Memo

To: Roy Coley, MBA / City of Miami Beach

Nelson Perez-Jacome, PE / City of Miami Beach

From: Agustin Maristany, PE / Ardurra

Date: February 13, 2020

Re: Biscayne Bay Preliminary Nutrient Loadings Estimates

Introduction

Recent reports of sewage spills and seagrass losses in Biscayne Bay have raised awareness of the potential impact of nutrient loadings to the health of the Bay. To better understand the extent of the City of Miami Beach loading contributions to the Bay, the City retained Ardurra Group, Inc. (Ardurra) to estimate preliminary nutrient loadings into the northern portion of the Bay from various sources, with primary emphasis on the relative nutrient loadings between the City and other major sources. Loadings are considered preliminary to the extent that they were based on readily available information, some source data were not available, and there is room for refinement based on additional data. However, the relative loadings amongst the various sources are not expected to change substantially from the results shown herein.

The northern portion of Biscayne Bay extends north of the Rickenbacker Causeway and has a surface area of approximately 17.9 square miles. Potential nutrient sources into the Bay include canal discharges, atmospheric deposition (wet and dry fall), coastal area discharges, coastal groundwater inflows, ocean outfalls, sewage spills, sediment resuspension/decomposition, nitrogen fixation, and tidal inflows. Of these potential sources, only canal discharges, atmospheric deposition, western coastal area discharges, and Miami Beach runoff were considered in the loading estimates because of insufficient data to cover the remaining sources. Excluded sources include coastal groundwater inflows, ocean outfall discharges, sewage spills, sediment resuspension/decomposition, nitrogen fixation, tidal inflows, and drainage from several coastal basins (Surfside, Bal Harbour, Bay Harbor Islands, Port Miami, Fisher Island, Virginia Key, and Indian Creek Island).

This technical memorandum summarizes the results of the work performed herein and is organized into the following sections:

- Introduction
- Inflow Sources
- Nutrient Data
- Loading Estimates
- Summary and Conclusions

ARDURRA

Inflow Sources

Data on inflow sources to the Bay were obtained from documents and databases, as follows:

- Flow records
    - South Florida Water Management District's (SFWMD) DBHYDRO database - daily average flows and rainfall at the Miami Airport (MIAMI.FS_R) for the period of record.
- Watersheds, Control Structures, and Operations
    - Map of Active DBHYDRO Stage Sites, SFWMD
    - Structure Books, SFWMD Operations Control Center
    - An Atlas of Eastern Dade County Surface Water Management Basins, SFWMD
    - Miami-Dade County GIS
- Miami Storm Event characteristics – "Analysis of Storm Event Characteristics for Selected Rainfall Gages Throughout the United States", EPA, 1989
- Miami Beach Land Use

Canal discharges into the western shores of the northern Bay contribute most of the inflow water into the northern Bay. Major canals discharging into the northern Bay include Snake Creek (C-9 East), Arch Creek, Biscayne Canal (C-8), Little River (C-7), and Miami River (C-6, C-5, and C-4). **Figure 1** shows the basin areas discharging into the Bay and **Table 1** provides a summary of canal flow data obtained from DBHYDRO.

Review of **Table 1** reveals occasional negative flows in all the basins which may be attributed to back flow through the control structure due to either storm surge overtopping the structure or high tides while the structured was partially open, although the nature of these occurrences was not investigated. A review of historic flow graphs at each station indicated that the occurrence of negative flows was very limited for all stations, except for G-58 which showed consistently negative values that could not be explained without a more in-depth investigation beyond the scope of this work. Therefore, the flow data for the G-58 station was not used in the calculations. Instead, flows for the Arch Creek Basin (G-58) were estimated as the product of its area and an average basin yield as discussed below.

Table 1 shows basin yields, defined as the volume of runoff per unit area, expressed in inches per year over the watershed. Rainfall at the Miami airport, for example, averaged 63.2 inches per year for the period April 1996 through August 2019. By comparison, some basin yields are very high due to seepage inflows from the Water Conservation Areas into the western reaches of these basins as well as surface water transfers from the regional system, including maintaining minimum flows and levels during dry periods. These unique hydrologic conditions inflate the basin yield and are not representative of basin yields for basins not affected by these hydrologic conditions.

In order to estimate average flows for coastal basins and Arch Creek, as shown in **Figure 1**, basin yields were calculated for a couple of neighboring basins that are not significantly affected by these hydrologic conditions. DBHYDRO records were downloaded for the Coral Gables and Cutler Drain canal basins as shown in **Table 2.**

Figure 1 – North Biscayne Bay Drainage Basins, Canals, and Control Structures

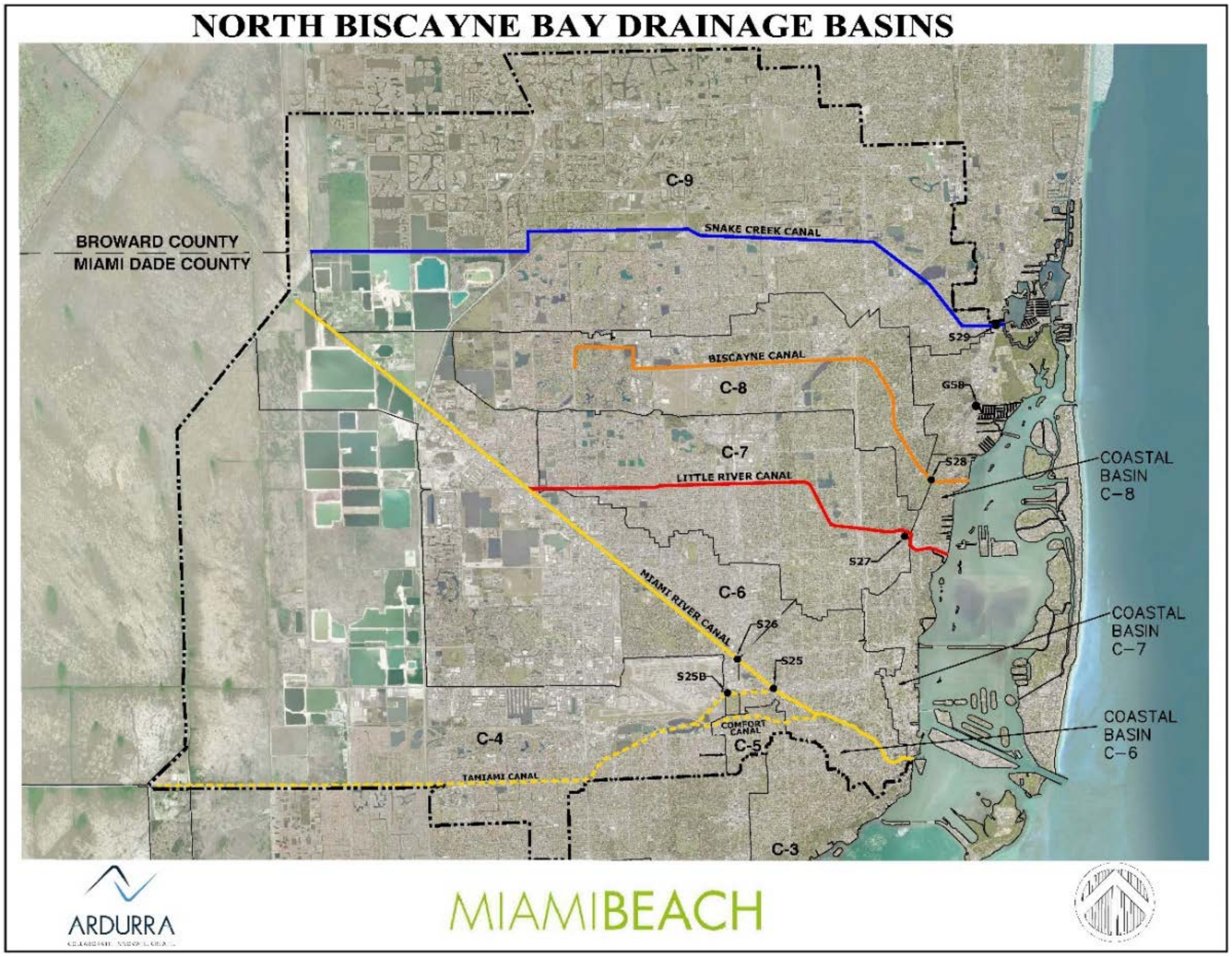


Table 1 – Summary of Canal Flows (DBHYDRO)

Canal			Period of Record		Area[1]	Daily Average Flow (cfs)				Yield
Name	Number	Structure	Start	End	(mi^2)	Count	Max	Min	Ave	in/yr
Snake Creek	C-9	S-29	5/31/85	8/6/19	98	12,196	2,778	-1,390	290	40.0
Arch Creek		G-58	9/5/87	7/31/19	7	10,350	118	-257	-32	
Biscayne	C-8	S-28	5/31/85	8/6/19	29	11,792	1,750	-131	108	51.5
Little River	C-7	S-27	5/31/85	8/6/19	32	12,032	1,645	-1,426	167	70.8
Miami River	C-6	S-26	5/31/85	8/21/19	54	12,536	1,960	1,212	213	53.6
Tamiami	C-4[2]	S-25B	5/31/85	8/6/19	84	12,473	1,817	-386	215	34.7
Comfort	C-5[2]	S-25	5/31/85	8/6/19	2	12,392	160	-29	9	62.4

[1] Basin area to control structure only
[2] C-4 and C-5 canals drain into the C-6 canal prior to discharging into Biscayne Bay

Table 2 – Basin Yields for Coastal Basins (DBHYDRO)

Canal			Period of Record		Area[1]	Daily Average Flow (cfs)				Yield
Name	Number	Structure	Start	End	(mi^2)	Count	Max	Min	Ave	in/yr
Coral Gables	C-3	S-93	9/30/91	8/7/19	11	10,106	430	-323	12.2	15.1
Cutler Drain	C-100	S-123	8/31/85	8/21/19	41	11,845	5,710	-2,773	39.3	13.0
[1] Basin area to control structure only										

From **Table 2**, the area weighted average basin yield of 13.4 in/yr was calculated as representative of coastal basins and applied to the coastal basin areas as well as Arch Creek to estimate average flows into the Bay.

Discharges from Miami Beach were estimated using the rational method as the product of the runoff coefficient (0.49), the average rainfall storm volume (0.71 inches less 0.1 inches to account for non-runoff producing storms), and the average number of storms per year (72.4 storms/year), as follows:

Miami Beach Runoff (in/yr) = 0.49 * (0.71-.1) * 72.4 = 21.6 in/yr

The runoff coefficient was estimated as the product of the fraction of land use and its respective runoff coefficient, as follows:

Runoff coefficient = $(0.64 * 0.4)_R + (0.275 * 0.8)_C + (0.085 * 0.15)_G = 0.49$

where: R = residential; C = commercial; G = golf course

Table 3 summarizes the inflows and drainage areas for each of the sources considered. Additionally, several inflow sources were consolidated for easy of reporting, as follows:

- Biscayne Canal was combined with its coastal area and Arch Creek
- Little River was combined with its coastal area
- Miami River was combined with its coastal area, as well as the Tamiami and Comfort canals which flow into the C-6 Canal before discharging into the Bay

Review of **Table 3** indicates that the bulk of inflow volumes are delivered to the Bay's western shores through various canals with a combined drainage area of 326.2 square miles, accounting for 91.7 percent of all inflows into the Bay. **Figure 1** depicts the combined basin outline discharging into the Bay. Miami Beach represents 1.8% of the drainage area of the northern portion of the Bay, contributing 0.9% of the inflows.

Table 3 – Summary of Inflow Sources

Inflow Source			Individual			Consolidated			
Name	Canal	Structure	Area (mi^2)	Flow cfs	Yield (in/yr)	Area (mi^2)	Area %	Flow cfs	Flow %
Snake Creek	C-9	S-29	98.4	290.1	40.0	98.4	28.1	290.1	25.9
Arch Creek	Arch Creek	G-58	7.3	7.2	13.4	38.0	10.8	117.7	10.5
Biscayne	C-8	S-28	28.5	108.3	51.5				
Biscayne	C-8	Coastal Basin	2.2	2.2	13.4				
Little River	C-7	S-27	32.0	167.0	70.8	36.9	10.5	171.9	15.3
Little River	C-7	Coastal Basin	5.0	4.9	13.4				
Miami River	C-6	S-26	53.9	212.8	53.6	152.8	43.6	449.1	40.0
Miami River	C-6	Coastal Basin	12.8	12.6	13.4				
Tamiami	C-4	S-25B	84.3	215.2	34.7				
Comfort	C-5	S-25	1.9	8.5	62.4				
Miami Beach		Miami Beach	6.4	10.2	21.6	6.4	1.8	10.2	0.9
Rainfall		Biscayne Bay	17.9	83.1	63.2	17.9	5.1	83.1	7.4
Total			350.5	1,122.1		350.5		1,122.1	

Nutrient Data

Nutrient data were obtained from various documents and databases, as follows:

- Canal Water Quality Data
  - South Florida Water Management District's (SFWMD) DBHYDRO database
- Miami Beach Water Quality Data
  - Monthly Water Quality Data - collected at 64 sampling stations throughout the coastal waters adjacent to Miami Beach for the period 8/16/16 to 5/20/19
  - Pump Station 32 Water Quality Sampling – 36 grab samples at the 6th Street Outfall for the period 10/31/18 to 11/15/18. Samples were obtained downstream of the vortex structure, at the wet well, and at the outfall when the pump station was on and off.
- Bulk deposition of phosphorus and nitrogen
  - Atmospheric Deposition of Phosphorus: Concepts, Constraints and Published Deposition Rates for Ecosystem Management, by Garth W. Redfield, 2/2002, South Florida Water Management District, EMA # 403, West Palm Beach, FL.
  - Quantifying Atmospheric Deposition of Phosphorus: A Conceptual Model and Literature Review for Environmental Management, by Garth W. Redfield, 3/1998, South Florida Water Management District, Technical Publication WRE #360, West Palm Beach, FL.
  - Outlier Detection in Phosphorus Dry Deposition Rates Measured in south Florida, by Hosung Ahn and R. Thomas James, Feb 1991, Atmospheric Environment 33 (1999) 5123-5131

Canal water quality data were available through DBHYDRO for numerous stations in Biscayne Bay. Data for stations closer to the point of discharge of each of the canals were selected and downloaded for further analysis. Subsequently, the nutrient data was paired with flow data from each of the canals to calculate flow-weighted concentrations for Total Nitrogen and Total Phosphorus. Generally, flow-weighted concentrations were higher than the simple averages, with nitrogen values experiencing a more pronounced increase compared to phosphorus. **Table 5** summarizes the flow-weighted concentrations at each of the stations. Bold values were used as the basis for calculating nutrient loads.

Table 5 – Summary of Canal Nutrient Data

Canal		Period of Record		Total Phosphorus (mg/l		Total Nitrogen (mg/l)	
Name	Station	Start	End	Count	Ave	Count	Ave
Snake Creek	SK01	7/11/88	9/8/14	155	**0.017**	27	1.11
	SK02	7/11/88	9/8/14	180	0.011	54	**1.31**
	SK03	7/8/91	9/8/14	146	0.007	52	1.04
Biscayne	BS01	3/19/79	9/8/14	219	0.016	28	0.55
	BS04	7/11/88	9/8/14	187	**0.019**	55	1.08
	BS10	7/8/91	9/8/14	152	0.016	50	**1.47**
Little River	LR01	3/19/79	9/8/14	216	0.013	28	0.53
	LR03	7/11/88	3/3/03	133	0.026	Insufficient Data	
	LR06	7/9/90	3/3/03	117	**0.029**	26	1.41
	LR10	7/8/91	9/8/14	151	0.012	50	**2.17**
Miami River	MR02	4/11/84	3/4/03	170	**0.021**	Insufficient Data	
	MR07	4/11/84	9/9/14	230	0.016	5	1.15
	MR08	2/1/88	9/9/14	193	0.010	54	**1.45**
	MR15	7/9/91	9/9/14	140	0.007	47	1.18
Tamiami	TM03	7/12/88	3/4/03	135	**0.011**	25	1.09
	TM08	7/9/91	3/4/03	94	0.005	23	**1.13**
Comfort	CM02	10/6/09	9/9/14	55	**0.033**	25	**0.53**

For coastal basins, an average of the bold phosphorus and nitrogen concentrations were used for the loading calculations: 0.022 mg/l for total phosphorus and 1.33 mg/l for total nitrogen.

Figure 2 shows the location and distribution of monthly water quality sampling stations monitored by Miami Beach. Locations included the Collins Canal, Indian Creek, Middle/North, South Beach, and Venetian Islands. Sixty-four (64) grab samples were obtained from adjacent coastal waters for the period 8/16/16 to 5/20/19. Thirty-two (32) of the 64 stations were located near existing outfalls (labeled “outfall”), while the remaining were obtained at representative locations throughout Miami Beach coastal waters (labeled “coastal”).

Table 5 provides a summary of Total Phosphorus and Total Nitrogen data from all the monthly grab sample data collected. Total Nitrogen was calculated by adding the organic nitrogen parameter (Total Kjeldahl Nitrogen) to the inorganic parameter (Nitrate plus Nitrite Nitrogen).

Figure 2 – Miami Beach Water Quality Sampling Stations

Table 5 – Summary of Miami Beach Nutrient Data in Adjacent Coastal Waters

Location	Count	Total Phosphorus (mg/l)			Total Nitrogen (mg/l)		
		Ave	Max	Min	Ave	Max	Min
All	64	0.038	0.103	0.030	0.474	0.828	0.347
Outfall	32	0.040	0.103	0.032	0.499	0.828	0.373
Coastal	32	0.036	0.081	0.030	0.448	0.603	0.347

In addition to the monthly samplings, the City conducted more detailed sampling at Pump Station 32 located at the 6th Street outfall. Sampling was conducted at multiple locations (as shown on **Table 6**) on the following dates and times:

- Daily grab samples on 10/31/18, 11/1/18, 11/2/18, and 11/5/18
- Four (4) grab samples on 11/6/18 between 11:05 am and 12:57 pm -
- Four (4) grab samples on 11/7/18 between 9:30 am and 1:40 pm
- Two (2) grab samples on 11/8/18 at 9:35 am and 10:00 am
- Two (2) grab samples on 11/9/18 at 11:11 am and 1:57 PM
- Daily grab samples on 11/14/18 and 11/15/18

Table 6 provides a summary of Total Phosphorus and Total Nitrogen data from all data collected at Pump Station 32. Total Nitrogen was calculated by adding the organic nitrogen parameter (Total Kjeldahl Nitrogen) to the inorganic parameter (Nitrate plus Nitrite Nitrogen).

Table 6 – Summary of Miami Beach Nutrient Data at Pump Station 32

Location	Count	Total Phosphorus (mg/l)			Total Nitrogen (mg/l)		
		Ave	Max	Min	Ave	Max	Min
All	36	0.054	0.120	0.036	0.697	1.250	0.275
Vortex	4	0.057	0.062	0.051	0.920	1.225	0.665
Wet Well	14	**0.055**	0.065	0.038	**0.788**	1.228	0.275
Pump On	14	0.055	0.120	0.036	0.574	0.860	0.275
Pump Off	4	0.043	0.050	0.038	0.589	0.896	0.355

After review of **Table 5 & 6**, the phosphorus and nitrogen concentrations used to calculate loadings from Miami Beach are highlighted in bold on **Table 6**. Generally, the higher values in **Table 6** were used and, within **Table 6**, the higher value between the “wet well” and “pump on” were selected for the load calculations.

For atmospheric deposition, bulk deposition values (wet and dry fall combined) were obtained from several studies in Florida as previously identified. Phosphorus bulk deposition averaged 56.1 mg/m^2/yr, ranging from 35 to 93.3 mg/m^2/yr. Similarly, nitrogen bulk deposition values averaged 839.7 mg/m^2/yr, ranging from 750 to 910 mg/m^2/yr.

ARDURRA

Loadings Estimates

Nutrient loadings were estimated as the product of average inflows and average concentrations of total phosphorus and total nitrogen. The exception was atmospheric deposition which was calculated as the product of the area of the northern portion of the Bay and the average literature values of bulk atmospheric deposition for phosphorus and nitrogen.

Table 7 provides the basis for the area, flow, and load calculations. **Table 8** provides a summary of area, flow, and loads by consolidated major sources.

Table 7 – Basis of Nutrient Loadings by Sources

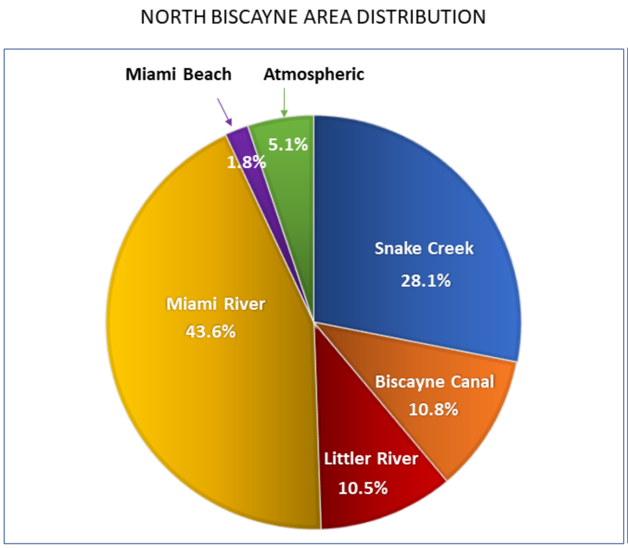
Inflow Source			Area	Yield	Flow	Phosphorus		Nitrogen	
Name	Canal	Structure	(mi^2)	(in/yr)	cfs	Conc. (mg/l)	Load lbs/d	Conc. (mg/l)	Load lbs/d
Snake Creek	C-9	S-29	98.4	40.0	290.1	0.017	26.81	1.31	2,053
Arch Creek	Arch Creek	G-58	7.3	13.4	7.2	0.022	0.84	1.33	52
Biscayne	C-8	S-28	28.5	51.5	108.3	0.019	11.14	1.47	859
Biscayne	C-8	Coastal Basin	2.2	13.4	2.2	0.022	0.26	1.33	16
Little River	C-7	S-27	32.0	70.8	167.0	0.029	25.87	2.17	1,952
Little River	C-7	Coastal Basin	5.0	13.4	4.9	0.022	0.58	1.33	35
Miami River	C-6	S-26	53.9	53.6	212.8	0.021	24.54	1.45	1,668
Miami River	C-6	Coastal Basin	12.8	13.4	12.6	0.022	1.48	1.33	91
Tamiami	C-4	S-25B	84.3	34.7	215.2	0.011	12.38	1.13	1,308
Comfort	C-5	S-25	1.9	62.4	8.5	0.033	1.53	0.53	21
Miami Beach		Miami Beach	6.4	21.6	10.2	0.055	3.03	0.79	43
Atmospheric		Biscayne Bay	17.9	63.2	83.1		15.7		235.1
Total			350.5		1,122.1		124.2		8,333.6

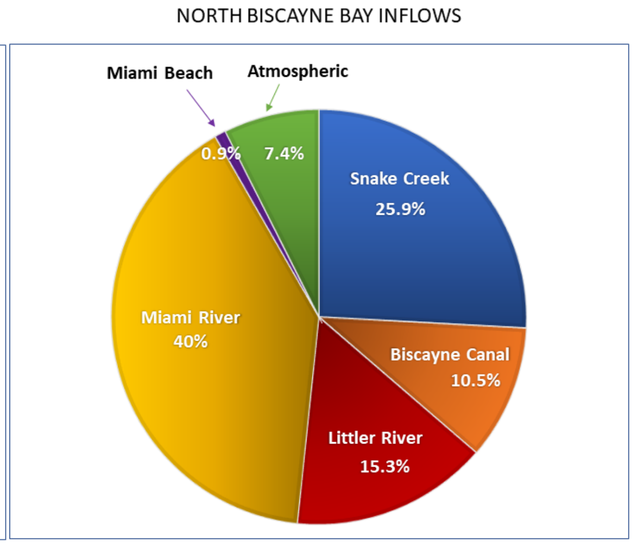
Table 8 –Summary of Nutrients Loads by Consolidated Sources

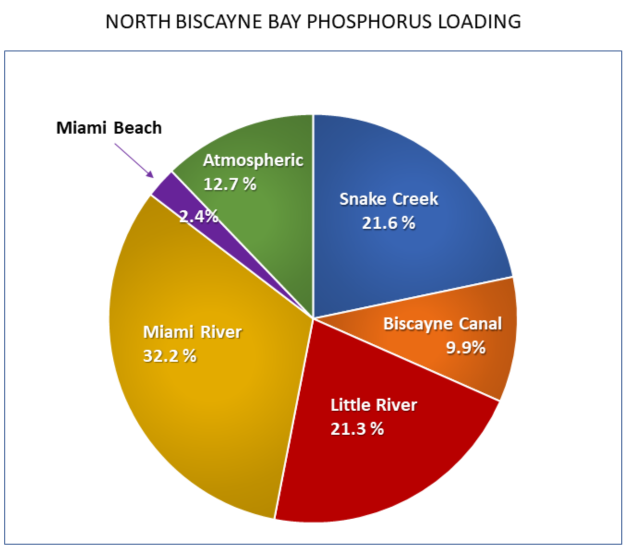
Inflow Sources		Area		Flow		Phosphorus Load		Nitrogen Load	
Name	Canal	(mi^2)	Percent	cfs	Percent	lbs/d	Percent	lbs/d	Percent
Snake Creek	C-9	98.4	28.1%	290.1	25.9%	26.8	21.6%	2053.1	24.6%
Biscayne	C-8	38.0	10.8%	117.7	10.5%	12.2	9.9%	927.0	11.1%
Little River	C-7	36.9	10.5%	171.9	15.3%	26.4	21.3%	1987.6	23.8%
Miami River	C-6	152.8	43.6%	449.1	40.0%	39.9	32.2%	3091.7	37.1%
Miami Beach		6.4	1.8%	10.2	0.9%	3.0	2.4%	43.2	0.5%
Atmospheric		17.9	5.1%	83.1	7.4%	15.7	12.7%	235.1	2.8%
Total		350.5		1,122.1		124.2		8,333.6	

Figure 3 shows pie charts with the relative contribution of each sources to area, flow, phosphorus, and nitrogen loadings. **Figures 4 through 7** provide aerial views of North Biscayne Bay contributing areas, inflow distribution, phosphorus, and nitrogen loadings, respectively.

Figure 3 – Relative Source Areas, Flows, and Loadings to North Biscayne Bay







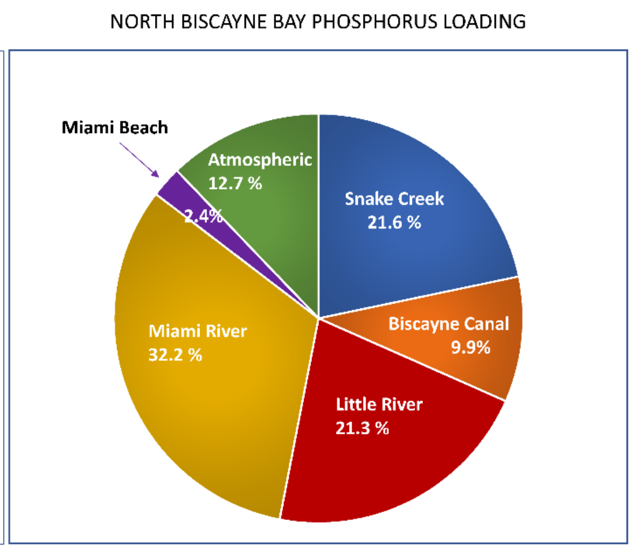


Figure 4 – North Biscayne Bay Contributing Areas

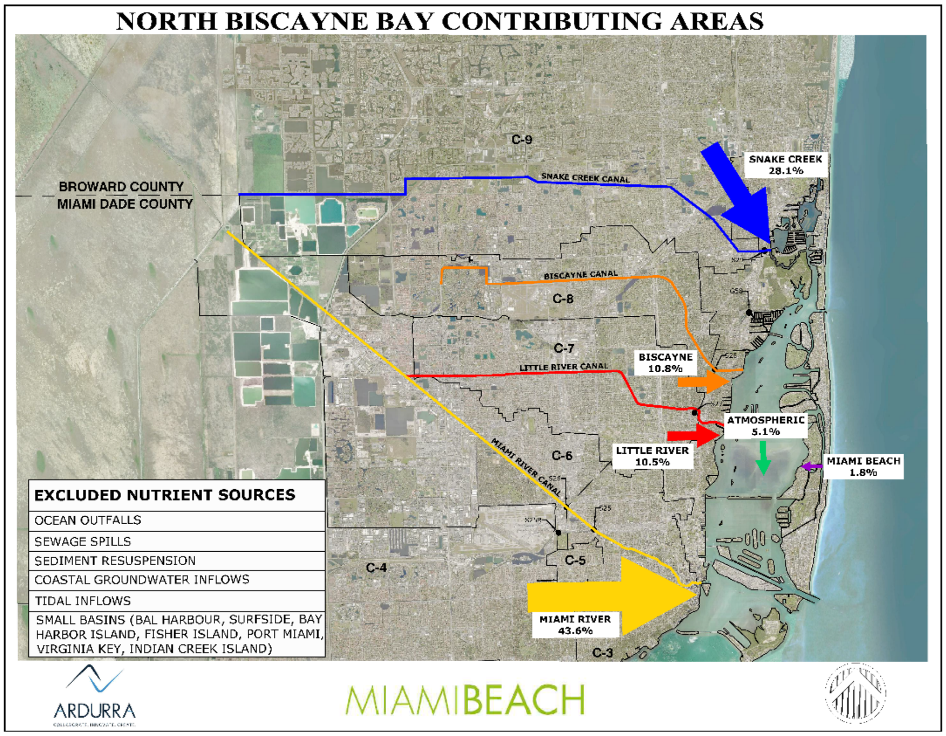


Figure 5 – North Biscayne Bay Inflow Distribution

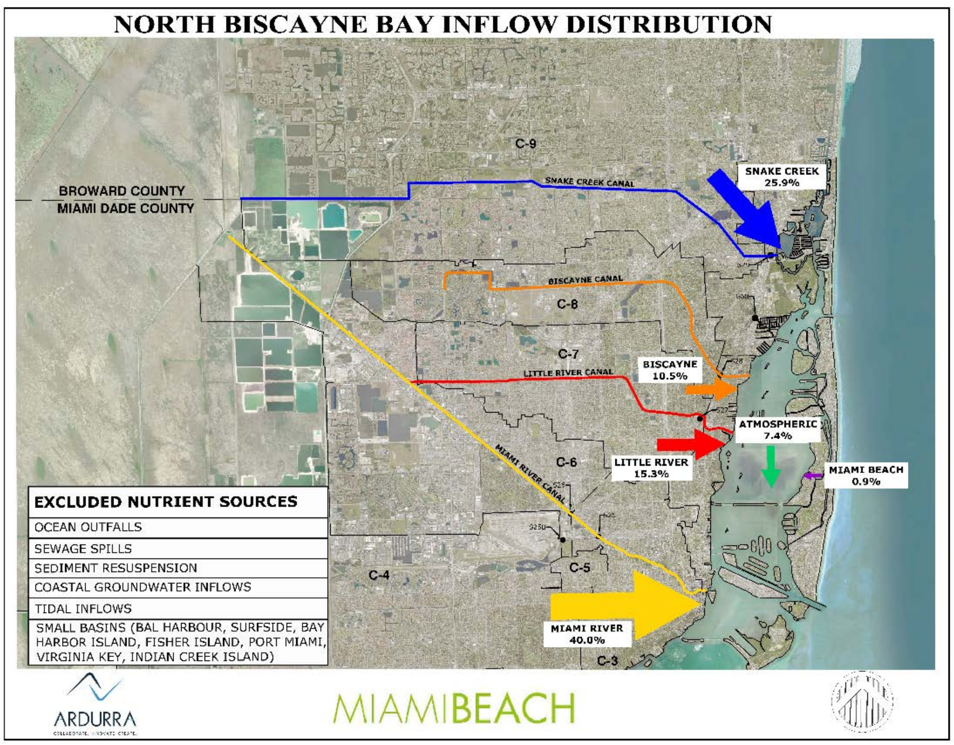


Figure 6 – North Biscayne Bay Phosphorus Loading

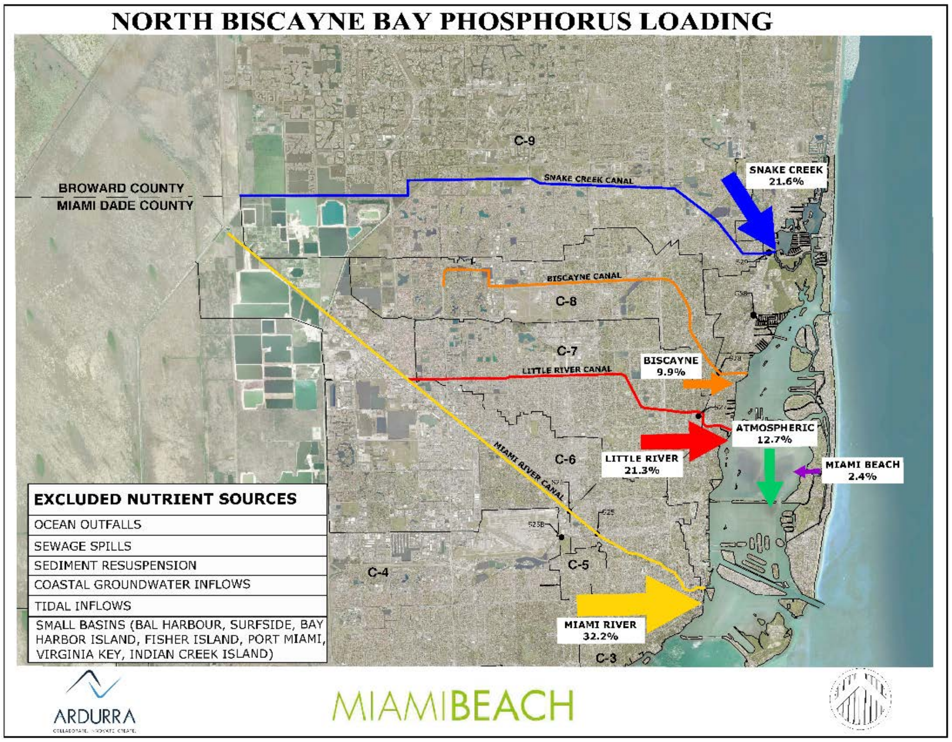
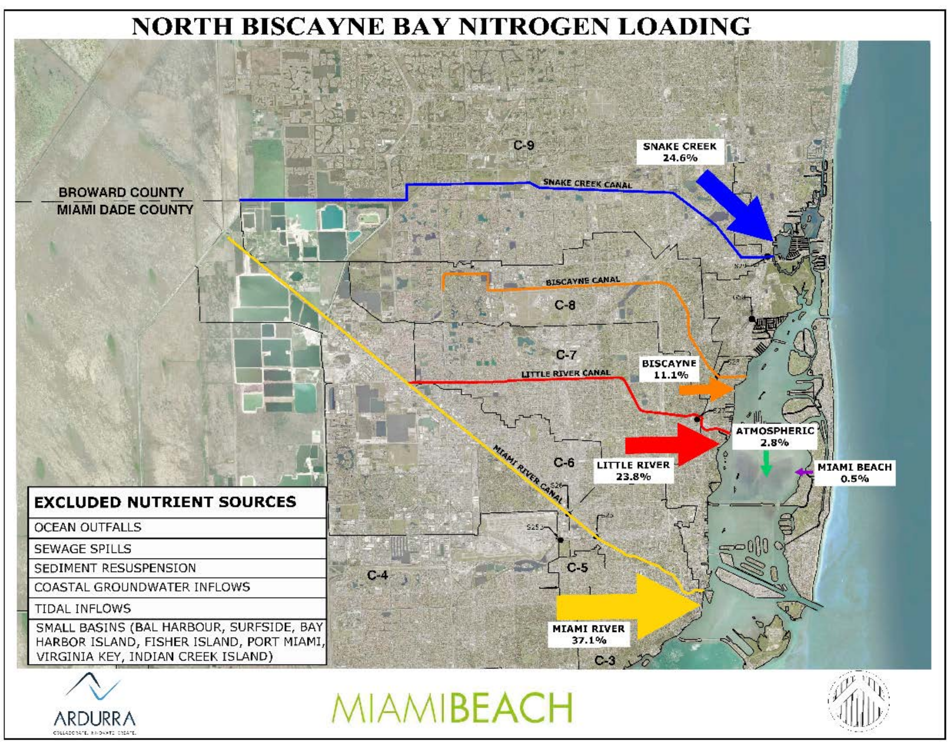


Figure 6 – North Biscayne Bay Nitrogen Loading



ARDURRA

Summary and Conclusions

The City of Miami Beach retained Ardurra to prepare preliminary estimates of nutrient loadings into North Biscayne Bay, with primary emphasis on establishing the relative nutrient loadings between the City and other major sources. Loadings are considered preliminary to the extent that they were based on readily available information, some source data were not available, and there is room for refinement based on additional data. However, the relative loadings amongst the various sources are not expected to change substantially from the results shown herein.

The northern portion of Biscayne Bay extends north of the Rickenbacker Causeway and has a surface area of approximately 17.9 square miles. Potential nutrient sources into the Bay include canal discharges, atmospheric deposition (wet and dry fall), coastal area discharges, coastal groundwater inflows, ocean outfalls, sewage spills, sediment resuspension/decomposition, nitrogen fixation, and tidal inflows. Of these potential sources, only canal discharges, atmospheric deposition, western coastal area discharges, and Miami Beach runoff were considered in the loading estimates because of insufficient data to cover the remaining sources. Excluded sources include coastal groundwater inflows, ocean outfall discharges, sewage spills, sediment resuspension/decomposition, nitrogen fixation, tidal inflows, and drainage from several small coastal basins (Surfside, Bal Harbour, Bay Harbor Islands, Port Miami, Fisher Island, Virginia Key, and Indian Creek Island).

Most of the calculations were based on actual data for drainage areas, flows, and water quality. Exceptions include (1) runoff from smaller western coastal areas which were based on average runoff yields for watersheds with similar hydrologic characteristics, (2) runoff estimates for Miami Beach which were based on standard methods to calculate runoff from developed areas, and (3) bulk atmospheric deposition rates which were based on literature data from studies conducted in south Florida. Further, the water quality data associated with canal flows were based on grab samples collected downstream of the salinity control structures, and therefore, the nutrient concentration may be somewhat diluted by Bay waters. To compensate, canal water quality data was flow-weighted to provide greater weight to data collected during flow events.

To provide a higher level of confidence to the calculations, the relative contribution of the various nutrient sources into the Bay was expressed in terms of contributing drainage area, inflows, and nutrient loads. The highest level of confidence is associated with the contributing areas, followed by inflows, and last, loadings estimates.

Results indicate that the City of Miami Beach is a very minor contributor to the Bay as summarized in **Table 9**. Its drainage area represents 1.8% of the total contributing area to the north Bay.

Table 9 – Miami Beach Contribution to Biscayne Bay

Miami Beach Contribution to North Biscayne Bay	
Parameter	Percent of Total
Contributing Area	1.8%
Inflow	0.9%
Phosphorus Loading	2.4%
Nitrogen Loading	0.5%

In terms of inflows, Miami Beach contributes 0.9% of all the inflows into the north Bay compared to 91.7% contributed by canal discharges. This lower percentage relative to its drainage area is explained by the fact that the runoff from the major canals draining the western portions of the County contribute not only the runoff generated by local rainfall, but also convey additional large volumes of water from surface water transfers from the regional system.

Finally, Miami Beach's contribution of phosphorus and nitrogen loads amounts to 2.4% and 0.5%, respectively, of the total loadings into the north Bay, compared to 84.9% and 96.7%, respectively, by runoff from canal discharges. The relative contribution of Miami Beach may be reduced somewhat with the addition of multiple additional potential sources that were not included in the calculations due to lack of data.

An interesting observation is that bulk atmospheric deposition (wet and dry fall) is significantly higher than the contributions from Miami Beach. It has been well documented in the literature that dust from the Saharan desert significantly impacts south Florida, especially during the summer, carrying phosphorus, nitrogen, and minerals.