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Atlantic Oceanographic and Meteorological Laboratory
Miami, Florida

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Disclaimer

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Measurements of Chemical Loadings through the Hillsboro and Boca Raton Inlets (Florida, USA)

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May 2015

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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Acronyms

ADCP	Acoustic Doppler current profiler
AOML	Atlantic Oceanographic and Meteorological Laboratory
AWQP	Ambient Water Quality Program
DIN	Dissolved inorganic nitrogen (NO_2 + NO_3 + NO_4)
DO	Dissolved oxygen
FDEP	Florida Department of Environmental Protection
N+N	Nitrate + nitrite
NH_4	Ammonium (NH_4^{+1})
NO_2	Nitrite (NO_2^{-1})
NO_3	Nitrate (NO_3^{-1})
PO_4	Orthophosphate (aka soluble reactive phosphorus, SRP)
Si	Silicate
TN	Total nitrogen (dissolved + particulate)
TP	Total phosphorus (dissolved + particulate)
WWTP	Wastewater treatment plant

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Abstract

We describe a cost-effective methodology for obtaining loadings for the environmentally significant chemical species of silicate, nitrate, nitrite, ammonium, and orthophosphate through the Hillsboro and Boca Raton inlets (Florida, USA). Field measurements included "grab" water samples obtained from each inlet during an 18-month period and four ebb tide sampling intensives conducted at both inlets. During sampling intensives, water currents were measured from a small boat using a downward-looking acoustic Doppler current profiler, and water samples were collected for analysis. Loadings were computed from the sampling intensives data and estimated for the entire period using flow estimates generated from tidal range data. These data are presented as monthly loadings from each inlet.

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1. Introduction

Coral reefs worldwide face a wide array of threats, including impacts from overfishing, coastal development, land-based pollution from agricultural and urban runoff and shipping, warming oceans, and ocean acidification (Hoegh-Guldberg *et al.,* 2007; Kennedy *et al.,* 2013). These impacts have resulted in a decline in coral diversity and density, increasing competition with macroalgae, bleaching, disease, and reduced herbivory (Waddell and Clarke, 2008; Burke *et al.,* 2011).

Land-based sources of pollution include sediments, nutrients, pesticides, metals, pharmaceuticals, and pathogens (Redding *et al.,* 2013; Costa *et al.,* 2008; Collier *et al.,* 2008; NOAA, 2012; Gregg, 2013). These materials enter the reefal environment in many ways, e.g., point sources (wastewater outfalls, inlets), non-point sources (groundwater discharge, urban runoff), and atmospheric deposition (Wilkinson, 2008; Fabricius, 2005). Natural processes such as ocean upwelling also provide additional sources of nutrients (Bassin *et al.,* 2005; Hitchcock *et al.,* 2005).

A significant source of land-based pollution in southeast Florida is the coastal inlet (e.g., NOAA, 2012). This work is an attempt to estimate the flux of significant chemical entities through the Hillsboro and Boca Raton inlets, two of seven significant inlets draining into ecologically-sensitive waters off southeast Florida. This project supports NOAA's goal of healthy ocean ecosystems in that it provides a quantitation of the flux of key species to the coastal ocean, which informs local and state managers in support of ecosystem-based management of those waterways (NOAA, 2013).

2. Study Area

2.1 Geography

The southeast Florida coast is an increasingly developed area with essentially contiguous urbanization (Banks *et al.,* 2008; Finkl and Andrews, 2008). The area contains three significant sea ports (Port Everglades, the Port of Palm Beach, and the Port of Miami) with significant cruise and container ship traffic (Kildow, 2008). Tourism is Florida's top industry, drawing about 81 million visitors a year, employing more than 1 million people, and accounting for 21 percent of sales tax revenues (Johns *et al.,* 2001; Sedensky, 2010).

To accommodate the increasing population, a system of drainage canals in south Florida was built beginning in 1880, resulting in substantial changes in surface and groundwater flow (Sklar *et al.,* 2002; Light and Dineen, 1994). Canal waters are known to contain chemical fertilizers, pesticides, suspended solids and highly colored organic materials, elevated iron and nutrient concentrations, and contaminants from septic tanks and landfills (SFWMD, 2010). Canals and other surface waters, including the Intracoastal Waterway, flow to the ocean predominantly through a series of inlets: Palm Beach Inlet (Lake Worth), Boynton Inlet (South Lake Worth), Boca Raton Inlet, Hillsboro Inlet, Port Everglades Inlet, Bakers Haulover Inlet, Government Cut, Norris Cut, and Bear Cut (Table 1; Figures 1 and 2).

As the final venue for surface waters flowing into the coastal ocean, inlet waters have been noted as major point sources of pollution into the coastal ocean (Lapointe and Bedford, 2010; Puglise and Kelty, 2007). In addition to inlets, six wastewater treatment plant (WWTP) ocean outfalls are permitted to operate in the area (Koopman *et al.,* 2006; Bloetscher *et al.,* 2010). Ocean outfalls are permitted by the Florida Department of Environmental Protection (FDEP); current legislation mandates that wastewater utilities must cease most use of ocean outfalls by 2025 (Florida, 2013a). Characteristics of these outfalls are listed in Table 2.

The management of coastal waters with respect to land-based sources of pollution requires appropriate estimates of the loading of nutrients and other species into the reefal waters, both natural and anthropogenic (e.g., Florida, 2013b). Towards this end, we have endeavored to estimate the annual loads of a number of key nutrient species through the Hillsboro and Boca Raton inlets.

A large database of daily canal flow and rainfall rates from locations near the inlets is maintained by the South Florida Water Management District of the FDEP via the

Table 1. Inlets in southeast Florida.

Name	Latitude (°N)	Longitude (°W)	Source Body	Width (m)	Depth (m)
Palm Beach Inlet	26.7725	80.0333	Lake Worth Lagoon	220	35
Boynton Inlet	26.5453	80.0417	Lake Worth Lagoon	35	3
Boca Raton Inlet	26.3359	80.0704	Lake Boca Raton	50	3
Hillsboro Inlet	26.2578	80.0808	Intracoastal Wateway	94	3
Port Everglades Inlet	26.0935	80.1097	Lake Mabel	250	15
Bakers Haulover Inlet	25.9000	80.1214	Biscayne Bay	61	3.4
Government Cut	25.7636	80.1328	Biscayne Bay	122	11
Norris Cut	25.7573	80.1455	Biscayne Bay	---	---
Bear Cut	25.7313	80.1570	Biscayne Bay	---	---

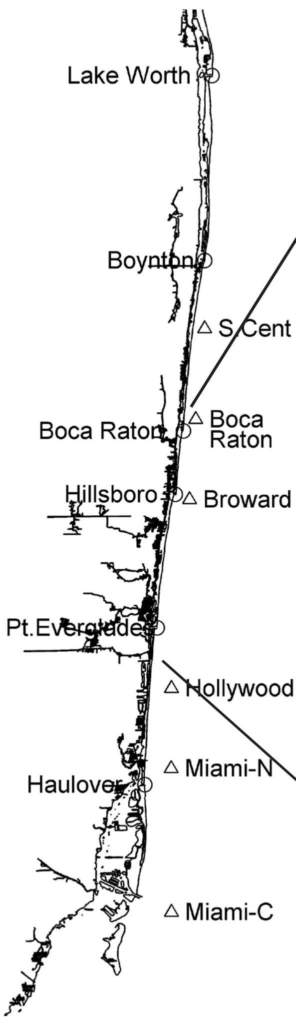

Figure 1. Inlets (circles) and wastewater treatment plant outfall sites (triangles) off of southeast Florida.

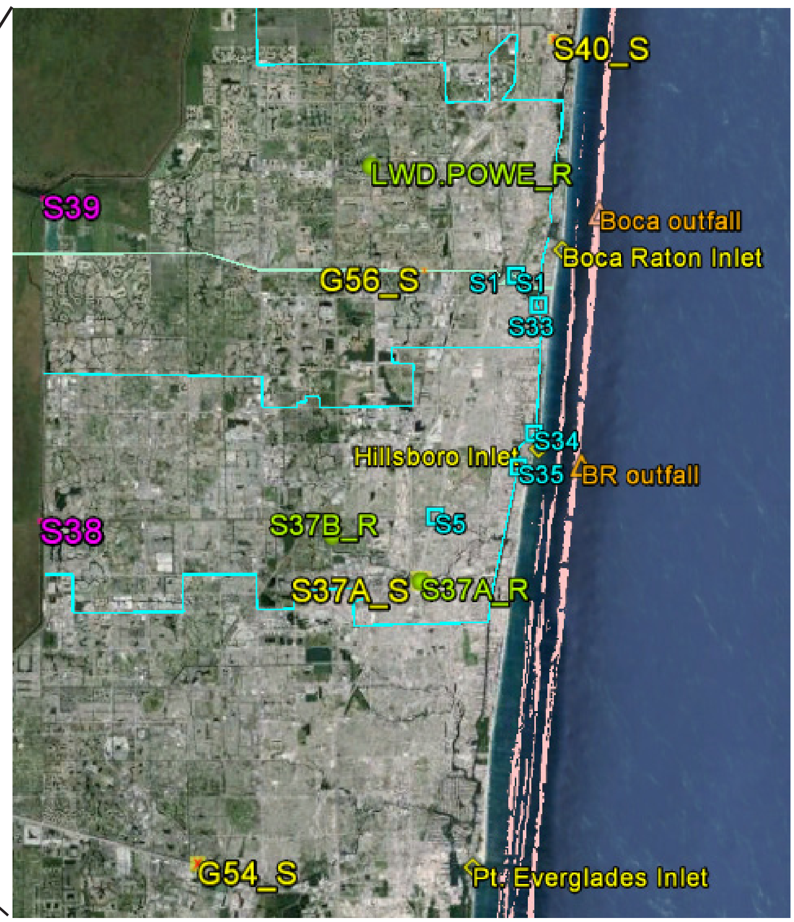

Figure 2. Southeast Florida and the offshore coastal ocean (GoogleEarth). DBHYDRO monitoring sites for Broward and southern Palm Beach counties, Florida, are noted: chemical measurement sites (S38 and S39) are shown in magenta; canal flow measurement sites (Table 3) in yellow; and rainfall sites (Table 7) in green; Broward County measurement sites (Table 4) with blue squares. Locations of the Hillsboro and Boca Raton inlets are denoted by yellow names; wastewater treatment plant outfall sites are denoted by orange triangles. Pink features offshore are the location of coral reefs (Florida Fish and Wildlife Conservation Commission, http://ocean.floridamarine.org/CSA). Blue lines indicate boundaries of the Inlet Contributing Areas for the Boca Raton and Hillsboro inlets.

Table 2. Wastewater treatment plant outfalls in southeast Florida.

Name	Latitude (ºN)	Longitude (ºW)	Length (m)	Depth (m)	Number of Ports	Annual Average Flow (MGD) 2006[1]	Annual Average Flow (MGD) 2011[2]
South Central	26°27.715	80°2.525	1.6	27.4	1	12.9	0
Boca Raton	26°21.016	80°3.243	1.6	27.4	1	10.3	7.3
Broward	26°15.083	80°3.724	2.2	32.6	1	37.4	22
Hollywood	26°1.147	80°5.156	3	28.3	1	40.1	12.4
Mia-North	25°55.384	80°5.370	3.6	32.9	12	81	45.8
Mia-Central	25°44.569	80°5.158	5.7	30.5	15	114.8	111.5
Totals						**296.5**	**199**

[1]From Koopman *et al.,* 2006.

[2]Communications from the WWTP utilities and the authors, 2012.

DBHYDRO internet site (www.sfwmd.gov/dbhydroplsql). Concentration data for various species (e.g., total nitrogen and total phosphorus) are also available at that website for some interior (canal) sites, generally monthly or biweekly. While of considerable value in understanding the meteorological, hydrological, and surface water chemistry characteristics of the inland areas, these data were deemed not sufficiently frequent for inlet loading calculation, nor were the monitoring locations sufficiently close to the inlets under study. Consequently, field operations were conducted by researchers with NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) from 3-May-2012 through 5-December-2013 to obtain inlet flow and concentration data in support of a methodology for a robust determination of the annual loadings of several important chemical species through the tidal inlets.

The Hillsboro and Boca Raton inlets are part of a sequence of inlets off of southeast Florida that provide the primary means for surface water from the land to enter the ocean (Figure 1). Hillsboro Inlet (26.2578°N, 80.0808°W) and Boca Raton Inlet (26.3359°N, 80.0704°W) are improved "choked" microtidal natural inlets separated by ~8.6 km (Kjerfve, 1986; Martin and Dominguez, 1994).

Boca Raton Inlet, which drains Lake Boca Raton, was first dredged in 1926 and has since undergone many modifications. Today, the entrance channel is approximately 150 feet wide and 10 feet deep (Palm Beach County, 2003). Hillsboro Inlet, in northern Broward County, was a meandering natural channel first improved with the addition of a rock jetty in 1930. In 1964, the channel was dredged to its present dimensions of 175 feet width and 10 feet depth (Broward County, 1997). The channel lies along the northeast bank. A shallow circular embayment on the southwest side had been the main channel of flow prior to dredging in the 1980s (Butler and McAllister, 2000).

The Hillsboro and Boca Raton inlets are connected by the Intracoastal Waterway, fed, in turn, by a complex canal system, as well as urban drainage, rainfall, and groundwater. The canals with the most significant contribution to the two inlets are described in Table 3. The extensive canal system in south Florida is maintained to provide groundwater control (e.g., to prevent salt water intrusion) and flood control (SFWMD, 2010). Canal flow data, along with surface water, meteorological, and other data are provided by the FDEP data portal DBHYDRO (www.sfwmd.gov/dbhydroplsql). The location of these sites is shown in Figure 2.

The nearest monitoring sites to the Hillsboro or Boca Raton inlets for rainfall, canal flow, and surface water chemistry are not close to these inlets, as can be seen in Figure 2. In particular, water chemistry sites S38 and S39, the only sites reporting total nitrogen (TN) and total phosphorus (TP) values for the period of this work, are each located ~25 km of distance along the C-14 and Hillsboro canals from the Boca Raton and Hillsboro inlets (respectively).

Table 3. Canal flow measurement sites (DBHYDRO).

Canal	Inlet Contributing Area*	Gate/Structure	Latitude (°N)	Longitude (°W)	Average Weekly Flow 2010-2013 (m^3/min)
C-15	Boca Raton	S40_S	26.119	80.612	85
Hillsboro	Boca Raton	G56_S	26.328	80.131	319
Pompano	Hillsboro	G57_S	26.231	80.124	23
C-14	Hillsboro	S37A_S	26.206	80.132	336

*Pickering and Baker, 2015.

Fortunately, the Broward County Department of Environmental Planning and Community Resilience has conducted an Ambient Water Quality Program (AWQP) which has obtained water samples at several pertinent sites, including quarterly sampling at the Hillsboro Inlet and the Intracoastal Waterway starting in February 2004; these data are available online (www.broward.org/NaturalResources/Lab/Pages/canalwaterquality.aspx). In particular, site S34 is on the Intracoastal Waterway just north of the Hillsboro Inlet. TN and TP concentrations from AWQP sites are shown in Figure 3. A summary of nutrient concentrations from these locations is provided in Table 4. However, these data were not considered sufficient for a useful determination of loadings through the inlet.

Flow rates at the four canals associated with the two inlets vary considerably, as well as during the year, with zero flow at each canal for extended periods of time during the dry season. Flow rates from the four canals affecting the Hillsboro and Boca Raton inlets from 2010-2013 are listed in Table 3 and shown in Figure 4. Comparison of Figures 3 and 4 indicate there is only marginal correlation between canal flow and nutrient concentrations.

2.2 Coastal Currents

We examine the characteristics of the coastal waters adjacent to the inlets into which their water flows. These characteristics determine the location of the effluent

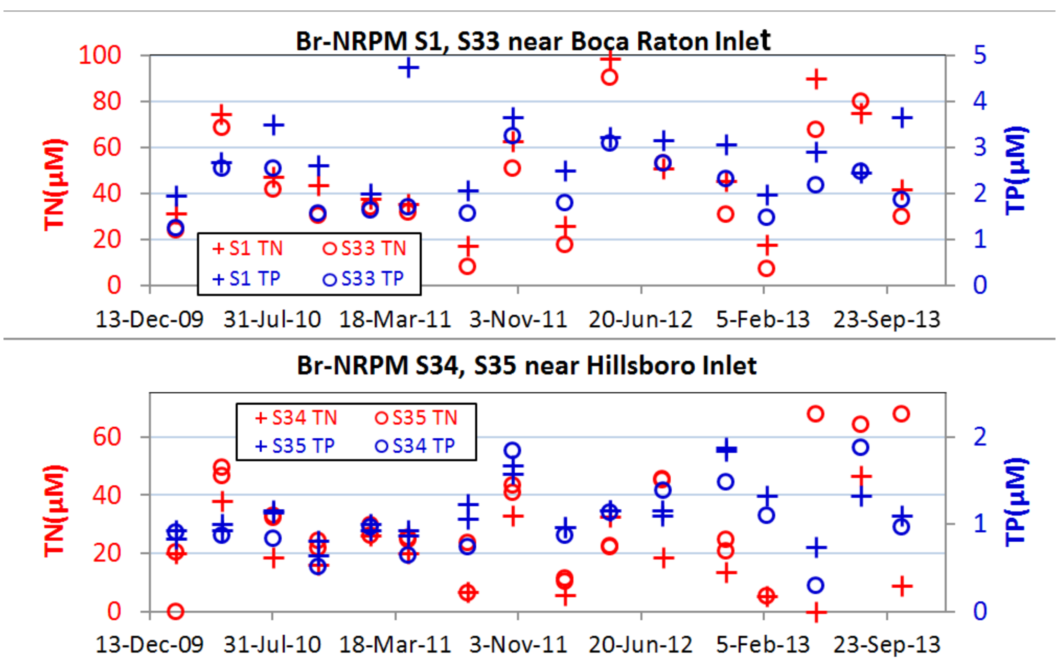

Figure 3. TN (red) and TP (blue) concentrations from AWQP sites S1 and S33 associated with the Boca Raton Inlet (upper panel) and from AWQP sites S34 and S35 associated with the Hillsboro Inlet (lower panel), 11-Feb-2014 through 21-Oct-2013.

Table 4. Broward County AWQP results from selected canal sites, 2010-2013 (concentration, standard deviation).

Name	Location	Latitude (°N)	Longitude (°W)	Chl-a (µg/L)	DO (mg/L)	Salinity (psu)	TN (µM)	TP (µM)
Site 1	Hillsboro Canal at US 1	26.326	-80.091	6.1 (3.3)	5.1 (1.2)	19.1 (16.9)	67.6 (28.6)	3.2 (1.0)
Site 5	C-14/Pompano Canal at US 1	26.231	-80.126	4.1 (2.6)	5.2 (1.5)	13.6 (11.4)	63.6 (27.5)	1.4 (0.3)
Site 33	Intracoastal Waterway south of Hillsboro Boulevard Bridge	26.314	-80.081	3.9 (2.8)	5.3 (1.3)	19.1 (16.3)	58.5 (28.8)	2.3 (0.8)
Site 34	Intracoastal Waterway 100′ north of Marker 71	26.264	-80.083	1.1 (1.7)	6.3 (0.7)	33.0 (4.9)	34.7 (27.5)	1.0 (0.4)
Site 35	Intracoastal Waterway 100′ north of NE 14 Street	26.251	-80.090	2.3 (2.0)	5.7 (1.2)	19.5 (12.0)	42.5 (23.9)	1.2 (0.3)

plume, either north or south of the inlet, as well as the mixing conditions (Fischer *et al.*, 1979).

The Southeast Florida Shelf, into which inlet waters flow, is narrow and shallow in this region, varying in width from 1-3 km and only about 30 m deep at the shelf break. To the east is the north-flowing Florida Current, a major component of the Gulf Stream. These waters are derived from the Caribbean (Cayman Current) and the Loop Current of the southern Gulf of Mexico. In the shelf, the current is generally northerly due to the proximity of the Florida Current but with frequent current reversals (Lee, 2011); these current reversals have been ascribed to Gulf Stream meanders and eddies (Lee *et al.*, 1991; Zantopp *et al.*, 1987). The current structure off Broward County has been measured by NOAA/AOML for more than 2 years using a group of four acoustic Doppler current profiler (ADCP) instruments (Carsey *et al.*, 2013), including nearshore and offshore instruments near the Hillsboro Inlet and nearshore and offshore instruments off of Port Everglades. The offshore instruments were located near the outer (third) reef tract. Details of the installation are given in Table 5.

The Hillsboro nearshore ADCP current flow rates and direction results for April 2011 are shown in Figure 5. As seen there and similarly from measurements made at the other three instruments (Carsey *et al.*, 2013), current directions did not typically change with depth, i.e., changes in the current direction occurred essentially concurrently throughout the water column. In all cases, current velocities decreased with depth.

It is also evident from Figure 5 that frequent current reversals were a dominant feature of the long-term data. These reversals have long been noted (e.g., Lee and Mayer,

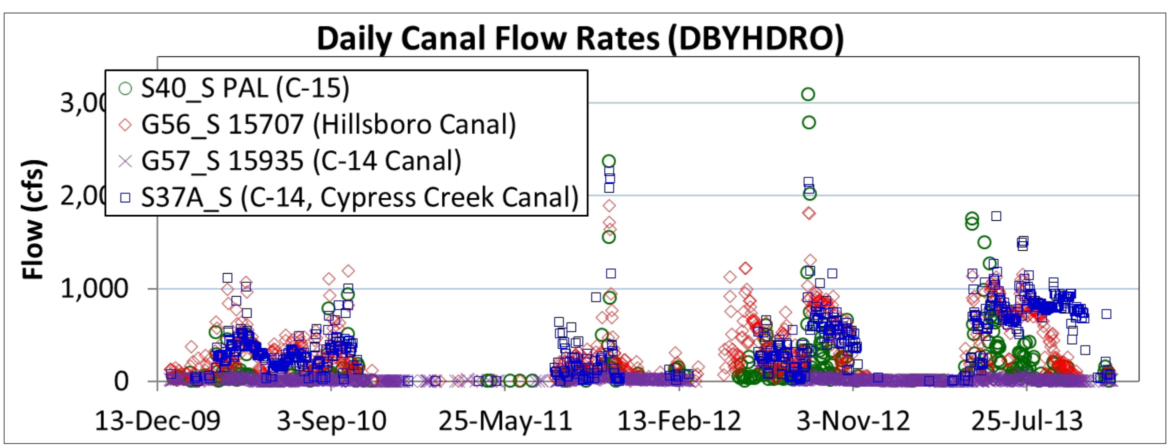

Figure 4. Flow rates from the four canals that flow into the Intracoastal Waterway near the Hillsboro and Boca Raton inlets (DBHYDRO) for the time span 2010-2013.

Table 5. Current measurements from the nearshore and offshore ADCP instruments.

	Hillsboro Inet Nearshore	Hillsboro Inet Offshore	Port Everglades Nearshore	Port Everglades Offshore
Latitude	26°15.887′N	26°15.00′N	26°1.149′N	26°1.1075′N
Longitude	80°4.568′W	80°3.752′W	80°6.518′W	80°5.1716′W
Depth (m)	8.2	32.4	7.3	26.2
Distance offshore (km)	0.37	2.18	0.59	2.87
Average speed (cm/s)	2.01	18.68	-1.3	7.8
Start date	14-Oct-10	17-Aug-10	14-Oct-10	17-Aug-10
End date	2-Apr-13	18-Dec-12	2-Apr-13	7-Feb-13
Percent south flow	40.2	27.1	51.7	33.7

1977). Our measurements from the four instruments (2010-2013 with some gaps, Table 5) were characterized by reversals every 6-8 hours.

Two different mechanisms have been employed to describe current reversals (EPA, 1992). The western edge of the Florida Current is not fixed; it is known to meander. Meanders are a northward-moving displacement wave of the mean profile of the Florida Current, with periods ranging from a few days to 2 weeks (Lee and Mayer, 1977). In some cases, meanders are correlated with onshore winds (Lee and Atkinson, 1983). Meanders can result in counterclockwise rotating fronts that cause upwelling of deeper, nutrient-rich waters of the Florida Current into the shelf. Eddy diameters range from 5-30 km and may take 1-2 days to pass. They appear to occur about once per week throughout the year (Zantopp *et al.,* 1987).

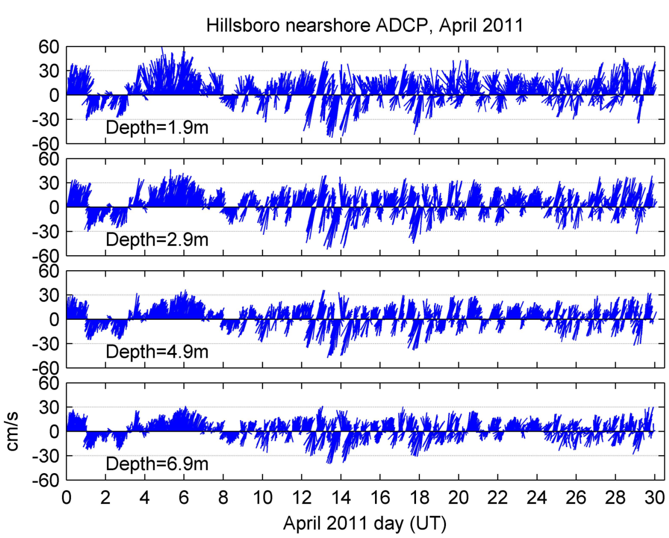

Figure 5. Ocean currents at the Hillsboro Inlet nearshore ADCP during April 2011, measured at four depths from the surface. Each panel presents current stick plots indicating the direction of current flow; the length of the stick indicates the flow velocity as denoted by the y-axis.

While meanders may result in current direction changes and temperature and salinity fluctuations via upwelled water, there is no exchange of water mass across a meander front. A related phenomenon leading to current reversals is that of a frontal (spin-off) eddy, which conveys Florida Current water into the coastal region via northward transport of upstream eddies (Lee *et al.,* 1991; Lee *et al.,* 1995).

ADCP measurements at the Hillsboro nearshore instrument during 2011-2012 found that north- or south-flowing events had an average duration of 6-8 hours, slightly longer in duration than the south-flowing events. Both north- and south-flowing events were of somewhat shorter duration near the surface. The average flow velocities during north- or south-flowing events were also examined; as expected, average velocities during the events decreased with depth. These results are summarized in Figure 6. Changes in the intensity and duration of reversed flow events with month are shown in Figure 7 (data from 2011 and 2012). While some trends are suggested, none are statistically significant.

Overall, the current flowed southward about 45 percent of the time with an average velocity of 12 cm/s. A histogram of the entire data set is given in Figure 8. A similar result was found at an instrument pair located near Port Everglades,

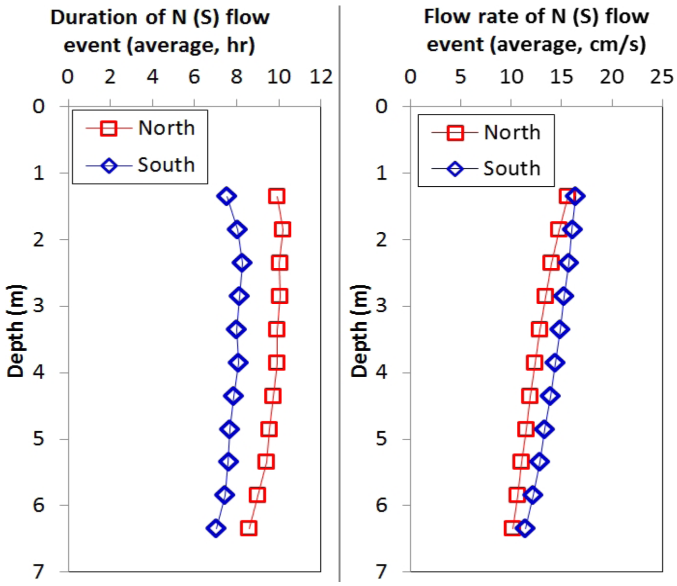

Figure 6. Depth analysis of north- and south-flowing events (exceeding 40 min in duration) as recorded at the Hillsboro Inlet nearshore ADCP. Left: Duration of each north or south event from all depth bins. Right: Average velocity during north or south flow events.

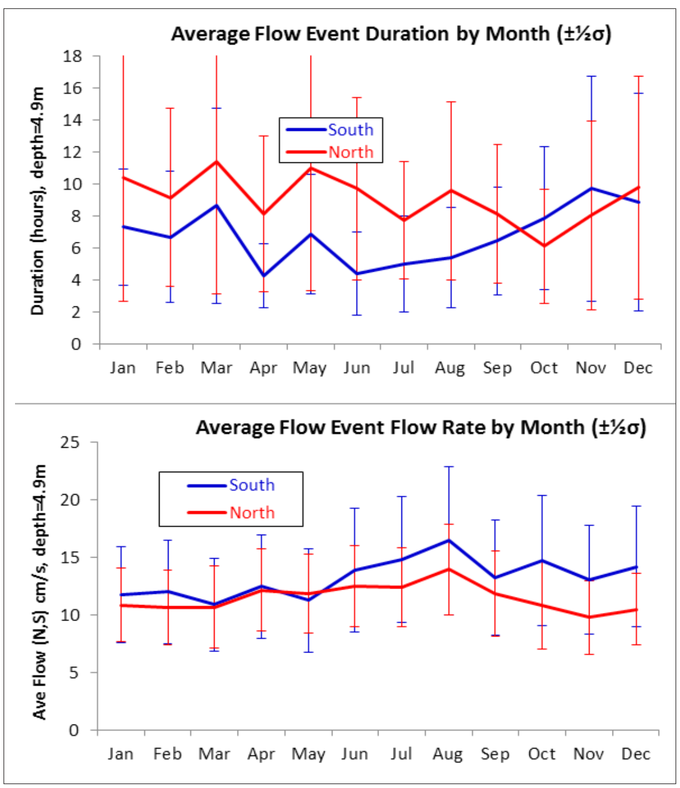

Figure 7. Average duration (upper plot) and flow rate (lower plot) by month for north-flowing and south-flowing events during 2011-2012 at the Hillsboro Inlet nearshore ADCP at a depth of 4.9 m. Vertical bars denote one standard deviation (± ½σ). While some trends are suggested in both data sets, no statistically significant changes across month of the year are evident.

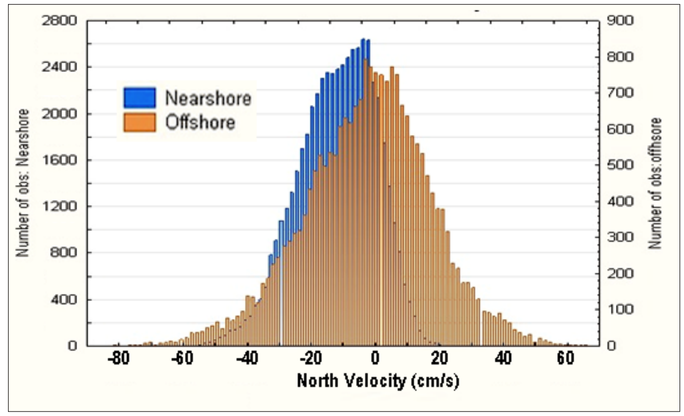

Figure 8. Histogram of the north component of the (water-columed averaged) currents as measured from the nearshore (blue) and offshore (red) ADCP instruments off of Hillsboro Inlet. The measurements were obtained from 17-August-2010 through 20-October-2011.

Table 6. Characteristics of nearshore and offshore currents from four ADCP instruments.

	Port Everglades	Hillsboro Inlet
Offshore north[1]	64%	73%
Nearshore north	44%	55%
Both nearshore and offshore north	36%	54%
Both nearshore and offshore south[2]	28%	25%
Offshore north, nearshore south	28%	20%
Offshore south, nearshore north	8%	2%
Offshore north velocity (cm/s, average)	20	31
Offshore south velocity (cm/s, average)	17	21
Nearshore north velocity (cm/s, average)	9	26
Nearshore south velocity (cm/s, average)	12	25

[1]Percent of total flow measurement with directions ≥270° and ≤90°.
[2]Percent of total flow measurement with directions ≥90° and ≤270°.

except that in the latter location more than 50 percent of current flow was southerly at the nearshore site (Table 6).

How do the current regimes compare from nearshore to offshore? During the period of May-September 2011, both the Hillsboro nearshore and offshore ADCP instruments were simultaneously operating. Stick plots from May and June 2011 are shown in Figure 9; clearly, there was a striking similarity in the current characteristics. These and similar data from the instruments listed in Table 6 suggest several overall themes. First, the current flowed in the same direction across the shelf most of the time; currents were

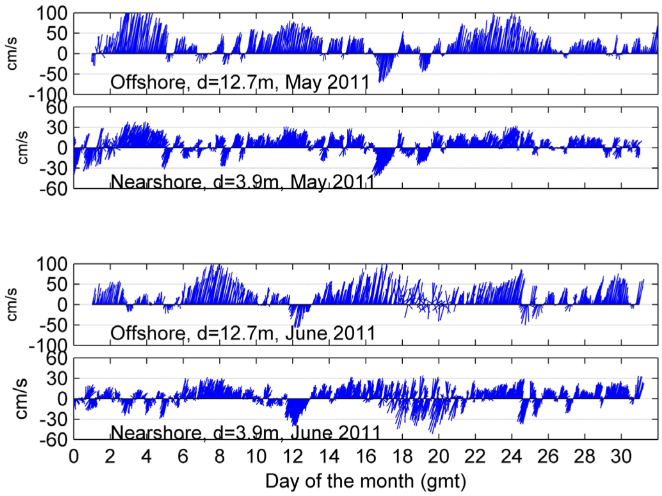

Figure 9. Current stick plots for May (upper plots) and June (lower plots) of 2011; for each month both offshore and nearshore results are presented. Format is similar to Figure 5.

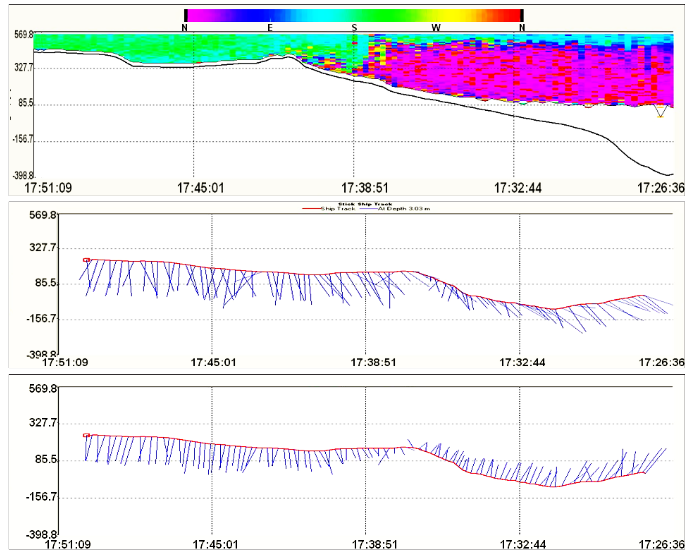

Figure 10. Current profile from a transect on 7-November-2012 off Hillsboro Inlet. Upper plot: Current directions as denoted in inset. Time proceeds left to right so that east (shoreward) is on the left, west is to the right. Y-axis is the ship's north direction in meters. Middle plot: Current stick plot at a depth of 3 m. Lower plot: Stick plot of the currents averaged over the water column.

found to flow north (or south) simultaneously at nearshore and offshore locations 64% of the time off Port Everglades Inlet and 73% of the time off Hillsboro Inlet. Second, the currents flowed in the same direction from the seafloor to the surface at both nearshore and offshore locations (velocities decreased with increasing depth). When current rotations occurred, as they did every 6-8 hours at the nearshore site, the rotation was rapid through the water column with very little east-to-west or west-to-east movement. Lastly, west-to-east or east-to-west velocities were much less than northward or southward velocities; in particular, the percent of time when both nearshore and offshore instruments simultaneously measured east (or west) movement was small. These results are summarized in Table 6, which incorporates data from all four ADCP instruments described in Table 5.

We also examined how ocean currents in this region changed longitudinally. A downward-looking ADCP was installed on a small boat (RV *Cable*) during a sequence of east-west transects off Broward County at ~26°16′N (south of the Hillsboro Inlet). Results from 7-November-2012 are shown in Figure 10. The current was northward east of the third reef tract and southward west of that location (below the surface layer). The surface current was southerly to southeasterly all along the track, even when the deeper current was northerly, probably due to the southwest winds observed during and prior to the measurements (Carsey *et al.*, 2013).

2.3 Rainfall

Rainfall rates from stations near the Hillsboro and Boca Raton inlets for the period 2010-2013 are shown in Figure 11 and summarized in Table 7. This region experiences a distinct rainy season, generally June through September (McPherson and Halley, 1996). As canal levels are maintained for groundwater control, as well as flood control (SFWMD, Canals of South Florida), the operations of canal control structures are not necessarily synchronous with rain events. Thus, it is not possible to predict canal flow based on rainfall. FDEP monitoring sites G56 and G57 have both rainfall and flow rate measurements; flow and rainfall rates from these sites for 2010-2013 are plotted in Figure 12. In the best case of G57, only about 23 percent of the canal flow is a function of nearby rainfall based on daily flow and rain rates.

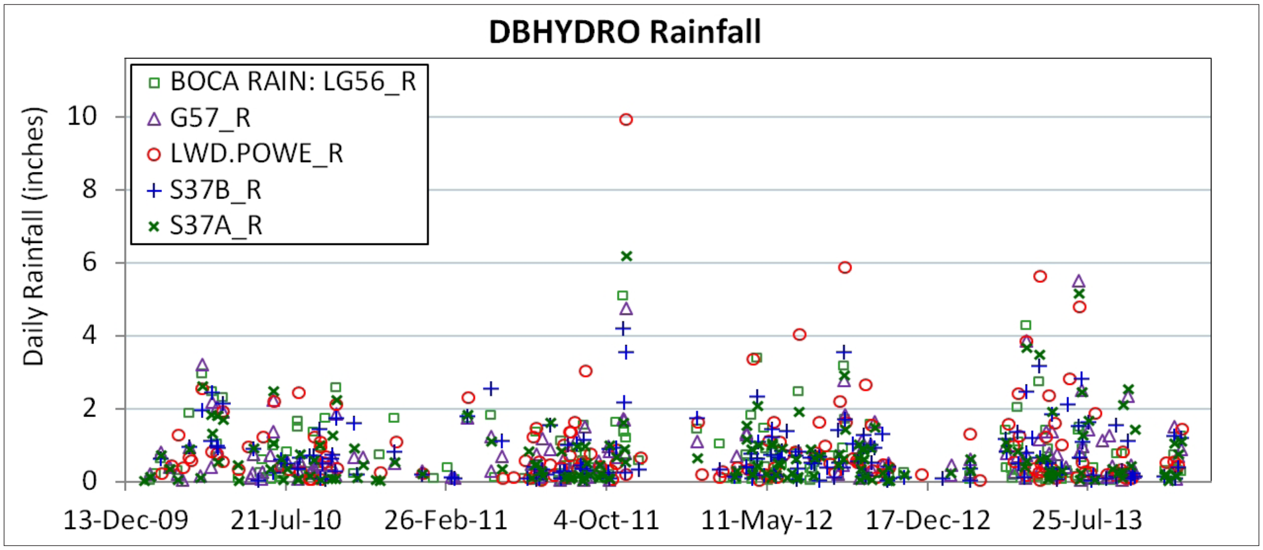

Figure 11. Weekly averaged rainfall from five FDEP rainfall stations within the stations near the Hillsboro and Boca Raton inlets.

Table 7. Rainfall measurement sites (DBHYDRO).

Rain station	Inlet Contributing Area*	DBKey	Latitude (°N)	Longitude (°W)	Average Weekly Rainfall 2010-2013 (cm, st dev)
LWD_POWE_R	Boca Raton	5793	26.36897	80.15393	0.39 (0.56)
G56_R	Boca Raton	K8627	26.32786	80.13088	0.39 (0.53)
G57-R	Hillsboro	K8628	26.23119	80.12421	0.37 (0.56)
S37B_R	Hillsboro	K8667	26.22397	80.17025	0.40 (0.54)
S37A_R	Hillsboro	K8664	26.20611	80.13166	0.40 (0.56)

*Pickering and Baker, 2015.

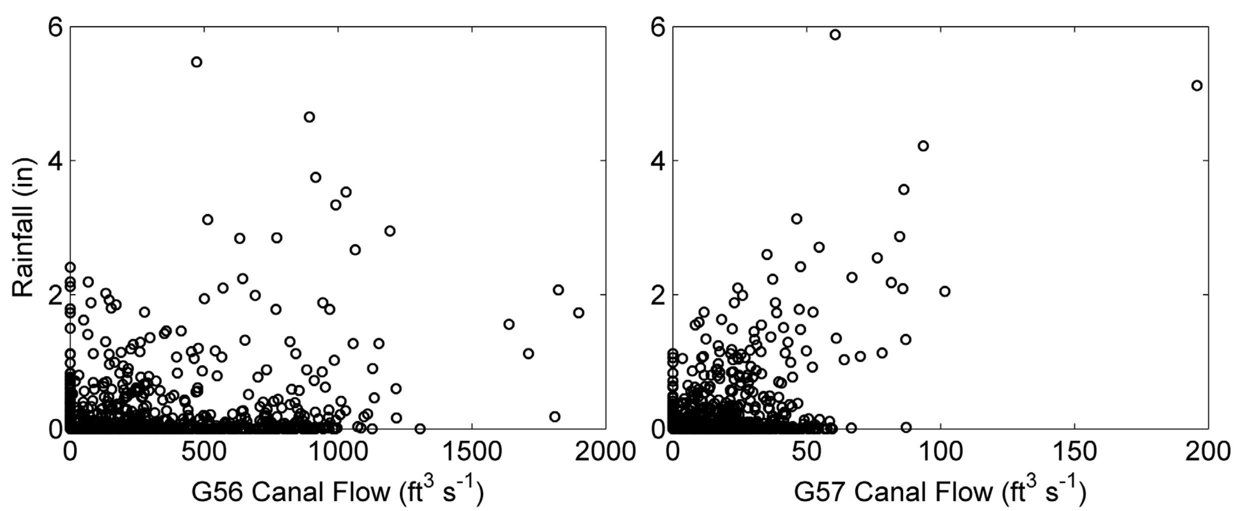

Figure 12. Canal flow versus rainfall for FDEP stations G56 (left) and G57 (right), 2010-2013. Each site reported rain and flow measurements obtained on the same day. The coefficient of determination (R^2) is 0.068 for the G56 location and 0.234 for G57.

2.4 Winds

Winds have been shown to have a significant effect on inlet flows, especially if there is a significant fetch across the nearshore water body (Fischer *et al.,* 1979; Smith, 1990; Stamates *et al.,* 2013). While neither the Hillsboro nor Boca Raton inlet is associated with a long fetch, both inlets are connected to sections of the Intracoastal Waterway that proceed more or less north and south from each inlet. Thus, strong northerly or southerly wind may increase flow from the corresponding branch of the Intracoastal Waterway and, consequently, change the source of material exiting from the inlet.

Meteorological data from the closest NOAA meteorological station at Port Everglades (PVGF1, http://www.ndbc.noaa.gov/station_page.php?station=pvgf1) were obtained for the days of the intensives and are shown in Figure 13. At Hillsboro, the winds were generally nearshore, east-northeast to east-southeast. At Boca Raton, winds were nearshore, as well as offshore during the intensives.

3. Methods

3.1 Water Grab Samples

Water grab samples were obtained via bucket at suitable locations at both inlets approximately every 2 weeks from 3-May-2012 through 5-December-2013 (Figure 14). At the Boca Raton Inlet, sampling took place on the north shore along a straight seawall (~26.3401°N, 80.0724°W). At the Hillsboro Inlet, it was considered that there might be differences in the chemistries of the north and south branches of the Intracoastal Waterway; sampling took place at two sites ("N" at ~26.2616°N, 80.0829°W, and "S" at ~26.2618°N, 80.0839°W). Because samples were obtained at two Hillsboro sites but only one Boca Raton site, there were more samples from Hillsboro Inlet (76) than from the Boca Raton Inlet (39).

The waters samples were characterized immediately with a hand-held probe instrument (YSI Pro-Plus, YSI, Yellow Springs, OH). Aliquots were returned to the laboratory for nutrient analysis as described in Carsey *et al.* (2013). A summary of the analyses is provided in Table 8.

3.2 Mass Loading Measurement Methodology and Tidal Prism Calculations

We estimated the mass loading of key chemical species via the Hillsboro and Boca Raton inlets into the coastal ocean. Chemical loadings were computed as the product of concentration and flow rate (equation 1) (Chapra, 1997). For the case of tidally-driven flow, we assumed a chemical loading per ebb tide (equation 2), which is the product of the average concentration and the tidal prism. The tidal prism, meaning the total amount of tidally-driven water flow into or out of an inlet, is the time-integral of the volumetric flow through an inlet for the duration of the ebb tide.

Loading = QC, where Q is the volumetric flow rate and C is the concentration. (1)

Loading per ebb tide = PC, where P is the tidal prism (volume) of an ebb tide. (2)

The next task was to determine the ebb tide prism for the Hillsboro and Boca Raton inlets. Estimates of the tidal prism at some Florida inlets exist in the literature. Marino (1986) reported a tidal prism value of 5.5×10^6 m^3 for Boca Raton Inlet. The details of this measurement were not available. Jarrett (1976) produced tidal prism data for many Florida inlets but not for the Hillsboro or Boca Raton inlets. There was no listing for the two inlets in the U.S. Army Corps of Engineers' Coastal Inlets Research Program (http://cirp.usace.army.mil). Consequently, because loads through inlets are highly variable (Stamates, 2013) and accurate values are necessary for this work, we generated accurate tidal prism measurements that were concurrent with nutrient concentration measurements.

3.3 Inlet Sampling Intensives

A series of four sampling intensives was conducted at both the Hillsboro and Boca Raton inlets (Table 9). These intensives were designed to obtain careful flow measurements and simultaneous water samples. A small boat (NOAA RV *Cable*, R-2104) made frequent crossings of the inlets along the paths indicated in Figure 14. A complete coverage of an outgoing (ebb) tide was planned; in some cases, the start or end of the tidal cycle

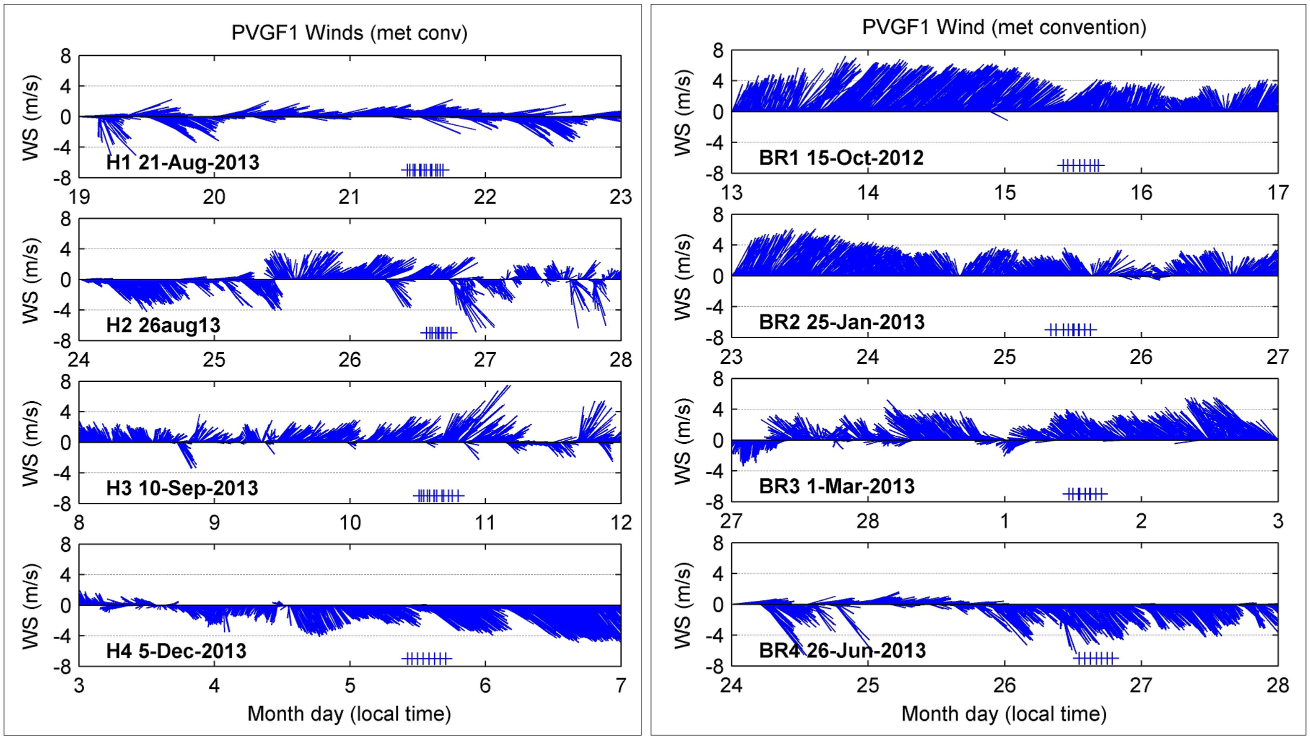

Figure 13. Winds from NOAA station PVGF1 (Port Everglades) for the Hillsboro (left) and Boca Raton (right) intensives. Wind barbs indicate direction wind is coming from. Intensive sampling times are denoted by blue "+" symbols on the day of the intensive.

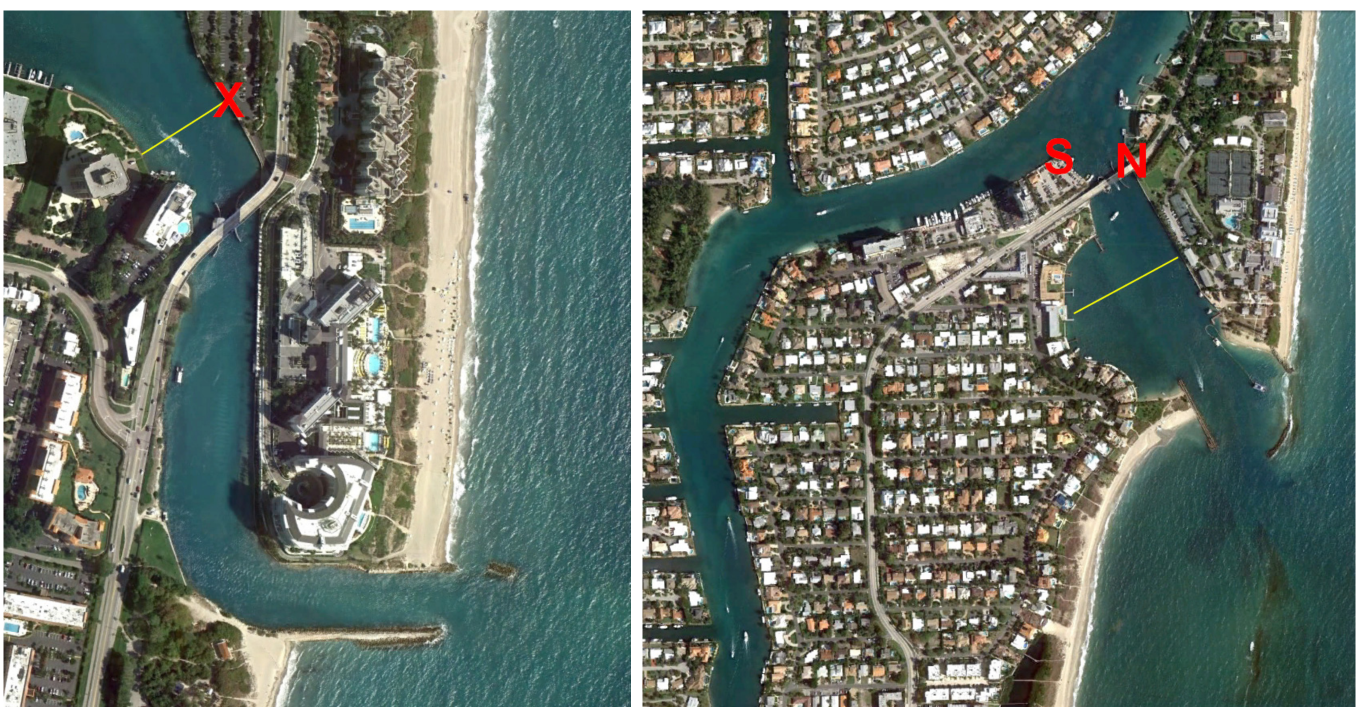

Figure 14. Grab sample locations for the Boca Raton (left) and Hillsboro (right) inlets, indicated by red lettering. Yellow line denotes approximate track of the RV *Cable* during sampling intensives. Images from GoogleEarth.

Table 8. Sample analytical parameters.

Sample	Name	Symbol	Unit	Detection Limit/ Resolution	Sample type	Minimum	Maximum
YSI Sonde	Barometric pressure	BP	kPA	0.1 mmHg	grab	101.0	102.6
"	Salinity	Sal	psu	0.01 ppt	grab	5.72	35.85
"	Dissolved oxygen	DO	mg/L	0.1 mg/L	grab	2.82	8.67
"	Oxidation-reduction potential	ORP	mV	0.1 mV	grab	80.6	273.0
"	pH	pH	units	0.01 units	grab	7.48	8.21
"	Water temperature	Temp.	°C	0.1°C	grab, intensive	22.00	31.09
Water (AOML)	Nitrite	NO_2	µM	4 nM	grab, intensive	0.01	4.66
"	Nitrate	NO_3	µM	21 nM	grab, intensive	0.00	15.11
"	Ammonium	NH_4	µM	32 nM	grab, intensive	0.00	21.11
"	Orthophosphate	PO_4	µM	11 nM	grab, intensive	0.00	3.30
Water (SERC)	Total phosphorus	TP	µM	0.03 µM	Intensive	0.1	1.3
"	Total nitrogen	TN	µM	5.71 µM	Intensive	3.1	42.3
"	Chlorophyll-a	Chl-a	µg/L	0.1 µg/L	Intensive	0.5	10.7

Table 9. Sample intensives summary.

No.	Inlet	Date Sampled	High Tide	TOD Start (local)	TOD End (local)	Number of WQ Samples	Number of Transects	PVGF1 Wind Speed (m/s)	PVGF1 Wind Dir (0°=N)	Rain 2 days (in)
1	Boca Raton	15-Oct-12	9:49	10:18	16:25	8	65	6.2	39	0.3
2	Boca Raton	25-Jan-13	8:03	8:05	15:05	11	117	3.8	12	0.0
3	Boca Raton	1-Mar-13	5:56	11:15	17:00	16	115	3.9	-66	0.5
4	Boca Raton	26-Jun-13	12:26	13:05	18:55	7	126	3.9	113	0.0
1	Hillsboro	21-Aug-13	9:08	10:00	16:25	18	105	3.7	94	0.0
2	Hillsboro	26-Aug-13	13:08	13:25	17:45	11	67	3.0	75	0.0
3	Hillsboro	10-Sep-13	12:38	12:05	19:00	14	80	3.4	56	0.0
4	Hillsboro	4-Dec-13	9:43	10:15	17:00	8	105	3.0	10	0.0

was missed. Flow measurements were obtained via a downward-looking ADCP instrument (RD Instruments 1200-kHz) mounted on the vessel as previously described. Water samples were obtained hourly in the center of the waterway via hand-deployed bucket during each crossing. In addition, water samples at both inlets were obtained during the intensives at three locations along the cruise track to examine the degree of homogeneity in the chemical and physical characteristics of the inlet waters in nearly simultaneous time.

Water samples from the intensives were analyzed in two laboratories. At AOML, water samples were analyzed for the dissolved nutrients nitrite (NO_2^-), nitrate (NO_3^-), ammonium (NH_4^+), orthophosphate (PO_4^{-3}), and silicate ($Si(OH)_4^{-4}$) according to published methods (Carsey *et al.*, 2013). (We will use the standard denotations NO_2, NO_3, NH_4, PO_4, and Si, respectively.) Samples were also sent to the Southeast Environmental Research Center of Florida International University (http://sercweb.fiu.edu) for analysis of chlorophyll-a, TN, and TP. A summary of the analytical parameters gathered during the eight intensives is given in Table 8, including wind speed and direction during each intensive from station PVGF1 (Port Everglades) and rainfall from the day of the intensive plus the day before (from DBHYDRO).

3.4 Tidal Prism Calculations

Measuring the volumetric flow rate of the channel required making simultaneous measurements of the channel bathymetry and channel velocity structure during transects across the channel. Determining the tidal prism required integrating multiple measurements of the volumetric flow rate (Q) made during an ebb tidal period.

To make measurements of the inlet channel bathymetry and of the water velocity structure throughout the channel, a 1200-kHz Teledyne RD instruments, Rio Grande ADCP, along with the survey software, Win River II (Teledyne RD Instruments San Diego, CA), was used. The instrument was deployed via a fixed mounting (U.S. Geological Survey Hydroacoustics) from the side of the RV *Cable*.

After deploying the instrument from the side of the vessel, the depth of the transducers below the water surface was measured and entered into the survey software. This instrument contains an internal compass. The compass provides the orientation of the system relative to magnetic north. The compass was calibrated before each survey effort using procedures specified by the manufacturer. The magnetic declination for the area (estimated to be 6°W) was entered into the survey software so that the processed velocity data were relative to true north. A differential Global Positioning System (GPS) was connected to the survey software for the location of each velocity measurement to be recorded along with that measurement. The ADCP transmitted a coded acoustical signal from four transducers, each of which was angled 20° from vertical. After transmission, the instrument received acoustical signals backscattered from particles in the water or from reflection off the seafloor.

To calculate bathymetry, the system calculated the distance along each beam's path from the instrument to the seafloor. The survey software corrected this data for the beam angle, system tilt and roll, and then calculated the depth vertically below the system.

To calculate water velocities, the radial Doppler velocities along each beam, returned from particles suspended in the water column (assumed to be moving at the same rate as the water), were calculated. The data were corrected for system tilt and roll, and a three-dimensional water velocity estimate was calculated. This water velocity estimate was then converted to north, east, and vertical components using information from the system compass. By dividing the returned acoustical signal into segments, the ADCP was capable of reporting velocity measurements in bins located through the water column. As configured for this application, the system made velocity measurements in 0.25-m bins starting 1 m from the surface and extending down to within 1 m of the seafloor. The velocities in the portions of the water column that were not directly measured by the ADCP (near the surface and near the seafloor) were estimated by the software using assumed velocity profiles.

Due to constraints imposed by vessel operations, the measurement system typically could not be brought to the absolute end of the transect line. The system operator was required to estimate the distance from the ADCP to the end of the transect line and estimate the shape of the bathymetry along this unmeasured distance. Using this information, the software estimated the bathymetry and velocity structure in the unmeasured portion of the transect line. Using the measured and estimated velocities and bathymetry data, the software calculated the Q for that transect upon its completion (Ruhl and Simpson, 2005).

To calculate the tidal prism, the Q measurements that were obtained over the ebb tidal period were interpolated at even time intervals (1 min). These Qs were then multiplied by this time interval and summed over the period of the ebb tide.

4. Results

4.1 Chemical Measurements from Grab Samples

As noted in section 3.1, water grab samples were obtained approximately every 2 weeks from 3-May-2012 through 5-December-2013 from the Hillsboro and Boca Raton inlets at the locations shown in Figure 14. These samples were analyzed for nutrients and other parameters as listed in Table 8, except that TN, TP, and chlorophyll-a were not measured. Results are provided in Figure 15 and summarized in Table 10.

Nominally, the dry season is taken to be November through May (McPherson and Haley, 1996). However, based on rainfall records from five sites in the vicinity of the Hillsboro and Boca Raton inlets, we have judged the dry season during the time of these investigations to be ~12-November-2012 through 31-March-2013 (Figure 15, lower panel). Clearly notable is the influence of the rainy season on the concentrations and the inverse relationship of concentrations with salinity; nutrient concentrations were up to 15 times higher in the wet season than in the dry season. With the absence of significant freshwater flow during the dry season, inlet waters at both inlets were dominated by coastal marine water brought in by previous flood tides; this marine water was much lower in nutrient concentrations.

This is evident in the relationship of key nutrients with salinity (Figure 16). Each of the nutrients, particularly silica, decreased in concentration with salinity, as the proportion of nutrient-rich coastal water decreased and the more pristine coastal ocean water increased.

While TN and TP were not measured in the grab samples, we investigated whether those concentrations could be estimated from the measured dissolved nutrient concentrations. This required the particulate nitrogen (or phosphorus) contribution to be proportional to the dissolved contribution. Figure 17 shows dissolved inorganic nitrogen (DIN) ([NO_2]+[NO_3]+[NH_4]) versus TN and PO_4 versus TP for all available concurrent sampling during the experiment. Because of the weakness of the regressions, it was concluded TN and TP concentrations could not be adequately estimated from the concentrations of the associated dissolved forms.

Additionally, this highly urbanized area will be affected by city runoff and limited groundwater flow (Finkl and Charlier, 2003; Santos *et al.*, 2012). Groundwater discharge has not been sufficiently studied in this area. This contribution may not be large; in the much larger Indian River Lagoon, Motz and Gordu (2001) reported that the loading of total soluble nitrate from groundwater discharge was ~0.2 percent of the total loading into that lagoon, while Martin *et al.* (2007) found terrestrial groundwater was much less a source of water to the lagoon than surface water or marine groundwater.

4.2 Inlet Flow Characteristics

The Hillsboro Inlet is unusual in that there is a substantial shallow embayment or widening on the southwest side of the inlet (section 2.1 and Figure 14). The main inlet flow is parallel to the northeastern bank, setting up a weak circulating flow in the shallow area, so that the southeastern portion of the current flows in an opposite direction to the inlet channel flow, albeit with significantly less velocity.

To investigate the implications of this flow, a series of transects were performed during three of the four intensives at Hillsboro Inlet. During those transects, water samples were obtained nearly simultaneously at locations near the northeast, center, and southwest extent of the ship's track. Some results are shown in Figure 18.

Two transects at the Hillsboro Inlet were conducted on 21-August-2013. Although in the height of the rainy season, little rain had been recorded in the previous 5 days from nearby stations, except for ~0.5 inch of rain at S37B_R on August 20. There had been significant flow (700-800 cfs) at the G56_S (Hillsboro Canal) and S37A_S (C-14, Cypress Creek Canal) sites for 2 weeks prior to August 21 (although flow at G56_S had dropped significantly on August 20). Analysis of the water samples (Figure 18) showed a pattern of decreasing NH_4, NO_2, Si, and PO_4 concentrations from the northeast channel to the shallow southwest bank early in the ebb flow (11:30 am); this decrease was essentially gone or reversed by the 2:30 pm transect near the end of the ebb tide pulse. The southwest bank, with its circular embayment, having been filled by coastal marine waters during the previous flood tide, was being replaced by nutrient-rich continental waters during the course of the ebb tide.

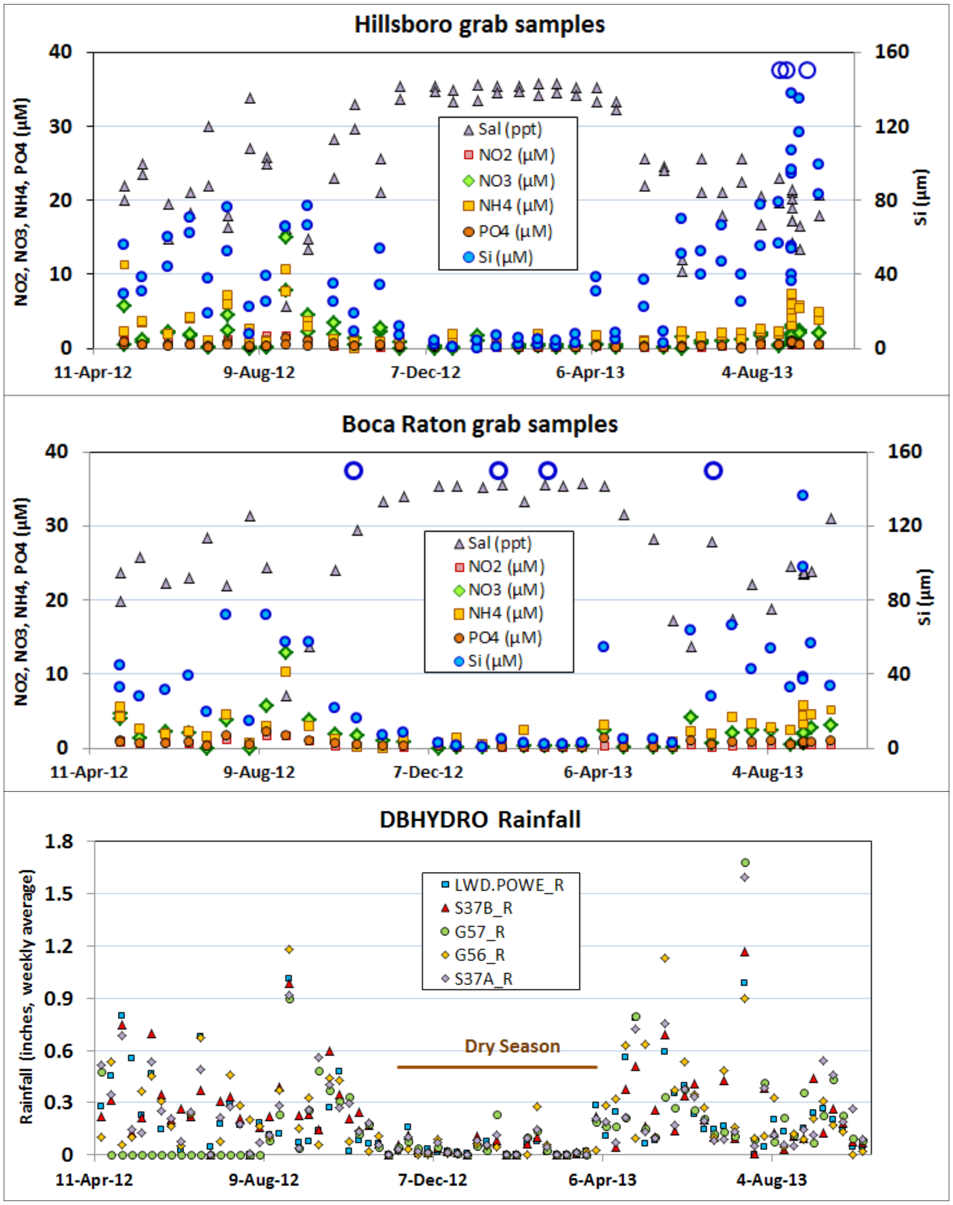

Figure 15. Grab sample nutrient results from the Hillsboro (upper panel) and Boca Raton (middle panel) inlets. Silica values are denoted by the right-hand axis; others by the left-hand axis. Intensive times are denoted by blue circles. Bottom panel: Rainfall (weekly averages) from sites near the inlets; the dry season is denoted by the brown line near middle of the panel (DBHYDRO).

Table 10. Grab sample concentrations during wet and dry seasons.

Location (Season)	Si (µM)	NO_2 (µM)	NO_3 (µM)	NH_4 (µM)	PO_4 (µM)	TN (µM)	TP (µM)	Sal (ppt)	Temp (°C)	DO (% sat)	pH (units)	Chl-a (µg/L)
Boca (wet)	34.61	0.43	1.82	2.35	0.67	18.98	1.03	25.33	28.45	78.7%	7.95	4.64
Boca (dry)	2.83	0.06	0.36	0.87	0.12	6.55	0.30	35.03	23.22	81.4%	8.15	8.15
Hillsboro (wet)	47.43	0.56	1.12	2.46	0.33	19.57	0.64	24.15	28.71	75.2%	7.95	7.95
Hillsboro (dry)	3.54	0.06	0.33	0.61	0.11	n/a	n/a	34.78	24.04	90.4%	8.13	8.13

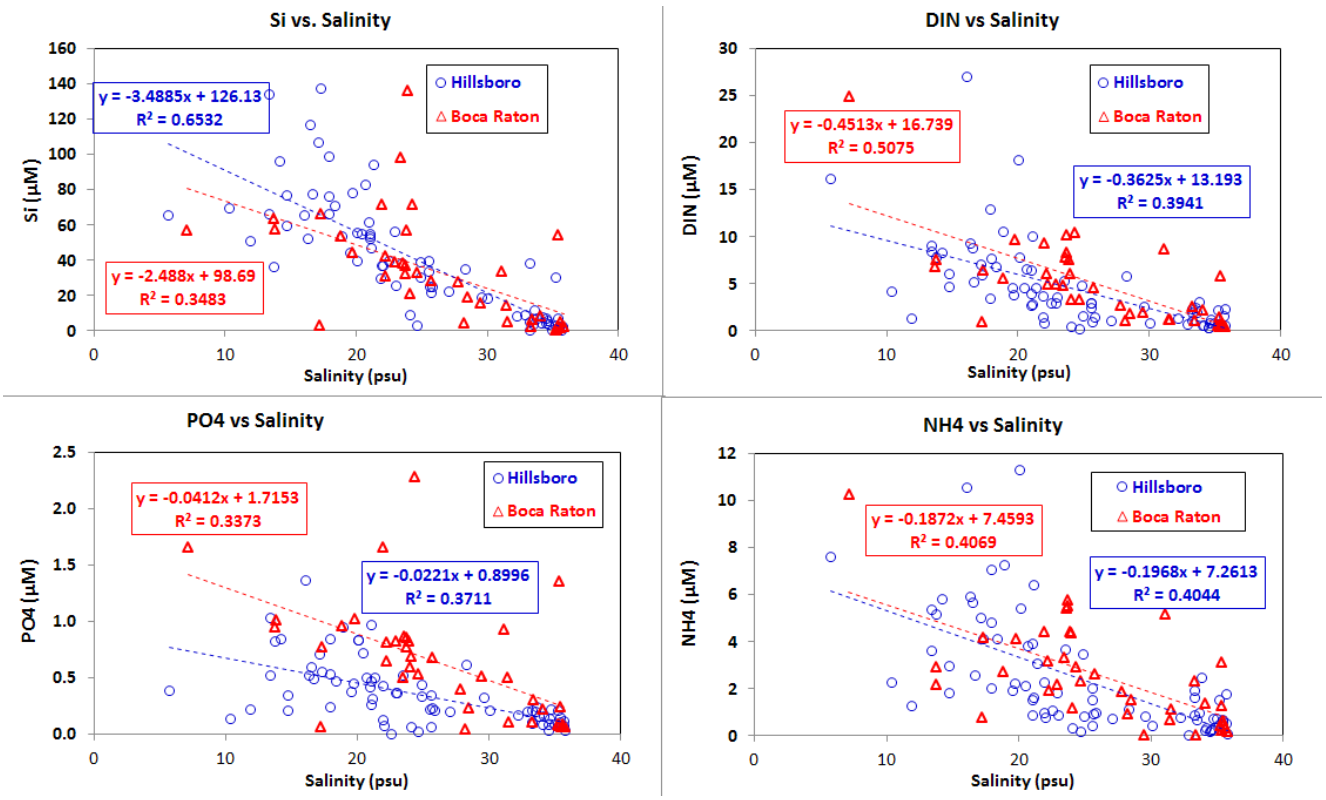

Figure 16. Regressions of grab sample nutrient concentrations versus salinity for the Hillsboro (blue) and Boca Raton (red) inlet grab samples. Regression statistics are shown, identified by color in the inset box.

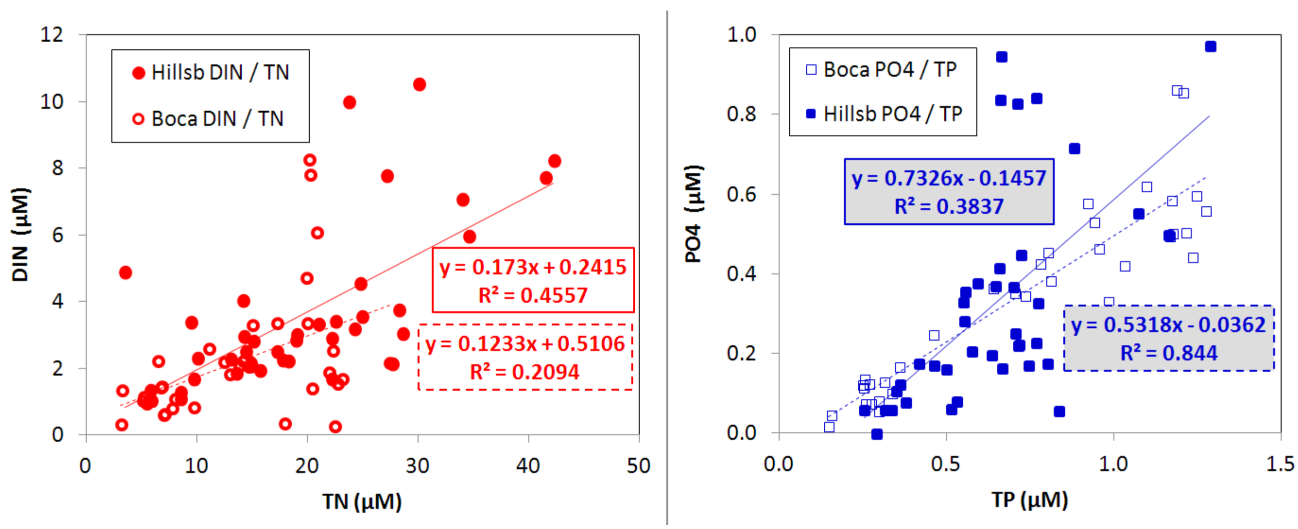

Figure 17. Regressions of averaged DIN concentrations versus TN (left) and PO_4 versus TP (right) from the inlets. Hillsboro data are shown by filled symbols, a solid regress line, and a solid regression parameter box; Boca Raton data are shown by unfilled symbols, a dotted regress line, and a dotted regression parameter box.

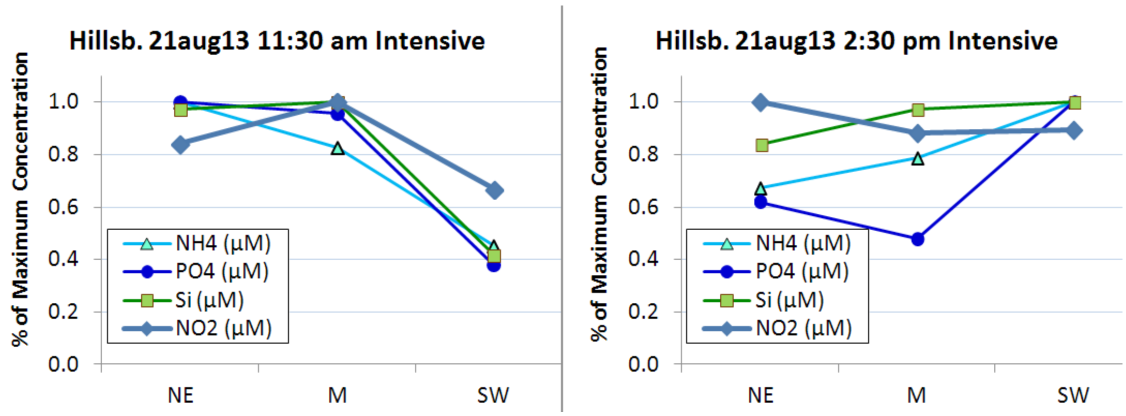

Figure 18. Left: Concentrations from the 21-August-2013, 11:30 am transects of the Hillsboro Inlet, plotted versus position (i.e., northeast, mid, and southwest). Concentrations are plotted as percentages of the maximum concentration of the transect (i.e., C% = C/CMax where C is the measured concentration and CMax is the highest concentration of the three sampling sites of that transect). Right panel: Similar plots for the 21-August-2013, 2:30 pm transect.

Similar investigations were performed at the Boca Raton Inlet; three transects were sampled on 1-March-2013, at ~27 percent, 44 percent, and 58 percent of the time interval of the ebb tide flow (Figure 19). This was the heart of the dry season; previous rainfall had been scant (~0.3 inches of rain fell on February 27 and none before that date since February 15). The main canal flow into the inlet (C-15 Canal at the S40_S structure and Hillsboro Canal at G56-S) had not been opened since November 2011. Biweekly grab sample results indicated that nutrient concentrations in the inlet were comparatively low; winds were from the northwest (Figure 13).

During the 1 pm transect, nutrient concentrations decreased north to south while salinity increased (33.39 psu to 35.02 psu), suggesting that water in the south portion of Lake Boca Raton, nearest the inlet, was more marine and lower in nutrients at this point in the ebb tide pulse. As was found at Hillsboro Inlet, it appears that the previous flood tide had freshened the southern portion of the lake with lower-nutrient marine waters. As the ebb tide progressed, concentrations tended to maximize in the center of the channel. It was not clear why ammonium was dissimilar, possibly due to a different source for this nutrient into Lake Boca Raton.

4.3 Hillsboro Inlet and the Intracoastal Waterway

As noted in section 3.1, grab samples were obtained near the north and south branches of the Intracoastal Waterway at Hillsboro Inlet (Figure 14) on 38 visits to the inlet. The results were analyzed to determine if significant differences existed from the two locations (null hypothesis or no difference).

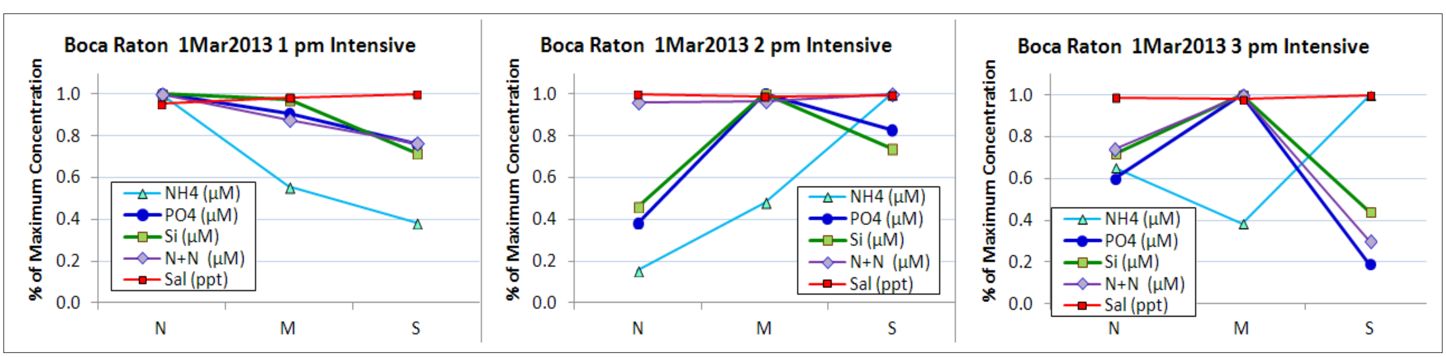

Figure 19. Relative nutrient concentrations across transects of the Boca Raton Inlet during the 1-Mar-2013 intensive. Format is similar to Figure 18.

Table 11. Comparison of concentrations at the north and south locations of Hillsboro Inlet.

Analyte	Unit	North Average	South Average	North-South Difference	Paired t-test
Si	µM	37.74	42.21	-4.47	0.165
N+N	µM	1.78	1.90	-0.13	0.662
NO_2	µM	0.42	0.47	-0.05	0.529
NO_3	µM	1.34	1.44	-0.10	0.717
NH_4	µM	2.25	2.56	-0.31	0.297
PO_4	µM	0.36	0.35	0.01	0.888
Salinity	µM	25.93	23.46	2.47	0.000
Temperature	°C	27.37	27.43	-0.07	0.402
Dissolved oxygen	% sat	0.85	0.81	0.04	0.000
pH		7.99	7.93	0.07	0.000

A (paired) t-test found significant differences for salinity, dissolved oxygen, and pH (Table 11). Salinity measurements indicated that the southern site waters were fresher (by an average of 2.5 psu) than the northern site waters (Figure 20). These differences in the salinity of the north and south channels of the Intracoastal Waterway were probably due to the nearness of the Boca Raton Inlet (a source of marine water) 8.7 km north of Hillsboro Inlet (compared to Port Everglades 18.5 km to the south). Fresher water was associated with elevated nutrients, as noted previously.

4.4 Chemical Measurements during Intensives

As described in section 3.3, water samples were taken from the center of the inlets during selected transects of the intensives. Analytical results are summarized in Table 12.

Many of the concentrations in Table 12 differ dramatically between the four intensive events at each inlet; e.g., silicate varies from 1.94-27.82 µM at Boca Raton and from 13.47-66.66 µM at Hillsboro. Average silicate concentrations at Boca Raton were well correlated with 5-day averages of rainfall from stations LWD.POWE_R and G56_R (R^2=0.76); Hillsboro intensive silicate concentrations were not correlated with local rainfall. The ratio of NO_2 to NO_3 varied considerably, with NO_2 exceeding or nearly equaling NO_3 concentrations for five of the eight intensives. All but the last Hillsboro intensive occurred during the wet season, while the Boca Raton intensives were evenly divided between wet and dry seasons.

For both inlets, measured concentrations displayed marked changes during the course of the ebb tide cycle of the intensives. In Figure 21, the changes in concentration of key nutrients are plotted through the ebb tide of selected ebb tide flow. At Hillsboro Inlet, nutrient concentrations generally increased during the course of the ebb tide

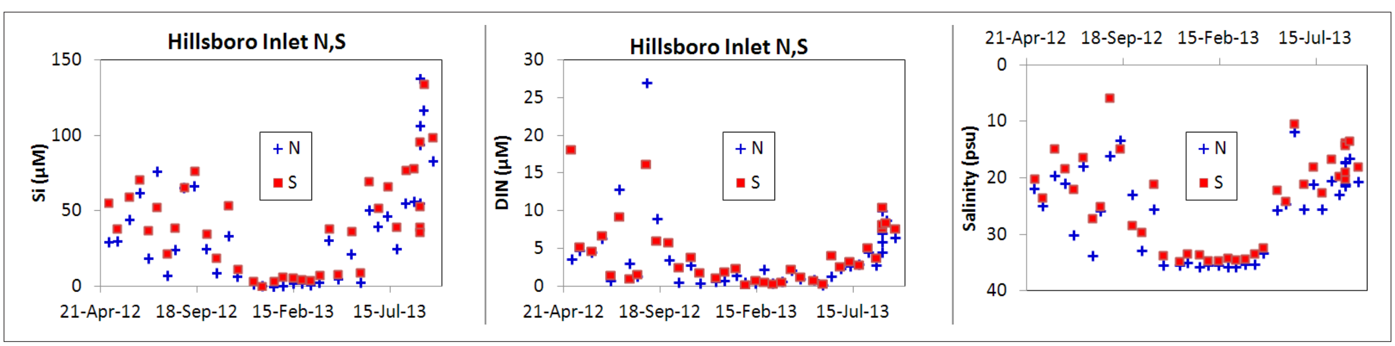

Figure 20. Nutrient and salinity concentrations from two locations at the Hillsboro Inlet. North locations are denoted by blue plus signs; south locations by red squares. Salinity has been plotted with a reversed y-axis for ease of comparison.

Table 12. Inlet intensives concentration measurements: Average, standard deviation.

Intensive	Date	Si (µM)	N+N (µM)	NO_2 (µM)	NO_3 (µM)	NH_4 (µM)	PO_4 (µM)	DO (% sat)	pH (units)	Sal (ppt)	Chl-a (µg/L)	TSS (mg/L)	TN (µM)	TP (µM)
Boca Raton1	15-Oct-12	14.22 (2.88)	1.47 (0.26)	0.20 (0.04)	1.26 (0.22)	0.41 (0.25)	0.53 (0.07)	69.6 (12.3)	8.04 (0.01)	28.11 (1.14)	4.89 (1.79)	2.54 (0.54)	22.98 (2.38)	1.16 (0.09)
Boca Raton2	25-Jan-13	1.94 (1.68)	0.25 (0.47)	0.06 (0.04)	0.23 (0.43)	1.04 (0.62)	0.13 (0.09)	78.4 (5.6)	8.16 (0.03)	34.67 (0.92)	2.47 (4.01)	0.73 (0.15)	5.51 (1.25)	0.25 (0.18)
Boca Raton3	1-Mar-13	3.60 (1.81)	0.63 (0.25)	0.08 (0.02)	0.56 (0.23)	0.81 (0.49)	0.13 (0.07)	79.3 (13.7)	8.13 (0.02)	35.12 (0.60)	1.07 (0.32)	0.82 (0.32)	4.86 (1.25)	0.29 (0.09)
Boca Raton4	26-Jun-13	27.82 (3.22)	0.67 (0.16)	0.13 (0.03)	0.55 (0.14)	1.81 (0.57)	0.44 (0.09)	80.0 (11.8)	7.98 (0.03)	28.34 (0.75)	3.39 (0.98)	1.50 (0.22)	15.10 (2.64)	0.79 (0.89)
Hillsboro1	21-Aug-13	41.46 (20.44)	0.69 (0.29)	0.69 (0.30)	0.01 (0.02)	1.68 (0.67)	0.20 (0.08)	67.0 (5.2)	7.99 (0.05)	25.17 (3.37)	2.26 (0.71)	n/a	16.40 (6.82)	0.60 (0.16)
Hillsboro2	26-Aug-13	43.53 (19.46)	0.49 (0.20)	0.39 (0.13)	0.10 (0.12)	2.07 (0.55)	0.20 (0.15)	66.3 (8.0)	8.05 (0.07)	28.03 (4.10)	2.32 (1.46)	n/a	14.45 (5.61)	0.49 (0.13)
Hillsboro3	10-Sep-13	66.66 (28.27)	1.37 (0.66)	0.71 (0.34)	0.66 (0.36)	1.80 (0.74)	0.28 (0.12)	60.7 (8.1)	8.00 (0.07)	26.70 (4.13)	4.74 (1.37)	1.44 (0.14)	n/a	n/a
Hillsboro4	5-Dec-13	13.47 (8.58)	1.89 (0.89)	0.18 (0.08)	1.70 (0.82)	2.13 (0.77)	0.33 (0.15)	n/a	n/a	32.86 (2.11)	n/a	n/a	n/a	n/a

until near the end of the flow, while salinities decreased. The increase of concentrations through the tidal cycle at Hillsboro Inlet can be viewed as the ebb tide withdrawing water from the Intracoastal Waterway, drawing water from farther away (upstream) from the inlet as the ebb tide progressed, and thus pulling waters less diluted with low-nutrient coastal waters derived from the previous flood tide.

In contrast, the concentrations at Boca Raton Inlet were higher at the beginning and end of the ebb tide (the latter was not sampled but is suggested in Figure 21). The flow at this inlet derives from Lake Boca Raton, less directly connected to the Intracoastal Waterway; the concentration changes may represent different flow patterns within the lake at different times during ebb tide flow.

It is useful to compare the salinity of the inlet waters during ebb flow to that of the coastal ocean. Coastal ocean salinity was estimated from data obtained at three depths (surface, mid, and bottom) near the Hillsboro Inlet during a 14-month field program (samples BR12 and BR16, November 2010–January 2012, reported in Carsey *et al.*, 2013); these data averaged 36.0 psu. If we assume

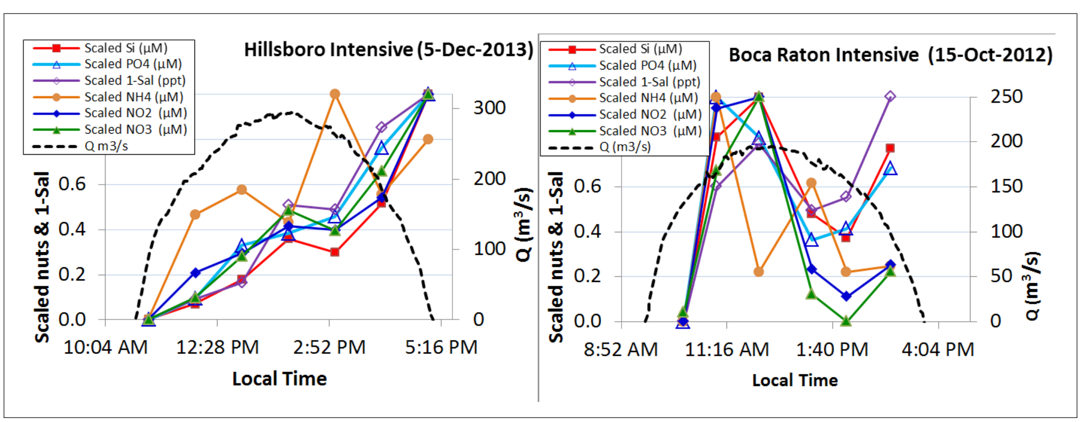

Figure 21. Scaled concentrations from an intensive at the Hillsboro (left panel) and Boca Raton (right panel) inlets. Concentrations (C) of each analyte were adjusted so that the change in concentration was scaled to 1 (Cmin=0, Cmax-Cmin=1). Analytes are identified in the legend. Horizontal axis is local hour. Salinities are plotted inversely (1-salinity). Black dotted line is the flow rate (right vertical axis). Only data taken at ebb tide flow are presented.

conservative mixing and the coastal ocean as the only source of salinity (Smith and Atkinson, 1994), the percent salinity is the percent of oceanic water in the inlet water (i.e., 36 psu=100%). These results are shown in Figure 22 for the eight intensives. At the Boca Raton Inlet, the percentages of oceanic salinity were all >70 percent and two were >90 percent. Hillsboro Inlet waters were fresher, but even the lowest salinity in any of the four intensives at Hillsboro (17.7 psu) was nearly 50 percent seawater. In general, salinities were highest at the start of the ebb tide and subsequently decreased, as would be expected; however, this was not observed during the 26-August-2013 intensive at Hillsboro. In that ebb flow event, salinities initially increased up to maximum flow and then decreased. No explanation could be found for this behavior. However, it was made clear from the salinity data that most of the ebb tide water was water that had entered the inlet during previous flood tides (in some cases nearly 100 percent).

4.5 Boca Raton Inlet Acoustic Measurements

Suitable transect paths for small boat operations at the Hillsboro and Boca Raton inlets were developed prior to the intensives. The transect line for the entire volume of water flowing through the inlet needed to be measured while allowing for practical and safe boat operations.

At the Boca Raton Inlet, locating the transect line across the inlet channel near the ocean was first investigated; however, this location was discarded because the bank was rocky and sloped, and the small boat could not access those portions of the channel. A line near Lake Boca Raton just landward of the AIA bridge was chosen (Figure 14); seawalls located at both sides of this line allowed for measurements to be made across nearly the entire width of this line.

Operations were conducted during the four intensives as noted in Table 9. Figure 23 shows a typical velocity structure at maximal flow and the bathymetry along the transect line. Flow measurements from the Boca Raton Inlet were processed as described previously for the four intensives and are shown in Figure 24. The flow pattern was not symmetrical about the maximum; flow increased rapidly at the beginning of the ebb tide and decreased more gradually at the end of the ebb tide cycle. The differences in timing and magnitude of the flow, clearly evident in Figure 19, were due to sampling during different points in the fortnightly tidal cycle.

4.6 Hillsboro Inlet Acoustic Measurements

At Hillsboro Inlet, the path for the small boat transect line presented unique difficulties because of inlet geometry. The narrow width and the presence of flow obstructions under the A1A Bridge (Figure 14) made this location unsuitable as a measurement site. At the entrance to the inlet, sandy shoals and the presence of dredging equipment made that area unsuitable for transects as well.

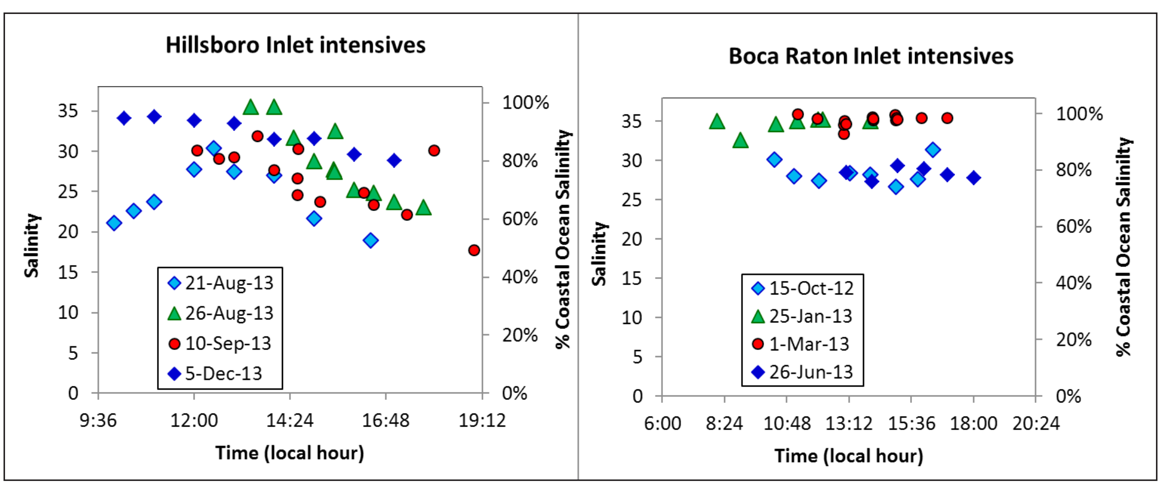

Figure 22. Salinity measurements from four intensives at the Hillsboro (left) and Boca Raton (right) inlets during ebb tide flow. Horizontal axis is the time in local hour. Right-hand axis indicates salinity as a percentage of approximate coastal ocean salinity (36.0 psu).

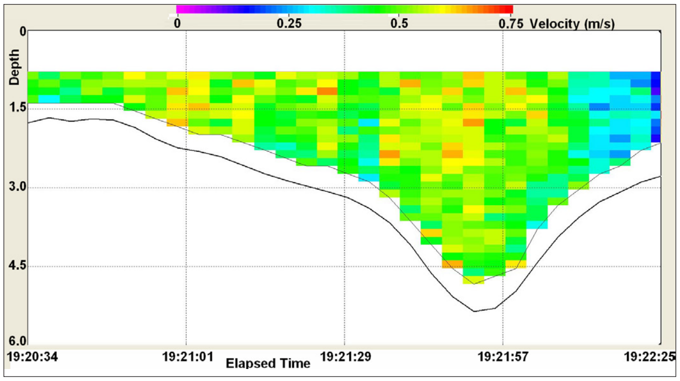

Figure 23. Magnitude of current velocity at the Boca Raton Inlet on a transect conducted 1-March-2013. Format is similar to Figure 7, except that time (on the horizontal axis) increases to the right. The black line denotes the inlet depth as the ship transected southwest to northeast along the track line shown in Figure 14. Time is UTC (EDT=UTC–4).

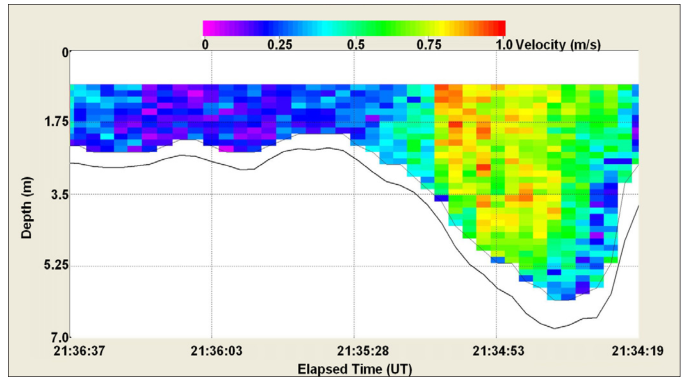

Figure 25. Magnitude of current velocity at the Hillsboro Inlet on a transect conducted 1-Sept-2013. The black line denotes the channel bottom. The horizontal axis is time (increasing right to left) as the ship transected northeast to southwest along the track line shown in Figure 14. Direction of flow is not indicated.

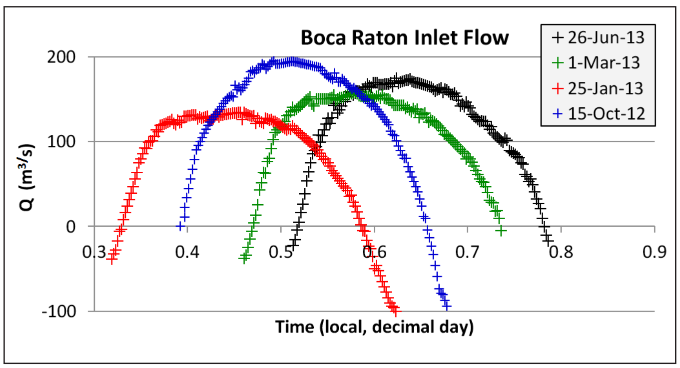

Figure 24. Flow rates (Q) from multiple passes across the Boca Raton Inlet during the four sampling intensives. Positive flow is ebb flow. Note that some measurements were made during flood tide (negative flows).

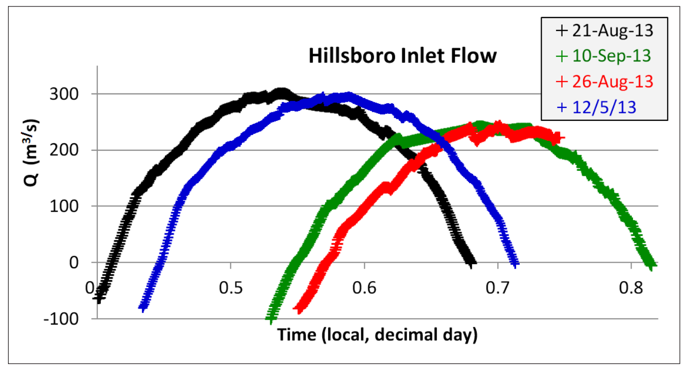

Figure 26. Flow rates (Q) from multiple passes across the Hillsboro Inlet during the four sampling intensives. Horizontal axis is the time in decimal days. Negative flows indicate measurements made during the previous or following flood tide.

The transect line was chosen seaward of the A1A bridge, across the shallow embayment area at the southwest side of the inlet, but away from the flow obstructions near the bridge. A seawall at the north end of the transect line allowed velocity measurements to be made along nearly the entire north end of the line. At the southeastern end of the transect line, several docks prevented the vessel from reaching the line's end. Fixed structures were used to mark the southwestern end of the transect line; a laser range finder was used to measure the distance from these structures to the end of the basin at this end. Water velocities at the southern end of the transect line were small compared with the northern end of the line; errors associated with estimating the flow at the south end of the line were not large.

An example of the flow structure as measured during one of the crossings of the transect line is shown in Figure 25. Note the dramatic difference in the flow structure compared to that of the Boca Raton Inlet; here, the flow is much more confined to the deep channel, with little water movement in the shallow embayment area to the southwest.

The flow from multiple crossings during the course of an ebb tide (and sometimes including flood time flow) is shown in Figure 26 for the four intensives at Hillsboro Inlet. Note the symmetry of the ebb tide flow and the similar form of each ebb tide. The 26-August-2013 intensive had to be terminated before the end of the ebb flow. However, the flow data that had been measured during the 26-August-2013 intensive appeared to closely mimic that of the 10-September-2013 ebb tide. Consequently, we concluded that the tidal prism value computed for the latter intensive could be used to estimate the 26-August-2013 intensive flow in subsequent computations.

4.7 Tidal Prism and Chemical Loading Measurements during Intensives

The total loading for each analyte during an ebb tide was computed as the averaged concentration multiplied by the tidal prism for that ebb tide. Total loadings for the four intensives at each inlet are provided in Table 13.

It should be noted that the tidal prism estimates in Table 13 are considerably in excess of the estimated volumes of the adjacent water bodies (i.e., Lake Boca Raton, Hillsboro Inlet). The relative volume of these quantities (Table 14) for the two inlets indicate that each ebb tide removes considerably more water volume than is contained in the adjacent water body and, thus, the majority of the water that flows through each inlet is from the Intracoastal Waterway. Thus, during the flood tide, incoming coastal ocean water can be assumed to replace all of the water inland of the inlet lagoon and proceed to flow into the connecting Intracoastal Waterway.

Nutrient concentrations and associated loadings were found to be closely correlated (Figure 27). Although Hillsboro Inlet flow rates were almost double those of Boca Raton Inlet, the ratio of loading to concentration was similar, probably a reflection of the similar nutrient sources feeding into the two inlets.

4.8 Tidal Prism Estimates

It was found that the measured tidal prism volumes at both inlets were closely correlated with the tidal range, defined as the tidal height at the start of the ebb tide minus the tidal height at the beginning of the following flood tide. The tidal height data were obtained from marine navigation software (Tides and Currents version 3.3, Nobeltec Corporation, Beaverton, OR 97006). These relationships are shown in Figure 28. The ebb tidal prism for any ebb tide throughout the 18 months of the study period could be readily calculated from the ebb tide range for that ebb tide time. These estimates did not take into account the variance in the ebb tidal prism attributed to winds, precipitation, or water management activities in the vicinity of the inlets. Thus, the tidal prism estimates by this method can be considered a lower limit to the actual tidal prism. Tidal prism volumes for the time domain of this experiment are shown in Figure 29 and listed in Table 13. Differences in magnitude of the tidal prism across time are attributed to differences in tidal forces at different times of the year.

Having established the tidal prism volumes for the duration of the experiment, we estimated the daily loadings for the analytes listed in Table 8 (grab samples) for both inlets. To

Table 13. Tidal prism and loadings (Kg/ebb tide) through the Hillsboro and Boca Raton inlets.

Inlet	Date	Tidal Prism (m^3*10^6)	Tidal phase	Si	TN	DIN	NH_4	TP	NO_3	PO_4
Hillsboro	21-Aug-13	4.89	Spring (full on 20-Aug)	5,696	1,123	162	115	91	0.4	30
Hillsboro	26-Aug-13	3.94*	Neap (¾ in 3 days)	2,398	796	141	114	27	6	25
Hillsboro	10-Sep-13	3.94	Neap (¼ in 2 days)	7,368	n/a	174	99	n/a	36	34
Hillsboro	5-Dec-13	4.81	Neap ¼ in 4 days	1,818	n/a	271	144	n/a	115	50
	Average	**4.55**		**4,320**	**960**	**187**	**118**	**39**	**39**	**35**
Boca Raton	15-Oct-12	3.25	Spring (new moon)	1,296	1,044	85	18	117	57	53
Boca Raton	25-Jan-13	2.27	Spring (full moon 26-Jan)	124	268	42	33	24	7	9
Boca Raton	1-Mar-13	2.71	Neap (¾ in 3 days)	274	184	55	31	24	21	11
Boca Raton	26-Jun-13	2.92	Neap (¾ in 4 days)	2,282	617	103	75	72	22	38
	Average	**2.79**		**994**	**528**	**71**	**39**	**59**	**27**	**28**

*Taken to be the same as the tidal prism for 10-September-2013.

Table 14. Adjacent water body volumes and tidal prisms.

Inlet	Area (m^2)	Depth (m)	Volume (m^3)	Tidal Prism (ave, m^3)	Ratio
Hillsboro	69,169	3 (1)*	158,419	4,546,667	28.70
Boca Raton	261,131	1.2	313,357	2,787,500	8.90

*Depth of the main channel = 3 m; depth of semicircular embayment = ~1 m.

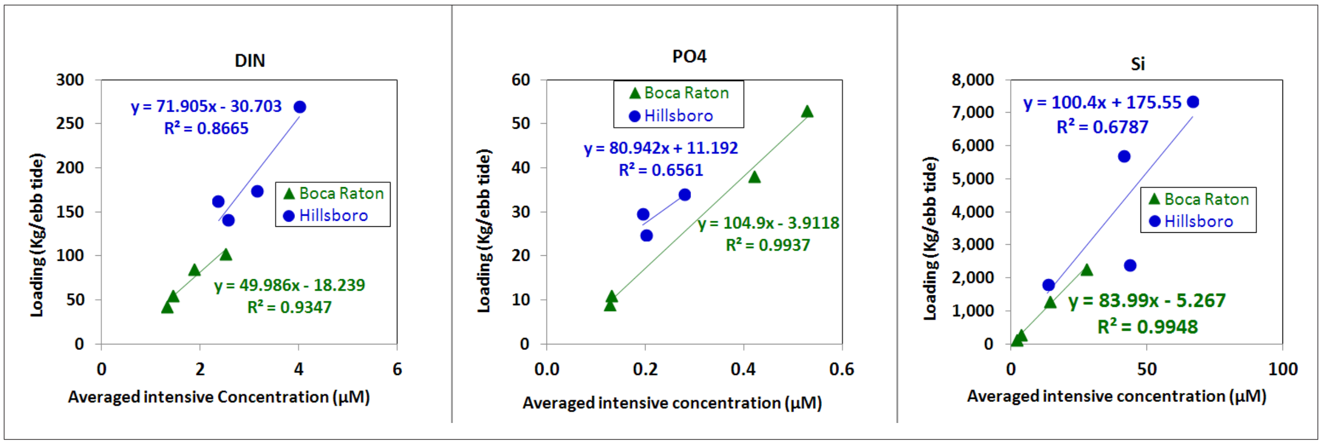

Figure 27. Loading estimates versus concentrations and statistical parameters for DIN, PO_4, and Si for the Hillsboro (blue circles) and Boca Raton (green diamonds) inlets as measured during the four intensives.

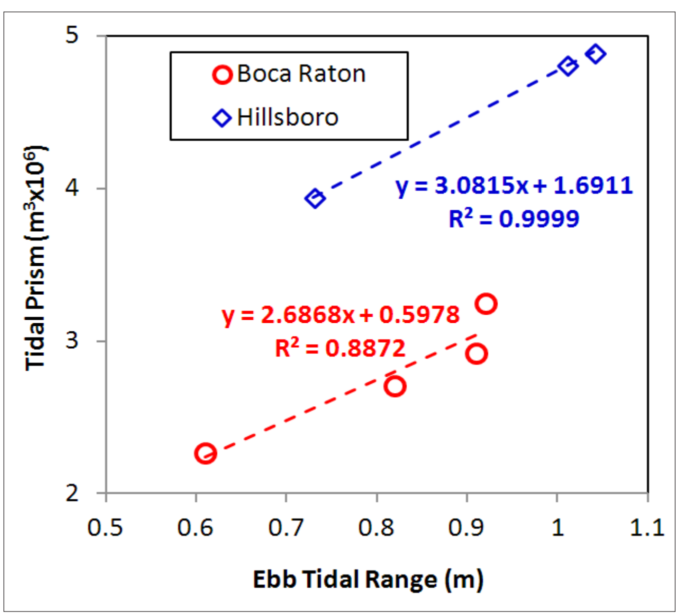

Figure 28. Tidal prism measurements (vertical axis) versus predicted ebb tide range (horizontal axis) for four intensives at the Boca Raton Inlet (red circles) and three intensives at the Hillsboro Inlet (blue diamonds). Statistical parameters are given in the inset.

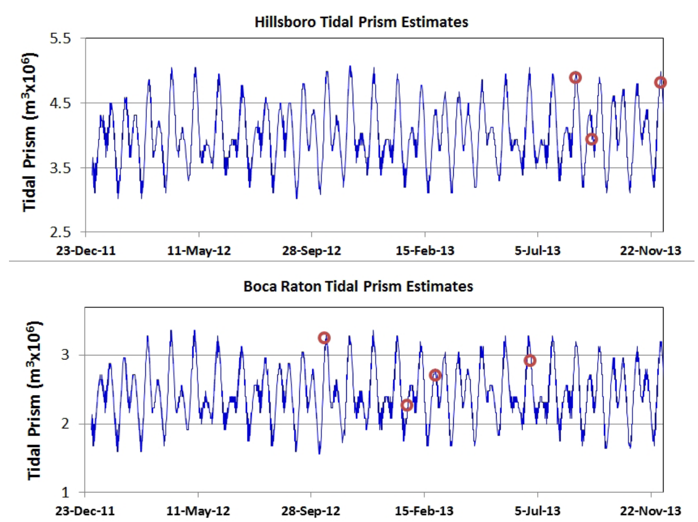

Figure 29. Blue lines show estimated tidal prism volumes for the Hillsboro (upper panel) and Boca Raton (lower panel) inlets for the 31-Dec-2011 through 24-Sept-2013 time period. Measured tidal prism values for the three Hillsboro intensives and four Boca Raton intensives are denoted by red circles.

estimate the nutrient loadings through the inlets for each of the ebb tides occurring during the study period, the biweekly nutrient concentration grab sample concentrations and the average of the nutrient concentrations measured during the intensive sampling efforts were combined to form a time series that was then linearly interpolated to the times of the ebb tides. These interpolated concentrations were then multiplied by the estimated volume of the ebb tidal prism as described in section 3.4. The product gave the total mass of a nutrient that was advected through the inlet into the coastal ocean (i.e., the load) for each ebb tide event. Loadings from the five nutrients estimated by this means are shown in Figure 30.

Monthly loadings provide an alternate and more useful presentation than shown in Figure 30. These data are shown in Figure 31 and summarized in Tables 15 and 16 (in the tables, we have assumed two ebb tides per day). As is evident in Figure 31, elevated loadings generally mimicked the occurrence of the rainy season. However, neither monthly rainfall nor monthly canal flow averages were well correlated with nutrient loading. Monthly loadings are plotted against canal flow and rainfall (from the closest monitoring stations) in Figure 32. Regression statistics for these relationships are shown in Table 17. Canal flow was found to be a better estimator of nutrient loading than rainfall with $R^2 > 0.5$.

While the loadings through the Boca Raton Inlet were about twice that through the Hillsboro Inlet, the general trends throughout the year were similar. The monthly rainfall exhibited a bimodal pattern with maxima in early and late summer (Duever *et al.*, 1994), which was reflected somewhat in canal flow; however, variances were significant in both data sets. The maximum loadings through both inlets occurred in September. This was also the peak for monthly averaged rainfall, and was at or near the maximum in canal flow during this time period.

5. Discussion

There is general agreement that maintaining a healthy ecosystem in the coastal waters of southeast Florida requires the implementation of appropriate science-based watershed management practices. A key measurement need is to assess pollution loading from pollution sources, including surface water and groundwater (e.g., NOAA CRCP, 2010). These loadings change significantly with time, as they are a result of the operation of the canal system (SFWMD, 2010), seasonal and sometimes intense rainfall, and insufficiently understood groundwater flow (Reich *et al.*, 2009). The procedure employed in the present work has provided the first loading data for several key nutrient species, incorporating more than a year of measurements (18 months). We have shown that nutrient loads can be obtained from inlet nutrient concentrations and flow measurements, including flows estimated from tidal height ranges.

Tables 15 and 16 provide robust estimates of the materials transiting the Hillsboro and Boca Raton inlets into

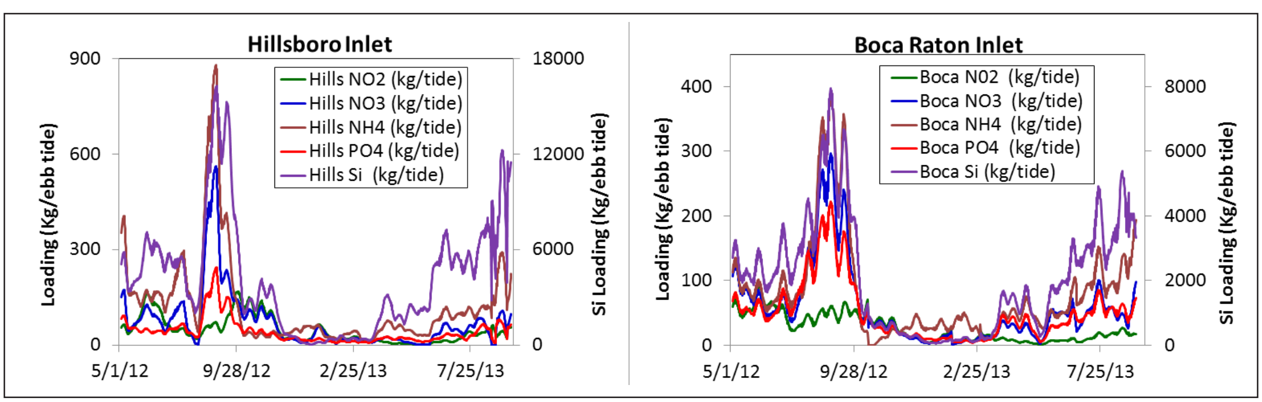

Figure 30. Estimated loadings (Kg/ebb tide) of five nutrients through the Hillsboro (left panel) and Boca Raton (right panel) inlets for the period of 3-May-2012 through 15-September-2013. Left vertical axis applies to all analytes except Si; Si is denoted by the right-hand axis.

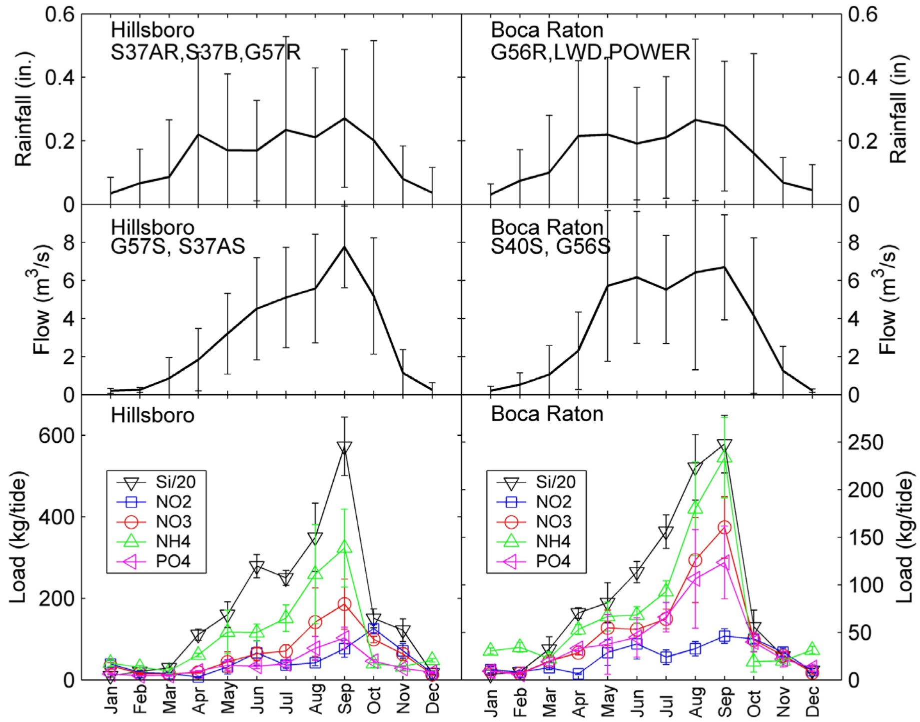

Figure 31. Upper panels: Monthly averaged rainfall from rain stations associated with the Hillsboro (left) and Boca Raton (right) inlets. Middle panels: Monthly averaged canal flow through canals associated with the Hillsboro (left) and Boca Raton (right) inlets. Bottom panels: Estimated loadings (Kg/ebb tide) of five nutrients through the Hillsboro (left) and Boca Raton (right) inlets, averaged over months. Silicate (Si) concentrations have been divided by 20 for ease of presentation. Vertical bars in all panels denote one standard deviation of the results for that month (± ½σ). Some months include data from multiple years.

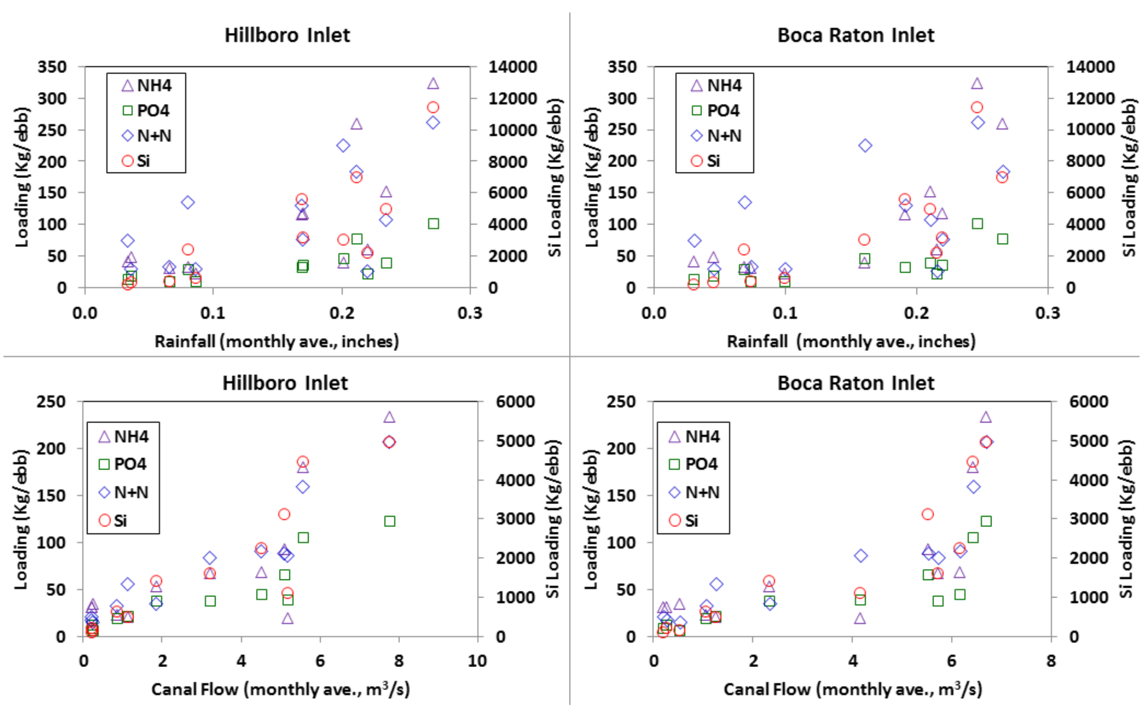

Figure 32. Upper panels: Nutrient loadings against rainfall (monthly averages) for Hillsboro (left) and Boca Raton (right) inlets. Silicate (Si) loadings are indicated by the right-hand vertical axis. Rainfall data were obtained from DBYHDRO sites LWD.POWE_R, G56_R, G57_R, S37B_R, and S37A_R. Lower panels: Loadings against canal flow (monthly averages) from C57S and S37A_S for Hillsboro Inlet and S40_S and G56_S for Boca Raton Inlet.

Table 15. Dissolved nutrient loads (monthly average [Kg/tide], standard deviations) through the Hillsboro Inlet.

Month	Si	NO_2	NO_3	NH_4	PO_4
January	201 (114)	39 (17)	35 (15)	41 (16)	14 (4)
February	414 (92)	18 (6)	15 (5)	31 (10)	10 (2)
March	590 (431)	16 (4)	14 (4)	22 (13)	11 (4)
April	2219 (551)	7 (2)	19 (4)	61 (9)	22 (3)
May	3201 (1250)	32 (35)	44 (50)	118 (106)	36 (25)
June	5585 (1140)	66 (61)	64 (34)	116 (41)	33 (12)
July	5004 (745)	36 (15)	71 (31)	152 (65)	39 (15)
August	7000 (3351)	42 (14)	142(168)	259 (65)	77 (59)
September	11460 (2870)	76 (42)	186(123)	324 (243)	103 (53)
October	3022 (926)	126 (20)	99 (16)	40 (16)	46 (7)
November	2438 (1116)	71 (35)	63 (32)	32 (6)	29 (9)
December	333 (213)	16 (5)	14 (5)	48 (8)	19 (4)
Ebb tide load (average)	4130 (3586)	46 (42)	72 (91)	125 (147)	41 (39)
Ebb tide load: Wet (average)	5501 (3303)	54 (46)	91 (100)	159 (160)	51 (42)
Ebb Tide Load: Dry (average)	592 (706)	26 (20)	23 (18)	36 (14)	15 (7)

Table 16. Dissolved nutrient loads (monthly average [Kg/tide], standard deviations) through the Boca Raton Inlet.

Month	Si	NO_2	NO_3	NH_4	PO_4
January	114 (40)	11 (7)	9 (6)	31 (6)	9 (13)
February	170 (44)	8 (3)	7 (3)	34 (10)	6 (5)
March	644 (527)	13 (4)	20 (9)	22 (14)	19 (9)
April	1407 (222)	6 (2)	28 (4)	53 (11)	38 (6)
May	1625 (840)	29 (27)	55 (38)	67 (30)	66 (63)
June	2268 (444)	38 (32)	53 (13)	68 (18)	45 (41)
July	3119 (702)	24 (15)	64 (21)	93 (23)	66 (31)
August	4471 (1379)	33 (15)	126 (89)	180 (98)	106 (104)
September	4959 (1208)	46 (15)	161 (65)	234 (85)	123 (76)
October	1117 (701)	43 (9)	42 (13)	19 (22)	40 (21)
November	500 (132)	29 (9)	26 (8)	20 (5)	22 (16)
December	200 (86)	10 (4)	8 (3)	31 (8)	13 (7)
Ebb tide load (average)	2054 (1763)	26 (21)	58 (60)	81 (79)	50 (45)
Ebb tide load: Wet (average)	2748 (1615)	75 (63)	102 (84)	65 (45)	107 (77)
Ebb Tide Load: Dry (average)	308 (329)	13 (9)	29 (10)	13 (9)	25 (16)

Table 17. Regression statistics (coefficient of determination, R^2) from Figure 32.

	Rainfall		Canal Flow	
Nutrient	**Hillsboro**	**Boca Raton**	**Hillsboro**	**Boca Raton**
NH_4	0.51	0.58	0.61	0.53
PO_4	0.56	0.53	0.82	0.69
N+N	0.38	0.26	0.87	0.75
Si	0.65	0.62	0.82	0.76

the coastal ocean; these loadings were approximately proportional to the rainfall in the region and the resulting canal flow.

We computed the hypothetical path of a water mass emerging from the Hillsboro Inlet using current data derived from the velocity data from the AOML nearshore ADCP at 26°15.887′N, 80°4.568′W. Unfortunately, current measurements from that site were not available during the time of this work. Instead, we investigated several illustrative time periods in 2011. This model did not incorporate advection or dispersion processes (National Research Council, 1993; Nielsen, 2009) which led to dilution of the plume with seawater. Starting with a point near the inlet mouth, the model computed a location in the water column from the u- and v-velocities every 20 minutes, with the starting position for a movement taken as the end position of the previous 20-minute movement. The computation was considered reliable in the vicinity of the ADCP. In Figure 33, we have performed this modeling for three time periods in 2011.

The 1-January-2011 model was computed for 6 hours. The resulting path hugged the coast and did not overlap even the first reef line at ~800 m offshore (the "middle reef" [Banks *et al.*, 2008] as the "inner reef" is not present at this location off of Hillsboro Inlet). The ADCP data suggest that subsequent movement would have continued the path northward. The 13-April-2011 model was run for an

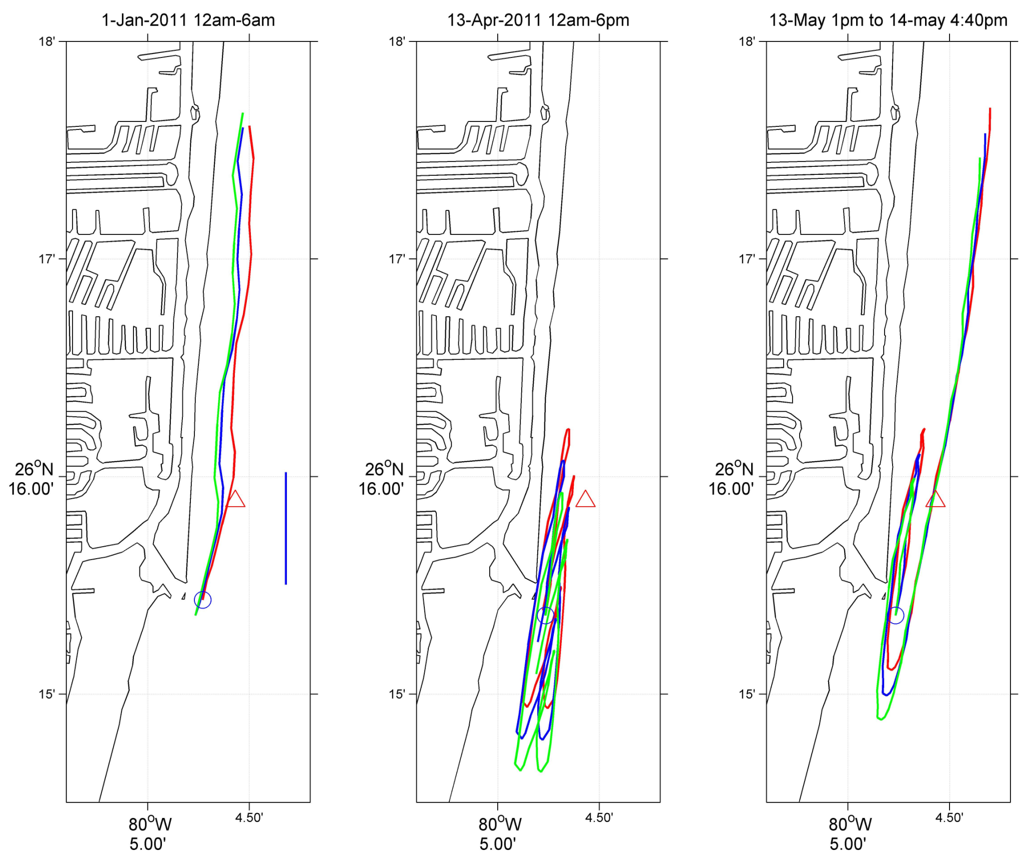

Figure 33. Three model results for a water mass emerging from the Hillsboro Inlet: 12:00 am 1-Jan-2011 (left), 12:00 am 13-April-2011 (middle), and 13:00 13-May-2011 (right). Colors represent water masses starting at the start time (T) (red), T+20 min (blue), and T+40 min (green). The red triangle denotes the location of the nearshore ADCP. The path origin was arbitrarily chosen off of the Hillsboro Inlet (blue circle). Blue vertical line in the leftmost plot represents 1 km.

18-hour interval (starting at noon) characterized by many current reversals (Figure 5). As can be seen in Figure 33, the current reversals confined the inlet plume within a region very near the inlet and without contact with the reef tract. Lastly, currents from 1 pm 13-May-2011 were calculated for a 15-hour track to exemplify the situation where the plume was initially confined to the inlet area but subsequently carried into the Gulf Stream.

A similar analysis was obtained for the Boca Raton Inlet using ADCP data from an instrument at 26.35°N, 80.053°W (~2.3 km northeast of the inlet mouth) operated by Hazen and Sawyer for the City of Boca Raton in 2005 and 2006. These results are shown in Figure 34.

As with the Hillsboro Inlet, data from instruments near the Boca Raton Inlet were not available during the times of the intensives. Instead, some representative scenarios are plotted in Figure 34: north flow; a current reversal; and south flow for the 6-hour event. There was even less east-west motion at Boca Raton than was measured at Hillsboro. While the projection of landfall indicated in the leftmost panel in Figure 34 is clearly wrong, the lack of eastward or westward velocity suggests (as it was for

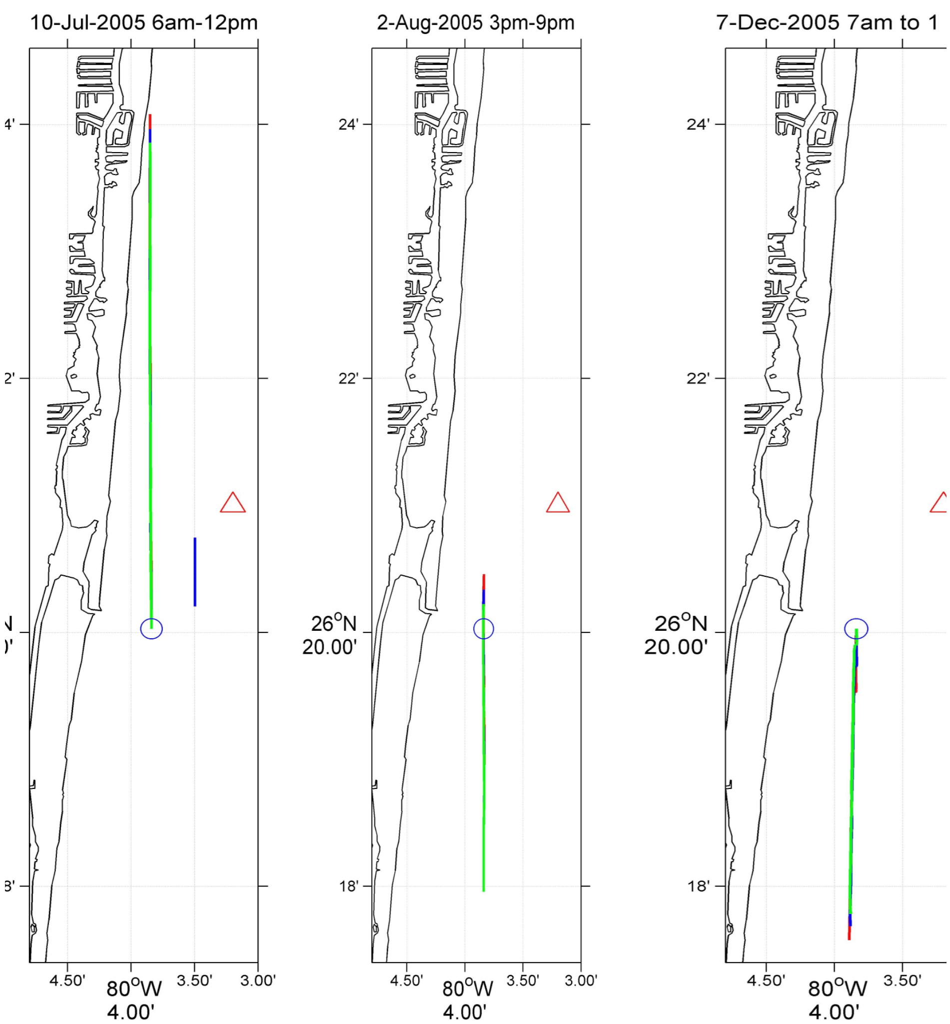

Figure 34. Three 6-hour model results for a water mass near the Boca Raton Inlet. Left: 6 am on 10-Jul-2005, currents were northward. Center: 3 pm on 2-Aug-2005, currents undergoing north to south reversal. Right: 7 am on 7-Dec-2005, currents were consistently southward. Blue line in leftmost panel represents 1 km of distance. Origin point (26.2584°N, 80.0720°W) was arbitrarily chosen as a location where water would become entrained into the coastal ocean flow. Symbols and format are similar to Figure 33.

Hillsboro) that effluent from the inlet will be confined to the nearshore environment; entrainment into the Gulf Stream is not suggested by these results.

In summary, we have developed an economical and robust procedure for the estimation of monthly loadings of key nutrients and have employed this procedure at two important southeast Florida inlets, resulting in the first estimates of loadings through those inlets into the coastal ocean. As can be seen from Figure 31, the largest loadings occurred concurrently with maxima in the rainfall and the flow through canal control structures. In this region, seasonal rainfall directly contributes to nutrient enhancement of inland waters via surface runoff. In a less direct manner, rainfall modulates the flow through the water management system. When it is deemed necessary to reduce inland canal levels, control structures are operated and, in some instances, a large volume of inland water (generally with elevated nutrient concentrations compared to the coastal ocean, Lapointe *et al.*, 2012) is released into the Intracoastal Waterway which subsequently reaches the coastal ocean through the inlets. During the dry season, the intracoastal water salinities rise, approaching that of the coastal water. During this time, nutrient concentrations and, hence, tidal loadings, are low when compared to the rainy season.

By using shore-based sampling, the expense associated with vessel operations is reduced. By interpolation of nutrient concentration data and the estimation of tidal prisms from published tidal data, reasonable estimates of tidal loadings through a tidal inlet may be made at significant savings compared to continuous measurement techniques. The resulting chemical loading data are of critical importance in understanding the impact of continental material into the coastal ocean and should be incorporated into coastal modeling efforts as these become available.

6. References

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Appendix 1:

Data Tables

Sample Site	Sample Day	Time local	Si µM	N+N µM	NO_2 µM	NO_3 µM	NH_4 µM	PO_4 µM	BP kPA	Sal ppt	Temp °C	DO %	pH	TN µM	TP µM
Hillsboro_S	3-May-12	10:50	55.38	6.92	1.24	*5.68*	11.29	0.84	101.97	20.06	25.30	0.84	7.80	N/A	N/A
Hillsboro_N	3-May-12	11:20	29.37	1.45	0.94	*0.52*	2.26	0.43	101.97	21.91	25.46	1.03	7.89	N/A	N/A
Boca_N	3-May-12	12:55	44.48	5.56	0.92	*4.64*	4.09	1.02	101.96	19.77	26.17	0.87	7.83	N/A	N/A
Boca_S_jetty	3-May-12	12:15	32.33	4.64	0.78	*3.87*	5.51	0.77	101.98	23.72	25.60	0.91	7.86	N/A	N/A
Hillsboro_S	16-May-12	10:25	38.34	1.64	0.53	*1.12*	3.65	0.52	101.72	23.50	27.90	0.78	7.88	N/A	N/A
Hillsboro_N	16-May-12	10:45	30.16	1.28	0.44	*0.84*	3.49	0.44	101.71	24.88	27.80	0.84	7.93	N/A	N/A
Boca_N	16-May-12	11:20	27.94	1.87	0.58	*1.29*	2.61	0.68	101.73	25.72	27.18	0.80	7.98	N/A	N/A
Hillsboro_N	4-Jun-12	14:00	44.10	2.68	0.72	1.97	1.91	0.38	101.41	19.56	28.74	1.03	7.94	N/A	N/A
Hillsboro_S	4-Jun-12	14:20	59.55	2.85	0.68	2.17	1.84	0.22	101.39	14.76	29.10	0.94	7.82	N/A	N/A
Boca_N	4-Jun-12	14:58	31.04	3.05	0.77	2.28	1.89	0.65	101.35	22.25	28.90	0.94	7.87	N/A	N/A
Hillsboro_N	20-Jun-12	13:40	61.80	2.46	0.76	1.71	3.92	0.42	101.60	21.01	28.11	0.81	7.95	N/A	N/A
Hillsboro_S	20-Jun-12	14:00	70.61	2.61	0.82	1.79	4.11	0.48	101.60	18.35	28.30	0.79	7.88	N/A	N/A
Boca_N	20-Jun-12	14:26	38.77	2.74	0.65	2.09	2.17	0.83	101.58	22.93	27.50	0.86	7.98	N/A	N/A
Hillsboro_N	3-Jul-12	13:34	18.50	0.41	0.40	0.02	0.42	0.21	101.87	30.06	29.37	1.11	8.17	N/A	N/A
Hillsboro_S	3-Jul-12	13:58	37.15	0.50	0.46	0.03	0.96	0.13	101.84	21.93	30.45	1.03	8.03	N/A	N/A
Boca_N	3-Jul-12	14:35	19.19	0.33	0.33	0.00	1.50	0.23	101.81	28.49	30.60	1.14	8.07	N/A	N/A
Hillsboro_N	17-Jul-12	10:47	76.13	5.81	1.42	4.39	7.05	0.85	101.73	17.93	29.44	0.69	7.80	N/A	N/A
Hillsboro_S	17-Jul-12	11:15	52.49	3.35	1.01	2.35	5.93	0.53	101.71	16.34	29.60	0.67	7.75	N/A	N/A
Boca_N	17-Jul-12	11:55	71.74	4.84	1.16	3.69	4.40	1.66	101.73	21.96	29.10	0.75	7.85	N/A	N/A
Hillsboro_N	2-Aug-12	13:37	7.10	0.57	0.39	0.18	2.47	0.16	101.57	33.80	30.07	1.02	8.13	N/A	N/A
Hillsboro_S	2-Aug-12	14:08	21.97	0.32	0.32	0.00	0.71	0.20	101.55	27.06	31.09	1.00	8.00	N/A	N/A
Boca_N	2-Aug-12	14:45	14.14	0.55	0.55	0.01	0.66	0.51	101.52	31.44	30.70	1.02	8.06	N/A	N/A
Hillsboro_N	14-Aug-12	10:10	24.56	0.46	0.41	0.05	0.96	0.21	101.77	25.84	30.50	0.92	7.95	N/A	N/A
Hillsboro_S	14-Aug-12	10:40	38.64	0.75	0.67	0.08	0.81	0.33	101.77	24.91	30.65	0.92	7.92	N/A	N/A
Boca_N	14-Aug-12	11:20	71.63	7.51	1.73	5.78	2.91	2.29	101.78	24.32	30.32	0.81	7.86	N/A	N/A
Hillsboro_N	28-Aug-12	10:45	65.43	16.43	1.50	14.94	10.56	1.37	101.70	16.11	29.10	0.78	7.76	N/A	N/A
Hillsboro_S	28-Aug-12	11:15	65.52	8.59	0.85	7.74	7.59	0.39	101.62	5.72	27.35	0.66	7.57	N/A	N/A
Boca_N	28-Aug-12	12:15	56.97	14.59	1.73	12.86	10.28	1.66	101.63	7.14	27.64	0.64	7.48	N/A	N/A
Hillsboro_N	13-Sep-12	11:10	66.47	5.47	0.92	4.55	3.59	1.04	101.86	13.41	28.23	0.72	7.75	N/A	N/A
Hillsboro_S	13-Sep-12	11:35	76.50	3.02	0.86	2.17	2.99	0.35	101.87	14.74	28.72	0.69	7.78	N/A	N/A
Boca_N	13-Sep-12	12:20	57.26	4.62	0.90	3.72	2.92	1.01	101.84	13.79	28.41	0.75	7.76	N/A	N/A
Hillsboro_N	2-Oct-12	11:32	25.20	2.70	0.82	1.88	0.86	0.36	101.54	23.00	28.50	0.76	7.96	N/A	N/A
Hillsboro_S	2-Oct-12	12:00	34.90	4.66	1.31	3.35	1.13	0.62	101.10	28.30	27.65	0.65	8.05	N/A	N/A
Boca_N	2-Oct-12	12:40	21.10	2.07	0.29	1.78	1.19	0.69	101.54	24.10	28.60	0.75	7.81	N/A	N/A
Boca_N	15-Oct-12	10:18	9.69	1.26	0.16	1.10	0.14	0.42	101.25	30.06	27.00	0.68	8.06	20.38	1.03
Boca_N	15-Oct-12	11:03	16.19	1.70	0.26	1.44	0.83	0.62	101.26	28.02	27.30	0.69	8.04	22.29	1.10
Boca_N	15-Oct-12	12:01	17.59	1.88	0.26	1.62	0.29	0.58	101.23	27.37	27.63	0.70	8.03	27.43	1.17
Boca_N	15-Oct-12	13:13	13.47	1.33	0.19	1.14	0.57	0.49	101.15	28.38	27.65	0.80	8.04	21.92	1.17
Boca_N	15-Oct-12	14:00	12.62	1.25	0.17	1.08	0.29	0.50	101.09	28.17	27.70	0.54	8.04	22.72	1.22
Boca_N	15-Oct-12	15:00	15.78	1.38	0.19	1.20	0.31	0.56	101.00	26.66	27.90	0.78	8.02	23.13	1.27
Boca_N	15-Oct-12	15:50	9.39	0.29	0.10	0.19	0.00	0.44	100.98	27.63	27.70	0.60	8.05	22.47	1.23
Boca_N	15-Oct-12	16:25	4.13	0.37	0.09	0.27	0.00	0.33	100.97	31.34	27.80	0.43	8.11	17.87	0.98

Sample Site	Sample Day	Time local	Si µM	N+N µM	NO_2 µM	NO_3 µM	NH_4 µM	PO_4 µM	BP kPA	Sal ppt	Temp °C	DO %	pH	TN µM	TP µM
Hillsboro_N	17-Oct-12	12:00	8.90	0.63	0.18	0.45	0.00	0.20	101.20	32.88	28.34	0.92	8.11	N/A	N/A
Hillsboro_S	17-Oct-12	12:22	18.90	1.70	0.37	1.33	0.81	0.33	101.19	29.59	28.40	0.88	8.07	N/A	N/A
Boca_N	17-Oct-12	13:02	15.70	1.87	0.18	1.69	0.03	0.51	101.15	29.48	28.39	0.89	8.01	N/A	N/A
Hillsboro_N	5-Nov-12	14:40	33.70	2.46	0.25	2.21	0.40	0.34	101.39	25.57	25.68	0.95	8.01	N/A	N/A
Hillsboro_S	5-Nov-12	15:06	53.60	3.04	0.27	2.77	0.87	0.47	101.39	21.06	25.20	0.92	7.91	N/A	N/A
Boca_N	5-Nov-12	15:40	6.50	1.04	0.12	0.91	0.00	0.31	101.39	33.40	26.40	1.03	8.14	N/A	N/A
Hillsboro_N	19-Nov-12	15:39	6.57	0.03	0.03	0.00	0.49	0.15	101.64	35.39	25.90	0.90	8.15	N/A	N/A
Hillsboro_S	19-Nov-12	16:04	11.64	0.90	0.09	0.81	0.99	0.24	101.64	33.63	25.50	0.90	8.13	N/A	N/A
Boca_N	19-Nov-12	16:40	8.28	0.83	0.10	0.73	1.35	0.23	101.66	34.06	25.16	0.92	8.14	N/A	N/A
Hillsboro_N	14-Dec-12	12:45	1.72	0.05	0.05	0.00	0.65	0.11	101.90	35.45	24.90	0.92	8.13	N/A	N/A
Hillsboro_S	14-Dec-12	13:18	3.62	0.40	0.06	0.35	0.73	0.22	101.85	34.71	25.00	0.92	8.13	N/A	N/A
Boca_N	14-Dec-12	13:55	2.24	0.06	0.06	0.00	0.60	0.24	101.85	35.38	24.75	0.91	8.14	N/A	N/A
Hillsboro_N	27-Dec-12	11:15	0.26	0.07	0.03	0.04	0.72	0.09	101.80	34.97	23.60	0.84	8.17	N/A	N/A
Hillsboro_S	27-Dec-12	11:48	0.20	0.03	0.03	0.00	1.94	0.10	101.78	33.26	22.90	0.89	8.12	N/A	N/A
Boca_N	27-Dec-12	12:33	0.99	0.15	0.03	0.12	1.28	0.08	101.72	35.34	23.80	0.86	8.18	N/A	N/A
Hillsboro_N	14-Jan-13	13:30	0.00	1.04	0.09	0.95	0.50	0.12	102.05	35.65	24.30	0.86	8.13	N/A	N/A
Hillsboro_S	14-Jan-13	14:05	3.61	1.77	0.17	1.60	0.65	0.20	102.02	33.50	24.18	0.86	8.05	N/A	N/A
Boca_N	14-Jan-13	14:38	0.27	0.14	0.02	0.12	0.41	0.09	102.03	35.21	24.28	0.86	8.11	N/A	N/A
Boca_N	25-Jan-13	8:05	1.35	0.49	0.06	0.43	0.98	0.12	102.51	35.05	22.95	0.75	8.16	6.84	0.25
Boca_N	25-Jan-13	9:00	6.11	1.45	0.16	1.30	1.15	0.36	102.54	32.63	22.00	0.78	8.10	11.11	0.64
Boca_N	25-Jan-13	10:22	2.49	0.39	0.09	0.30	0.72	0.17	102.58	34.58	22.70	0.66	8.16	8.03	0.36
Boca_N	25-Jan-13	11:10	1.12	0.05	0.05	0.00	0.60	0.07	102.54	35.05	23.30	0.84	8.18	7.08	0.27
Boca_N	25-Jan-13	12:00	0.55	0.03	0.03	0.00	2.31	0.06	102.47	35.18	23.60	0.83	8.18	N/A	N/A
Boca_N	25-Jan-13	12:10	1.26	0.06	0.06	0.00	0.78	0.11	102.47	35.18	23.60	0.83	8.18	9.73	0.25
Boca_N	25-Jan-13	13:00	1.56	0.05	0.05	0.00	1.71	0.10	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Boca_N	25-Jan-13	13:05	0.82	0.03	0.03	0.00	0.77	0.06	N/A	N/A	N/A	N/A	N/A	7.76	0.30
Boca_N	25-Jan-13	14:00	2.23	0.05	0.05	0.00	0.30	0.10	102.29	35.03	23.60	0.80	8.17	N/A	N/A
Boca_N	25-Jan-13	14:05	1.72	0.04	0.04	0.00	0.57	0.10	102.29	35.03	23.60	0.79	8.17	6.93	0.34
Boca_N	25-Jan-13	15:05	0.00	0.10	0.01	0.09	1.32	0.02	102.22	35.85	24.60	0.77	8.21	6.68	0.15
Hillsboro_N	28-Jan-13	12:27	0.17	0.02	0.02	0.00	0.60	0.07	102.60	35.39	24.30	0.92	8.20	N/A	N/A
Hillsboro_S	28-Jan-13	13:05	6.55	0.02	0.02	0.00	0.23	0.04	102.53	34.50	24.20	0.94	8.16	N/A	N/A
Boca_N	28-Jan-13	13:42	4.67	0.02	0.02	0.00	0.48	0.06	102.46	35.54	24.40	0.91	8.19	N/A	N/A
Hillsboro_N	13-Feb-13	12:38	1.95	0.23	0.04	0.19	0.28	0.06	101.52	35.48	24.06	0.95	8.15	N/A	N/A
Hillsboro_S	13-Feb-13	13:05	5.48	0.52	0.07	0.44	0.29	0.14	101.47	34.63	24.00	0.95	8.11	N/A	N/A
Boca_N	13-Feb-13	14:00	2.37	0.28	0.04	0.24	2.31	0.11	101.91	33.29	24.91	0.79	8.13	N/A	N/A
Hillsboro_N	27-Feb-13	12:10	1.96	0.47	0.05	0.42	1.78	0.08	101.45	35.72	24.44	0.89	8.15	N/A	N/A
Hillsboro_S	27-Feb-13	12:34	4.41	0.32	0.06	0.27	0.22	0.09	101.44	34.11	24.70	0.89	8.10	N/A	N/A
Boca_N	27-Feb-13	13:08	1.85	0.37	0.06	0.31	0.29	0.08	101.42	35.61	24.30	0.89	8.16	N/A	N/A
Boca_N	1-Mar-13	11:15	1.43	0.16	0.02	0.14	0.15	0.04	101.54	35.85	22.70	0.70	8.13	3.12	0.15
Boca_N	1-Mar-13	12:00	3.52	0.62	0.07	0.55	0.55	0.14	101.51	35.30	22.60	0.84	8.13	5.20	0.26
Boca_N: N	1-Mar-13	13:00	5.14	1.00	0.11	0.89	1.87	0.25	101.44	33.39	22.70	1.04	8.09	0.00	0.00
Boca_N: M	1-Mar-13	13:01	5.00	0.87	0.12	0.76	1.04	0.23	101.45	34.51	22.80	0.59	8.10	0.00	0.00
Boca_N: S	1-Mar-13	13:02	3.69	0.77	0.08	0.69	0.72	0.19	101.45	35.02	22.80	0.68	8.12	0.00	0.00

Sample Site	Sample Day	Time local	Si µM	N+N µM	NO_2 µM	NO_3 µM	NH_4 µM	PO_4 µM	BP kPA	Sal ppt	Temp °C	DO %	pH	TN µM	TP µM
Boca_N	1-Mar-13	13:05	4.63	1.11	0.10	1.01	1.11	0.25	101.43	34.58	22.70	0.68	8.10	6.46	0.46
Boca_N: N	1-Mar-13	14:07	1.57	0.51	0.04	0.47	0.20	0.05	101.34	35.50	22.80	0.92	8.17	N/A	N/A
Boca_N: M	1-Mar-13	14:08	3.39	0.52	0.08	0.44	0.63	0.13	101.35	35.15	22.70	0.84	8.14	N/A	N/A
Boca_N: S	1-Mar-13	14:09	2.52	0.53	0.06	0.47	1.31	0.10	101.35	35.33	22.75	0.88	8.16	N/A	N/A
Boca_N	1-Mar-13	14:10	2.39	0.46	0.06	0.40	0.57	0.07	N/A	N/A	N/A	N/A	0.00	5.07	0.26
Boca_N: S	1-Mar-13	15:00	1.78	0.27	0.06	0.21	1.61	0.04	101.31	35.75	22.70	0.96	8.17	N/A	N/A
Boca_N: M	1-Mar-13	15:01	4.05	0.88	0.10	0.78	0.62	0.19	101.32	35.11	22.50	0.57	8.13	N/A	N/A
Boca_N: N	1-Mar-13	15:02	2.91	0.65	0.08	0.58	1.05	0.11	101.32	35.38	22.60	0.83	8.15	N/A	N/A
Boca_N	1-Mar-13	15:05	8.90	0.59	0.08	0.51	0.75	0.13	101.30	35.19	22.40	0.88	8.13	3.19	0.31
Boca_N	1-Mar-13	16:00	3.04	0.58	0.07	0.51	0.44	0.08	101.32	35.42	22.55	0.81	8.14	5.59	0.30
Boca_N	1-Mar-13	17:00	3.65	0.58	0.08	0.50	0.38	0.12	101.35	35.36	22.30	0.68	8.13	5.39	0.27
Hillsboro_N	12-Mar-13	12:55	1.24	0.42	0.03	0.39	0.06	0.04	101.59	35.75	22.66	0.95	8.16	N/A	N/A
Hilsboro_S	12-Mar-13	13:17	4.08	0.17	0.05	0.11	0.15	0.08	101.55	34.48	22.70	0.95	8.11	N/A	N/A
Boca_N	12-Mar-13	13:55	2.00	0.26	0.05	0.21	0.21	0.08	101.49	35.36	22.70	0.95	8.15	N/A	N/A
Hillsboro_N	26-Mar-13	12:25	2.55	0.21	0.06	0.15	0.47	0.07	102.02	35.20	22.54	0.86	8.12	N/A	N/A
Hilsboro_S	26-Mar-13	12:50	7.66	0.29	0.06	0.24	0.30	0.16	102.01	34.19	22.90	0.86	8.08	N/A	N/A
Boca_N	26-Mar-13	13:32	2.25	0.26	0.04	0.22	0.14	0.06	101.96	35.80	22.30	0.85	8.17	N/A	N/A
Hillsboro_N	10-Apr-13	13:10	30.49	0.63	0.12	0.51	1.49	0.21	101.87	35.20	24.66	1.04	8.15	N/A	N/A
Hilsboro_S	10-Apr-13	13:38	38.45	0.67	0.13	0.54	1.62	0.21	101.83	33.27	25.07	1.05	8.08	N/A	N/A
Boca_N	10-Apr-13	14:10	54.30	2.66	0.33	2.33	3.12	1.36	101.82	35.36	25.10	0.98	8.15	N/A	N/A
Hillsboro_N	24-Apr-13	11:43	4.79	0.14	0.05	0.09	0.88	0.11	102.04	33.25	25.90	0.99	8.11	N/A	N/A
Hilsboro_S	24-Apr-13	12:05	8.08	0.51	0.12	0.40	0.74	0.17	102.03	32.23	26.38	0.96	8.05	N/A	N/A
Boca_N	24-Apr-13	12:45	4.72	0.07	0.04	0.03	1.14	0.10	101.97	31.53	26.80	0.96	8.02	N/A	N/A
Hillsboro_N	15-May-13	16:00	21.82	0.03	0.03	0.00	0.91	0.23	102.04	25.70	27.67	0.95	8.09	N/A	N/A
Hilsboro_S	15-May-13	16:25	36.60	0.03	0.03	0.00	0.79	0.08	102.00	22.03	27.70	0.93	8.03	N/A	N/A
Boca_N	15-May-13	16:55	4.33	0.07	0.04	0.03	0.94	0.05	101.97	28.21	27.20	0.94	8.12	N/A	N/A
Hillsboro_N	29-May-13	15:03	2.75	0.05	0.02	0.02	0.17	0.03	101.86	24.64	26.40	0.88	7.99	N/A	N/A
Hilsboro_S	29-May-13	15:38	9.06	0.05	0.01	0.04	0.32	0.07	101.77	24.07	26.47	0.88	8.00	N/A	N/A
Boca_N	29-May-13	16:10	2.71	0.17	0.02	0.15	0.75	0.07	101.76	17.24	26.50	0.84	7.90	N/A	N/A
Hillsboro_N	11-Jun-13	14:18	50.78	0.10	0.09	0.00	1.24	0.22	101.81	11.91	29.03	1.18	8.09	N/A	N/A
Hilsboro_S	11-Jun-13	14:38	69.77	1.86	0.32	1.54	2.27	0.14	101.76	10.36	29.00	0.91	7.87	N/A	N/A
Boca_N	11-Jun-13	15:17	63.19	4.59	0.54	4.06	2.18	0.96	101.76	13.74	29.00	0.82	7.82	N/A	N/A
Hillsboro_N	25-Jun-13	13:10	39.60	0.85	0.15	0.70	1.52	0.22	101.98	25.55	29.30	0.93	7.98	N/A	N/A
Hilsboro_S	25-Jun-13	13:40	51.96	1.12	0.19	0.93	1.52	0.26	101.97	21.06	29.90	0.88	7.90	N/A	N/A
Boca_N	25-Jun-13	14:25	27.79	0.74	0.14	0.60	1.87	0.40	101.94	27.82	29.90	0.94	7.99	N/A	N/A
Boca_N	26-Jun-13	13:05	28.17	0.72	0.16	0.56	2.64	0.45	101.91	28.44	29.50	0.77	7.96	19.92	0.80
Boca_N	26-Jun-13	14:05	32.66	0.92	0.17	0.74	2.44	0.58	101.87	27.30	29.70	0.69	7.93	17.25	0.92
Boca_N	26-Jun-13	15:05	24.21	0.77	0.12	0.65	1.33	0.35	101.84	29.32	30.00	0.86	8.00	13.83	0.70
Boca_N	26-Jun-13	16:05	24.36	0.57	0.12	0.45	1.65	0.35	101.81	28.99	29.70	0.62	8.01	14.17	0.74
Boca_N	26-Jun-13	17:00	27.85	0.51	0.11	0.40	1.69	0.38	101.75	28.21	29.60	0.93	7.99	12.47	0.81
Boca_N	26-Jun-13	18:00	29.64	0.54	0.10	0.44	1.29	0.43	101.74	27.76	29.50	0.93	7.98	12.96	0.78
Boca_N	26-Jun-13	18:55	32.09	0.73	0.11	0.62	1.34	0.46	101.70	27.27	29.30	0.85	7.98	14.64	0.96
Hillsboro_N	10-Jul-13	13:08	46.54	1.16	0.16	1.00	1.61	0.32	101.86	21.12	28.70	0.81	7.97	N/A	N/A

Sample Site	Sample Day	Time local	Si µM	N+N µM	NO_2 µM	NO_3 µM	NH_4 µM	PO_4 µM	BP kPA	Sal ppt	Temp °C	DO %	pH	TN µM	TP µM
Hilsboro_S	10-Jul-13	13:28	66.41	1.32	0.31	1.01	2.03	0.24	101.83	17.92	29.02	0.74	7.87	N/A	N/A
Boca_N	10-Jul-13	14:05	65.97	2.30	0.27	2.03	4.17	0.78	101.84	17.35	28.90	0.70	7.87	N/A	N/A
Hillsboro_N	24-Jul-13	12:28	24.93	0.88	0.88	0.00	2.04	0.07	101.60	25.60	29.12	0.89	8.03	N/A	N/A
Hilsboro_S	24-Jul-13	12:50	39.36	1.81	0.59	1.22	1.09	0.00	101.58	22.53	29.22	0.87	7.97	N/A	N/A
Boca_N	24-Jul-13	13:25	42.11	2.88	0.53	2.35	3.17	0.82	101.58	22.21	29.50	0.78	7.90	N/A	N/A
Hillsboro_N	7-Aug-13	12:12	55.14	2.46	0.49	1.97	2.14	0.72	101.52	20.48	30.16	0.82	7.94	N/A	N/A
Hilsboro_S	7-Aug-13	12:43	77.18	2.58	0.83	1.75	2.56	0.50	101.54	16.65	30.27	0.70	7.77	N/A	N/A
Boca_N	7-Aug-13	13:20	53.68	2.85	0.53	2.32	2.74	0.96	101.52	18.85	30.45	0.74	7.86	N/A	N/A
Hillsboro_N	20-Aug-13	11:35	56.37	1.09	0.78	0.31	1.82	0.37	101.79	22.93	30.01	0.75	7.98	22.25	0.70
Hilsboro_S	20-Aug-13	12:00	78.44	1.55	1.09	0.47	2.21	0.45	101.79	19.70	30.24	0.72	7.90	28.28	0.72
Boca_N	20-Aug-13	12:35	32.92	0.99	0.49	0.50	2.32	0.53	101.79	24.65	30.20	0.77	8.01	14.97	0.94
Hillsboro_M	21-Aug-13	10:00	7.10	0.34	0.34	0.00	0.96	0.06	101.79	21.09	30.08	0.73	7.92	8.53	0.33
Hillsboro_M	21-Aug-13	10:30	7.62	0.32	0.32	0.00	0.73	0.06	101.80	22.57	29.95	0.73	7.94	5.91	0.31
Hillsboro_M	21-Aug-13	11:00	32.32	0.45	0.39	0.06	1.83	0.17	101.81	23.70	29.85	0.72	7.96	13.03	0.46
Hillsb-NS_N	21-Aug-13	11:30	39.91	0.52	0.48	0.04	1.55	0.21	N/A	N/A	N/A	N/A	N/A	14.98	0.57
Hillsb-NS_M	21-Aug-13	11:31	41.08	0.57	0.57	0.00	1.28	0.20	N/A	N/A	N/A	N/A	N/A	13.61	0.63
Hillsb-NS_S	21-Aug-13	11:32	17.05	0.38	0.38	0.00	0.70	0.08	N/A	N/A	N/A	N/A	N/A	8.57	0.38
Hillsboro_M	21-Aug-13	12:00	39.55	0.71	0.71	0.00	1.22	0.28	101.88	27.69	30.05	0.67	8.03	15.70	0.55
Hillsboro_M	21-Aug-13	12:30	24.89	0.31	0.31	0.00	1.38	0.16	101.88	30.33	30.00	0.59	8.06	9.71	0.50
Hillsboro_M	21-Aug-13	13:00	40.37	0.73	0.73	0.00	2.29	0.25	101.83	27.44	30.25	0.60	8.03	19.01	0.70
Hillsboro_M	21-Aug-13	13:30	49.35	0.63	0.63	0.00	1.63	0.22	N/A	N/A	N/A	N/A	N/A	17.79	0.72
Hillsboro_M	21-Aug-13	14:00	46.02	0.87	0.87	0.00	1.94	0.16	101.79	26.94	30.20	0.68	8.02	15.14	0.67
Hillsb-NS_N	21-Aug-13	14:30	50.58	1.23	1.23	0.00	1.97	0.22	N/A	N/A	N/A	N/A	N/A	24.30	0.71
Hillsb-NS_M	21-Aug-13	14:31	58.67	1.09	1.09	0.00	2.31	0.17	N/A	N/A	N/A	N/A	N/A	22.55	0.74
Hillsb-NS_S	21-Aug-13	14:32	60.24	1.10	1.10	0.00	2.93	0.36	N/A	N/A	N/A	N/A	N/A	14.20	0.56
Hillsboro_M	21-Aug-13	15:00	36.96	0.70	0.70	0.00	1.00	0.23	101.74	21.62	30.80	0.65	7.94	22.18	0.77
Hillsboro_M	21-Aug-13	15:30	69.67	0.82	0.82	0.00	2.74	0.33	N/A	N/A	N/A	N/A	N/A	24.91	0.77
Hillsboro_M	21-Aug-13	16:00	83.47	0.98	0.98	0.00	2.07	0.18	N/A	N/A	N/A	N/A	N/A	28.63	0.80
Hillsboro_M	21-Aug-13	16:25	43.03	0.79	0.79	0.00	1.35	0.06	101.65	18.91	30.60	0.64	7.88	27.66	0.83
Hillsboro_M	26-Aug-13	13:25	73.42	1.14	1.14	0.00	3.75	0.06	101.87	35.49	30.50	0.69	8.14	3.50	0.25
Hillsboro_M	26-Aug-13	14:00	19.54	0.42	0.42	0.00	0.94	0.00	101.81	35.50	29.70	0.79	8.14	5.78	0.29
Hillsboro_M	26-Aug-13	14:30	25.08	0.43	0.43	0.00	2.95	0.12	101.80	31.61	29.90	0.67	8.09	9.51	0.36
Hillsboro_M	26-Aug-13	15:00	45.42	0.62	0.62	0.00	2.34	0.17	101.77	28.77	29.55	0.80	8.05	14.29	0.42
Hillsb-NS_N	26-Aug-13	15:30	41.11	0.21	0.18	0.03	2.30	0.06	101.72	27.69	30.00	0.65	8.05	14.42	0.51
Hillsb-NS_M	26-Aug-13	15:31	32.93	0.36	0.27	0.09	1.80	0.08	101.72	27.40	30.10	0.56	8.04	14.88	0.53
Hillsb-NS_S	26-Aug-13	15:32	17.00	0.23	0.23	0.00	2.09	0.11	101.72	32.53	29.90	0.68	8.11	10.09	0.35
Hillsboro_M	26-Aug-13	16:00	59.99	0.61	0.43	0.17	1.90	0.33	101.68	25.20	29.50	0.54	8.00	17.29	0.55
Hillsboro_M	26-Aug-13	16:30	62.51	0.64	0.45	0.20	1.59	0.37	101.70	24.85	30.00	0.61	7.99	18.28	0.64
Hillsboro_M	26-Aug-13	17:00	61.64	0.59	0.43	0.16	2.27	0.38	101.69	23.73	30.00	0.71	7.96	19.00	0.59
Hillsboro_M	26-Aug-13	17:45	70.12	0.83	0.46	0.38	2.50	0.41	101.72	23.06	29.80	0.63	7.94	21.01	0.66
Hillsboro_N	29-Aug-13	7:00	55.15	3.57	0.53	3.04	6.42	0.97	101.59	21.10	28.80	0.56	7.81	23.79	1.29
Hillsboro_N	29-Aug-13	7:05	94.07	1.46	0.73	0.73	3.08	0.50	101.60	21.36	28.80	0.54	7.82	24.82	1.16
Hilsboro_S	29-Aug-13	7:30	39.45	2.40	0.52	1.89	5.40	0.84	101.61	20.12	28.85	0.55	7.84	27.16	0.66

Sample Site	Sample Day	Time local	Si µM	N+N µM	NO_2 µM	NO_3 µM	NH_4 µM	PO_4 µM	BP kPA	Sal ppt	Temp °C	DO %	pH	TN µM	TP µM
Hilsboro_S	29-Aug-13	7:35	53.29	3.28	0.56	2.72	7.24	0.95	101.61	18.92	28.90	0.55	7.80	30.11	0.66
Boca_N	29-Aug-13	8:06	97.83	1.41	0.78	0.64	3.32	0.50	101.64	23.44	28.40	0.61	7.89	19.88	1.18
Boca_N	29-Aug-13	8:10	38.33	2.42	0.51	1.91	5.39	0.86	101.65	23.58	28.50	0.63	7.89	20.23	1.19
Hillsboro_N	29-Aug-13	8:55	106.54	2.06	0.74	1.32	5.01	0.72	101.64	17.15	29.10	0.55	7.71	34.02	0.88
Hillsboro_N	29-Aug-13	9:00	137.67	1.87	0.87	1.00	4.11	0.55	101.65	17.31	29.10	0.52	7.70	34.60	1.07
Hilsboro_S	29-Aug-13	9:26	36.01	2.55	0.61	1.95	5.18	0.83	101.64	13.77	29.20	0.52	7.61	41.51	0.71
Hilsboro_S	29-Aug-13	10:03	96.17	2.41	0.77	1.64	5.83	0.84	101.64	14.22	29.30	0.49	7.61	42.28	0.77
Boca_N	29-Aug-13	9:58	136.01	1.71	0.95	0.76	4.38	0.60	101.65	23.98	29.20	0.56	7.84	20.83	1.25
Boca_N	29-Aug-13	10:03	36.72	2.52	0.49	2.03	5.75	0.86	101.65	23.73	29.20	0.61	7.83	20.15	1.21
Hillsboro_N	4-Sep-13	11:50	116.66	3.11	0.79	2.33	5.65	0.59	101.80	16.52	29.10	0.61	7.74	N/A	N/A
Hilsboro_S	4-Sep-13	12:15	134.41	3.01	0.91	2.10	5.39	0.53	101.82	13.40	29.10	0.57	7.65	N/A	N/A
Boca_N	4-Sep-13	12:47	56.52	3.08	0.37	2.72	4.39	0.83	101.79	23.88	29.30	0.71	7.91	N/A	N/A
Hillsboro_M	10-Sep-13	12:05	30.84	0.85	0.32	0.53	2.12	0.15	101.74	30.08	29.60	0.72	8.07	N/A	N/A
Hillsboro_M	10-Sep-13	12:38	37.40	0.72	0.33	0.39	2.82	0.17	101.70	29.03	29.60	0.69	8.04	N/A	N/A
Hillsboro_M	10-Sep-13	13:00	36.71	0.55	0.33	0.22	0.95	0.17	101.72	29.21	29.40	0.76	8.06	N/A	N/A
Hillsboro_M	10-Sep-13	13:35	19.82	0.27	0.25	0.02	0.91	0.13	101.67	31.87	29.70	0.61	8.09	N/A	N/A
Hillsboro_M	10-Sep-13	14:00	47.17	1.29	0.49	0.80	2.39	0.21	101.66	27.64	30.00	0.64	8.03	N/A	N/A
Hillsb-NS_N	10-Sep-13	14:35	55.86	1.10	0.54	0.56	1.45	0.22	101.63	26.58	30.30	0.46	8.02	N/A	N/A
Hillsb-NS_M	10-Sep-13	14:36	68.50	1.30	0.59	0.70	1.05	0.24	101.62	24.56	30.40	0.56	8.00	N/A	N/A
Hillsb-NS_S	10-Sep-13	14:37	30.01	0.40	0.29	0.12	1.25	0.11	101.62	30.26	30.60	0.57	8.07	N/A	N/A
Hillsboro_M	10-Sep-13	15:10	72.47	1.47	0.60	0.87	2.50	0.26	101.59	23.71	29.60	0.66	7.98	N/A	N/A
Hillsboro_M	10-Sep-13	16:15	66.06	1.23	0.68	0.55	1.43	0.29	101.59	24.87	29.60	0.67	7.99	N/A	N/A
Hillsboro_M	10-Sep-13	16:30	74.97	1.48	0.96	0.51	1.46	0.30	101.60	23.29	29.80	0.52	7.96	N/A	N/A
Hillsboro_M	10-Sep-13	17:20	80.35	1.80	0.98	0.82	2.41	0.40	101.59	22.08	29.40	0.65	7.92	N/A	N/A
Hillsboro_M	10-Sep-13	18:00	102.96	2.16	1.03	1.14	1.62	0.43	101.74	30.08	29.60	0.72	8.07	N/A	N/A
Hillsboro_M	10-Sep-13	19:00	115.11	2.53	1.37	1.16	3.27	0.50	101.65	17.74	29.00	0.61	7.86	N/A	N/A
Hillsboro_N	18-Sep-13	11:15	83.06	2.68	0.69	1.99	3.82	0.50	101.62	20.71	28.10	0.69	7.90	N/A	N/A
Hilsboro_S	18-Sep-13	11:37	98.72	2.82	0.79	2.03	4.83	0.54	101.60	17.96	28.10	0.66	7.83	N/A	N/A
Boca_N	18-Sep-13	12:08	33.58	3.49	0.47	3.03	5.15	0.93	101.58	31.11	28.40	0.80	8.03	N/A	N/A
Hillsboro	5-Dec-13	10:15	6.06	0.99	0.14	0.85	1.39	0.19	N/A	34.10	25.50	N/A	N/A	N/A	N/A
Hillsboro	5-Dec-13	11:00	4.65	0.78	0.08	0.70	0.79	0.15	N/A	34.30	25.50	N/A	N/A	N/A	N/A
Hillsboro	5-Dec-13	12:00	6.42	1.07	0.13	0.93	1.94	0.19	N/A	33.80	25.50	N/A	N/A	N/A	N/A
Hillsboro	5-Dec-13	13:00	9.22	1.54	0.16	1.38	2.21	0.29	N/A	33.40	25.50	N/A	N/A	N/A	N/A
Hillsboro	5-Dec-13	14:00	13.81	2.05	0.18	1.87	1.85	0.31	N/A	31.50	25.50	N/A	N/A	N/A	N/A
Hillsboro	5-Dec-13	15:00	12.28	1.83	0.18	1.65	3.25	0.35	N/A	31.60	25.40	N/A	N/A	N/A	N/A
Hillsboro	5-Dec-13	16:00	17.81	2.50	0.22	2.29	2.15	0.48	N/A	29.60	25.40	N/A	N/A	N/A	N/A
Hillsboro	5-Dec-13	17:00	30.06	3.43	0.33	3.10	2.76	0.58	N/A	28.80	25.40	N/A	N/A	N/A	N/A

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