Journal of Coastal Research	19	4	934–943	West Palm Beach, Florida	Fall 2003

Sustainability of Subtropical Coastal Zones in Southeastern Florida: Challenges for Urbanized Coastal Environments Threatened by Development, Pollution, Water Supply, and Storm Hazards

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ABSTRACT

FINKL, C.W. and CHARLIER, R.H., 2003. Sustainability of subtropical coastal zones in southeastern Florida: Challenges for urbanized coastal environments threatened by development, pollution, water supply, and storm hazards *Journal of Coastal Research,* 19(4), 934–943. West Palm Beach (Florida), ISSN 0749-0208.

The subtropical Atlantic coastal zone of southeastern Florida supports nearly 7 million inhabitants on a coastal plain conurbation that stretches from West Palm Beach to Miami. About a quarter of the present population originally settled on higher topography along the shore-parallel Atlantic Coastal Ridge. From about the middle 1900s, however, urbanization intensified along the shore and spread westward into freshwater marshlands. Population densities approaching 2500 persons per km^{-2} along some coastal sectors and dredge and fill operations to create urban land in western marshes degraded coastal environments bringing in question sustainability. Efforts to maintain environmental integrity initially focused on shore protection first via "hard" engineering works, which later ont included massive beach renourishment projects along developed coasts subject to critical erosion. Marine algal blooms, led to eutrophication, degraded coastal water quality, and deterioration of coral reefs indicate environmental problems at least as serious as beach erosion. Recognition of a potential eco-catastrophe, collapse of entire marine and coastal wetland ecosystems in southern Florida, led turn to the Everglades Restoration Project, the largest single environmental recovery effort in the world. Cleanup of terrestrial systems is essential to sustainability of marine ecosystems now jeopardized by nutrient loading.

Serious degradation of the Florida Reef Tract, a coral-algal barrier reef system, is beyond question as extensive sectors of coral reef die from increased loading of nearshore waters by elevated nitrogen (N) and phosphorus (P) nutrient levels delivered to the coast by submarine groundwater discharge (SGD). The source of N-P input into the Biscayne Aquifer, which has one of the highest carbonate aquifer transmissivities in the world, is sugar cane farming in the Everglades Agricultural Area on the inner portion of the coastal plain. Groundwater discharges for Palm Beach County are, for example, estimated from a groundwater MODFLOW model at 1,659 X 10^6 m^3 yr^{-1}. Total N in groundwater below the coastal plain adjacent to remnant Everglades averages about 1.25 mg l^{-1}. SGD nutrient fluxes to the coast are 5727 and 414 metric tons per year for P and N, respectively. Surface water contributions for P and N are respectively 197 and 2,471 metric tons per year. Nutrient delivery to beach and nearshore environments is a serious problem that threatens coastal water quality which in turn will impact tourism-related activities such as sunbathing, beach walking, swimming, snorkeling, SCUBA diving, and surf fishing. The full magnitude of the problem has yet to surface because it takes about three to eight decades for groundwater from the interior parts of the coastal plain to reach the nearshore zone. Pollution of groundwater increases with time due to higher doses of fertilizers on croplands and runoff from expanding urban areas.

Solutions to present environmental threats are obvious and, perhaps surprisingly, do not fall within the scientific arena because causes and remedies are already known and future impacts are anticipated. The present environmental cleanup efforts, which are of mammoth proportions and financial cost, are doomed to failure until the causes of problems are eliminated or neutralized. Even though sustainable management procedures are well known, sustainability cannot be achieved by treating symptoms. Sustainable coastal habitats in subtropical southeast Florida will be secured when there is application of best management practices based on environmental ethics rather than capital gain, development of political will directed towards continuous multiple land use rather than terminal single use, and inculcation of proactive public perception of best land management practices rather than politically-correct land-use policies.

ADDITIONAL INDEX WORDS: *Environmental integrity, submarine groundwater discharge, nutrient loading, water quality, remediation, ecosystem collapse, coastal management.*

INTRODUCTION

Like many coastal conurbations throughout the world, the urban corridor in southeastern Florida experiences adverse impacts resulting from over-populating of sensitive environments (*e.g.* FINKL, 1994). The problem has been the subject of workshops organized by UNESCO and the Intergovernmental Oceanographic Commission (proceedings are published in the UNESCO CSI information series) (UNESCO,

03800J received and accepted in revision 10 July 2003.

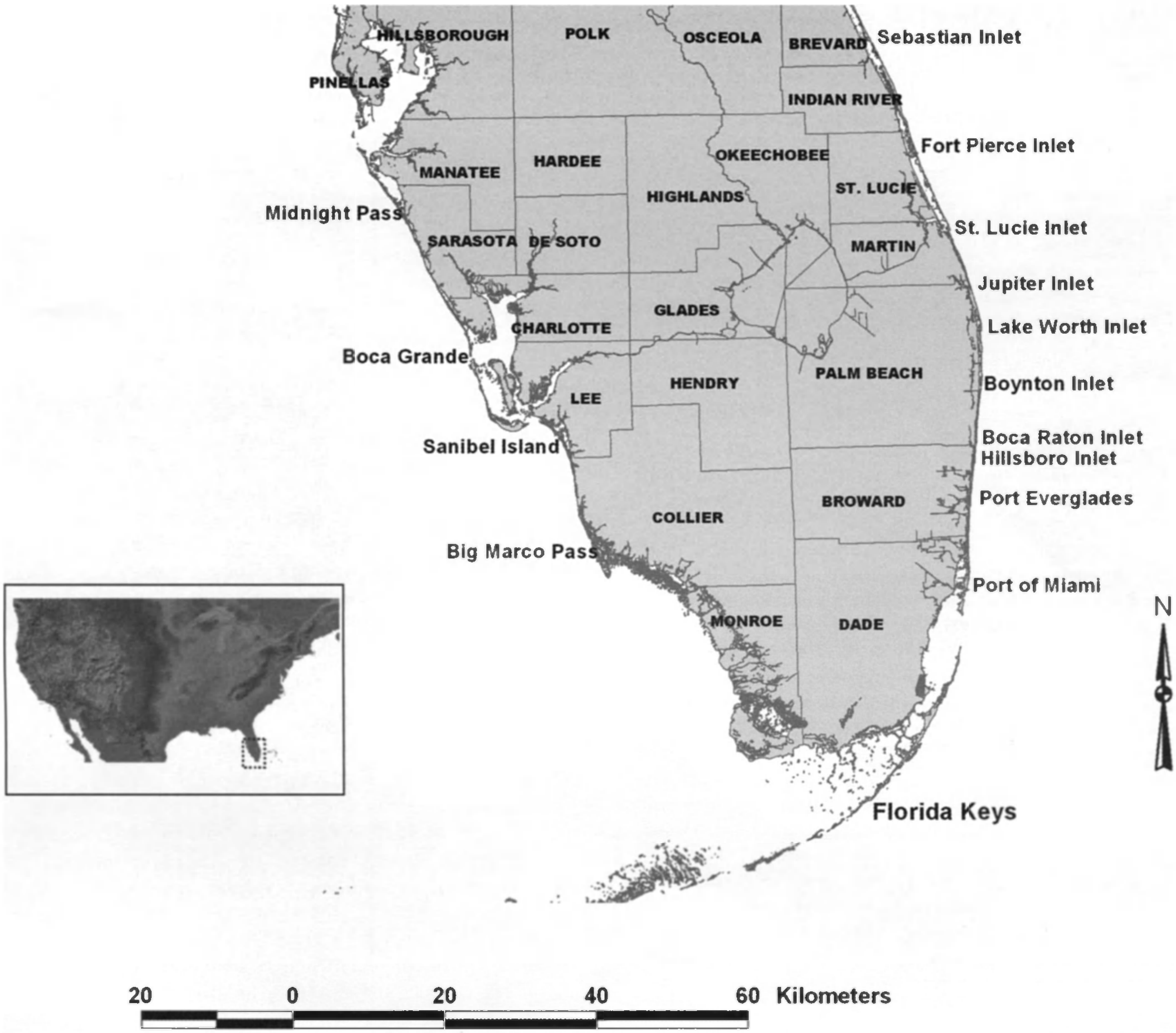

Figure 1. Study area along the southeast coast of the Florida peninsula (Palm Beach, Broward, and Dade counties), from the Florida Keys to the Indian River Lagoon. Surface water flow is from the Kissimmee River Valley (center of map from the north through Polk and Osceola Counties) into Lake Okeechobee and southwards via drainage canals to surface recharge of the surficial aquifer system (SAS) and to the coast via conveyances (not shown). Lake water drawdown and surface water runoff enter the nearshore zone through inlets viz. St. Lucie Inlet, Jupiter Inlet, Lake Worth Inlet, Boynton Inlet, Boca Raton Inlet, Hillsboro Inlet, and Port Everglades. Lake Okeechobee also empties to the west coast the Caloosahatchee River estuary and enters coastal waters through inlets near Boca Grande and Sanibel Island in Lee County. (Map supplied by Lindino Benedet, Coastal Planning & Engineering, Inc., Boca Raton, Florida.)

2000). Prior to permanent human settlement starting in the mid 1800s, this subtropical coastal zone was a vast wetland that stretched westward from the Atlantic coast to the Gulf of Mexico and southward to Florida Bay (HOFFMEISTER, 1974). The post WWII years witnessed here an enormous influx of people who settled mostly along limestone ridges that stood above the freshwater wetlands. The move was nurtured and encouraged by real estate speculators who had, of course, no regard for the environment and for whom the word let be the concept of sustainability. The Atlantic Coastal Ridge (WHITE, 1970), as it is now known, was rapidly urbanized and by the mid 1900s urban sprawl was extending into wetlands that were dredged and drained. Some parts of the Florida Everglades were set aside as water conservation areas so that today about half of the original Everglades remained and remains unprotected from settlement. A large part of the Everglades was diked and drained as a reserve for agriculture attracted by the deep rich organic soils that could support many crops. Development of the Everglades Agricultural Area (EAA) south of Lake Okeechobee (Figure 1) limited inland urban development, confining urban sprawl to Atlantic coastal areas. With nearly 7 million people inhabiting the coastal plain between West Palm Beach and Miami (CULLINTON, 1998), there emerge numerous environmental problems associated with high population densities in and near sensitive coastal/marine ecosystems that are increasingly subjected to ever-greater insults that threaten biological integrity of the systems. Focus should, according to CULLINTON (1992) be on saving beaches and not buildings, but the present *modus operandi* is to use beaches to save buildings.

Environmental problems in this region are legion and salient among them are drinking and irrigation water supply, urban and agricultural waste disposal, pollution, and coastal hazard mitigation from extreme meteorological events such as tropical storms and hurricanes. The questions have been asked and the answers are already known, but political and socio-economic constraints limit planning and managerial response to mostly unworkable and untenable responses that are politically correct. Political correctness does not solve problems and at best confounds the issues. What is required is an exegesis of present scientific understanding of ecosystem function and value as impacted by urban and agricultural practices. Adverse environmental impacts in this coastal region are well known and yet urbanization is allowed to spread into undeveloped wetlands, as presently seen in western Palm Beach County. Broward and Miami Dade counties are fully developed and high urban population densities are accommodated by re-urbanization to more intense uses. Population along the coastal southeast corridor of Florida is projected to reach 15 million by 2020 (*e.g.* CULLINTON, 1998). Clearly, a doubling of the population pressure on the man-modified wetlands will exacerbate present environmental problems.

Sustainability of this subtropical coastal region remains a moot point because although scientists recognize signs of environmental degradation and raise red flags for further land development, political forces encourage continued development for financial gain. And herein lies the problem of how to inculcate in a politically dominated management system the realization that population cannot exponentially increase in sensitive coastal wetlands. The problems are not different in the Black Sea coastal regions (BOLOGA, 1998, 2001). Urban dwellers are generally ignorant about environmental issues and agriculturalists, particularly those engaged in the monoculture of sugar cane in the EAA, tend to farm without regard for continued productivity of the land and environmental impacts of amendments such as fertilizers and pesticides. Impairment of water quality does not faze them and eventual deterioration along the coast is hardly a concern of theirs. That the practices are not sustainable and will lead in the long term to ruin is a message that apparently is poorly transmitted.

The end result is a collision of desires for continued human development in coastal/marine ecosystems that have a finite resiliency to accommodate byproducts and end products of human activities. Societal response to warnings about potential collapse of the Everglades ecosystem is to adopt the ostrich posture of head in the sand; activist NGO response is to resist developmental impacts either in the courts or by acquiring land to remove it from potential development; governmental response is to initiate more research and implement massive environmental restoration projects to clean up the mess. Under the present scenario, sustainability is questionable at best and new efforts must be launched to forestall an ecocatastrophe in southern Florida. There is thus urgency in informing and educating the public.

SUSTAINABILITY OF BEACH SYSTEMS

Loss of recreational beach width due to erosion, formerly a major problem along Florida shores, became particularly troublesome when developed coastal segments were threatened by retreating shorelines. Investment in coastal infrastructure requires protective measures to ensure against land loss and temporary flooding due to super-elevations of sea level by storm surges associated with hurricanes. Studies by ESTEVES and FINKL (1998) show that about 75% of the Florida sandy beaches comprise shorelines. Statewide, 61% of beaches front developed shorelines. Florida's beaches are mostly in good shape with 82% of sandy beaches in a state of accretion or stability. This somewhat enviable situation does not, unfortunately, prevail along most shores of the Black Sea. About 6% of the total beach length is eroded and 10% is critically eroded. About 73% of the total Gulf coast beach length shows a long-term erosional trend whereas only about 27% of Atlantic coast beaches exhibit erosional trends. Thus, in a word, Gulf coast beaches are in much worse condition than Atlantic beaches. Although long-term Atlantic coast erosion is less than that along Gulf shores, a surprisingly high percentage (91%) of Atlantic beach erosion, as reported by ESTEVES and FINKL (1998), occurs directly downcoast from stabilized inlets. Most developed shorelines are protected by sea defenses, which include beach renourishment projects, but erosion along natural shorelines remains unmitigated.

Although beach replenishment activities have been criticized (*e.g.* PILKEY and CLAYTON, 1989; PILKEY, 1995), mostly on the basis of the high costs involved for temporary shore protection and potential environmental damage in offshore borrow areas and in sensitive environments near the shore (*e.g.* hardgrounds, Sabellariid worm reefs, coral reefs), the procedure provides conditional protection from storm damage by providing sacrificial sand. Maintenance of beaches along the southeast Florida coast by periodic renourishment sustains beach widths for multipurpose use (FINKL, 1996) and forestalls economic depression due to desertion by and eventual lack of tourists. Sustainability of beaches is not only feasible, but thus widely practiced to advantage. Even though beach erosion is a potential problem, repetitive renourishments show that an unstable natural system can be managed in a way that supports continued use and receives beneficial feedback. Unfortunately, the success and effectiveness of this environmental engineering practice is overshadowed by poor land management on the coastal plain. The beach erosion problem, which could have become a major developmental

Table 1. *Surface water and ground water nutrient fluxes in Palm Beach County, Florida.*

Discharge Type	$m^3 \times 10^6\ a^{-1}$	Phosphorous Flux[1] (metric tons per year)	Nitrogen Flux[1] (Metric tons per year)
Surface Water (Actual Flow)	1,661	196.72	2,471.87
Groundwater (Darcy Flow)	2,211	414.61	5,727.0
Total	3,872	611.33	8,198.87
Difference Between SW/GW	550	217.89	3,255.13
Percent of Surface Water	133%	210%	231%

[1] Modified from Krupa and Gefvert (2001). Flow rates are given in millions of cubic meters per year and nutrient fluxes are calculated in terms of metric tons per year.

stumbling block for the southeast coast, was solved to the credit of coastal engineers and planners. This is one of the sites where a policy of "let nature take its course" cannot be considered, as discussed in another paper at this seminar. The beaches sustain economic prosperity (HOUSTON, 2002), but the coastal waters and coral-algal reef tracts fronting the beaches are now jeopardized by incipient pollution from contaminated groundwater that reaches the seabed through the reefs (*e.g.* FINKL and KRUPA, 2003).

SUSTAINABILITY OF AGRO-URBAN COASTAL ENVIRONMENTS

Overpopulation of the Florida southeast coast invites myriad problems that put in jeopardy the delicate sustainability of viable natural systems. The most serious threat emanates from unseen hazards (FINKL, 2000; FINKL and KRUPA, 2003) that degrade coastal waters. Causes of the problem and the mechanics of polluted discharge along the coast are detailed below in terms of land use practices on the coastal plain that directly impact the integrity of coastal ecosystems. Submarine groundwater discharge (SGD) threatens sustainability of the entire southeast Florida coast because it contaminates coastal waters with high levels of nutrients such as nitrogen and phosphorus. Intensive agriculture and pesticides use are at the origin of much of this contamination.

Occurrence of Submarine Springs and SGD

Although submarine springs are commonplace in coastal zones throughout the world, their presence is unnoticed because they are visually obscure. The amount of freshwater delivered by submarine springs can be significant, with notable, widely spaced examples occurring at Crescent Beach, Florida (42 $m^3\ s^{-1}$) (BROOKS, 1961), and Chekka, Lebanon (60

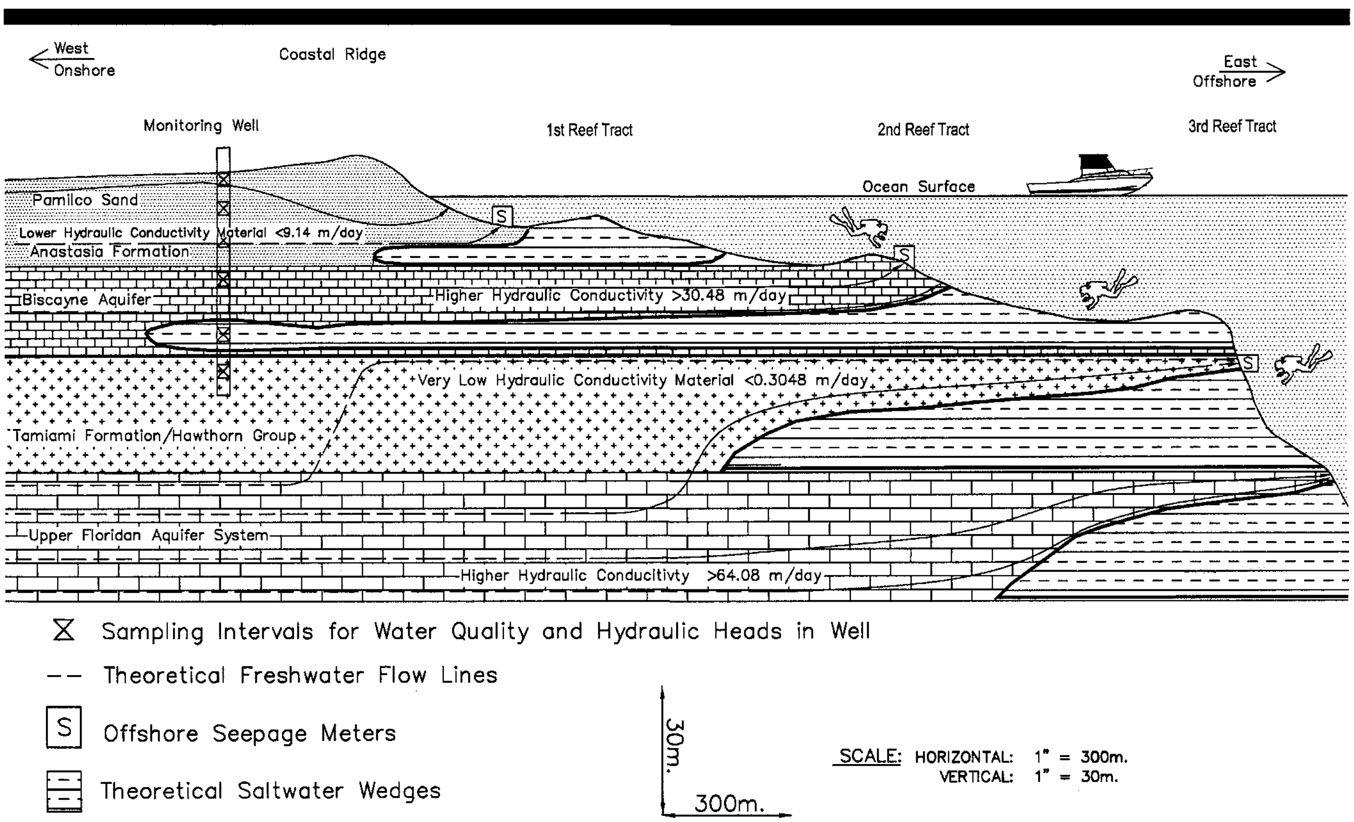

Figure 2. Diagrammatic cross section showing hypothetical view across the coastal zone in Palm Beach County, Florida. Submarine groundwater discharge (SGD) occurs onshore but is most pronounced offshore along exposure (truncation) of the Biscayne Aquifer (part of the SAS) which has a high hydraulic conductivity (> 30 m d^{-1}). SGD is known to occur along the 2nd reef tract as springs, undershelf seepages (usually on the ocean side of the reefs), and as ill-defined sub-sediment issuances in inter-reefal sand tracts. (Drafted by Steve Krupa, South Florida Water Management District.)

$m^3 s^{-1}$) (SCHWERDTFEGER, 1981). Areas with localized SGD along the southeastern Atlantic coast have been known for some time (*e.g.* MATSON and SANFORD, 1913; MANHEIM, 1967). Estimated discharges for Palm Beach County, compiled by FINKL and KRUPA (2003) and summarized in Table 1, show that annual groundwater discharge (2211 m^3 X 10^6 a^{-1}) is 133% of surface water discharge (1661 m^3 X 10^6 a^{-1}). Along the southeast coast of Florida in Palm Beach County, SGD occurs where aquifers are truncated on the inner continental shelf (Figure 2). Low-angle truncation of geologic formations with high hydraulic conductivities up to 30 m d^{-1} provides a large surface area for SGD. As shown in the conceptual diagram (Figure 2), SGD occurs all along the coast but is especially pronounced where the surficial aquifer system (SAS) outcrops on the seabed in association with the 2nd reef tract. Fresh water discharge takes place in submarine springs and through fissures in the porous limestone, but closer to shore, SGD occurs in materials that have a lower hydraulic conductivity.

The Process of Submarine Groundwater Discharge

SGD is driven, in simplest terms, by a land-based source of freshwater which lies at a higher elevation than the surface water into which it flows. In addition to a higher hydraulic head or topographic gradient, other possible mechanisms include, but are not limited to, geothermal heat flow in areas with active volcanism, slow thermal convective upwellings in nonvolcanic areas, advective flow, tidal pumping, *etc.* (KOHOUT, 1966). RIEDL (1971) further highlights the significance of surface action on the movement of seawater through marine sediments in intertidal and subtidal zones of sandy beaches. SGD in the Florida Keys differs from most coastal environments because (1) subsurface fluids tend to be saline to hypersaline, and (2) the driving force is thought to be tides rather than topography (SHINN *et al.,* 1993; CORBETT *et al.,* 1999). Groundwater entering Florida Bay along the north coast is, however, characterized by a typical topographic gradient flow, from north to south.

When an unconfined aquifer is in hydraulic contact with the sea and the head is above the sea level, groundwater is discharged along the coast (*cf* Figure 2). The presence of a saltwater wedge beneath marine beaches impedes the downward mixing of lighter, low salinity groundwater. Unconfined groundwater thus discharges into coastal waters through a gap between the freshwater-seawater interface and the water table outcrop at the beach (*e.g.* GLOVER, 1959).

Recognition of SGD and Interpretation of Causes

Threats that are not visually or sensually evident, *i.e.* hazards that do not represent an immediate danger, are difficult to deal with from a psychological management point of view. Most people tend to ignore these kinds of hazards because, in their mind, an 'inconvenience' does not yet exist and personal or public safety is not a concern. They hope that the disruption is a minor nuisance that will dissipate, subside, or just go away. This is also a difficult subject area because it involves political systems and economic response. "Unseen" coastal hazards are not really invisible, as first suggested; rather, they are events or processes that operate at rates (fast or slow) that are imperceptible to the naked eye or they take place beneath a covering layer of material, or within a medium such as porous rock or a water column. Unless there are visible materials associated with the process, such as the transport of suspended sediments or dissolved materials with color (*cf* Figure 3), the process operates in an unseen (invisible to the naked eye) manner. We see the results of the process much as we do not literally see the wind blowing if the air is clean but we do see vegetation bending, leaves blowing, and so on. Likewise, unless rip currents carry sediments offshore, they might be unnoticed by the casual beachgoer.

Within the general class of unseen hazards, there are many discrete and interrelated processes that result in high nutrient levels in the coastal waters of southeastern Florida. The problem occurs in southeast Florida because surface recharge to the SAS takes place at the ground surface in inland agricultural and coastal urban areas. Water quality is subsequently degraded along the coast and especially by freshwater discharges to estuaries (*e.g.* MILLER, 1980; HAUNERT and STARTZMAN, 1985; MORRIS, 1987). Of the two inputs, the largest contribution of nitrogen and phosphorus to the SAS takes place in the Everglades Agricultural Area (EAA) that is primarily involved in the production of sugarcane. The cane crop is heavily fertilized and organic and inorganic minerals are eventually leached into the soil profile. Once in solution, dissolved inorganic N (DIN = NO_3 + NO_2^- + NH_4^-) and P (as soluble reactive phosphate, SRP) are transported downward to the groundwater table where they begin their journey through the porous limestone layers on their way to the sea.

Seepage, which occurs in many places in both freshwater and saltwater environments, is generally dependent on underlying lithology. SGD is more complex because it is affected by such additional factors as tidally-controlled groundwater near estuaries, re-circulation at or near the interface of the salt/fresh water boundary and the biochemical, chemical, geological, ecological and sedimentary processes that occur at the fresh-saltwater interface. Baseflow is groundwater from the aquifer that occurs under normal conditions, as they exist locally for topography, climate, surface- and groundwater elevations, hydraulic gradients, aquifer characteristics, and anthropogenic affects (*e.g.* pumping, drainage) (ROBINSON, 1996; UCHIYAMA *et al.,* 2000). The baseflow is the product of the hydraulic gradient, and the hydraulic conductivity times a unit width of the aquifer; it is usually defined in terms of length^3/time. Baseflow SGD is determined by taking the cross sectional area of the aquifer and multiplying it times the groundwater velocity. Velocities can be measured *in situ* or calculated (using heat pulse technology or downhole flowmeters) or by estimating the hydraulic conductivity of the aquifer times the hydraulic gradient. Groundwater studies, based on our calculations of hydraulic head and conductivity of the SAS, suggest that travel times are about fifty to seventy-five years for nutrients entering the groundwater in the EAA to reach the coast. This time lag has significant implications for perception of the problem, especially the causes and sequential linkages between environmental systems, and to mitigation.

Nexus Between Cause and Effect

The link between cause and effect along the land-sea boundary is often difficult to prove on a sound scientific basis (*e.g.* proof of a terrestrial source of pollution that becomes manifested in the marine environment), even though common sense and normative logic point to possible, and indeed probable, connections. A nexus is regarded as 'established' when no other reasonable explanation or possibility is known to exist. Environmental concerns over water quality in the study area have grown over the last several decades (*e.g.* PHILLIPS and INGLE, 1960; DEIS, 1978; LAPOINTE *et al.*, 1990; LAPOINTE *et al.*, 1993; SHINN *et al.*, 1993; LAPOINTE and MATZIE, 1996; SZMANT and FORRESTER, 1996; LIDZ and HALLOCK, 2000). Nutrient infiltration to nearshore waters and the movement of discolored water, as seen in aerial photographs, for example from sewage outfalls off Key West or plumes moving from Florida Bay seaward to offshore reefs through passes in the Keys, indicate that the middle Keys are influenced by geographic location relative to tidal passes and thus by direct communication between deleterious nearshore and bay waters and the offshore reefs (LIDZ and HALLOCK, 2000). The findings, as summarized by LIDZ and HALLOCK (2000), establish the link between polluted water passing through tidal passes and declining reefs, as previously proposed by LIDZ *et al.* (1985) and other workers.

The development of algal blooms along the coast is now well-documented (*e.g.* LAPOINTE *et al.*, 1990) and adverse environmental impacts of these blooms periodically become evident. These green tides (harmful algal blooms, HABS) have been studied in several European locations, particularly along the French Atlantic coast, even though the phenomenon also gravely affects Italian resorts, such as for instance Orbetllo (CHARLIER and LONHIENNE, 1998). Although the macroalgae drift about with the currents, they are of sufficient mass and spread over such areal extent to inhibit penetration of sunlight through the water column to the reef surface. In a very real sense, these macroalgal blooms are smothering the reefs, as well as other life forms in non-tropical settings. The presence of the macroalgae and deterioration of corals further contributes to degraded water quality in the nearshore zone. Poor water quality in turn adversely impacts use of sandy beaches that depend on good quality water. Most beach users enter the water during part of their holiday stay in southeast Florida and water quality is thus an important aspect of beach use. The real problem here boils down to an economic consideration because poor water quality can terminate beach use, and if the beaches are not used there will be a marked decrease in beach-generated income for state and local communities. The perceived mental stretch from poor water quality to decreased beach use to decreased income is not great. The connection is obvious and the scenario is simple: if water quality is poor, people do not go to the beach, and as beach-related income drops, business ultimately suffers. The impact is not just for local communities in southeast Florida, but will affect other parts of the state where there exists the following conditions: sandy beaches, agriculture and urban activity on adjacent coastal plains, surface recharge of aquifers, and SGD of nutrient-rich water.

Perhaps more difficult to understand is the connection between sugarcane farming 30 km inland on the coastal plain, and poor water quality along the coast in estuarine and marine environments. Many studies along the southeast coast (*e.g.* LAPOINTE *et al.*, 1990; SFWMD, 1992, 1993; FINKL, 1995, 2000; FINKL and KRUPA, 2003; LIDZ and HALLOCK, 2000) show causal links between land use activities on uplands and impacts along the shore. In addition to high nutrient values in surface waters, shallow groundwaters may provide the most direct linkage to coral reef communities nearshore. Total N in the groundwater (10 to 50 m below mean sea level) in Palm Beach County, for example, is quite high in areas adjacent to water conservation areas on the coastal plain ($\approx$ 3 mg l^{-1}) (KRUPA and GEFVERT, 2003). SGD along the southeast Florida coast provides notable inputs of freshwater to the ocean reef complex. Total surface water discharges from canal flows to the southeast coast during 1980–1989 were about 1.66 X 10^9 m^3 (SFWMD, 1993). The associated nutrient concentrations of total N and P for this decadal time slice were about 2473 t (247 t a^{-1}) and 197 t (1.97 t a^{-1}), respectively (Table 1). SGDs are presently estimated to be on the order of 9.99 X 10^5 m^3 d^{-1} (3.6 X 10^8 m^3 a^{-1}) (FINKL, KRUPA and GIDDINGS, 1995). These adverse impacts are now surfacing because they are the result of incipient agricultural practices of 50–60 years ago. The half-century to three-quarter century time lag is due to slow travel (residence) times in the aquifer, as previously discussed. Pulsed effects of contaminated groundwater are thus expected to cause greater impacts in future as estuaries and nearshore environments respond to cumulative effects of continued nutrient loading (FINKL, 1995). Accompanying impacts that reduce aquatic productivity include accelerated accumulation of flocculated detritus; reduced dissolved oxygen concentrations; change in detritus, microbial, and macro-invertebrate communities; and changing periphyton communities toward reduced diversity and dominance of pollution-tolerant species (SFWMD, 1993).

The study by SIMMONS and LOVE (1987) is important because of the implications to the productivity and perturbation of coral reef ecosystems, deleterious affects that have now been confirmed by LIDZ and HALLOCK (2000). The association between algal blooms in the marine environment and septic tanks on uplands was made because the impacts were visible, although the initial cause was invisible. As the population grew, so did use of septic tanks and eventually enough N-laden effluent reached coastal waters and provided the nutrients necessary for rapid growth of algae. Although many apparently independent processes were operating simultaneously, the environmental impacts occurred over a relatively small geographic area within a short time frame. The situation is, in short, hard to ignore and vested local interests can not hide the fact that eutrophication and general degradation now characterizes parts of the third largest coral reef system in the world. MORAND and BRIAND (1996) report similar observations, focusing on impacts of macroalgal blooms, that destabilize natural environments due to inputs of nutrients.

Occurrence of *Codium* blooms farther north along the coasts of Miami-Dade, Broward, and Palm Beach counties elicited further investigation. An obvious source of poor quality water was pulses freshwater flowing from Lake Okeechobee via the St. Lucie Canal to the estuary. The Lake is typically lowered before the rainy season and large slugs of freshwater are sometimes dumped into the St. Lucie Estuary. Studies of regulatory discharges from the lake, which focused on the sensitivity of the estuarine ecology to by the rapid introduction of fresh water runoff, showed that a controlled three-week 28,316 l^3 s^{-1} (reported as 1000 cfs, cubic feet per second) discharge had no significant effect on biota (HAUNERT and STARTZMAN, 1985). A three-week 70,090 l^3 s^{-1} (reported as 2500 cfs) controlled release, however, caused substantial changes in the composition and abundance of benthos and distribution of fish when salinities were reduced far below normal level. The water from Lake Okeechobee is high in nutrients from surrounding farming activities. Nutrients are also brought to the lake from the Kissimmee River whose valley was heavily involved in cattle farms. All sorts of environmental problems are now known to be associated with the rapid release of polluted freshwater from the lake to the estuary, *viz.* algal blooms, lesions of fish, *etc.*

Potential Impacts of Ignorance and Inaction in Relation to Sustainability

Due to the time lag factor, continued farming in the EAA, and expansion of coastal urban areas that contribute polluted runoff to coastal waters, the 'invisible' beach-impact problem can only expand in future. Although we are now seeing the first warning signs of water-quality problems in the coastal zone in the form of algal blooms and degraded fringing reefs, more serious problems loom on the horizon. The potential for significantly degraded coastal water quality is high and this environmental problem will be quickly translated into the economic and political arenas as public awareness increases. Although there is a high level of ignorance among public sectors, the scientific community has been cognizant of the situation for a decade or more (*e.g.* LIDZ *et al.,* 1985; HAUNERT, 1988; CAPONE and SLATER, 1990; LAPOINTE, *et al.,* 1990; SFWMD, 1992, 1993; LAPOINTE and MATZIE, 1993; FINKL, 1995; FINKL *et al.,* 1995; SZMANT and FORRESTER, 1996).

The average citizen is, however, not totally unaware of problems associated with coastal water quality and beach use because increasingly reports in local newspapers are now sounding the alarm. Water-quality tests from Key Largo, near Miami, for example, revealed the presence of live enteroviruses such as polio, coxsackie A and B, and echoviruses (FUSS, 2000). Coxsackie A and B cause diseases such as hyperangina and myocarditis. Echoviruses can cause a variety of illnesses that range from fever to viral meningitis. Viruses in canals and nearshore waters have migrated from of old sewage lines in poor repair, makeshift plumbing systems in old homes, and from houseboats where waste is not disposed of properly (BIERMAN, 2000; FUSS, 2000).

Inaction by municipalities in the case of obvious sewage spills is not possible due to public pressure. It simply is not expedient to allow water quality to deteriorate to the point that the situation incurs the public's wrath. SGD is, however, an invisible problem because nutrients are carried in solution to areas of discharge along the inner continental shelf. The process is difficult to detect (see discussion below) because it is normally invisible to the human eye. Fortunately, a nexus can be established between SGD, coastal water quality, and upland land use. Studies by SIMMONS and REAY (1992) in the southern part of Chesapeake Bay, for example, also showed that elevated hydraulic heads within upland regions caused SGD. These studies demonstrate that SGD is a nearshore phenomenon and its quality is related to adjacent land use activities (WOODS *et al.*, 2000), as was found in the Florida Keys. From these observations it is concluded that, in general, SGD is elevated in inorganic N off un-buffered urban and agricultural land use practices in comparison to buffered wetland sites.

Degradation of Coastal Environments by Contaminated SGD

Groundwater discharge has been documented to be highly significant for nutrient supply in some coastal areas (*e.g.* CAPONE and SLATER, 1990; LAPOINTE *et al.,* 1990; FINKL *et al.,* 1995; SFWMD, 1993; CORBETT *et al.,* 1999). Fringing coral reefs along the SE Florida coast are seasonally blanketed by a macroalgae that looks like long green seaweed. *Codium isthmocladum* grows on the undershelf of reefs that used to be clear and colorful, but now the *Codium* is choking everything. Additional problems include blooms of *Caulerpa* algae that cover 80–90% of the upper surfaces of many reef tracts (BROWNING, 1998). *Caulerpa* normally grows in mangrove habitats but is now found offshore due to nutrient loadings in coastal waters. Blooms of macroalgae occur all along the SE coast and range up to two meters thick on the downside ledges of the reefs. According to the US Geological Survey, Florida's wastewater emissions have shot up 37% since 1985. About 57% of the wastewater ends up in surface water after being treated. About 20% is injected deep below the aquifer to locations where it supposedly cannot recirculate upwards and contaminate the aquifer. The remaining 23% is flushed into septic tanks. There are 1.56 million septic tanks in Florida and each one digests and emits about 510 liters of bacteria-rich water each day. With 116,300 septic tanks, Miami-Dade County has more than any other Florida county. In the Florida Keys, these primitive tanks have been lethal to the ecosystem where septic tanks and 10,000 cesspits have poisoned large tracts of coral reef (LIDZ *et al.,* 1985; LAPOINTE *et al.,* 1990; SHINN *et al.,* 1993, 1994; BROWNING, 1998).

STATUS QUO AND SUSTAINABILITY PROGNOSIS

So, where are we? We have a mammoth potential problem staring us in the face. There is ample evidence from studies of national water-quality assessment (*e.g.* HAMILTON and MILLER, 2002) and from this study area that tells us that the introduction of wastewater from agricultural and urban activities on the coastal plain to the marine environment causes a lot of problems. These kinds problems are not new, they just now happen to be in their initial developmental stages. Solutions to the problem are not related to perception of extant conditions or recognition of impact scenarios but to the attitudes of local inhabitants and governments that are too concerned with the short-term situation. The issue is not so much one of science or technology but of will, desire to initiate mitigation when correction is relatively easy, compared to what might be involved several decades down the road. We are in the position now where the bell has been rung, the shepherd has cried wolf, and scientists wait to see what the politicians will do. As in so many cases like this, we anticipate that nothing positive will happen until the problem of coastal marine pollution becomes a major political issue among the electorate: let sleeping dogs lie, is the motto.

The purpose of these comments is not to lament present attitudes or lack of concern for so-called "unseen" beach hazards, but to hope that mitigation efforts can be initiated before pollution of coastal waters by SGD becomes unmanageable. One immediate solution would be to curtail sugarcane farming by buying the land, as suggested by the Florida Oceanographic Society (SWARTZ, 2000). Such action is, however, politically unpalatable because the federal government subsidizes the sugarcane farming. Eliminating application of fertilizers, pesticides, herbicides, and other amendments would, however, eventually lead to cleaner groundwater and SGD. Ironically, the cause of groundwater contamination via surface recharge in the EAA and adjacent areas may resolve itself for a little-known reason that is associated with the degradation and loss of peat-rich soils (Histosols), which form in un-drained or poorly drained areas but which subside when drained and cultivated (STEPHENS *et al.,* 1984). The causes of soil loss include mechanical compaction, burning, shrinkage due to dehydration, and most importantly, oxidation. The eventual demise of agriculture in the EAA (Everglades Agricultural Area) has been predicted for some time (see summaries in MCPHERSON and HALLEY, 1997; SHIH *et al.,* 1979, 1997); it should not be lamented if sustainability of the area is indeed at stake, the more since sugarcane is widely available around the world. Since drainage and cultivation were initiated over fifty years ago, there has been widespread subsidence between 9 and 27 m in the EAA. Because lowering of the Histosol (organic soil) surface averages about 7.6 cm a^{-1} (MCPHERSON and HALLEY, 1997), use of these depth-limited soils will be naturally curtailed in many areas of the EAA within the next decade.

Under the present 'do nothing' scenario, sustainability will eventually turn into an unsustainable situation because the Histosol cover is allochthonous, not genetically related to the underlying limestone bedrock, and the transition from soil to bedrock is abrupt. Sugarcane farming will thus eventually come to an end not because of a political or economic decision, but because the soil gave out (*i.e.* the soil profile became too thin to maintain agriculture). There is thus a nexus between coastal plain soils and beaches: when the soil gives out, agriculture will mostly come to a halt and one of the major causes of contaminated SGD will be removed. The catch in this scenario is the groundwater travel time of 50–75 years from the EAA to the coast. Assuming that really high levels of dissolved inorganic N and P start reaching the coast via SGD by the time the Histosols are depleted, there may be many decades that beaches along the southeast Florida shore will be unusable due to poor water quality.

A second irony is that virtually all remedial efforts today focus on beach erosion hazards that are related to relative sea-level rise and the downdrift erosive impacts of inlets stabilized by jetties. There are thus many unlikely and unwitting partners in this story: beaches and agriculture, beaches and soils, beaches and coastal water quality. Perhaps the strangest facet of all is that most people can hardly conceive of beaches being closed or generally unusable for long periods of time. Such an occurrence would have far ranging political and economic impacts that most coastal dwellers and politicians prefer not to think about. We conclude with this final comment. The ostrich approach, burying one's head in the sand to avoid an unpleasant situation, may be cheaper in the short run. However, the longer we wait to correct the problem of contaminated SGD, the more expensive it will become to maintain usable beaches along the southeast coast of Florida.

The lesson from this, if one can be drawn before the scenario plays out in the fullness of time, is that humans cannot make arbitrary use of the earth and literally consume it, as in the case of Histosols in the EAA, and not expect a rebellion on the part of Nature, as philosophically explained by WEIGEL (1992). From a practical point of view, it is becoming painfully clear that the coastal plain of southeastern Florida can not sustain the means of production that agriculture and urban conglomeration demand and, as a consequence, we see not only degradation of the land but also of the coastal sea. The demand for the quality of life in general, ironically may bring the southeast coast of Florida to a problematical ecological question that involves desired uses of soils, water, and beaches.

CONCLUSIONS AND ECOPHILOSOPHY

Urban development of the subtropical southeastern coast of Florida, which took place in the last half century, was based on anthropocentric interpretations of the natural environment that fostered destructive development. Dynamic beach-dune systems were stabilized by construction of condominiums and commercial infrastructure, wetlands on the coastal plain were diked and drained for settlement, and inlets were blasted through bedrock to connect coastal waterways with the sea. Results of development (1) created accelerated coastal erosion, by fixing the position of the shoreline and stabilizing inlets, (2) interrupted and degraded natural water supply and quality by draining wetlands for agricultural and urban use, (3) introduced farming byproducts such as fertilizers and pesticides into the groundwater by leaching through organic soils, and (4) destabilized marine ecosystems along the Florida Reef Tract by pollution and contamination. These facts, as documented in the scientific literature, are a poor prognosis for sustainable development. By focusing remedial measures on the spectacular impacts of beach erosion, the insidious degradation of the Florida Everglades and water supply was largely ignored. When the originally 'unseen' deterioration of water quality in Florida Bay, the Florida Keys, and along the Florida Reef Tract became apparent, remedial efforts were implemented in year 2000 to 'restore' the Everglades. This $8 billion project is the most ambitious restoration project in human history and is expected to take at least three decades to accomplish. The effectiveness of the effort to correct this environmental disaster is a challenge to restoration and management.

Although reconstructive efforts have begun, the magnitude of the problem is yet to be realized because (1) the source of pollution and contamination of water supply (farming in the EAA) has not been mitigated and because (2) present high levels of contamination will not reach the Florida Reef Tract, via groundwater flow, until 2050–2075. Coral growth will likely be curtailed in the next half century by pollution of coastal marine waters with high nutrient levels of N and P. Sustainability of the present coralline ecosystem is thus unachievable and only time will tell whether the Everglades can withstand the environmental insults of land drainage, pollution of surface water, and restoration.

Before concepts of sustainability can be entertained as realistic action items in degraded coastal environments such as southern Florida, a societal metanoia needs to occur. According to Hessel (1998), there needs to be a change in the concept of humanity against nature in a manipulative, polluting way of life. Traditional approaches to the 'rational, scientific conquest of nature' have produced ecological malfunctions and malformations that now require ecological reformation. Perception of the southern Florida environment as a dynamic relational system by some researchers will hopefully foster earth-keeping habits or ecologically just patterns (eco-justice) (Stone, 1997) that will bring about a true earth-centered pneumatology that can be applied by water and land managers. The future in this region portends a societal will or desire to adopt ethics of sustainability, principles of sustainable livelihoods, and initiatives for sustainable development. The desire for living sustainably must involve a paradigm shift in academic knowledge to forestall other 'south Florida eco-disasters' from occurring elsewhere and develop methodologies to cope with ecocatastrophes that are in the making.

The relevance of these remarks from southern Florida are pertinent for the Black Sea coastal zone because, perhaps on a somewhat lesser scale similar problems have developed and are due to exacerbate. Perhaps they can inspire the local decision-makers to adopt courageous rectification and planning policies; the more so since some of the present US approaches are very costly and yet permanent.

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☐ RESUME ☐

La zone côtière a une densité de population très élevée atteignant les 2550 habitants au km2. Elle s'est transformée, en Floride méridionale, en une conurbation, surtout depuis 1900. Les floraisons d'algues ont mené à l'eutrophication en de nombreux endroits et, de ce fait, a conduit à une détériorisation de la qualité des eaux. Ceci se traduit par un danger de provoquer une éco-catastrophe qui engendrerait l'éclatement des écosystemes marins et côtiers. Le gouvrnement a alors lancé le projet de restauration des Everglades., le plus grand effort de remise en forme antérieure jamais entrepris au monde.

Suite à l'excès de phosphore et de nitrate, il s'est également produit une sérieuse dégradation de la barrière récifale (coraux). La concentration de nutrients près de la plage et dans les eaux la baignant constitue un problème majeur avec une incidence sérieuse pour le tourisme et les activités récréatives. Le "nettoyage" est une entreprise de proportions gigantesques et engendre des dépenses énormes. Et cependant tous ces efforts seront vains si les causes de cette situation ne sont pas neutralisées ou éliminées. La durabilité de l'habitat ne sera assurée que lorsque les meilleures pratiques de gestion basées sur une éthique environnementale sera mise en place plutôt qu'un souci de gain capitaliste. Cela requiert, toutefois, une volonté politique sans faille.