wada, 1971), which means that the nitrite initially produced in this process will have a nitrogen isotopic composition ($\delta^{15}N$) approximately 20‰ lower than the ammonia. Overall, nitrogen isotopic fractionation during assimilation by plants and algae is known to be species-specific (Emmerton *et al*., 2001) and dependent on growth conditions (Needoba *et al*., 2004).

Fractionation in the N isotopic system occurs during the following processes: nitrogen fixation, nitrification, denitrification, ammonification, ammonia volatization, solution of gas, and assimilation. In other words, changes in the abundance of nitrogen isotopes occur during practically every transformation involving nitrogen-bearing compounds. While fractionation is fairly well understood in isotopic systems of other elements, this is not the case for nitrogen. In addition to the complexity of the nitrogen cycle, until relatively recently the measurement of nitrogen isotopes was difficult and thus restricted to true isotope geochemists. The advent of modern analytical methods has made isotopic measurement relatively easy for most nitrogen compounds, as long as there is a reasonable concentration of nitrogen. For materials with relatively low concentrations of nitrogen, such as most natural waters, measurement procedures are more complex. Hence, while it is straightforward to examine the nitrogen isotopic abundances in organic materials, simultaneous measurements are rarely made on nitrogen-bearing species in the associated waters.

Ranges in Nitrogen Isotopic Composition

Atmosphere: Nitrogen in the atmosphere is the largest reservoir on earth and is also the most homogeneous (Dole *et al*., 1954; Junk and Svec, 1958). The $^{15}N/^{14}N$ ratio is 0.07353.

Land Plants. It is well established that bacteria associated with plants from the legume family are able to convert molecular nitrogen into nitrogen compounds. In addition, certain algae and anaerobic bacteria can also "fix" nitrogen. The changes in the isotopic composition of nitrogen accompanying fixation are minor, with the fractionation factor (α) varying between 1.000 and 1.004‰ (Hoering and Ford, 1960; Delwiche and Steyn, 1970), and some legumes show negative $\delta^{15}N$ values (Dijkstra *et al.*, 2003). Reported values for land plants vary and depend greatly on the species and growth conditions (Dijkstra *et al.*, 2003; Emmerton *et al.*, 2001; Robinson *et al.,* 1998). A survey of 223 literature values of $\delta^{15}N$ values for plants summarized by Kaplan (1983) gives an average value of +5‰, reflecting alteration during fractionation by biological processes and mixing with nitrogen released by rock weathering. The refractory or less reactive nitrogen tends to be isotopically more positive, while the hydrolysable forms of nitrogen are closer to the isotopic composition of the atmosphere.

Nitrogen Balance in the Oceans. The major input of nitrogen to the ocean is derived from rain, river run-off, and fixation of molecular nitrogen, while nitrogen is removed from the system by burial, assimilation, and denitrification. Both assimilation and denitrification have been suggested to fractionate the isotopic composition of nitrate, leaving enriched nitrogen behind. Early studies suggested that denitrification was the major source of fractionation (α=1.020) (Miyake and Wada, 1971), with little fractionation occurring during assimilation (Kaplan, 1983). However, later work suggested that assimilation leads to large enrichments in the isotopic composition of nitrogen (Wada and Hattori, 1976; Montoya, 1990; Goering *et al.*, 1990; Altabet *et al.*, 1986; Liu and Kaplan, 1989; Horrigan *et al.*, 1990) and that consequently the $\delta^{15}N$ can be used as an indicator of productivity.

As a result of either assimilation or denitrification, marine waters which are rapidly upwelled possess more negative $\delta^{15}N$ values compared with waters which are more slowly brought to the surface. The $\delta^{15}N$ is often quite high in oxygen-depleted waters (Cline and Kaplan, 1975; Liu and Kaplan, 1989), and it is likely that high $\delta^{15}N$ will be found in organisms from these areas. Once at the surface, upwelled water gradually becomes lower in the concentration of nitrate and more enriched in $\delta^{15}N$ values. Hence, it can be expected that coral reefs, which normally contain low concentrations of nutrients, will have elevated $\delta^{15}N$ values simply as a result of assimilation of nitrate by algae and phytoplankton. Fractionation also takes place during nitrification (NH_4^+ to NO_3^-) leaving behind ammonium (α=1.020) that is enriched in ^{15}N and producing NO_3^- depleted in ^{15}N.

The preferential removal of ^{14}N during a process such as assimilation and its influence on the stable nitrogen isotopic composition of the residual nitrate can be easily modeled using a Raleigh distillation equation as denoted in equation 3.

$$\frac{^{15}N/^{14}N_{nitrate}}{^{15}N/^{14}N_{initial}} = f^{(\frac{1}{\alpha}-1)} \tag{3}$$

In this equation, the value α is the fractionation factor and *f* is the fraction of the original nitrate that has been removed. Consider a body of water that initially has a high concentration of nitrate, say 10 μM. As this nitrate is assimilated by phytoplankton, the nitrate concentration becomes lower, reaching a value typical of oligotrophic[11] water in Florida (0.1 μM). At this point approximately 99% of the nitrate has been removed. If a fractionation factor (α) of 1.004 is employed during assimilation, the residual nitrate in the water column would have a δ^{15}N value of +18.5‰. This calculation can be seen in Figure 10. A larger fractionation factor arising from denitrification (α=1.02) would result in even higher δ^{15}N values.

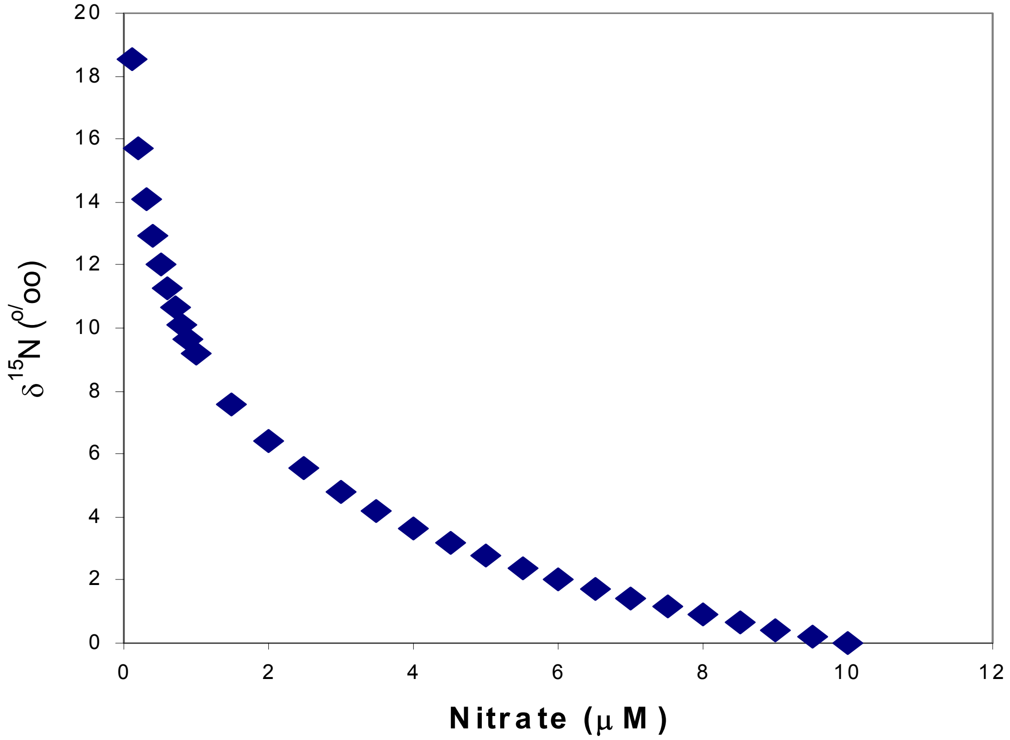


Figure 10. Model showing the influence of assimilation on the nitrogen isotopic composition of nitrate as a result of fractionation during assimilation. This model starts with a nitrate concentration of 10 μM with a δ^{15}N of 0‰. The concentration is gradually reduced by assimilation. As a result of the preferential use of nitrate by the phytoplankton (α=1.004), the remaining nitrate is enriched in ^{15}N so that at concentrations typical of oligotrophic waters the δ^{15}N can be as high as +18‰.

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[11] Oligotrophic: Low in nutrients.

Particulate Organic Material. Particulate organic matter (POM) plays an important role in the transport of material into and out of the photic zone[12] and is influenced by the abundance and forms of inorganic nutrients. Particulate organic material rarely represents a single group of compounds, but rather includes a mixture of phytoplankton, detritus, zooplankton, and bacteria. The processes which are important in the coastal zone are considerably different than those in the open ocean, where POM primarily represents a mechanism whereby nitrogen is lost from the photic zone. As POM sinks below the photic zone, it is preferentially degraded and an enrichment arises as a result of preferential degradation. In contrast, in the coastal zone there is a considerable degree of resuspension as a result of weather conditions, as well as run-off from the adjacent coastal zone. Hence, on the continental shelf the $\delta^{15}N$ of the POM may reflect in part the resuspension of sedimentary organic material and may be related to wind speed. There are significant variations in POM seen in different locations primarily caused by a combination of fractionation during assimilation combined with a loss of ^{15}N through sinking particles.

Trophic Influences. As in the case of carbon, the $\delta^{15}N$ of animals reflects that $\delta^{15}N$ of its diet with a slight enrichment. Macko *et al.* (1982) has shown this enrichment to be approximately -0.3 to +2.3‰, regardless of the food source. When enrichment in trophic levels occurs, excretory products depleted in $\delta^{15}N$ (urea and ammonia) are formed and eliminated from the organism. Other workers have reported up to a 3.2‰ change per trophic level.

Uptake of Nitrogen by Algae. Algae are able to use all forms of dissolved inorganic nitrogen, and some can take up organic forms as well. The fractionation factors involved in uptake have been measured experimentally for a range of different phytoplankton (Wada and Hattori, 1978; Cifuentes *et al.*, 1988; Montoya, 1990; Montoya *et al.*, 1991; Needoba *et al.*, 2004), although there exists little information on macroalgal species. In the case of nitrate, most data agrees that the lighter isotope of nitrogen is preferentially accumulated, so that the algae are lighter or more negative than the ambient nitrate. The fractionation factor (α) for this process varies between 1.0007 and 1.023 (Wada and Hattori, 1978; Montoya, 1990). In the case of NH_4^+, the data are much sparser with values of between 0.9936 and 1.0091 (Wada and Hattori, 1978; Montoya *et al.*, 1991; Cifuentes *et al.*, 1988). Fractionation factors during the uptake of NO_2^- are close to unity (α=1.0007) (Wada and Hattori, 1978). The wide range in values reflects the uncertainty in appropriate fractionation factor, as well as the apparent dependency of fractionation upon physical and biological conditions. For example, it has been determined that differences in aeration and physical flow can lead to differences in fractionation (Wada and Hattori, 1978), and that fractionation is inversely related to growth rates in light limited cultures. If results from phytoplankton cultures are applicable to macroalgae, it is likely that fractionation of dissolved inorganic nitrogen (DIN) is related to light levels, a parameter which in turn can be influenced by seasonality, depth, water turbidity, or other factors.

Overall, isotopic fractionation is species-specific (Emmerton *et al.*, 2001) and growth-condition dependent (Needoba *et al.*, 2004). In fact, $\delta^{15}N$ values in plants can differ depending on the part of the plant sampled (Emmerton *et al.*, 2001; Dijkstra *et al.*, 2003). Additional processes occurring in plants such as transamination, deamination, leaching, and volatilization, may also affect the nitrogen isotope composition of plant tissues (Robinson *et al.*, 1998). These

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[12] Photic zone: The depth of water exposed to sufficient sunlight for photosynthesis to occur (~20 m in the open sea).

differences apply to both nitrate and ammonium assimilation (Dijkstra *et al*., 2003). In addition, organisms compete for bioavailable nitrogen species, meaning that there is not equal opportunity for "light" nitrate (Cifuentes *et al*., 1988). The complex interactions between N sources and metabolic $^{15}N/^{14}N$ fractionations help explain why Robinson *et al*. (1998) state that "it is now clear that ^{15}N is usually a poor natural tracer of N pools." Although a more detailed discussion of mechanisms of assimilation is beyond the scope of this report, it is clear that there is a considerable amount of both conflicting data and uncertainty regarding the mechanisms of uptake, the appropriate fractionation factors, and how these fractionation factors vary with environmental conditions.

Distinguishing Sewage

The nitrogen isotopic method has been used to distinguish nitrogen derived from fertilizers (0‰) (Savage, 2005; Shearer *et al*., 1974; Kreitler, 1979; Heaton, 1986), nitrates produced from the oxidation of nitrogen waste (+10 to +22‰) (Kreitler, 1979), and nitrates produced from the oxidation of organic nitrogen in the soil (+4 to +9‰) (Gormley and Spalding, 1979; Mariotti, 1974). It is generally considered that values greater than +10‰ are needed to assign a value as being from a pollutant source (Heaton, 1986), although some workers have assigned lower values as being indicative of sewage (Lapointe *et al*., 2004a). Numerous papers have been published which report the use of stable isotopes in benthic organisms in order to distinguish sewage (Heikoop *et al*., 2000a,b; Sammarco *et al*., 1999; Risk and Erdmann, 2000; Costanzo *et al*., 2001, 2004; Rogers, 2003; Savage and Elmgren, 2004). Many of these studies simplistically interpret positive $\delta^{15}N$ values as reflecting input of sewage without examining the other parameters which may have varied along the same gradient. The systematics of nitrogen isotope fractionation in a particular environment must be assessed to properly interpret $\delta^{15}N$ values.

Surprisingly, some studies have even shown that sewage-derived nitrogen has more negative $\delta^{15}N$ values compared with normal planktonic nitrogen. Wada and Hattori (1976) showed that sewage effluent has a $\delta^{15}N$ a value of only +2.5‰, while the planktonic $\delta^{15}N$ was greater than 9‰. Similar positive planktonic $\delta^{15}N$ values have been reported by other workers (Wada and Hattori, 1978; Sweeney and Kaplan, 1980; Montoya, 1990; Peterson and Howarth, 1987; Goering *et al*., 1990; Harrigan *et al*., 1989). These enriched planktonic values appear not to be related to anthropogenic sources, but rather a result of the uptake of isotopically-positive nitrate which is, in turn, a result of fractionation during the process of assimilation or fractionation during denitrification. Some of the uncertainty regarding the interpretation of N-isotopic values arises from the fact that while the terrestrial materials themselves (solid waste) are probably actually isotopically more negative than most marine organisms, the isotopic processing during the treatment of sewage produces inorganic nitrogen which has positive values. Hence, sewage discharge could quite possibly introduce isotopically-positive DIN into the marine environment while also discharging large amounts of suspended material with isotopically more negative values. Depending upon how the ecosystem utilizes the N, different isotopic signatures might arise in the biota.

Published work regarding macroalgae illustrates that it is not possible to assign a precise value for $\delta^{15}N$ from sewage. For example, Savage and Elmgren (2004) lists $\delta^{15}N$ values for *Fucus vesiculosus* at a control site as 4‰. In contrast, Rogers (2003) report average values for *Ulva* from two control sites as 7.6‰ and 7.8‰, and states that these data "are within the expected range of marine algae from non-contaminated environments." These differences clearly illustrate the need to fully characterize a site and the species of study before assigning meaning to a $\delta^{15}N$ value. The Rogers (2003) study collected data prior to the closure of a marine outfall and followed $\delta^{15}N$ values after the outfall was closed. That the study site was impacted by sewage was not an issue of debate. Although most studies cite that highly positive $\delta^{15}N$ values are associated with sewage, in this case macroalgal $\delta^{15}N$ values were more negative than the control sites. Lowest values were found at sites closest to the outfall (2.3‰ and 5.7‰), and values increased with distance from the outfall (7.0‰ and 7.3‰) until reaching the values at control sites. Within three weeks of the outfall closure, *Ulva* at the sites closest to the outfall had begun to increase and reached 7.0‰ after nine months time.

Interpreting $\delta^{15}N$ values in groundwater can also be problematic. Denitrification acts to increase $\delta^{15}N$ values, thus complicating assessment of nitrogen sources (Silva *et al.*, 2002). The range of $\delta^{15}N$ values and the nitrogen transformations that occur in groundwater make it difficult to distinguish nitrogen derived from geologic sources (organic matter) from nitrogen derived from septic tanks or commercial fertilizer (Fogg *et al.*, 1998).

Other Stables Isotopic Indicators of Pollution. In addition to nitrogen, the stable isotopic composition of carbon and sulfur have been used to trace the input of sewage in marine and freshwater systems (Burnett and Schaeffer, 1980; Sweeney and Kaplan, 1980; Sweeney *et al.*, 1980; Krouse, 1980; Rau *et al.*, 1981; Macko, 1981; Ostrom and Macko, 1991; Tucker *et al.*, 1999; Wayland and Hobson, 2001; Rogers, 2003). Carbon (^{13}C and ^{12}C) can be used to distinguish between terrestrial-derived and marine-derived material as shown in Figure 11 but does not carry specific information on whether material is "sewage" derived or not. Carbon isotope data will not be definitive but can help constrain the biological system under study.

Sulfur also has multiple isotopes, but usually abundances of the ^{34}S are reported relative to ^{32}S. Sulfur isotopes have been used in pollution studies involving acid rain, and there have been some investigations involving sulfur cycling in marine organisms impacted by sewage waste (Tucker *et al.*, 1999). The dominant source of sulfur is sulfate in seawater, and the major fractionation step is associated with sulfate reduction to hydrogen sulfide. Hence, H_2S, which can be associated with sewage, will have depleted sulfur isotope values in the H_2S and possibly enriched values in the sulfate. However, this process also occurs during the natural degradation of organic material and results in a large range of $\delta^{34}S$ values (Tucker *et al.*, 1999). Therefore, these values can not be considered diagnostic by themselves.

Studies on Nitrogen Isotopic Systematics in South Florida

Despite the controversy which exists regarding the influence of nitrogen upon the health of coastal habitats, there has been only one published systematic study on the nitrogen cycling in the coastal environments of south Florida (Swart *et al.*, 2005), although other studies are underway (Anderson, unpublished; Hollander, unpublished). Several studies on the abundance of nitrogen-bearing compounds in the waters do exist (Szmant and Forrester, 1996; SERC, unpublished), although none of these actually measured the N isotopic composition of all the relevant pools involved. Nitrogen isotopes have been measured in groundwaters of the Florida Keys (Griggs *et al.*, 2003) associated with wastewater. Values in these waters were found to be elevated consistent with denitrification. No evidence exists that such waters reach the reefs offshore (Bohlke *et al.*, 1999; Shinn *et al.*, 1994). Studies of *Codium isthmocladium* on reefs in Palm Beach County (Lapointe, 1997) and the Florida Keys (Leichter *et al.*, 2003) are discussed in more detail below. Similarly, several studies measured C/N ratios in various organisms and reported nitrogen isotopic compositions. These include studies which examined the $\delta^{15}N$ of seagrasses in Florida Bay and the Florida Keys (Anderson and Fourqurean, 2003), as well as studies associated with harmful algal blooms on the west coast of Florida (Havens *et al.,* 2004). The study of Anderson and Fourqurean (2003) found relatively low $\delta^{15}N$ values (1-2 ‰) in seagrasses and seasonal fluctuations. The Havens *et al.* (2004) study found values between 4-6‰ in dinoflagellate algal blooms.

An EPA study measured the level of $\delta^{13}C$ and $\delta^{15}N$ in algae and other marine organisms in the lower Keys, including material growing adjacent to the sewage outfall in Key West (Hoch *et al.*, 2004). In this study, 73% of the dissolved inorganic nitrogen (DIN) was reported as being in the form of NH_4^+ with an isotopic composition of +11‰. Carbon and nitrogen isotopic compositions were not related to the distance from the sewage outfall and showed a relationship to the sedimentary $\delta^{15}N$. A summary of these data are shown in Figure 11, together with data from Swart *et al.* (2005) on the $\delta^{13}C$ and $\delta^{15}N$ composition of the organic tissues of corals growing off Key Largo. These data indicate that the range of $\delta^{15}N$ of the sewage effluent is between +10 and +12‰, while the range of $\delta^{15}N$ in other organisms is between -2‰ and +6‰. A later study funded by the EPA examined the nitrogen isotopic composition of particulate organic material from a wide range of sites in the Florida Keys (Figure 12). The conclusions from the study were that "in spite of the suggestion that the $\delta^{15}N$ of organic material might be used as an indicator of anthropogenic pollution in the marine environment, the values of $\delta^{15}N$ measured fell within a comparatively narrow range and showed no excessively high values, which strongly suggested direct influence of sewage."

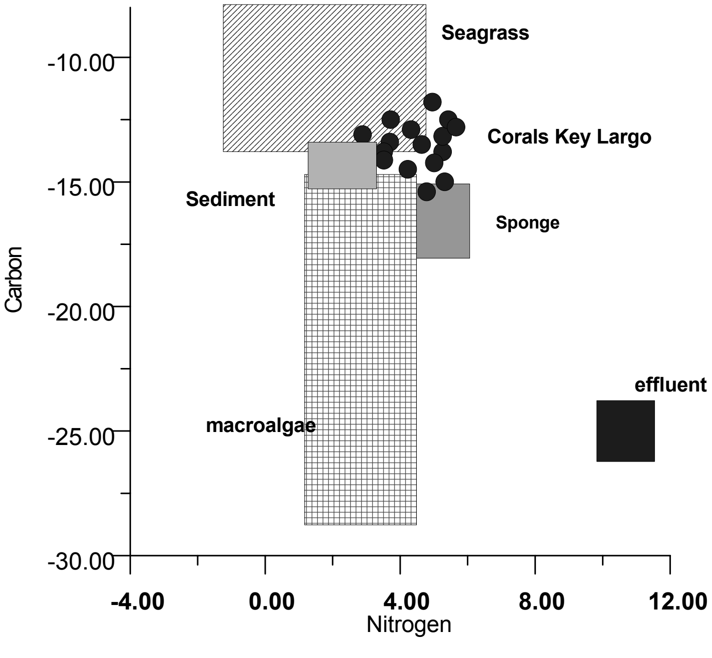

Figure 11. Ranges of C and N isotopic compositions measured in the study by Hoch *et al.* (2004). Additional coral data in from Swart *et al.* (2005). Units are parts per thousand (‰).

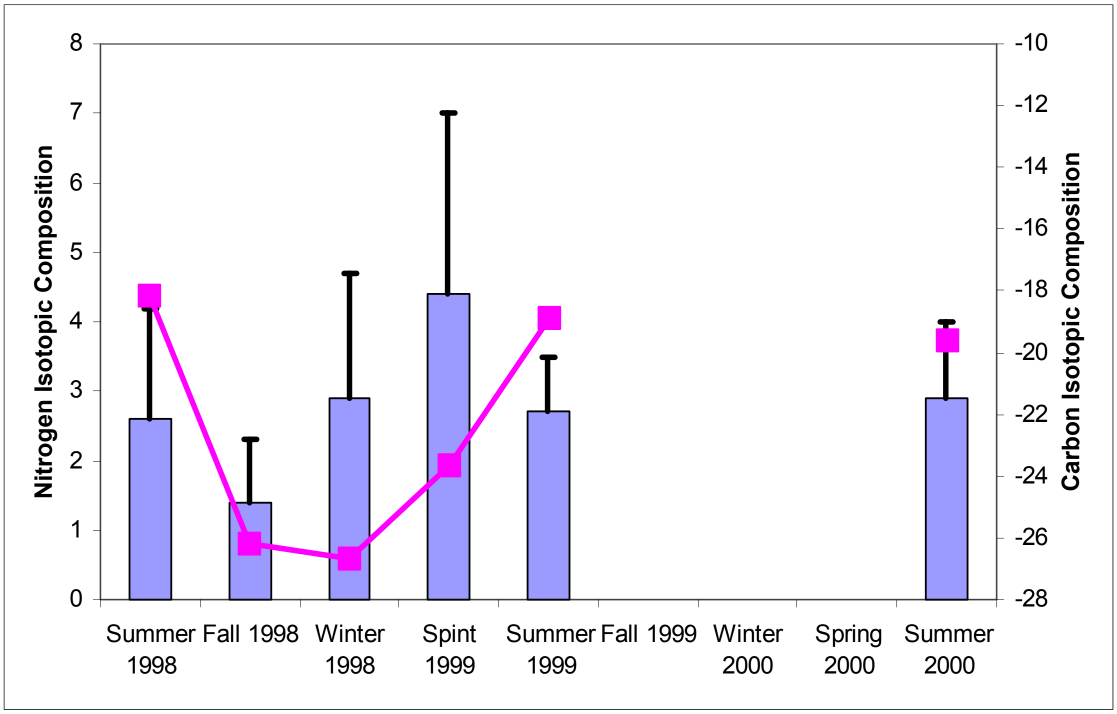

Figure 12. Ranges and means of δ^{13}C and δ^{15}N values measured on POM in the Florida Keys from 1998 and 2000. Bars = nitrogen, symbols = carbon. Error bars = 1 standard deviation. Units are parts per thousand (‰).

In the absence of significant anthropogenic input, the most important source of nitrogen to the oceanic euphotic zone is in the form of upwelled nitrate (Altabet and McCarthy, 1985; Altabet, 1989). Although the δ^{15}N of nitrate has not been measured in waters from the Florida Keys, tropical North Atlantic water has δ^{15}N values between +7 and +10‰ (Liu and Kaplan, 1989). These values have been attributed to denitrification (Cline and Kaplan, 1975), although an alternative explanation for the enrichment of surface waters arises because phytoplankton preferentially utilizes the lighter isotope of nitrogen (Sigman *et al.*, 1997). Hence, as the NO_3^- concentration of the surface waters decrease, the δ^{15}N becomes more positive. Regardless of the explanation, the low nutrient surface waters are enriched in δ^{15}N as a result of normal processes.

Hence, the isotopic signature of upwelled water will depend on the processes that have occurred there--its history with regard to assimilation, denitrification, nutrient limitation, the speed of upwelling, and depth or layer of water that was upwelled. The δ^{15}N value of an organism (e.g., macroalgae, coral) will depend on the species, nutrient regime, and growth conditions. Just as in the case of sewage, it is not possible to simply assign δ^{15}N as showing upwelling. For example, Leichter *et al.* (2003) observed that the δ^{15}N of *Codium isthmocladium* from around Crocker Reef in the Florida Keys increased with depth. In contrast, Lapointe and Barile (2001) found macroalgae δ^{15}N to be lighter with depth. Unfortunately, simultaneous measurements of the δ^{15}N of the dissolved inorganic nitrogen (DIN) in the surrounding waters were not taken for these studies, and there have been no published measurements on the $\delta^{15}N$ of DIN in Florida Keys natural waters. However, unpublished data from our group at the University of Miami seem to support the notion that the deeper waters in south Florida are depleted in ^{15}N and that the nutrient-poor surface waters are enriched in ^{15}N. This observation is not consistent with Leichter *et al.* (2003) which attributed higher $\delta^{15}N$ at depth to be due to upwelled water. Our observation is consistent with the decreasing $\delta^{15}N$ with depth observed by Lapointe and Barile (2001) in southeast Florida, but it suggests that such a distribution could occur naturally and is not necessarily indicative of a near-shore sewage source. To further demonstrate the complexity of this issue, the same report (Lapointe and Barile, 2001) measured increasing macroalgal $\delta^{15}N$ with depth in one reef area (Palm Beach), which necessitated a different explanation of those anomalous results. *C. isthmocladium* was also studied several years earlier by Lapointe (1997). These workers found a seasonal pattern in $\delta^{15}N$ values in *C. isthmocladium* tissues. Elevated values from +10 to +12‰ were interpreted as implying the primary nutrient source was from wastewater-contaminated groundwater (Figure 13). Leichter *et al*. (2003) countered that deep-water nitrogen sources appear to offer a simpler explanation of the seasonal patterns observed in $\delta^{15}N$ of *C. isthmocladium*. There is little doubt that natural biological processes that increase $\delta^{15}N$ values complicate assessment of nitrogen sources in groundwater (Fogg *et al*., 1998; Silva *et al*., 2002). These examples illustrate that data are conflicting and difficult to interpret when $\delta^{15}N$ values of bioindicators are given out of context, i.e., without analysis of the $\delta^{15}N$ values of surrounding waters and other potential nitrogen sources.

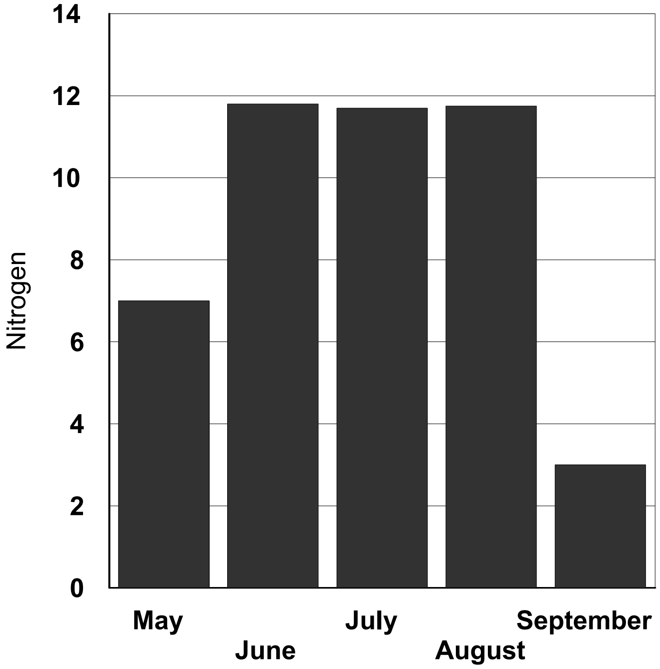

Figure 13. Data from Lapointe (1997) showing relatively positive N-isotopes which the authors suggested resulted from anthropogenic influences. Vertical units are parts per thousand (‰).

A recent paper by Lapointe *et al.* (2004a) reports data on the $\delta^{15}N$ from coral reef communities in the lower Florida Keys. Here, they conclude that $\delta^{15}N$ values in excess of +4‰ indicate anthropogenic pollution. Values significantly more positive than this are found in open oceanic plankton and throughout the recent geological record. Furthermore, an extensive set of other water quality data, such as concentrations of nutrients and fecal-indicating bacteria obtained in the Florida Keys, do not support the contention that the entire reef tract is contaminated with anthropogenic pollution. Another recent study (Ward-Paige *et al.*, 2005) reports that values of 5.2‰ in sponges found in the Florida Keys were indicative of human waste and that they were higher than samples collected from Belize. However, the total number of samples which they analyzed was only 14, and only one sample was analyzed from Belize. Such a sample size cannot be realistically used to make the point that Florida environments are different than other environments. Based on information from numerous peer-reviewed sources presented in this report, it is the conclusion of this panel that not only are $\delta^{15}N$ values as low as +4‰ not indicative of sewage, but also that the entire issue of whether specific isotopically positive $\delta^{15}N$ values reflect sewage needs to be critically reexamined.

Report on Macroalgal Blooms off Southeast Florida (Lapointe, 2001)

An unpublished report by Lapointe (2001) on $\delta^{15}N$ values from macroalgae collected from various localities off Broward and West Pam Beach Counties is of particular relevance to this analysis and, therefore, its data and findings are discussed in more detail. In that study, the $\delta^{15}N$ of *Caulerpa brachypus* was measured at a number of localities and at different depths. In addition, specimens of *Caulerpa racemosa* and *Codium isthmocladium* were also analyzed. In the dry and wet seasons, the $\delta^{15}N$ averaged between +6 and +8‰. The report gives the data as parts per million (ppm). If the data are, in fact, ppm, the $\delta^{15}N$ values reported in the conventional notation would be between 0.006 and 0.008‰, and thus would not be elevated. The following discussion is based on the assumption that the data are actually reported according to the conventional notation and not as indicated in the report. Lapointe (2001) concluded that these values are consistent with sewage-derived nitrogen for the following reasons. First, the highest $\delta^{15}N$ values occurred closest to the shore and decreased with distance. Second, the highest values occurred during the dry season, prior to upwelling. Third, the lowest $\delta^{15}N$ values occurred at a deep reef during strong upwelling. Fourth, high ammonia concentrations were measured at all localities. These workers collected water samples for direct measurement of the $\delta^{15}N$ in the dissolved inorganic components, but no data are reported, as "methodological complications prevented the discrimination of the $\delta^{15}N$ in the upwelled samples." The question which arises with regard to these data is whether the $\delta^{15}N$ values are sufficiently unique to state unequivocally that the samples have been influenced by anthropogenic nitrogen.

Based on the following criteria and the detailed discussion above, our conclusion is that the $\delta^{15}N$ values are not unequivocally diagnostic. First, no studies were carried out on the $\delta^{15}N$ of the inputs into the investigated system. In addition to the anthropogenic sources that need to be measured, the $\delta^{15}N$ of DIN in the porewaters, rainwaters, upwelled water, and ambient water need to be tested. Second, a detailed study of the $\delta^{15}N$ on all components in the ecosystem needed to be conducted. In addition to the species under consideration, studies need to be conducted on other macroalgae and flora, microalgae, the dissolved organic material, the particulate organic material, as well as other benthic and neritic[13] components. Of particular importance would be to examine variability within a single organism. Third, although the $\delta^{15}N$ values reported are at the elevated end, such positive values can occur in normal marine environments as a result of preferential uptake of the lighter isotope of nitrogen. Hence, planktonic organisms frequently have elevated values, a feature completely unrelated to anthropogenic sources. In fact, the trend in the macroalgae data reported is that increasing $\delta^{15}N$ with shallower depth is consistent with fractionation as a result of assimilation. Lastly, studies have shown that the $\delta^{15}N$ of sewage is not necessarily all that elevated (Wada and Hattori 1976; Rogers, 2003); no such measurements were made of possible sewage sources in this study.

Other Nitrogen Isotopic Data Relevant to South Florida

Recently, stable nitrogen isotopic data from various species of benthic macroalgae collected from Brevard County were published (Barile, 2004). This study had previously been presented in non-peer-reviewed sources and the units incorrectly cited. For example, one article stated that ratios of ^{15}N to ^{14}N ranged from 8:1 at Satellite Beach to 12:1 at Cocoa Beach (www.surfriderpbc.org/July30peter.html). However, the conventional method of presenting data as defined by equation 2 reports the ^{15}N as $\delta^{15}N$ in parts per thousand (‰). In this paper, Barile (2004) quoted values of between +8.7 to +9.9‰ for macroalgae and stated that these values were similar to the values from sewage-polluted areas. Values for most of the macroalgae measured by Barile (2004) were elevated at the start of the sampling period (March 2003) and decreased towards the end of the sampling period (December 2003).

The $\delta^{15}N$ values mentioned in the Barile article seem elevated; however, there is simply no context within which to evaluate these values. We also reemphasize studies which have shown elevated $\delta^{15}N$ values in non-polluted areas (i.e., Rogers, 2003). There have been no studies documenting the nitrogen isotopic values in other organisms in the area. Neither has any data been published on the nitrogen isotopic composition of the DIN or DON (dissolved organic nitrogen) in the water or groundwater. It is simply unknown whether the groundwaters of the Brevard County area contain isotopically anomalous compositions of nitrogen. There have been only a few studies of the $\delta^{15}N$ of DIN throughout the oceans, and $\delta^{15}N$ values for Atlantic surface and deep waters simply are not known. In fact, published studies indicate that there is an association between waters with low nutrients and elevated $\delta^{15}N$, with low nutrient waters containing isotopically positive $\delta^{15}N$ values (Sigman *et al.*, 1997). This is a result of the fact that there is fractionation during assimilation of nitrate by algae (see Figure 9) so that algae remove the ^{14}N preferentially, leaving the waters isotopically positive. It is, therefore, incorrect to simply state that values over a certain limit indicate contributions from an anthropogenic source. As explained in the discussion above, contextual information is needed to adequately interpret isotopic ratios.

Changes in the Nitrogen Isotopic Composition throughout Geological Time

The $\delta^{15}N$ of organic material is increasingly being used as an indicator of productivity through geological time. Basically, during periods of greater nitrate utilization the $\delta^{15}N$ values become more positive (as in the case of Figure 6). Examples of such changes are published in

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[13] Neritic: The region of the sea over the continental shelf, i.e., between low tide and ~200 m depth.

papers such as Crosta and Shemesh (2002) and Haug *et al*. (1988). In such examples, values as positive as +9‰ are found during glacial periods. In studies in our laboratory at the University of Miami, we find values of between +5 to +6‰ throughout Pliocene portions of sedimentary cores deposited off Great Bahama Bank (Lamb and Swart, unpublished data). Obviously, such changes are unrelated to anthropogenic sources.

Summary

- A variety of factors affect $\delta^{15}N$ values, including species, growth conditions, the isotope composition of nitrogen sources, and the processes acting on those nitrogen sources.
- While the nitrogen isotope method may be used to help identify sources of pollution, $\delta^{15}N$ values cannot be utilized as the sole indicator of such pollution. Positive $\delta^{15}N$ values can be present in marine organisms for a number of reasons both natural and/or anthropogenic. Anthropogenic nitrogen can yield isotopically-positive nitrogen isotope values, but not all positive nitrogen isotopic values are a result of anthropogenic influences.
- Data have been presented which suggest elevated nitrogen isotope data in benthic algae in Brevard County. The high values are of interest and may represent elevated $^{15}N/^{14}N$ ratios; however, there is insufficient data to state whether these values are truly representative of anthropogenic influences.
- Recent suggestions that $\delta^{15}N$ values as low as +4‰ indicate anthropogenic sources do not appear to be justified by scientific evidence. Values significantly more positive than this are found in open oceanic plankton and throughout the recent geological record.
- Analyses of additional isotopes such as carbon and sulfur can aid interpretation of $\delta^{15}N$ data. Studies involving stable isotopes of nitrogen should include, where possible, the analyses of additional isotopes. These should always include carbon and, where appropriate, sulfur.

Question 6

Are there appropriate alternate method(s) that would indicate whether sewage or related effluent is the source of elevated nutrients?

Goals and Objectives of Monitoring and "Hypothesis Driven" Studies

It should be stated at the outset that the utility of indicators in sewage investigations depends upon the goal(s) of the investigators and that studies are designed and executed and laboratory methods chosen to achieve specific study goals. Sewage investigations can be put into two general classes for the purpose of this discussion. One general class of study can be termed the "pure assessment" approach where the goal is simply to determine if sewage contamination has occurred and a specific risk is thereby posed. The investigator may or may not have any *a priori* information regarding a sewage source. An example of such an approach is the fecal indicator monitoring for beach safety that is done on Brevard County beaches. The goal is simply to determine if beaches are safe for bathers, and no hypothesis is offered or tested regarding the presence or amounts of sewage contamination. It is not necessary in this case to know how much sewage was present or its source or if sewage-derived nutrients are present, only that pathogen contamination has (or has not) occurred. Nitrogen and ^{15}N investigations along Brevard County beaches to date (Barile, 2004) can also be considered an example of a "pure assessment" study. Samples were collected at a number of locations with the goal of detecting sewage-derived nitrogen if present with no *a priori* information regarding specific sewage or other sources of nitrogen. In such studies, detection is typically the only achievable goal. Quantification of sewage and sewage-derived nutrients is not possible. Moreover, even if sewage and/or sewage-derived nutrients were detected, the information would be insufficient to design or implement any remediation to initiate any management action.

A second general class of sewage investigation may be labeled the "hypothesis driven" approach. In this case, the goal is more than simple detection. Such studies have a range of goals that may include the detection, characterization, quantification, transport, distribution, and long-term fate and effects of sewage pollutants including nutrients. The data requirements of hypothesis-driven studies are significantly higher in terms of quantity and quality of the data and require a more sophisticated study design. In the case of nutrient or pollutant studies, the investigator usually, but not always, has prior information regarding the source or sources of sewage they are tracking and other potential sources of the pollutants under investigation. If not, such data is the first gathered in an early phase of the project.

The question as it is posed above suggests that some level of quantification is needed in order to determine if sewage nutrients are present in amounts needed to raise ambient nutrient concentrations above their natural background ranges (and ultimately what might be done about this). The response to the question is structured around the notion that methods providing more than simple detection of sewage may be required.

Quantification of Sewage Constituents

At issue are the volumes of sewage from all potential sources that would need to be introduced into the coastal environment of Brevard County to result in a significant elevation (above background) in nutrient concentration. Because the near shore environment is an open system, the water mass along the Brevard County coast is constantly being replaced as it moves with long shore currents, freshens with adjacent oceanic water, and receives inland water via inlets and coastal discharges. Therefore, any effluent discharged into it will likewise be affected as it mixes with ambient water.

A simple mixing model to illustrate the change in nutrient concentrations, C_r, resulting from a sewage discharge into coastal waters can be presented as:

$$Cr = \left(C_{eff} \times \frac{1}{D} \right) + C_b \tag{1}$$

where C_{eff} is the concentration in the effluent, C_b is the background concentration, and D is the dilution factor.

The concentration of nutrients in an identified sewage effluent (C_{eff}) will depend on the distance between the sewage source and the target area and the dilution dynamics (D) along the Brevard County coast. The dilution of an effluent discharged into the ocean depends on the physical and chemical characteristics of both the effluent stream and the ambient waters into which the effluent is discharged. A dynamic system can lead to rapid dilution of the sewage effluent. As an example, the SEFLOE II studies (Proni *et al*., 1994) examined four ocean outfalls (buoyant surface plumes) with an average total nitrogen concentration of 13.6 mg/L that discharged into ambient seawater with an average background total nitrogen concentration of 0.54 mg/L. The physical factors controlling the mixing of effluent with seawater from the end of the pipe to the surface and subsequent downstream transport resulted in total nitrogen concentrations in the sewage plume diluted to or below background values within 400 m of the point of discharge. At the present time, relatively little is known about potential sewage sources along Brevard County shores or the local hydrodynamics.

It is also difficult to determine a valid background nutrient concentration (C_b), particularly in a case such as this where multiple sewage sources (ground water, surface discharges, vessels) are possible and their distribution along Brevard County beaches are not known.

Tracing and Quantifying Sewage Nutrients in Near-Coastal Waters

The fundamental problems of tracing and quantifying sewage-derived nutrients of interest (N and P) in the coastal environment are (1) these environments are receiving nutrient inputs from a variety of other sources including surface run-off, non-point flows (rivers, inlets, canals, etc.), atmospheric deposition, groundwater, upwelling, storm water discharges, etc., and (2) that in either their elemental or molecular forms, N and P from sewage possess very few characteristics that clearly distinguish them from nutrient species from these other sources.

Some or all of the potential sources of nutrients listed are present along the length of the Brevard County coast. In addition, nutrients and other constituents from non-human animal wastes may be present from some of these sources. An added complication arises when more than one potential source of human sewage may be present. These sources may produce nitrogen and phosphorus in different molecular forms (which differ in their bioavailability) and in varying amounts at different times. Storm water discharges, for example, may be a significant localized source of nutrients during certain times of the year. Determining the relative contributions to the coastal environment of each natural and anthropogenic nutrient (and its forms) from each source is challenging.

There has been and continues to be considerable interest in the use of the stable nitrogen isotope ratio $^{15}N/^{14}N$ to distinguish sewage in freshwater and marine ecosystems (see Question 5). One obvious advantage of using stable nitrogen isotopes over other sewage indicators is that as one of the principle nutrients of concern, nitrogen can be traced by this method as it is assimilated by primary producers in the environment and as it moves through various plant and animal communities. It is clear, however, that a number of factors arise when interpreting stable nitrogen isotope data collected from the marine environment that prevent its consideration as an unambiguous tracer of sewage-derived nitrogen.

A valid question may be posed: Is it possible to estimate the quantity of sewage-derived nutrients indirectly by using an indicator unique to the sewage source as a proxy for the nutrients of concern? Or, stated another way, if the initial sewage concentrations of a conservative tracer and nutrient species of concern are known, can the final tracer concentration be considered an indirect measure of the final nutrient concentration of the effluent?

Sewage Markers

Sewage is a general term used for the collection of human waste products that include excretory wastes and, depending on the source, kitchen and laundry wastes and pre-treated industrial waste products. Sewage effluent discharged into the environment may contain a variety of chemical compounds that reflect human digestive and metabolic processes, dietary habits, usage of over-the-counter and prescription medications, personal care products, and cleaning and other household chemicals, as well as those from industrial processes (Oros *et al.*, 2003; Stackelberg *et al.*, 2004). In addition, sewage effluent may contain substances added during the waste treatment process such as chlorine for disinfection. A variety of these chemical compounds that commonly occur in sewage wastewater have been used or proposed for use as sewage markers.

Stackelberg *et al.* (2004) found 28 organic wastewater-related household and industrial chemicals in stream water and untreated drinking water samples. Some of the sewage-related household chemicals used or studied for use as sewage markers include plasticizers (Vitali *et al.*, 1997), household and hospital disinfectants (Kummerer, 2001), flame retardants (Barcelo, 2003; Andersen *et al.*, 2004), detergent metabolites (Ishiwatari *et al.*, 1983; Takada and Ishiwatari, 1987; Valls *et al.*, 1989; Ferguson *et al.*, 2001, 2003; Eganhouse *et al.*, 1983, 1988; Chalaux *et al.*, 1992; Raymundo and Preston, 1992), perfumes (Buerge *et al.*, 2003a), and fabric brighteners (Hayashi *et al.*, 2002).

Pharmaceutical drugs (over-the-counter and prescription), diagnostic agents, and personal care products (PPCPs) occurring in sewage wastewater have been studied intensively as pollutants for their ecotoxicological effects (Halling-Sorensen *et al.*, 1998; Daughton, 2001, 2003). Several characteristics of PPCPs may make some particularly useful as sewage markers:

(1) the compounds and their metabolites are used only for humans or certain animals (veterinary use) thus establishing the connection to sewage wastes; and (2) many PPCPs have known dates of introduction into usage and to the environment due to FDA approval, allowing the dating of sewage contamination of groundwater (http://www.epa.gov/esd/chemistry/pharma/tracers.htm). Some PPCPs under investigation as sewage markers include estrogen (Atkinson *et al.*, 2003), analgesic/anti-inflammatory agents (Lee *et al.*, 2003), antioxidants, anti-epileptics (Clara *et al.*, 2004), and caffeine (Seiler *et al.*, 1999; Papadopoulou-Mourkidou *et al.*, 2001; Chen *et al.*, 2002; Gardinali and Zhao, 2002; Siegener and Chen, 2002; Buerge *et al.*, 2003b). Some rare earth elements used in diagnostics may also be effective sewage markers (Knappe *et al.*, 2001; Moller *et al.*, 2002).

Naturally-occurring fecal products and metabolic byproducts have been used extensively as sewage indicators. The mammalian fecal sterol 3β-coprostanol and several related compounds, produced from cholesterol via the anaerobic action on sewage sludge, have been used extensively as indicators of sewage contamination (Hatcher and McGillivary, 1979; McCalley *et al.*, 1980; Walker *et al.*, 1982; Wade *et al.*, 1983; Brown and Wade, 1984; Pierce and Brown, 1984; Vivian, 1986; Venkatesan and Santiago, 1989; Venkatesan and Kaplan, 1990; EPA, 1993; Fitzsimons *et al.*, 1995; Elhmmali *et al.*, 2000; Standley *et al.*, 2003). Metabolic byproducts normally found in human urine also have been proposed as sewage markers (Grimalt *et al.*, 1990).

Naturally-occurring human enteric bacteria, viruses, and protozoans are commonly used as biological markers. These have the added advantage of providing an indication of the potential for human health risk. Biological markers include enteric bacteria (fecal coliforms, *E. coli*, *Enterococcus* sp., *Clostridium perfringens*), viruses (i.e., coliphages), and protozoa (i.e., *Cryptosporidium parvum*) (Gregory and Frick, 2001; Carey *et al.*, 2004). Bacteriophage have been used in deliberate tracer studies to evaluate the impact of sewage disposal practices on coastal waters (Paul *et al.*, 1995b; Paul *et al.*, 1997). Sophisticated molecular techniques referred to as microbial source tracking can be used to provide a “finger print” to determine the source (human, livestock, etc.) of pathogenic microorganisms (Scott *et al.*, 2002, 2003).

Stable isotopes of N (discussed in previous section), C, S, H, and Os have also been successfully used as sewage markers (Burnett and Schaeffer, 1980; Rau *et al.*, 1981; Van Dover *et al.*, 1992; Ravizza and Bothner, 1996; Tucker *et al.*, 1999).

Another important class of sewage markers are those that are artificially added to the effluent to provide a tracer. These may be compounds that do not naturally occur in sewage wastes and are not found in the environment such as fluorescent dyes (Rhodamine) and sulfur hexaflouride (SF_6). SF_6 has been used by researchers at AOML to trace sewage outfall plumes (R. Wanninkhof, personal communication). Another approach is to artificially increase the concentration of a substance that naturally occurs in sewage, such as ^{15}N, to a level sufficiently above background to allow it to be tracked. Good candidates are those that are not harmful to the ecosystem, can be easily detected in low concentrations, are reasonably cost effective, or those that have special utility (i.e., ^{15}N). This approach has a number of advantages: (1) the investigator can control the sewage source to which the marker is added (to parcel out competing sewage sources); (2) the initial concentrations are controlled; (3) the markers can be added to any system (vessels, publicly-owned treatment works [POTWs], septic systems, injection wells); and (4) the markers can be introduced at any point in the system.

Sewage Marker Considerations

The utility of a chemical or biological marker as a direct or indirect method of quantification of sewage nutrients will depend on several factors. Sewage-derived nutrients are available to the environment in both dissolved and particulate forms. Dissolved and particulate constituents are differentially distributed in the environment due to physical and chemical characteristics of the sewage effluent and hydrodynamic variables that affect the dilution of fluids and particle dispersion in seawater. Some chemical markers, such as long chain linear alkylbenzenes, used as industrial precursors for anionic surfactants, occur as dissolved constituents in sewage effluent, while others, such as the fecal sterol coprostanol, are associated with sewage particulates. Stable isotopes of N and C can be analyzed from both the dissolved and particulate fractions of sewage effluent. Bacterial, viral, and protozoan markers may be small particles, colonies associated with organic particulates, or free-swimming individuals.

Another important consideration is the stability or resistance to degradation, biogeochemical alteration, or biological assimilation of the marker when it is introduced into the environment. Interpretation of data from markers that behave differently from the sewage constituents under investigation will lead to erroneous conclusions. From the discussion of stable isotopes presented in the preceding chapter, it is apparent that nitrogen may undergo a variety of chemical transformations in the environment affecting both the concentrations of the molecular forms of nitrogen and the ^{15}N /^{14}N ratio of each. Bacterial colonies may be short lived in the marine environment, while bacteriophages are resistant to seawater. The sewage marker coprostanol is relatively stable in the marine environment and could, under certain conditions, persist for some time after the source of sewage is eliminated.

Specificity to sewage and to particular sewage sources is also an issue. As we have seen, high ^{15}N values in marine plants may result from causes other than the presence of sewage nitrogen. Some potential sewage sources, e.g., sanitary discharges from day boats, may not contain detergents and, therefore, would not contain linear alkylbenzenes. Coprostanol is a product of the digestive tract of terrestrial mammals (cattle, hogs, etc.) and marine mammals as well as humans. Some research has also shown that coprostanol may be produced in the environment under anaerobic conditions. Fecal coliforms are present in other animal wastes that may occur in canal and storm water discharges. A raw sewage spill or leak may have a high pathogen content, whereas a highly disinfected effluent may have low numbers.

Another important consideration is the distance from the source a sewage marker must be accurately detected. Markers vary widely in their ability to be detected at low concentrations with current technology. Chemical or biological sewage markers will be affected by the same dilution processes described above.

Conclusion

Appropriate scientific methods currently exist that would indicate whether sewage is contaminating the near-shore waters along Brevard County beaches. However, *quantifying* the relative contribution of nutrients from one or more sewage sources to a complex environment is a difficult task. Nutrients, from both natural and anthropogenic sources, exist in the marine environment in a variety of forms of varying biological and ecological significance. **Because of the complexity involved, a rigorous approach to quantifying sewage contributions to ambient waters would include several chemical and biological markers in addition to stable isotopes, hydrodynamic studies, and modeling efforts.** A good deal of information regarding the sewage sources in question, other potential sources of nutrients, and the ambient environment must be gathered and considered. It should be clear that the analysis of nitrogen from a few water samples taken along the beach or ^{15}N data from plants in the surf zone will not yield this kind of information, nor will the application of a few additional sewage markers in similar fashion. These kinds of data, along with other data taken in the context of a carefully applied program of study, are needed to provide the answer to this question.

Question 7

If sewage or treated effluent is identified as the source of elevated nutrients, are there reliable methods to determine whether the nutrients are from local or remote sources?

As stated in the response to Question 6, the process of determining whether sewage-derived nutrients are the source of elevated ambient nutrient concentrations would likely require quantification of nutrients from all sources, local and remote, along with estimates of fate and transport. If sewage-derived nutrients turned out to be a significant source, based on the potential sources identified, local sources may include contaminated ground water (septic, injection, broken sewer lines), surface run-off or stormwater, or possible vessel discharge (see Question 8). Truly remote sources are the major southeast Florida POTWs, the nearest of which is the Delray Beach POTW, in northern Palm Beach County. Again, a combination of chemical and biological markers in addition to stable isotopes, tracer studies, hydrodynamic studies, and modeling efforts are required to determine the relative impact of different sources. A comprehensive water quality monitoring program would be well-served to coordinate with ongoing surveys (e.g., bacteriological monitoring) and to extend ongoing efforts to cover synoptic rain events.

Question 8

Is it likely that shipping activities in the area are contributing to the nutrient levels observed?

Shipping Activities

The shipping activities relevant to this question concern regular cruise ship and gambling ship activity based in Port Canaveral. If cargo vessels transporting fertilizers (e.g., phosphates) were a major fraction of Port traffic and should one of the hulls be accidentally breached near shore, pollution from a maritime accident might also be relevant. Since we were unable to ascertain the extent of such cargo transport activity and the probability of an accident is impossible to accurately estimate, our discussion will focus upon the cruise and gambling vessels. Cruise ship discharges have been the subject of attention in many other locales (both homeports and destinations).

In the case of Port Canaveral, there are currently seven cruise ships homeported there with one other that uses it as a port of call. In addition, there are two gambling ships homeported at Port Canaveral that go out twice daily, seven days a week. Over the course of a year (October 1-September 30, 2003), these ships accounted for 1,987 landings. This is in comparison to 408 landings from cargo ships and 62 from layberth vessels. In 2003, cruise ships carried 2,168,450 passengers and the gaming vessels carried 1,941,102. The potential impact of waste streams generated by cruise and gaming vessels is a concern. Such vessels generate black water and gray water. Black water is treated sewage waste, while gray water includes sink, shower, and galley wastes. Clearly, both can be significantly richer in nutrients than the coastal ocean. Treating the sewage may reduce human health risks but does little to reduce nutrient concentrations.

Surveys conducted from the Port Canaveral Authority provided data for four out of five cruise line companies and for both of the gambling vessels (survey results obtained by the Canaveral Port Authority). The surveys show that cruise ships generate approximately 11,000-40,000 gallons of black water per day and 117,000-330,000 gallons of gray water per day. In contrast, the information available for the gaming vessels reported 1,000-2,800 gallons of black water and 3,400-4,200 gallons of gray water per day. Gaming vessel discharges are constrained to the Brevard County area, whereas cruise ships discharge in the area approximately once a week for seven-day cruises and twice a week for three to four day cruises.

Four of the cruise ships conduct seven-day cruises, three conduct three- to four-day cruises, and one uses Port Canaveral only as a port of call (once a week discharge was assumed for this case). Using this information and assuming that the discharge from the one cruise line for which there was no data is similar to others of its size, estimates of the total weekly discharge to the Brevard coastal area were made. The calculations indicate that cruise ships discharge approximately 241,825 gallons of black water and 2,185,361 gallons of gray water per week. The gaming vessels discharge about 26,600 gallons of black water and 53,200 gallons of gray water per week to the area, or nine times less black water and 41 times less gray water than the cruise ships. Cruise ships, therefore, contribute the bulk of current discharge (Table 9).

Table 9. Comparison of cruise and gaming vessel discharge and estimates of nitrogen loading.

	Cruise Vessels (n = 8)	**Gaming Vessels (n = 2)**
Discharge volume of black water and gray water (millions L per day)[a]	1.3	0.043
Estimated nitrogen load (metric tons N per day)[b]	0.017	8.6×10^{-4}
Box volume (L)[c]	2.9×10^{12}	4.8×10^{11}
Residence time (day)[d]	2.5	2.5
Resulting concentration (mg/L)[e]	3.6×10^{-4}	4.5×10^{-6}

[a] Estimated from reports to the Cape Canaveral Port Authority, see text for black water versus gray water discharge values.

[b] Black water estimated at 40 mg/L nitrogen; gray water at 10 mg/L nitrogen.

[c] Cruise ship discharge into 6 km x 22 km x 0.02 km box and gaming vessel discharge into 6 km x 7 km x 0.01 km box. Width of box based on 12 nautical mile discharge from shore for cruise vessels and 4 nautical mile discharge from shore for gaming vessels. Depth of box based on depth approximated from bathymetry maps for those distances from shore.

[d] Estimate based on ADCP data, see text.

[e] (nitrogen load * residence time)/ box volume.

Legal Framework

Under federal and state law, vessels can discharge gray water without restriction and treated sewage (but not raw sewage) beyond 3 nautical miles from shore except in designated No Discharge Zones. There are no relevant No Discharge Zones in the area. The same would apply to cruise ships except that cruise ship practices in Florida are governed by agreements, called Memoranda of Understanding (MOUs), between the state and the cruise line associations, the Florida-Caribbean Cruise Association (FCCA), and the International Council of Cruise Lines (ICCL). Beyond 12 nautical miles there is neither state nor federal restriction upon discharge of gray water, black water, or even raw sewage.

The Florida MOU (MOU, 2003) stipulates that cruise ships will not discharge even gray water in port. Instead, gray water and treated black water will be discharged only at a distance greater than 4 nautical miles from shore while underway at a speed greater than 6 knots.

Some cruise ships report they are following MARPOL IV, the International Convention for the Prevention of Pollution from Ships (www.imo.org/Conventions/contents.asp?doc_id =678&topic_id=258) with regard to black water and gray water discharge. MARPOL Annex IV addresses the prevention of pollution by sewage from ships. Updates to Annex IV were adopted in April 2004 for entry into force on August 1, 2005. The Annex states:

> *"The discharge of sewage into the sea will be prohibited, except when the ship has in operation an approved sewage treatment plant and is discharging comminuted and disinfected sewage using an approved system at a distance of more than 3 nautical miles from the nearest land; or is discharging sewage which is not comminuted or disinfected at a distance of more than 12 nautical miles from the nearest land."*

MARPOL essentially makes current U.S. law the international norm. MARPOL is actually less restrictive (protective of Florida waters) than the Florida MOU. MARPOL allows discharge at 3 nautical miles, potentially on station, versus the MOU which allows discharge at 4 nautical miles traveling at 6 knots for treated sewage. For gray water, MARPOL provides no regulation whatsoever versus the MOU which provides regulation similar to that for treated sewage.

The Port of Canaveral reports that the gaming ships have agreed to voluntarily comply with the practices stipulated in the Florida MOU. Some waste and disposal surveys conducted by the Port report discharge practices consistent with the Florida MOU for both cruise and gaming vessels. Some surveys reported that their practices were consistent with MARPOL IV which, as noted above, has a 3 mile "stationary" limit for treated sewage and no gray water regulation. However, some cruise lines report that the survey responses were meant to imply that discharge practices exceed MOU requirements in that no discharge of any kind occurs within 12 nautical miles. The panel was unable to obtain independent data confirming compliance with MOU speed and distance requirements for either cruise or gaming vessels with respect to any discharge.

Possible Fate of Discharge Plumes

In 1998, the Government Accounting Agency (GAO) reported to Congress on marine pollution issues relating to cruise ships. In 2000, the EPA was petitioned to undertake regulatory action concerning pollution by cruise ships (e.g., to regulate gray water discharge). In response to that petition, they initiated a series of public hearings and conducted specific experiments including one in which NOAA assisted in measuring discharge plumes from cruise ships operating out of the Port of Miami (EPA, 2004b). One conclusion that can be drawn from the EPA plume study (EPA, 2004b) is that discharge plumes from cruise ships are unlikely to remain intact. The study concluded that the earlier model results of Collonell *et al.* (2000) significantly underestimated the initial dilution in not considering the effect of the ship's propellers. In fact, initial dilutions of 200,000 to 666,000:1 were measured. The EPA has yet to finalize their assessment and initiate the regulatory process, although they have initiated an interagency workgroup to continue to study the topic.

With regard to discharge, both the speed and the distance from shore are relevant. As discussed in the Physical Context discussion provided in response to Question 9, the predominant flow in the region in which discharge is occurring is alongshore and to the north. Current speeds were estimated by analysis of the mean offshore and longshore components of water column current vectors measured using an acoustic Doppler current profiler (ADCP). The ADCP is located 2.6 miles east of Cocoa Beach in 15 m of water. Current measurements from January 22, 2003 to February 22, 2004 were analyzed (courtesy of P. Dammann, AOML) and the mean longshore current was calculated to be 0.1 km/hr and the mean onshore current was calculated as 0.01 km/hr. The mean residence times of a water parcel can be estimated from these current velocities. The estimate will be conservative because currents should be faster the farther from shore. For example, cruise effluent discharged into a box of dimensions 4 miles long (6 km) and 12 nautical miles (22 km) wide would reside for 2.5 days. The estimate is the same for a 4 nautical mile (7 km) wide box, as assumed for gaming vessels (Table 9). The mean onshore velocity is such that a parcel of water in the box should not reach the shore before being flushed out by the longshore currents. In addition, the nutrient load would be highly diluted, yielding concentrations well below background (Table 9). However, the exact effect of the Southeast Shoal on discharges is not known, but it will certainly affect water circulation in the near shore. Given the proximity of the Southeast Shoal off of Cape Canaveral, large vessels need to head southeast upon leaving or entering the port. At 4 nautical miles from shore along this course, discharges will occur in waters approximately 15 m deep and currents flowing north will intersect the Southeast Shoal. Even at 12 nautical miles from shore along this course, the water depth is only about 20 m. Not until the 30 m depth contour is reached can the possibility of significant interaction with the Shoal be truly discounted and, depending on course, this can be well beyond the 12 nautical mile limit.

Although the predominant flow in the region is alongshore and to the north, southerly flows do occur. In addition, across-shelf flows can result in seasonal upwelling. Moreover, the current velocities measured are comparatively low in the near shore, particularly in the region shielded by the Southeast Shoal. This implies that under the right conditions, nutrient loads resulting from wastes discharged in compliance with the MOU may still be retained within Brevard coastal waters and could even be transported to the south, although they would be highly diluted in comparison to the initial discharge (Table 9).

Because of the particular hydrography of the region, neither the Florida MOU nor prevailing federal law provide the same level of protection for the Port Canaveral area as for ports farther south. Port Everglades, the Port of Miami, and Key West are much nearer to deep waters because the shelf to the south is much narrower. Using Florida MOU practices, cruise ship waste streams discharged in southern Florida are virtually certain to be entrained into the high current velocities associated with the Gulf Stream system and rapidly diluted. As noted above, a distance of more than 12 nautical miles is required to avoid an interaction with the Shoals. Depending on the Gulf Stream position, entrainment may require much farther distances offshore. Nonetheless, as discussed above, the limited data available do not indicate that nutrients are currently elevated within the region (see Question 1).

Knowledge of other nutrient loads to the area is needed to thoroughly assess the impact of ship discharges. Exact numbers are seldom available, and thus estimates are dependent on the set of assumptions made. The loading estimates are particularly sensitive to box size and residence time. An example of the types of parameters that can be used in making simple box model calculations are given in Table 10. As an example, load estimates for the 22-km wide box described above are 1.9, 0.27, and 0.04 metric tons N per residence time (2.5 days) for seawater, atmospheric deposition, and cruise/gaming vessels, respectively. This table is not an all-inclusive list; for example, nutrient diffusion from sediments could also be important, particularly for a box constructed closer to shore. With regard to the fate of nutrient loads, it is interesting to note that the analytical model of Boehm *et al*. (2005) implies that although weaker cross-shore currents provide some protection from ship discharges, this situation provides less protection from near-shore discharges.

Table 10. Parameters for nitrogen load estimates for use in simple box model calculations.

Nitrogen Source	Parameter[g]
Seawater[a]	0.1 mg N/L
Atmosphere[b]	749 g N/km^2 per day
Cruise and gaming vessels[c]	1.8 x 10^4 g N per day
Percolation ponds[d]	2.3 x 10^3 g N per day
Upwelling[e]	8.4 x 10^3 g N per upwelling event per km longshore
Septic tanks[f]	13 g N per day per septic tank

[a] Table 1, Brevard County.
[b] Dreschel *et al.* (1990).
[c] Sum from Table 9**.**
[d] See Question 1.
[e] See Question 1.
[f] See Question1; also: 12-16 g N per day per septic tank Horsley *et al.* (1996).
[g] Estimates of relative nutrient loads are highly sensitive to box size and residence time. As an example of loading calculations, the 22 km wide box described in Table 9 and in the text yields nitrogen loads of 1.9, 0.27, and 0.04 metric tons N per every 2.5 days for seawater, atmosphere, and cruise/gaming vessels, respectively.

Although preliminary analyses and rough calculations are unable to confirm that ecologically significant nutrient additions to the Brevard littoral zone result from the cruise ships or gaming ships based in Port Canaveral, it would be possible to eliminate the possibility. With respect to gaming ships, discharge of even treated waste could be prohibited, pumpout facilities could be provided, and their use required. With respect to cruise ships, discharge (black water and gray water) could be held until after having cleared the shoals (or before entering) and upon entering the surface current field of the Gulf Stream.

Conclusions

The extent of risk posed by ship activities will depend upon the relative nutrient loading associated with ship discharges in comparison with other sources, the overall system nutrient load, and the amount of dilution afforded to the discharges by local hydrography. At present, the total nutrient load of ship discharges, the fate of these discharges in the area, and how the input compares to other nutrient loads in the area (e.g., waste water, septic tank, storm water) have not been thoroughly evaluated. Comprehensive assessment will also require verifying industry claims of present practice. Assuming industry claims of present practice, unless the number of gambling cruises increases, the available data indicate that gaming vessel discharges are less likely to be regionally significant than cruise ship discharges.

Although the coastal nutrient data presently available do not indicate nutrient elevation, if further analysis of coastal nutrients were to show a problem, our suggestion would be to request a port-specific amendment to the Florida Cruise Ship MOU such that cruise ship discharge begins not at 4 nautical miles but at least 12 nautical miles offshore for both gray water and treated black water. Gaming vessel discharges could be made into pumpout facilities. Assuming such an agreement was enforceable and compliance was monitored, this would give additional legal protection to Brevard County coastal waters. Given the presence of the Southeast Shoal, if nutrient loading was found to be a problem and analysis indicated that nutrient loading from cruise vessels was a significant contributor, studies might be needed to verify if 12 nautical miles offered sufficient protection to Brevard County.

Question 9

If nutrient levels are determined to be elevated, what recommendations for future research could be made to determine near shore nutrient sources?

Since the data do not support the premise that nutrient levels are elevated, the remarks below should not be taken out of context. After an initial discussion of the physical context, regional circulation, and hydrology, specific suggestions are put forward as to what research, modeling, and monitoring efforts would be required to quantitatively partition nutrient loads amongst potential sources, determine the ecological impact of these loads, and determine if trends and patterns observed are significant, thereby guiding regulatory and resource management decisions. We do not disagree with the general conclusions of the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) (http://gesamp.imo.org/) and numerous other expert panels that eutrophication resulting from anthropogenic nutrient loading represents the greatest present and future environmental threat to the coastal marine ecosystem. Nonetheless, the evidence for incipient eutrophication is at best suggestive in Brevard County marine coastal waters.

Physical Context

On the largest scale, circulation along Florida's east coast, including Brevard County, is dominated by the Gulf Stream and its associated meanders, shingles, and eddies. This has been extensively studied for more than four decades (Lee *et al.*, 1984; Wang *et al.*, 1984; Kourafalou *et al.*, 1984; Blanton *et al.*, 1984; Zantopp *et al.*, 1987; Johns and Schott, 1987; Leaman *et al.*, 1987; Lee and Williams, 1988; Lee *et al.*, 1991, and many others) in a series of well-reported, multidisciplinary large-scale programs. Wave-like meanders and eddies are consistent features along the cyclonic front and appear to amplify just downstream of Brevard County where the shelf begins to widen and the Bahama Bank falls off sharply, relaxing the physical constraints of the channel. Features rapidly grow and elongate in this region with eddy dimensions doubling in a few days. Such features can induce upwelling and, thereby, add nutrients to the coastal ecosystem through which they travel. Cape Canaveral is a preferred region for eddy growth but the nutrient flux off Brevard is predominantly offshore (Lee *et al.*, 1991) in contrast to that in the eddy decay region farther to the north. On the other hand, the onshore component of eddy flows have been observed to penetrate the entire shelf to at least the 15 m isobath at Cape Canaveral.

Circulation in the near shore is also strongly affected by the local wind regime (and tidal rectification) and, while the alongshore mode is dominant (see question 8), the direction is not invariably with the Gulf Stream flow and eddy propagation. This is clear from recent data we obtained during an experiment with the EPA off of Cape Canaveral (Figures 14a and 14b). In the four months of 2003, moderate integrated water column flows were predominately alongshore with the exception of August when some eastward and westward flows were observed. This is likely to be related to Ekman transport and may result in wind-driven upwelling.

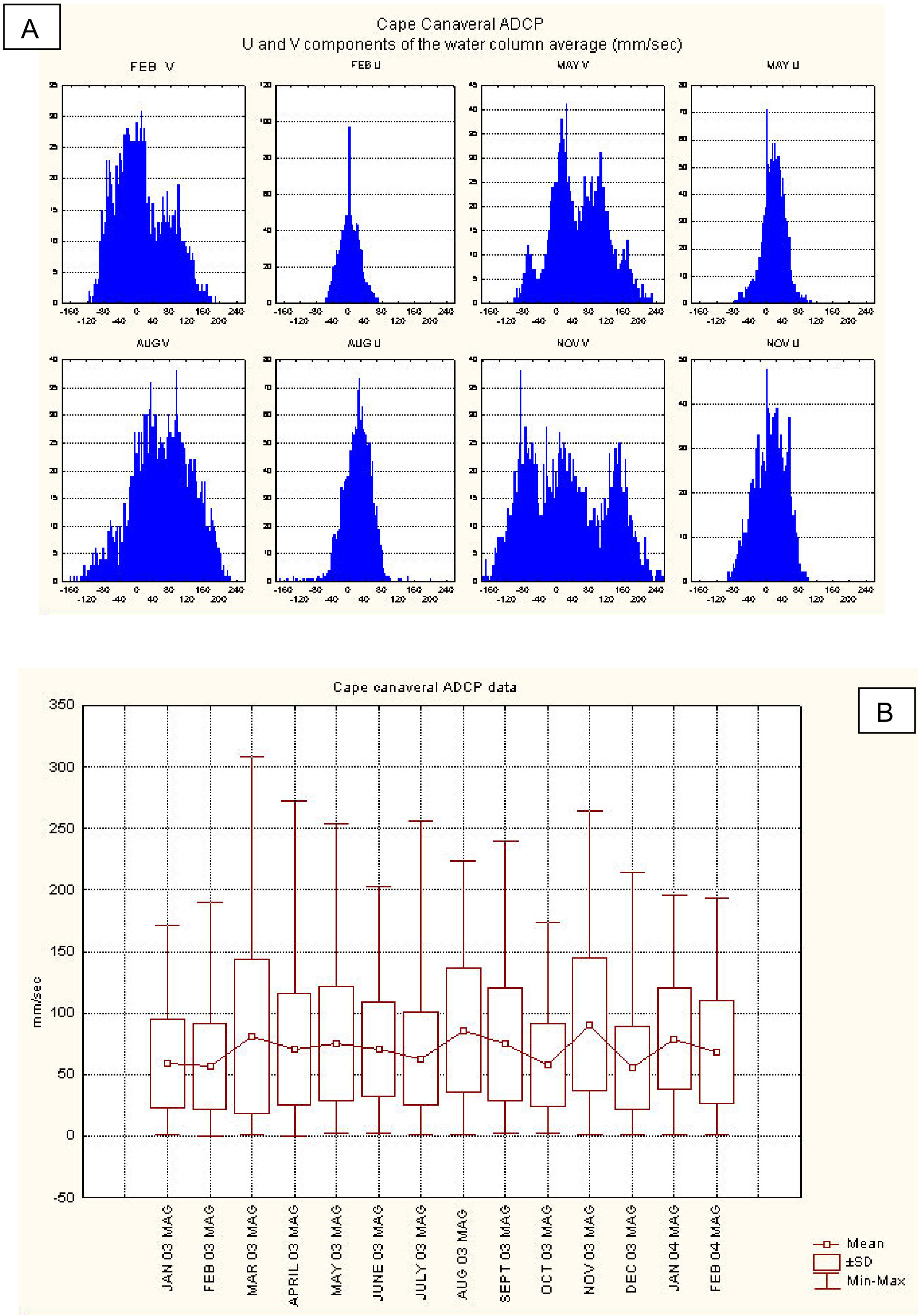

Figure 14. Cape Canaveral currents integrated over the water column for four months in 2003. (A) Polar diagram indicating absolute direction and velocity. (B) Histogram separating the V (almost N-S) and U (almost E-W) components.

Taylor and Stewart (1959) observed summer upwelling on the east coast of Florida along the length of the Indian River Lagoon and, based on an association with local wind and sea level records, interpreted this as a purely wind-driven phenomenon relating to southwest winds seen in July and August. More recent analyses (Smith, 1983) make a similar observation of summer upwelling and concluded that the primary cause was, in fact, the Gulf Stream system. Hseuh and O'Brien (1971) describe a reasonable mechanism for upwelling in response to a northward flowing longshore coastal current due to an interaction with the bottom. For our purposes, the mechanism is not important and probably both occur. Winter upwelling also occurs and has been explained by frontal eddies embedded in the cyclonic shear zone of the Florida Current as discussed above (Smith, 1987). Nonetheless, the periodic occurrence of strong upwelling events is of major importance. As reiterated most recently in the Florida Keys, such upwelling when present can contribute a significant amount of nutrients to a coastal reef system (Leichter *et al.*, 2003). Upwelling cannot be neglected in any mass balance of nutrients calculated along the Brevard coast.

It is also important to recognize that the barrier beaches forming the coast in question also border the Indian River Lagoon (IRL), which can be divided into distinct subregions both physically and biologically. The IRL has been substantially altered over time due to canal inputs, adjacent development, and the loss of wetlands (Woodward-Clyde Consultants, 1994; Phlips *et al.*, 2002). It exchanges with the coast through the Sebastian Inlet and the Port of Canaveral in Brevard but also through other inlets in adjacent counties, in particular, the Ft. Pierce and St. Lucie Inlets. Flows are greatest through the Ft. Pierce Inlet due to its dredged cross-section, but St. Lucie Inlet may release the most fresh water due to its proximity to the canal system used to lower Lake Okeechobee. Under high flow conditions, freshwater from these inlets is reported to pass through the IRL and reach the coast with minimal mixing inside the lagoon. In the more northern inlets, increased freshwater, whether canal or local rainfall related, inhibits rather than enhances tidal mixing through the inlets due to buoyancy considerations (Smith, 1990, 1992, 1993).

One cannot neglect the possibility of groundwater flow adding nutrients into the coastal marine ecosystem. In fact, a recent publication argues that this may be occurring in Palm Beach where the Biscayne Aquifer emerges offshore, and freshwater springs have been documented. The author points to the Everglades agricultural area as the primary recharge to this aquifer and the source of nutrients added to the aquifer (Finkl and Charlier, 2003). Unfortunately, no direct measurements were made of nutrients either in the aquifer or in emergent underwater springs. Calculations based on the pressure head indicate that the transit time for emergent water is ca. 75 years; thus, substantial nutrient modification is expected to occur during water transit. A number of hydrologic and geological features argue against such a scenario in Brevard County (see question 1). However, a recent report has highlighted the importance of seep water flux as a source of nutrient loading into the IRL (Swarzenski *et al.*, 2001) and pointed to an interesting and potentially relevant mechanism in which such nutrients may transport through the barrier island and into the coastal zone (Li *et al.*, 1999; Boehm and Paytan, 2005). Essentially, groundwater flux mixes sediment pore waters with the overlying Lagoon water and, through mineralization of organic nitrogen previously accumulated, these pore waters become considerably enriched in total nitrogen (up to five times above IRL water was measured). These “recycled” waters add significantly to IRL nitrogen loading. It is not inconceivable that a similar exchange process could happen in the near shore with organic nitrogen provided perhaps from local septic tank contamination of the surficial aquifer on the barrier islands. Li *et al*. (1999) discuss a reasonable physical mechanism by which this could occur based on wave setup and tides, and the study of Boehm and Paytan (2005) demonstrates a method to estimate such flux into the near shore.

Research Recommendations

Water Quality Monitoring

Although the data available do not indicate elevated nutrient concentrations in the Brevard surf zone, as noted earlier, nutrient monitoring in Brevard coastal waters has been minimal. Although observation of *Caulerpa* overgrowth does not appear to have been scientifically documented, it is of concern and should be verified. A prudent first step would be to determine the distribution of macroalgae on suitable rock ledge habitats in Brevard County (including control sites) and whether or not “nutrient-loving” species are becoming more abundant and widespread. Data collected during environmental impact assessments for beach renourishment may yield historic data for comparison. If macroalgal overgrowth of species such as *Caulerpa* appears to be a problem, nutrient sources may be quite localized and a first step would be to determine whether septic tanks and/or seepage ponds are located adjacent to areas of concern. If that were the case, the function of these systems may need to be evaluated. In addition, more systematic monitoring of coastal waters for the relevant inorganic nutrients might need to be initiated. If such monitoring were performed, the sampling plan would need to include transects offshore and alongshore near Sebastian Inlet and along the beach front. Samples near inlets would need to be taken throughout the tidal cycle and during both the rainy and dry seasons. Sampling also would need to cover all relevant chemical constituents (see Question 1) and to be accompanied by measurements of temperature, salinity, and tidal state. In addition, baseline measurements would need to be made in marine sediments and in samples taken from groundwater seepage meters appropriately distributed alongshore. Such data is essential to determine the degree to which N mineralization of organic forms originating from local sources (e.g., septic tanks) may be contributing significant inorganic nutrients into the near shore coastal ecosystem. Furthermore, ongoing bacteriological and chemical water quality sampling would need to be integrated.

Stable Isotope Studies

The nitrogen isotope studies which have been carried out to date have not been comprehensive in nature. They usually have only examined the nitrogen isotopic composition of a single type of organism and ignored changes in the isotopic composition of the water and other components of the system. Hence, the nitrogen isotopic compositions which have been observed cannot be linked directly to changes in the composition of an N-bearing species in the water column. Some correlation has been made to changes in the concentration of N, but there is little information as to the time scales over which such changes are reflected in the organism. Hence, the correlation between increases in N and isotopic composition must be considered tenuous. This does not mean that stable isotope studies have no role in elucidating nutrient pathways in such systems. However, future stable isotope work needs to measure the isotopic ratios and elucidate the nitrogen cycle and fractionation factors occurring in the system, as detailed in

Question 5. Using multiple stable isotopes (e.g., C and S) can also help in the interpretation of nitrogen isotope data. A single species of bioindicator (e.g., macroalgae) should be used because fractionation is known to be species dependent. Laboratory studies confirming the fractionation behavior of that species need to be conducted in order to properly interpret environmental results (e.g., what nutrient is assimilated under different nutrient regimes and the corresponding fractionation). Moreover, if macroalgal samples are used, the part of the plant analyzed and sample handling and preservation should be standardized.

Sewage Markers

As noted in Questions 6 and 7, chemical and biological markers may be particularly useful in determining which local source amongst possibilities may, in fact, be the most significant contributor in empirically determining dilution rates and distances. If direct inputs (sewage outfalls) are ever a consideration for the area, their design needs to be based on detailed oceanographic and deliberate tracer studies to achieve the desired dilutions and minimize environmental impacts.

Circulation

To design and interpret nutrient, stable isotopic, and tracer studies, a background study of local circulation patterns would be necessary. Perhaps the most economical way of doing this would be to install acoustic current meters at a few carefully selected points for an extended period (perhaps over an annual cycle) and making a limited number of hydrographic surveys during the course of that year. Physical measurements also would need to be taken near Sebastian Inlet, including some current velocity time series. These measurements should not have to be regularly repeated.

Models

Given the complexity of the physical system (the number of open boundaries), the variety of possible sources, and the biogeochemical processes that modify nitrogen and phosphorus compounds, if the County or State ever embarks upon an ambitious field program as described above, both mass-balance and numeric modeling would need to be part of the overall scientific program to rigorously interpret any results obtained. As part of such effort, compilation and coordination of existing data held by various County and State divisions would be needed so that nutrient loads could be more readily and accurately estimated.

In short, additional data are needed to determine the degree to which further efforts are warranted. At a minimum, this would involve additional water quality sampling and investigation of the observation of algal overgrowth. Scientifically rigorous answers to the difficult questions posed would require a comprehensive interdisciplinary program that would include nutrient and microbiological water quality monitoring (water column and, initially, in sediments and likely sources), stable isotopes (N, C, and S), specific biochemical sewage markers, and possibly the introduction of deliberate tracers, circulation studies, and mass-balance and numeric modeling. The scope and expense of such a program imply it would be feasible only with the leveraging that can be obtained by close cooperation and coordination with ongoing and planned federal and state programs.

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