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A glimpse of the Florida Area Coastal Environment (FACE) program

T. Carsey[1], K.D. Goodwin[1], J. Hendee[1], J.R. Proni[2], C. Sinigalliano[3], J. Stewart[4], J-Z. Zhang[1], N. Amornthammarong[3], J. Craynock[1], S. Cummings[1], P. Dammann[1], C. Featherstone[1], J. Stamates[1], K. Sullivan[3]

1) National Oceanographic & Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, 4301 Rickenbacker Causeway, Miami, FL 33149, USA
2) Applied Research Center, Florida International University, 10555 West Flagler Street, Miami, FL 33147, USA
3) Cooperative Institute for Marine and Atmospheric Studies, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, USA
4) National Oceanographic & Atmospheric Administration, Hollings Marine Laboratory, 219 Fort Johnson Road, Charleston, SC 29412, USA

Abstract. The Florida Area Coastal Environment (FACE) research program gathers a variety of data related to water inputs into the coastal zone of southeast Florida. The water inputs studied include treated wastewater discharges, inlet flows, and upwelling events. Measurements include currents, nutrients, microbial contaminants, and stable isotopes. This report provides a glimpse of the data collected in this program. Data collected from the Boynton inlet point to the significance of this discharge as a source of nutrient and microbiological loads to coastal waters and demonstrate the importance of accounting for all major discharges in order to fully understand the impact of land use and water management decisions on coastal resources.

Key words: wastewater, inlets, Florida, nutrients, microbial contaminants.

Introduction

The Florida Area Coastal Environment (FACE) program is an ongoing research effort lead by the NOAA's Atlantic Oceanographic and Meteorological Laboratory in Miami, FL since 2004. The broad objectives of the studies include: (1) quantify the sources of selected nutrients and microbial contaminants, (2) ascertain the relative contributions of those sources to the nutrient budget and microbiologic loads of the region, and (3) determine the likely exposure of certain coral reef resources to those nutrient and microbiologic sources. The study area of FACE covers 364 km of coastline in the counties of Miami-Dade, Broward, Palm Beach, and Brevard, and includes six treated wastewater plants (TWWPs): Miami Central, Miami North, Hollywood, Broward, Boca Raton, and South Central (Fig. 1), which together contribute ~1 million cubic meters (284 millions of gallons) per day to the region. In addition, this coastal area receives fresh water discharged through six inlets, from the Miami Harbor inlet in the south to the Boynton inlet in the north (Fig. 1).

The FACE field campaigns have included inlet and outfall plume tracer studies, nutrient surveys, ocean current measurements via ADCP, microbiological survey studies, and stable isotope studies on a variety of research vessels (NOAA's R/V Cable and R/V Nancy Foster, R/V Coral Reef II, and the University of Miami's R/V Walton Smith). These field programs are outlined in Table I.

Material and Methods

Tracer Studies. An outfall tracer study was conducted on the Hollywood outfall in June 2004 by injecting sulfur hexafluoride (SF_6) gas into the outfall pipe over the course of six days. Methods for this study are available in Wanninkhof et al. (2005). A second outfall tracer study was performed near the outfall of the South Central Regional Waste Water Treatment Plant (SC) in 2007. In the latter study, rhodamine-WT dye (RD) was introduced into the effluent flow for a 48-hour period commencing on 26-Feb-2007. RD was also introduced into an outgoing tidal flow in the Boynton Inlet (26°32'43" N, 80°2'30"W), on 22-Feb-2007 to track the discharge of the inlet. The RD was tracked by ship using a towbody equipped with a hose and a pumping system to obtain water samples. Two sensors (YSI model 6600, for temperature, RD, chlorophyll, salinity, and

depth) were moored at the bottom and at mid-water above a location on Gulfstream Reef.

Inlet Intensive Studies. In addition to the tracer study at the Boynton Inlet, two 48-hour intensive water sampling periods were conducted at that location. The objective was to collect water samples over four complete tidal cycles in order to investigate the nutrient and microbial loads contributed by this inlet. The first sampling event was conducted June 4-6, 2007 and the second on September 26-28, 2007.

Table 1. FACE field programs.

Study Name	Goals	Study Area	Platforms	Notes	Dates
Hollywood Tracer	Define HW outfall plume 10-66 km	HW outfall	R/V Coral Reef II	Rhod-amine dye, SF_6	7-9 June 2004
Outfalls Survey 1	Survey of all six TWWP outfall plumes	all outfalls	R/V N. Foster	Nutrients, multibeam, microbio	6-19 Oct 2006
Outfalls Survey 2	Survey of all six TWWP outfall plumes	all outfalls	R/V N. Foster	Nuts, bio, isotopes	8-16 Feb 2008
FOCITE-1	SC outfall / Boynton Inlet tracer experiment	SC plume, Boynton Inlet	R/V Coral Reef II	Winter	19-22 Feb 2007
FOCITE-2	SC outfall / Boynton Inlet tracer experiment	SC plume	R/V Walton Smith	Summer	10-13 June 2008
Boynton Intensive-1	Water, Chem & Bio Flux thru Boynton Inlet	Boynton Inlet	ADCP	4 ebb & 4 flood tides	3-4 June 2007
Boynton Intensive-2	Water, Chem & Bio Flux thru Boynton Inlet	Boynton Inlet	ADCP	4 ebb & 4 flood tides	26-28 Sep 2007
Boynton Inlet Flows	1-year measurment of Boynton Inlet flow	Boynton Inlet	ADCP	horizontal ADCP	Feb-07 thru Oct-08
GSR-ADCP	1-year measurement of ocean current at GSR	GSR reef	ADCP	vertical ADCP	Apr-07 thru Jul-08
SC Monitoring Cruises	WQ sampling program around SC outfall	SC outfall	R/V Cable	six bimonthly cruises	June, Aug, Oct 07; Feb, May, Jul 08

Current Measurements. Three in-situ Acoustic Doppler Current Profilers (ADCP, RD Instruments) were installed to measure ambient currents in the area of the SC. A 300-kHz ADCP was installed at the south end of Gulfstream Reef (26°29.272'N, 80°2.35'W, 16.4 m depth, deployed 29-Sep-2006 to 1-Jul-2008). A 600-kHz ADCP was installed at the north end of Gulfstream Reef (26°31.247'N, 80°1.939'W, 14.5m depth, deployed 4-Apr-2006 to 9-Aug-2007).

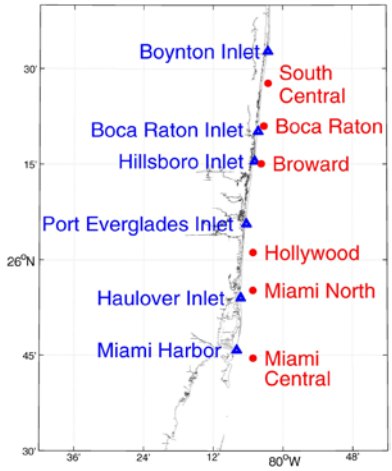

Figure 1. Locations of coastal inlets (triangles) and treated wastewater treatment plant outfalls (circles) in the FACE area of study.

Thirdly, a 1200-kHz ADCP was installed midway between the Boynton Inlet and the north end of Gulfstream Reef (26°32.004'N, 80°2.146'W, 14.8 m depth, deployed 20-Feb-2007 to 13-Apr-2007). These ACDPs yielded ambient current direction and magnitude measurements through the water column from near the ocean bottom to near the ocean surface. They also recorded ambient water temperature and pressure.

Nutrient Measurements. Water samples from bottom, mid, and surface waters at fifteen locations around the SC and the Boynton Inlet (Fig. 2) were obtained on bimonthly cruises for one year (see Table 1) and analyzed for a variety of nutrients, including ammonia (EPA Method 349.0; Zhang et al. 1997a), nitrate + nitrite (EPA Method 353.4; Zhang et al. 1997b), orthophosphate-P (EPA method 365.5; Zhang et al. 2001), total phosphorous (EPA Method 367.0; Zhang et al. 1998), and silicate (EPA Method 366.0; Zhang and Berberian 1997). Analyses were performed on a modified 5-channel Perstop Auto analyzer generally within three hours after sample collection.

Microbial Studies. Water samples collected from all cruises and inlet studies in Table 1 were analyzed for a variety of microbes, including fecal-indicating bacteria (FIB), pathogens, and source tracking markers. Viable enterococci FIB were enumerated using IDEXX Enterolert™ (EPA 2003). *Cryptosporidium* oocysts and *Giardia* cysts (protozoan pathogens) were determined by immunomagnetic separation and immunofluorescent microscopy (EPA 2001). Water samples for molecular analysis of viruses, bacteria, and source

tracking markers (1 L) were processed by membrane filtration prior to nucleic acid extraction. Water samples for analysis of protozoans (>100 L) were processed using FiltaMax™ cartridges (IDEXX). RNA viruses (noroviruses and enteroviruses) were analyzed by real-time quantitative reverse-transcription PCR (qRT-PCR). Standard PCR was used for detection of *Campylobacter jejuni*, *Salmonella* spp., *Escherichia coli* O157:H7, *Staphylococcus aureus*, human-specific enterococci, and adenovirus (LaGier et al. 2004). Real-time PCR (qPCR) was used to quantify enterococci, human-specific *Bacteroides*, and human-specific *Methanobrevibacter smithii*.

Results

Dilution of the outfall plume based on tracers. The tracer study conducted on the Hollywood outfall in 2004 demonstrated the utility of using SF_6 as a tracer for study of the farfield plume (i.e., > 400 m from the outfall). Transportation and dispersion of the plume depended on the physical oceanographic conditions encountered during the time of the study. The plume was incorporated into the ambient ocean current, generally northerly during these experiments, and remained in the upper portion of the water column following the initial rise out of the outfall pipe. The relationship determined for the dilution of treated wastewater (Dilution = 212 x distance [km] from the outfall, Wanninkhof et al. 2005) over 60 km was consistent with earlier outfall studies performed in that area within 2 km (Proni et al. 1994). In the 2007 tracer study, RD results suggested a dilution of approximately 233:1 in the area around the SC boil.

Currents. ADCP data for the 2004 tracer study were collected in the region of Dania Beach, FL. These currents were generally northward with an average flow of about 20 cm/s measured at 1.5 km from shore; although reversals to the south were observed during the six-day period of the study (Wanninkhof et al. 2005). ADCP data were collected near the SC outfall over a longer time frame. As observed in the area of the Hollywood outfall, currents to the south were measured; however, a northern current was measured ~86% of the time. The mean northward current was ~32 cm/s to the north at 3 m depth, tending to decrease with depth below 3 m. In addition, there was a mean eastward component to the current, measured at 6 cm/s at 3 m depth. The eastward component was fairly uniform with depth.

Nutrients. Only a small subset of the nutrient data collected to date is presented here. Averaged (over surface, mid, and deep-water values) nitrate + nitrite ("N+N", Fig. 3) and silicate concentrations (Fig. 4) were elevated in the area of the Boynton Inlet and the Lake Worth lagoon (Fig. 2) relative to surrounding areas, including in comparison to concentrations measured on and around the boil of the SC treated wastewater outfall. Ammonia concentrations (Fig. 5) were sometimes elevated in the lagoon (Oct 2007, July 2008) and sometimes at the boil (Aug 2007, May 2008). The highest average concentrations of orthophosphate-P were measured in the lagoon and inlet (0.54 and 0.2 µM, respectively; n=6 bimonthly cruises). Concentrations were lower at the boil (0.07 µM) and elsewhere (<0.04 µM).

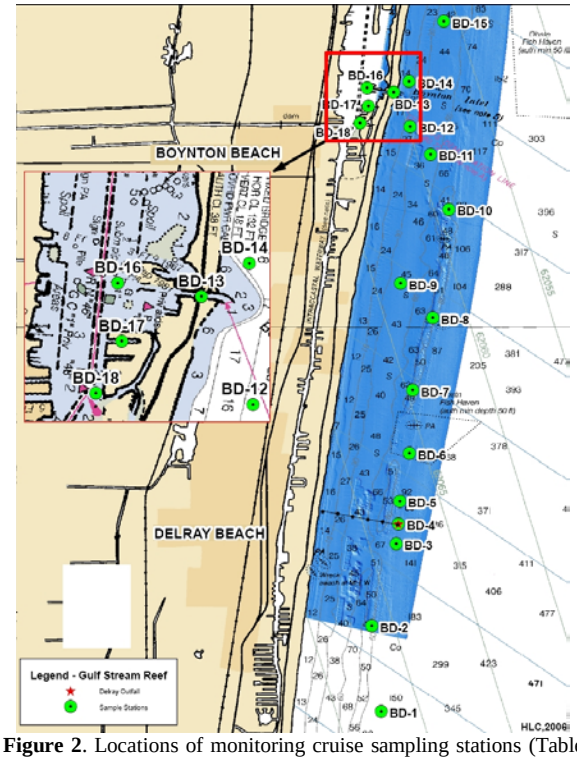

Figure 2. Locations of monitoring cruise sampling stations (Table 1). The SC ocean outfall is at BD-4, the Boynton Inlet at BD-13. Samples from within the Lake Worth lagoon are BD16, 17, and 18.

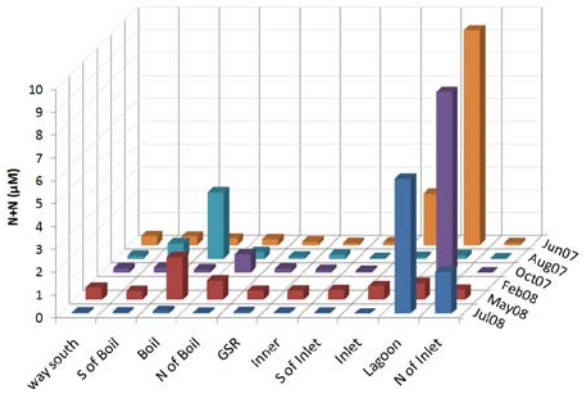

Figure 3. Concentrations of nitrate+nitrite from bi-monthly cruises. Referring to Figure 2, averaged concentrations are given for Way South = BD1 and BD2; S of Boil = BD3; Boil = BD4; N of Boil = BD5; GSR = BD6, BD7, BD8, and BD10; Inner = BD9; S of Inlet = BD11 and BD12; Inlet = BD13; Lagoon = BD16, BD17, and BD18; N of Inlet = BD14 and BD15.

Two 48-hour sampling intensives at the Boynton Inlet examined the nutrient loads from a total of eight ebb tides. A side-looking ADCP provided accurate flow data. A comparison was then made between the nutrient loads from the SC outfall (Koopman et al. 2006) and that from the nearby Boynton Inlet, shown in Table 2. Although there was significant variance in the Inlet ebb tide pulse masses, the average daily loading significantly exceeded or was comparable to that from the SC outfall.

Table 2. Mass loadings (kg/d) on ebb tide pulses from the June and September Boynton Inlet experiments (left) compared to the output of the South Central TWWP (right). For phosphorous, intensive units are dissolved inorganic phosphate; for SC the units are total phosphate (*), which includes particulate phosphate.

	June Intensive				Sept Intensive				Inlet Ave	SC Ave
	1	2	3	4	1	2	3	4	Mass	Mass
N+N kg [N]	204	99	138	23	569	476	303	105	479	191
Si kg [Si]	1196	955	1452	798	5255	4134	2248	1215	4313	
P kg [P]					362	195	116	31	352	79*
NH_4 kg [N]	171	68	89	41	599	524	286	78	464	545

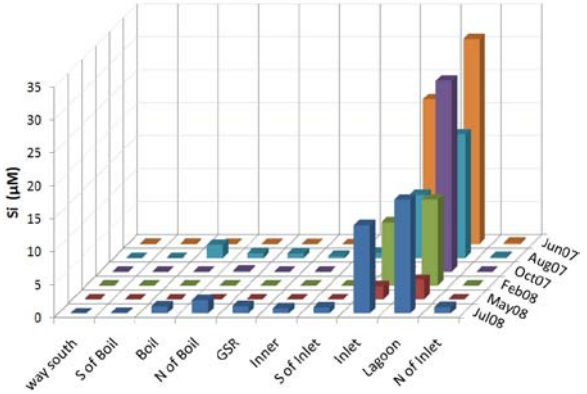

Figure 4. Concentrations of silicate from bi-monthly cruises. Sample denotations are as described in Figure 3.

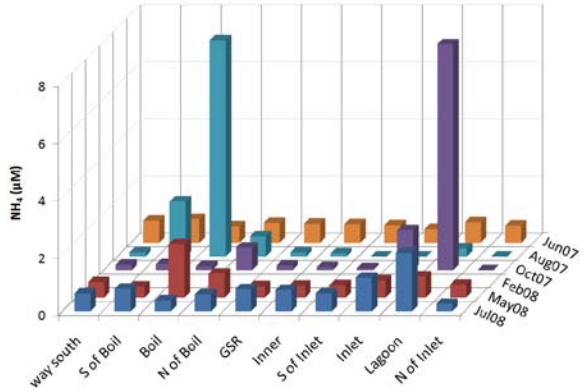

Figure 5. Concentrations of ammonia from bi-monthly cruises. Sample denotations are as Figure 3. No measurements were obtained from the February 2008 samples.

Microbiology. Only a small subset of the data collected to date is presented here. The inlet appeared to be a source of microbial contaminants to near shore waters as indicated by a higher percentage of positive detections for pathogens, FIB, and source tracking markers associated with the outgoing tide versus the ingoing tide (Fig. 6). A variety of microbial contaminants were detected in outgoing tides from the inlet. In comparison, water samples taken from the boil and near the bottom of the SC outfall (the closest outfall (the closest outfall to the Boynton inlet) did not yield positive results in February 2007 (Table 1). A low amount of enterococci DNA (<30 genome equivalents) was detected at the SC boil during a July 2008 cruise, and the abundance declined with distance from the outfall (Fig. 7).

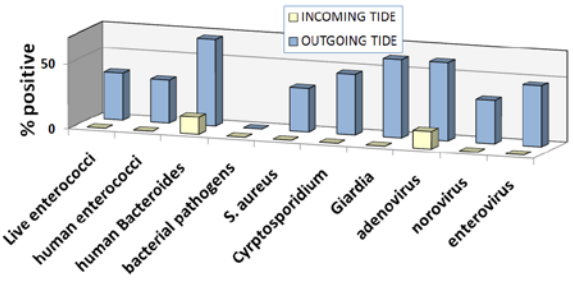

Figure 6. Detection of microbial contaminants for incoming vs. outgoing tides during a 48-hr intensive study at the Boynton inlet. Data show the percentage of samples showing positive detection for microbial contaminants out of 15 discrete time points. "Bacterial pathogens" is a composite for *Campylobacter jejuni*, *Salmonella* spp., and *Escherichia coli* O157:H7.

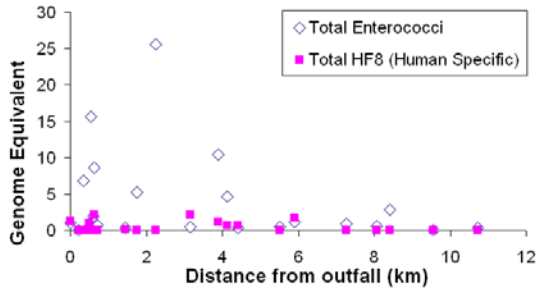

Figure 7. The abundance (genome equivalents) of enterococci and a human-specific *Bacteroides* (HF8) as measured by qPCR versus distance from the SC outfall (data from July 2008 R/V Walton Smith cruise).

Table 3. Microbiological data from surface water and bottom (btm) of the SC wastewater boils from a Feb. 2007 cruise aboard the Coral Reef II. No detection is indicated by "nd".

Target	surface	bottom
Live enterococci	-	-
human *Bacteriodes*	-	-
human enterococci	-	-
adenovirus	-	-
norovirus	-	-
MS2 phage	-	-
enterovirus	-	-
Salmonella ssp.	-	-
S. aureus	-	-
Cryptosporidium /100 L	2	nd
Giardia /100 L	3.4	nd

Compared to the SC outfall, samples from other outfalls yielded higher abundances of *Cryptosporidium* oocysts and *Giardia* cysts (Table 4) In general, the abundance of protozoan cysts appeared to dilute with distance because cysts were not detected at a distance of 1 km from the outfall (data not shown).

The abundance of norovirus and the human-associated FIB, *M. smithii* also were higher at the other outfalls tested (Table 4). These data provide a measure of total abundance; the percentage of viable organisms currently is unknown and is potentially low for these chlorinated effluents discharged into sun-lit coastal waters.

Table 4. Abundance of *Cryptosporidium*, *Giardia*, human-specific FIB, *M. smithii*, and human viral pathogens of the norovirus group measured by qPCR from surface water of wastewater boils from a Feb. 2008 cruise aboard the R/V Nancy Foster. (GE = Genome Equivalents).

Location	*M. smithii* (GE/100ml)	*Norovirus* (GE/100ml)	*Cryptosporidium oocysts*	*Giardia cysts* /100 L
SC boil	700	nd	nd	nd
Hollywood boil	3.0E+05	235	55	67
Boca Raton boil	2.7E+04	2.3	<1	<1
Broward boil	3.7E+04	6.3	8	2
Miami-N boil	1.3E+05	347	236	246
Miami-C boil	3.4E+05	11	8	120
deep water control	nd	nd		

Discussion

The data derived from the FACE work to date indicate that: (1) for the majority of the time the ambient current at the SC outfall vicinity flows to the north (slightly northeast) approximately 86% of the time; (2) minimal downward mixing of the effluent plume at any outfall was observed within the limits of the observations; (3) The water quality measurements made in the vicinity of the SC outfall showed that there was not a significant elevation of nutrient concentrations (N+N, NH_4, P) in samples at the GSR compared to the southernmost samples (in northward current regimes); (4) The flux of nutrients from the Boynton Inlet significantly exceeds (N+N and P) or is on the same order (NH_4) as that of the nearby SC outfall, indicating the importance of inlets as a source of nutrients to the coastal ocean.

In the case of microbial contaminants, the levels of microbial contaminants observed in the immediate vicinity of the southern outfalls and in some outgoing tides of the Boynton Inlet would be of public health concern were they in drinking water or full-body-contact recreational water. However, given the rapid dilution observed, it is likely that infectious risk to humans and fisheries is very low, except potentially in the immediate vicinity of the southern outfall boils.

The FACE project has collected a variety of data, including nutrient, microbiological, and oceanographic information to help understand the processes that effect Florida's coral reef habitat. The data presented here highlight the need to assess the coastal zone in a cohesive way, especially if data will be used to determine the impacts of land-based pollutants, and for the formulation of science-based regulation.

Acknowledgement

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