SUMMARY OF NITROGEN LEVELS IN AND AROUND MARCO ISLAND WATERS

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INTRODUCTION

Over the past several decades, it has become well-established that an over-abundance of the plant nutrients nitrogen and/or phosphorous can have adverse impacts on the water quality and ecology of lakes, rivers and estuaries. Excessive nutrient supply can stimulate the growth of nuisance plants, creating, on occasion, algal blooms. Algal blooms can reduce water clarity and impact benthic communities, such as corals and seagrasses, which provide food and shelter for the majority of recreationally and commercially important species of fish and invertebrates like crabs and shrimp. Once algal blooms die-off, their decomposition can reduce levels of dissolved oxygen, which is essential to most forms of aquatic life. Successful management of coastal waterbodies thus requires the collection, analysis and interpretation of results from water quality monitoring programs, including data related to nutrient supply.

The Environmental Protection Agency (EPA) began providing guidance on development of numeric nutrient criteria (NNC) in 2000. Following multiple lawsuits and development input from both the Florida Department of Environmental Protection (FDEP) and EPA, NNC for many waterbodies, including most estuaries were adopted by FDEP in 2012. The Marco Island NNC are expressed as annual geometric mean concentrations that are not to be exceeded more than once in a three-year period. The allowable concentrations are as follows:

Total Nitrogen (TN) = 0.30 mg/L;
Total Phosphorus (TP) = 0.046 mg/L, and
Chlorophyll a = 4.9 µg/L.

The City of Marco has been monitoring the quality of waters around the island since approximately 2001. The City chose twelve (12) locations around the island to collect samples. The monitoring intensity has varied over time from monthly, to bi-monthly, to quarterly. From In 2015 sampling was continued at the same twelve sites under an approved field sampling manual and was changed to quarterly collection instead of bi-monthly. The data collected was initially entered into STORET until the State switched its database from STORET to the new WIN database. The City's data from August 2016 until present has been entered into the WIN system. One of the twelve sampling locations was dropped in 2017 because access to the site was no longer available.

Increasing nitrogen levels observed in the sampling data has caused concern over the health of the waterways and led to the City Council commissioning this summary of nitrogen data relative to the Marco Island waterways. The topics to be discussed in the summary include:

1. Comparison of current Marco Island nitrogen data to historic data in and around the Island.
2. Comparison of current Marco Island nitrogen data to other contemporary data being collected outside of the Island canal waters.
3. Discussion of potential sources of the nitrogen within the Marco Island Waterways.
4. Discussion of options or actions that could provide improvements to nitrogen levels within the Marco Island waterways.

This summary has been compiled with the assistance of City staff and Collier County Pollution Control staff to provide a general overview of the nitrogen data available. It is presented to the City of Marco Island to assist them in upcoming decisions regarding the direction of future monitoring, water quality improvement, and stormwater planning efforts.

DESCRIPTION OF GENERAL PROJECT AREA

Marco Island is, as the name implies, an island community located in southern Collier County. Early development on the island began in the late 1800's with the establishment of the Village of Marco in 1870. Clamming was a major industry throughout the early 1900's though had pretty much died out by the mid to late 1940's.

Figure 1: Marco Island Pre-1960

Major development on Marco Island was started by the Mackle Brothers of the Deltona Corporation in the early 1960's. Development of the Island was a massive dredge and fill project involving clearing, excavating, and filling hundreds of acres of mangrove wetlands to make way for the waterfront lots, commercial areas, schools, and parks that we see today. The work involved hydraulic dredges and draglines along with seawall construction to create the miles and miles of canals and waterways throughout the Island.

Figure 2: Dredge and Fill Operations under way on Marco Island

Today Marco Island is a thriving community consisting of residential neighborhoods, commercial areas, golf courses, parks and the canal system. Residents and visitors alike are drawn to Marco Island for the recreational, sporting, and commercial opportunities that it offers.

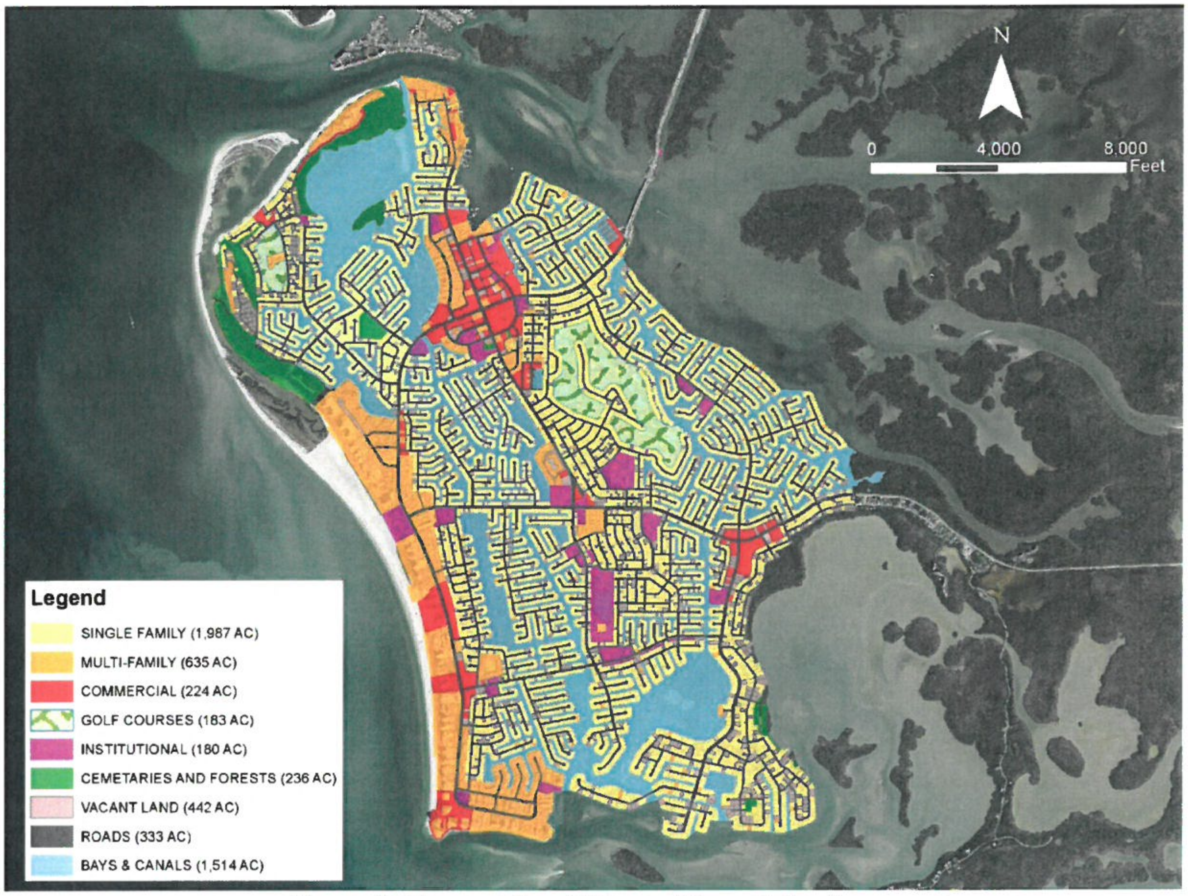


Figure 3: Current Land Use on Marco Island

RECENT MARCO ISLAND WATER QUALITY TESTING

As stated previously, the City of Marco has been monitoring water quality within the canals and waterways of the island since approximately 2001. The City chose twelve (12) locations around the island to collect samples and these locations cover the separate drainage areas (basins) across the island. The drainage of the island is separated by the major roadways and directed through series of pipes and swales into the canal waters.

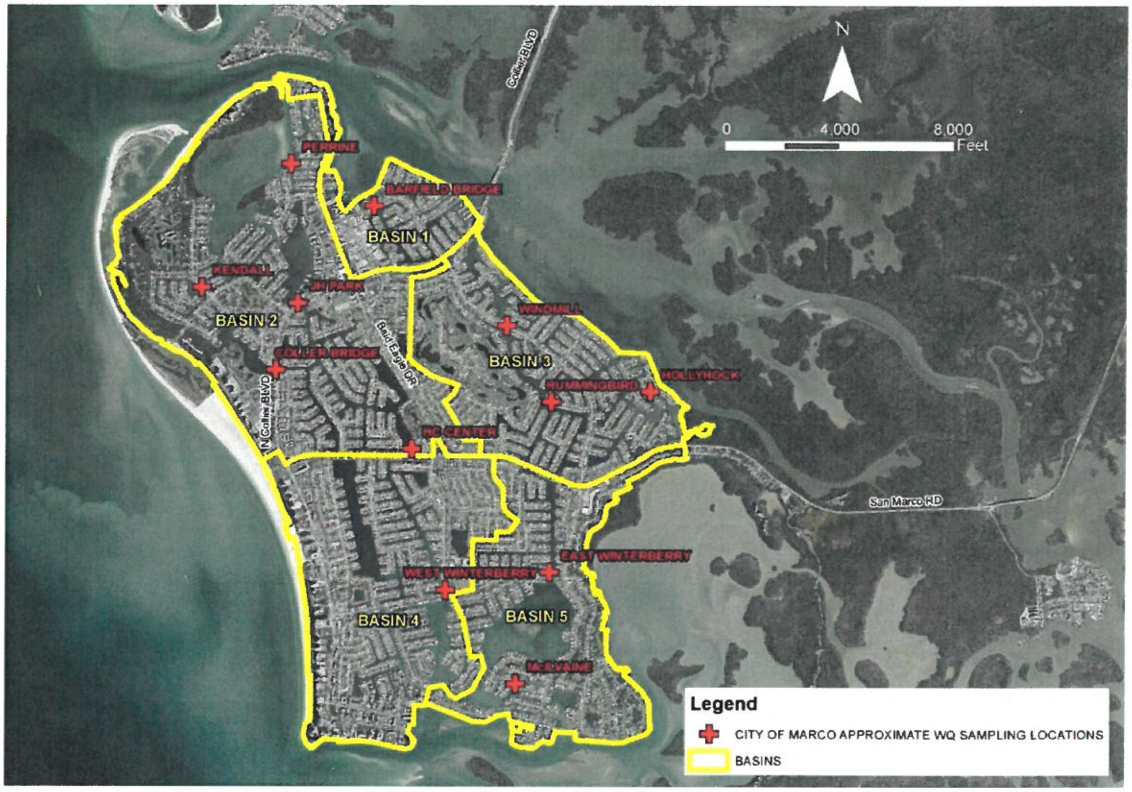


Figure 4: Water Quality Monitoring Locations

The monitoring intensity has varied over time from monthly, to bi-monthly, to quarterly. From 2007 to 2014, the twelve sites were sampled every other month for a suite of parameters but since the samples were not collected under an approved field sampling quality manual, they are not considered reliable for use in the Florida Storage and Retrieval Database (STORET). In 2015 sampling was continued at the same twelve sites under an approved field sampling manual and was changed to quarterly collection instead of bi-monthly. The data collected was initially entered into STORET until the State switched its database from STORET to the new WIN database. The City's data from August 2016 until present has been entered into the WIN system.

The waters around Marco Island are located in Water Body Identification (WBID) number 3278O (Figure 6). In 2015, the FDEP also instituted numerical nutrient criteria (NNC) for estuarine waters. Marco Island is located with Estuarine Nutrient Region 3 (Figure 5).

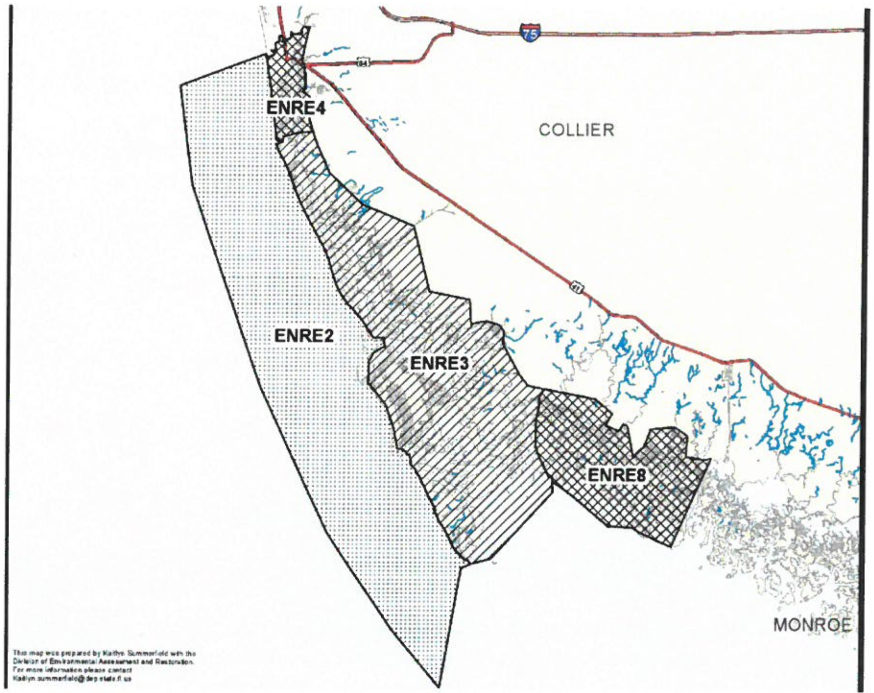


Figure 5: Estuary Nutrient Regions Around Marco Island

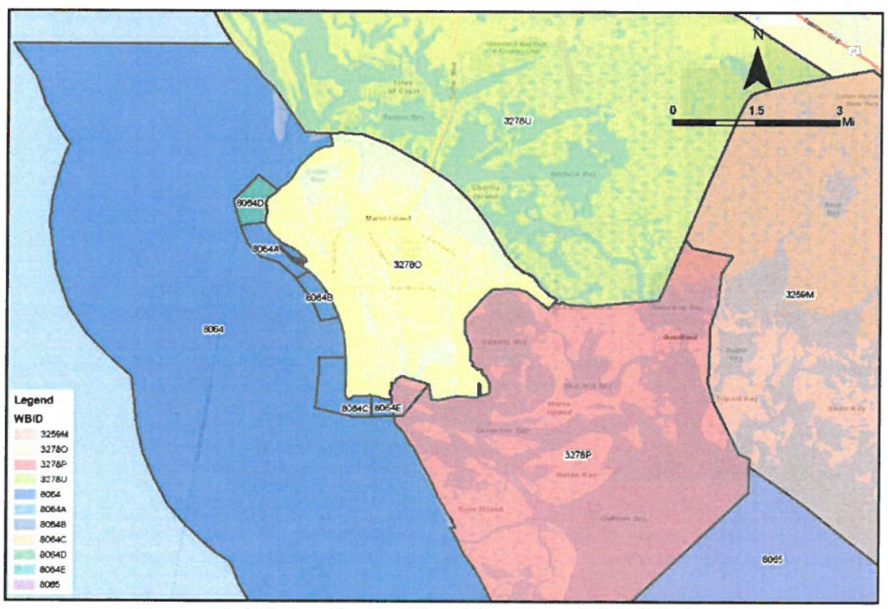


Figure 6: Water Body Identification (WBID) Areas

The surface water quality criteria for Marco Island are listed in Florida Administrative Code (FAC) 62-302.500 and the nutrient specific criteria are listed in Chapter 62-302.532 FAC. The nutrient criteria for Marco Island waters is based upon the annual geometric mean of values rather than on any single individual reading. Even in "pristine" estuaries with little to no human impacts, nutrient concentrations are lowest on high tides, in areas close to passes, and during dry periods with little rainfall-generated stormwater runoff. Nutrient concentrations generally increase away from passes, on lower tides, and during wet seasons, wet years, or even during shorter time periods of rainfall-generated runoff. Therefore, a single nutrient concentration criterion does not make much sense, if water quality data from even pristine locations could potentially pass or fail proposed criteria simply as a function of location, tidal stage or antecedent rainfall.

As outlined in Chapter 62-302.532 FAC, the water quality status of waterbodies is to be determined on an annual basis, preferably within a calendar year. Impairment would be determined if the parameter criteria (expressed as annual geometric mean) is exceeded more than once in a three-year period.

For this report, the current data upon which other data is being compared consists of 16 sampling efforts over 48 months (from 2015 through 2018). The data was separated into calendar years 2015, 2016, 2017, and 2018 to look at the geometric means for each year based on the quarterly sampling events.

For each year, total nitrogen (TN), total phosphorus (TP), and chlorophyll-*a* values collected within the waters around Marco were recorded and the annual geometric mean (AGM) was determined for each sampling site as well as for the entire sampling area as a whole. The AGM is defined as the nth root of the product of the values ($\sqrt[n]{x_1 x_2 x_3 \ldots x_n}$) where n is the number of individual values. Even though this report was focused on the total nitrogen values the TP and chlorophyll-*a* values were also examined to see if there was any correlation or similar results between these nutrient parameters.

The rule also requires that the AGM be based on at least four temporally-independent samples per year with at least one sample taken between May 1 and September 30 and at least one sample taken during other months of the calendar year (i.e. not all taken between May and September). To be treated as temporally-independent, samples must be taken at least one week apart. The sampling effort being conducted by the City is compliant with these requirements.

While the data is presented to show the AGM at each individual testing location, the determination of impairment for the waterbody will be based on all of the sampling sites analyzed together, not on any single sampling site. The reason information for the individual sites was included is to assist the City in its planning efforts by identifying locations where there may be concern related to elevated nutrient levels.

Total nitrogen concentrations have been rising over the past three years and this trend continued during 2018. Samples are collected by the Collier County Pollution Control Lab staff and analyses in the County lab. Results are provided to the City of Marco Island and posted to the WIN database.

TN, TP, and Chlorophyll-*a* concentration AGMs were calculated and compared to the FDEP limit thresholds to quantify the presence or absence of elevated concentrations of the three parameters, with graphical representations of the results provided in Appendix A.

2015 Nutrient Sampling Results (Sampling done in January, May, August, & November)

Over the period analyzed none of the AGMs for the individual sampling sites exceeded the state criteria for either TP or Chlorophyll-*a*. One of the sites (Barfield_Bridge) exceeded the state criteria for TN. However, the overall AGM for the entire watershed was well below the state criteria for all three parameters.

2016 Nutrient Sampling Results (Sampling done in February, May, August, & November)

Over the period analyzed none of the individual sampling sites exceeded the state criteria for TP. One of the sites (Windmill) did exceed the state criteria for Chlorophyll-*a*, though the overall watershed was still well below. Five of the sites (Collier_Bridge, HC_Center, Hollyhock, Hummingbird, and Windmill) exceeded the state criteria for TN. The elevated TN levels are a result of higher levels in samples collected in February (8 of 12 samples above standard) and August (12 of 12 samples above standard). It appears as though these results could be associated with high rainfall amounts preceding the sampling. However, the overall AGM for the entire watershed was still below the state criteria.

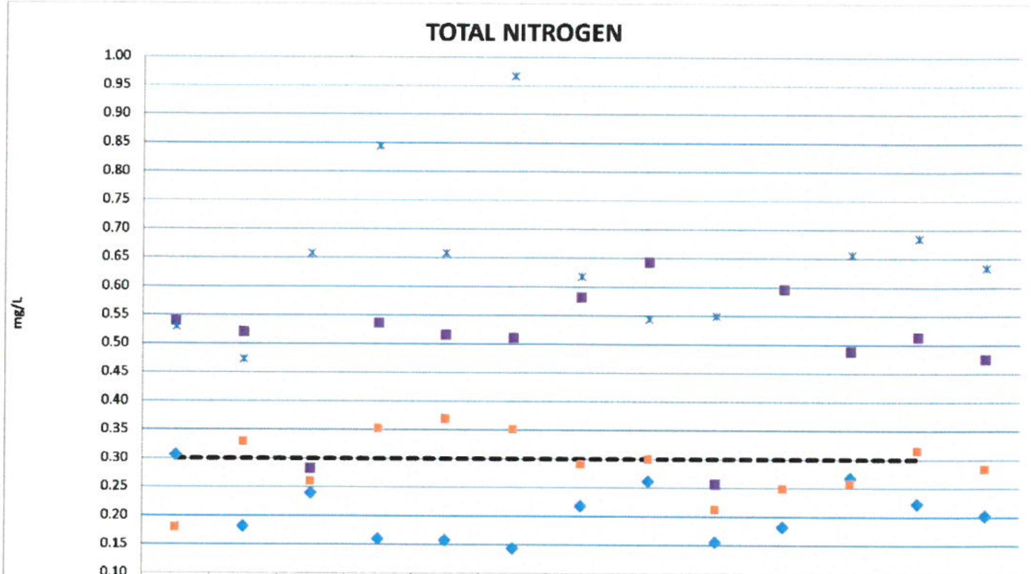
2017 Nutrient Sampling Results (Sampling done in February, May, August, & November)

Over the period analyzed none of the individual sampling sites exceeded the state criteria for TP. One of the sites (Hummingbird) did exceed the state criteria for Chlorophyll-*a*, though the overall watershed was still well below. Ten of the sites (all except for E_Winterberry_Bridge and McIlvaine) exceeded the state criteria for TN. The elevated TN levels are a result of higher levels in samples collected throughout the year (40 of 44 individual samples collected were above standard). All of the annual location results were higher than the 2016 levels (even the two sites below the criteria level were still higher than the preceding year). As a result, the watershed was over the state criterion for TN.

2018 Nutrient Sampling Results (Sampling done in February, May, August, & November)

Over the period analyzed two of the individual sampling sites (Collier Bridge and Hummingbird) exceeded the state criteria for TP. Three of the sites (East Winterberry, Hummingbird, and Windmill) exceeded the state criteria for Chlorophyll-*a*, though the overall watershed was still below. All eleven of the sites exceeded the state criteria for TN. The elevated TN levels are a result of higher levels in samples collected throughout the year (34 of 43 individual samples collected were above standard). All of the stations were over the criteria for the May, August, and November sampling events. Eight of the eleven annual location results were higher than the 2017 levels. As a result, the watershed was over the state criterion for TN.

Based on the 2018 sample results, the Marco Island waterways have been over the State criteria for two consecutive years and so would meet the standard to be determined impaired for TN. However, the State looks at other water quality data within the WBID boundary along with the Marco Island data and in the most recent Verified Assessment Period of the Impaired Waters Rule (IWR) ending June 30, 2018, there were no nutrient parameters identified as meeting the listing threshold (IWR_Run55_07022018). If the current trend of increasing values continues, it is likely that the Marco Island WBID would meet the listing threshold on the next IWR run. It is interesting to note that both the Marco Island South area (WBID 3278P) and the Gulf of Mexico offshore from Marco (WBID 8064) did meet the listing threshold for TN in the most recent IWR run (See Verified Assessment Period Report Card for WBID 3278P and 8064).



	BARFIELD_BRIDGE	COLLIER_BRIDGE	E_WINTERBERRY_BRIDGE	HC_CENTER	HOLLYHOCK	HUMMINGBIRD	JH_PARK	KENDALL	MCILVAINE	PERRINE	W_WINTERBERRY_BRIDGE	WINDMILL	OVERALL
2015	0.31	0.18	0.24	0.16	0.16	0.14	0.22	0.26	0.16	0.18	0.27	0.22	0.202
2016	0.18	0.33	0.26	0.35	0.37	0.35	0.29	0.30	0.21	0.25	0.26	0.32	0.284
2017	0.54	0.52	0.28	0.54	0.52	0.51	0.58	0.64	0.26	0.60	0.49	0.51	0.476
2018	0.53	0.47	0.66	0.84	0.66	0.97	0.62	0.54	0.55	0.00	0.66	0.69	0.634
State Std.	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	

Figure 7: Annual Geometric Means of TN levels for Marco Island Waters

TOTAL NITROGEN DATA

TN		mg/L										
	BARFIELD_BRIDGE	COLLIER_BRIDGE	E_WINTERBERRY_BRIDGE	HC_CENTER	HOLLYHOCK	HUMMINGBIRD	JH_PARK	KENDALL	MCILVAINE	PERRINE	W_WINTERBERRY_BRIDGE	WINDMILL
1/27/15	0.253	0.133	0.077	0.120	0.185	0.137	0.162	0.373	0.174	0.152	0.113	0.137
5/12/15	0.220	0.051	0.246	0.051	0.090	0.051	0.131	0.183	0.051	0.179	0.322	0.094
8/25/15	0.653	0.390	0.745	0.243	0.205	0.239	0.297	0.231	0.647	0.200	0.677	0.814
11/19/15	0.243	0.416	0.234	0.443	0.182	0.258	0.359	0.296	0.103	0.203	0.209	0.235
2/1/16	0.262	0.511	0.290	0.504	0.509	0.398	0.554	0.432	0.275	0.134	0.346	0.368
5/10/16	0.111	0.182	0.125	0.205	0.211	0.213	0.125	0.153	0.144		0.141	0.205
8/11/16	0.713	0.528	0.750	0.600	0.708	0.822	0.600	0.624	0.465	0.789	0.573	0.772
11/9/16	0.051	0.241	0.170	0.251	0.246	0.220	0.173	0.198	0.112	0.147	0.156	0.171
2/21/17	0.548	0.522	0.617	0.453	0.679	0.462	0.555	0.478	0.492	0.597	0.475	0.577
5/18/17	0.608	0.454	0.163	0.644	0.604	0.573	0.632	0.752	0.247		0.595	0.581
8/16/17	0.399	0.494	0.389	0.490	0.493	0.503	0.568	0.410	0.415		0.313	0.578
11/13/17	0.638	0.626	0.164	0.578	0.351		0.577	1.164	0.087		0.643	0.359
2/8/18	0.177	0.140	0.261	1.160	0.268		0.225	0.134	0.278		0.290	0.231
5/21/18	0.969	1.220	1.207	0.670	0.868	1.178	0.929	1.149	0.671		0.792	1.370
8/16/18	0.652	0.569	0.619	0.767	1.140	0.875	0.747	0.553	0.590		0.834	0.595
11/15/18	0.704	0.516	0.961	0.853	0.709	0.875	0.935	1.03	0.827		0.967	1.17
	Yellow hatch represents individual values over the state standard of 0.30											

Figure 8: Total Nitrogen level data by sample date.

VERIFIED ASSESSMENT PERIOD REPORT CARD

MARCO ISLAND

Current Assessment Cycle Information

Cycle:	4	***Verified Period start:***	1/1/2011
		Verified Period end:	6/30/2018

WBID: 32780

WBID Information

Group Number:	Group 1	***Nutrient Region:***	
		Class: **2**	Shellfish Propagation or Harvesti
Group Name:	Everglades West Coast	***WaterBodyType:***	ESTUARY
Planning Unit:	Southwest Coast	***Assessment Type:***	Estuary

Historic Assessment Information for WBID **32780**

Is on 303D1998? ***No***

Associated 303D wbids: ***1998 303D Impaired Parameters:***

Verified Parameters Cycle 1:

Verified Parameters Cycle 2:

Current Cycle Summary Assessment Info:

Analytes meeting listing threshold for planning list: ***PP:*** *Mercury (in fish tissue)*

VP: *Mercury (in fish tissue)*

Analytes meeting listing threshold for study list:

Analytes meeting listing threshold for verified list:

Detailed Assessment Information for the Current Cycle for WBID: **32780**

Master Parameter	*Assessment Status*	*Listing Threshold*	*Exceedances*	*Non-exceedances*	*Weeks*	*Seasons*	*Samples*
Dissolved Oxygen (Percent Saturation)	NI	22	0	164	31		164
Dissolved Oxygen (Trend)	ID						
Enterococci	NI	18	5	117	12		122
Enterococci (2)	ID						
Fecal Coliform	NI	9	5	50	5		55
Fecal Coliform (2)	ID						
Fecal Coliform (3)	ID						
Mercury (in fish tissue)	PL						
Nutrients (Chlorophyll-a Trend)	ID						

VERIFIED ASSESSMENT PERIOD REPORT CARD

MARCO ISLAND (SOUTH SEGMENT)

WBID: 3278P

Current Assessment Cycle Information

Cycle: 4

Verified Period start: 1/1/2011

Verified Period end: 6/30/2018

WBID Information

Group Number: Group 1

Group Name: Everglades West Coast

Planning Unit: Southwest Coast

Nutrient Region:

Class: **2** Shellfish Propagation or Harvesti

WaterBodyType: ESTUARY

Assessment Type: Estuary

Historic Assessment Information for WBID **3278P**

Is on 303D1998? ***No***

Associated 303D wbids:

1998 303D Impaired Parameters:

Verified Parameters Cycle 1:

Verified Parameters Cycle 2:

Current Cycle Summary Assessment Info:

Analytes meeting listing threshold for planning list:

PP: *Mercury (in fish tissue), pH, Nutrients (Total Nitrogen)*

VP: *Mercury (in fish tissue)*

Analytes meeting listing threshold for study list:

Analytes meeting listing threshold for verified list: *Nutrients (Total Nitrogen)*

Detailed Assessment Information for the Current Cycle for WBID: **3278P**

Master Parameter	***Assessment Status***	***Listing Threshold***	***Exceedances***	***Non-exceedances***	***Weeks***	***Seasons***	***Samples***
Dissolved Oxygen (Percent Saturation)	NI	25	8	175	75		183
Dissolved Oxygen (Trend)	ID						
Enterococci	NI	5	0	12	12		12
Enterococci (2)	ID						
Fecal Coliform	NI	27	4	202	52		206
Fecal Coliform (2)	ID						
Fecal Coliform (3)	NI						
Fluoride	NI	5	0	23	15	4	23
Mercury (in fish tissue)	PL						

VERIFIED ASSESSMENT PERIOD REPORT CARD

GULF OF MEXICO (COLLIER COUNTY; *WBID:* 8064

Current Assessment Cycle Information

Cycle:	4	***Verified Period start:***	1/1/2011
		Verified Period end:	6/30/2018

WBID Information

Group Number:	Group 1	***Nutrient Region:***	
		Class:	**2** Shellfish Propagation or Harvesti
Group Name:	Everglades West Coast	***WaterBodyType:***	COASTAL
Planning Unit:	Southwest Coast	***Assessment Type:***	Coastal

Historic Assessment Information for WBID **8064**

Is on 303D1998? ***No***

Associated 303D wbids: ***1998 303D Impaired Parameters:***

Verified Parameters Cycle 1:

Verified Parameters Cycle 2: *Mercury (in fish tissue)*

Current Cycle Summary Assessment Info:

Analytes meeting listing threshold for planning list: ***PP:*** *Mercury (in fish tissue), Nutrients (Total Nitrogen)*

VP: *Mercury (in fish tissue)*

Analytes meeting listing threshold for study list:

Analytes meeting listing threshold for verified list: *Nutrients (Total Nitrogen), Nutrients (Total Phosphorus)*

Detailed Assessment Information for the Current Cycle for WBID: **8064**

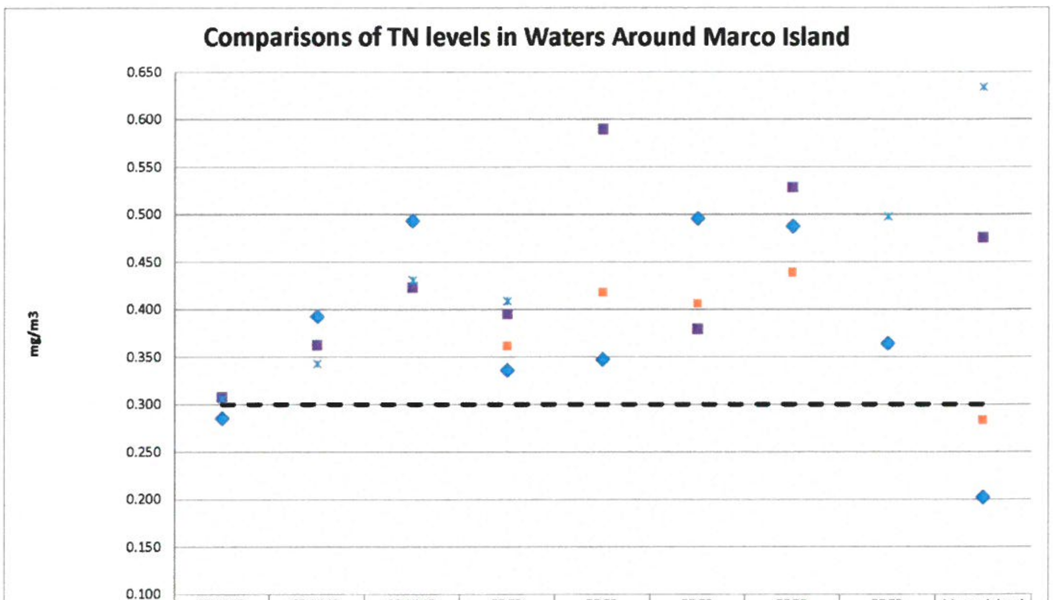
Master Parameter	*Assessment Status*	*Listing Threshold*	*Exceedances*	*Non-exceedances*	*Weeks*	*Seasons*	*Samples*
Dissolved Oxygen (Percent Saturation)	NI	5	0	20	19		20
Dissolved Oxygen (Trend)	ID						
Enterococci	NI	98	3	815	231		818
Enterococci (2)	ID						
Fecal Coliform	NI	19	2	130	33		132
Fecal Coliform (2)	ID						
Fecal Coliform (3)	NI						
Fluoride	ID		0	1	1	1	1
Mercury (in fish tissue)	PL						

RECENT ADJACENT WATERS WATER QUALITY TESTING

One issue we ran into with trying to find comparable data is that very few sites around Marco have been sampled consistently for any length of time. While some of the seasonal time frames do match up. Most do not. In order to try and compare data, we calculated the AGM for each of the sites that had data within the same yearly time frame, and which met the FDEP standards for using the data (at least 4 samples during the calendar year and spread throughout the year).

The three SFWMD sites are located just offshore to the northwest of Marco (16689), in the center of the intracoastal waterway by the Jolly Bridge (16690), and in the intracoastal waterway by the Goodland Bridge (16692). The FDEP sampling stations are located in the open waters at the north tip of the island (G1SD0001), at the south end of Cape Romano to the south of the island (G1SD0002), at the south end of Marco Island (G1SD0003), in the intracoastal waterway near the Goodland Bridge (G1SD0006), and in the open channel between Kice Island and Helen Key (G1SD00036),

As can be seen, all of these stations had TN levels over the state standard during 2017 and 2018 so it appears the elevated levels are not limited to the Marco canals. Potential reasons for the elevated levels are discussed later in this report.



	SFWMD 16689	SFWMD 16690	SFWMD 16692	FDEP G1SD0001	FDEP G1SD0002	FDEP G1SD0003	FDEP G1SD0006	FDEP G1SD0036	Marco Island WQ
2015	0.285	0.393	0.493	0.336	0.347	0.496	0.487	0.364	0.202
2016				0.362	0.419	0.407	0.439		0.284
2017	0.308	0.363	0.424	0.395	0.590	0.379	0.528		0.476
2018	0.306	0.343	0.431	0.409				0.498	0.634
State Standard	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Figure 9: Comparison TN data from surrounding waters

COMPARISON OF RECENT DATA TO HISTORIC DATA

Another question that was asked is if the current trend of increasing TN levels is a recent occurrence or if it has happened in the past. To investigate this, Marco Island water quality data for 2007 through 2014 was examined and compared to the more recent data. The historic data only contained the TKN component of the nitrogen suite, so the values used are less than actual but since the TKN component is the vast majority of the TN component, it does allow for some comparison. As with the current data, the annual geometric mean was calculated for each year and the resulting level is depicted in the figure below.

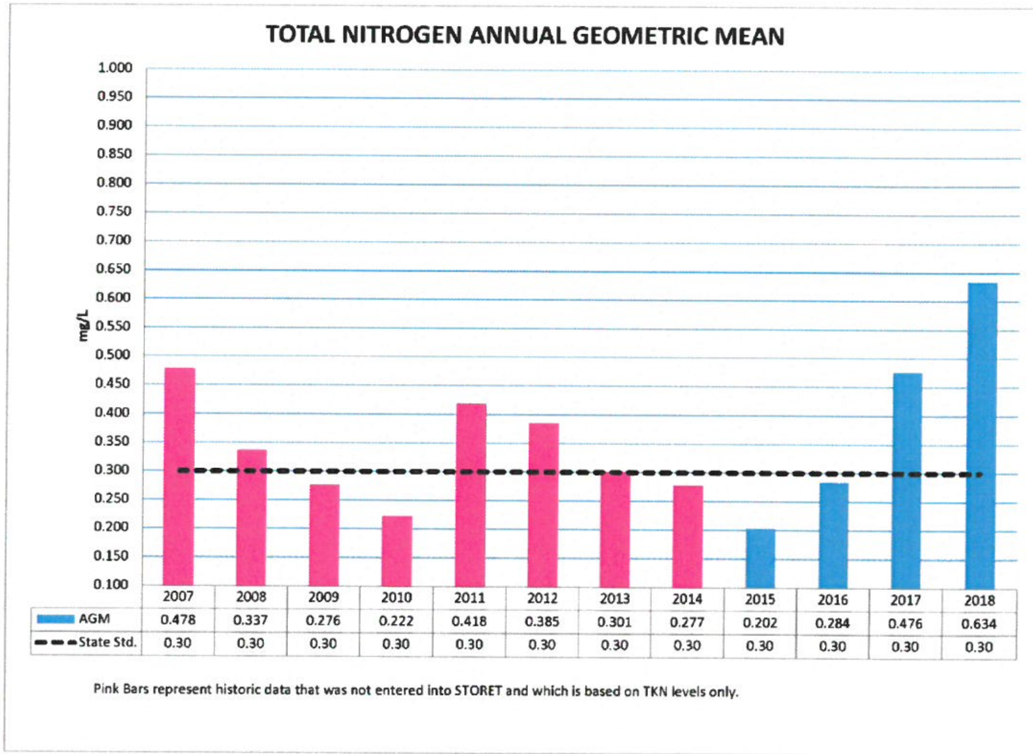


Figure 10: Comparison of Marco Island Nitrogen data from Previous Years

Based on this information, it appears as though the TN levels can vary significantly from year to year. These variations do not appear to be linked to rainfall or salinity though no salinity data was available for the 2007 through 2014 data set. The increases and decreases do not consistently follow any rainfall pattern either. One item of interest is that three of the years showing higher peaks (2007, 2011, and 2017) are also years where severe wildfires burned in western Collier County. No correlation can be made at this time between the fires and the elevated nitrogen levels, but it is a data point to keep note of going forward.

POTENTIAL SOURCES OF NITROGEN IN MARCO ISLAND WATERS

A critical component of trying to control or reduce nitrogen levels is to determine where the nitrogen is coming from. This summary report did not investigate the nitrogen compounds to try and determine source. Isotopes of N and O in Nitrates can be analyzed to help determine sources of the nutrient, but the collection and laboratory analysis needed to do this are outside the scope of this summary investigation. Several potential sources of nitrogen are discussed below. This discussion is by no means all encompassing but does provide information on what are most likely the major contributors to nitrogen levels within the Marco Island canals and waterways.

BACKGROUND LEVELS

Based on the data examined from the surrounding waters both north and south of the Island, it is clear that nitrogen levels throughout the region are elevated, as compared to the State standard. If the background water entering the Marco canals and waterways is already elevated, then any additional inputs from the Island will only exacerbate the total nitrogen levels and result in non-compliant testing results.

Looking at the locations that were sampled to establish the NNC for the Estuary Nutrient Region (ENR), it is interesting to note that only one data point falls within WBID 3278O and that is in the center of the intracoastal waterway at the Jolly Bridge.

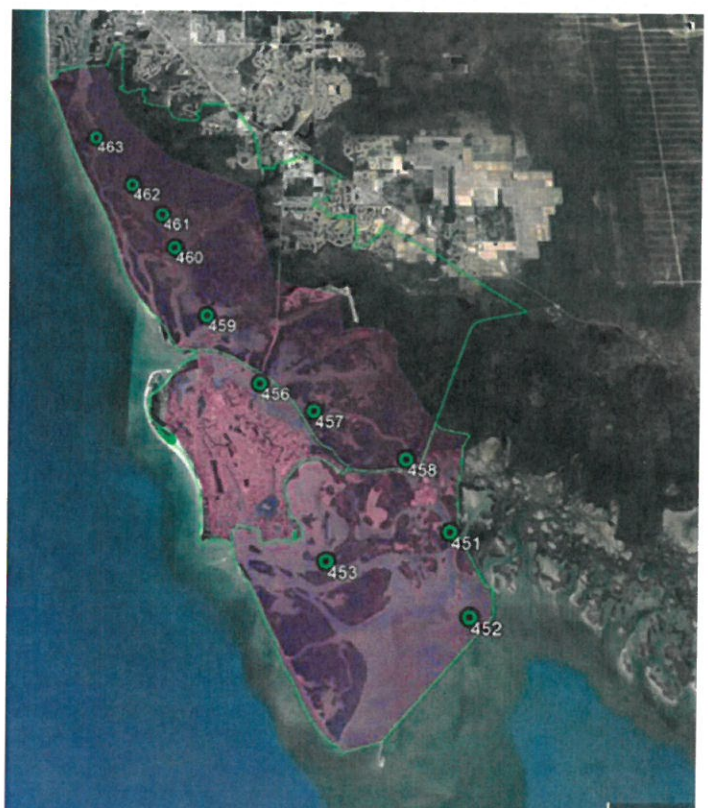


Figure 11: Data Collection Locations Used to Help Establish Numeric Nutrient Criteria

No data was collected from the canals and waterway systems throughout the majority of the WBID. From the map depicted in the figure below, the SFWMD does sample some of the locations. Location 458 from the figure corresponds to SFWMD 16692 and Location 456 corresponds to SFWMD 16690. As seen in Figure 9 above, the total nitrogen levels, expressed as an annual geometric mean, have been consistently over the state standard that was established for this ENR. Since the background nitrogen levels are already over the state standard, it will be very difficult for the waters within the Marco Island canals and waterways to achieve values lower than the background levels. This is not to say that improvements to the Canal water quality cannot be made as there are potential contributing sources that could serve to make the levels substantially worse than the background levels. These potential sources are discussed below.

ATMOSPHERIC DEPOSITION

Molecular nitrogen gas comprises approximately 78% of our atmosphere. Molecular nitrogen is stable and converting it to other chemical compounds requires considerable energy, such as lightning or very high temperatures. These can cause nitrogen and oxygen in the air to form nitrogen oxides. Photosynthetic energy in plants and chemical energy in soil microorganisms also can convert nitrogen to other chemical forms. All of these natural processes occur in the cycling of nitrogen in our environment.

In addition to molecular nitrogen, trace amounts of nitrogen oxides, nitric acid vapor, gaseous ammonia, particulate nitrate and ammonium compounds, and organic nitrogen circulate through the atmosphere. In the United States, nitrogen contributions from human activities rival or exceed contributions from natural sources for many of these trace compounds.

Atmospheric nitrogen compounds cycle to the land and water through atmospheric deposition. Wet deposition, predominantly rain and snow, carries nitrate and ammonium. Dry deposition involves complex interactions between airborne nitrogen compounds and plant, water, soil, rock, or building surfaces.

Most studies done in this region (between Tampa bay and the Florida Keys, put the atmospheric deposition rate for total nitrogen at between 2 and 4 kg per acre per year. That means that a ½ acre lot on Marco would have between 1 and 2 pounds of nitrogen per year falling on it between wet and dry deposition.

ANIMAL WASTE

Marco Island is home to a diverse array of wildlife species. Bird rookeries, bat colonies, pets, and other animals can all contribute to nutrient loading into local waterways either transported via stormwater or directly into the local waters. Four of the bridges on Marco Island either are currently or have in the past supported bat colonies. Guano from the bats falls directly into the water under the bridges and is then transported throughout the waterways. Likewise, the multitude of birds flying and roosting around the Island also contribute nutrients into the local waters.

Figure 12: Bats under the East Winterberry Bridge

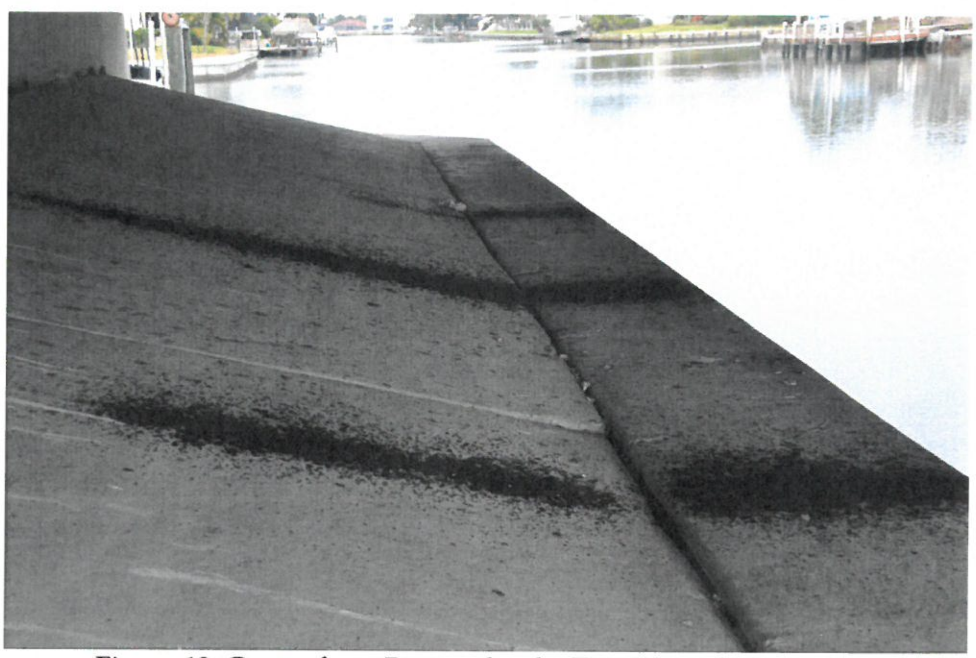


Figure 13: Guano from Bats under the East Winterberry Bridge

HURRICANE AND STORM DEBRIS

Hurricanes and tropical storms have the ability to greatly increase the amount of organic material within the local waterways. Leaves, limbs, and soil driven by storm force winds can be blown from adjacent upland and wetland areas to be deposited into the local waterways. Heavy rainfall and storm surges can also transport material from adjacent lands into the waterways. As this material rots and is broken down, the nutrient components enter the water column and sediment components of the waterways. In the sediment, the nutrients are susceptible to re-suspension every time the waters are agitated either by natural winds and storms, or by boat wakes and propellers.

Studies have shown that leaf debris such as mangrove or oak leaves can take 9 to 12 months to break down, depending on environmental conditions, so effects on the water quality from large inputs of this type of material can take over a year to be observed and may linger for quite a while until flushed or exported from the system.

It is impossible to calculate the amount of debris that hurricane Irma deposited into the Marco Island waterways but it is likely that this material is still present and having an effect on the water quality nutrient levels.

Figure 14: Mangroves stripped of leaves by Hurricane Irma

REUSE WATER

Marco Island does provide reclaimed water for irrigation purposes to Commercial and multi-family properties located mainly along the western and internal portions of the Island. Reuse water can contain substantial amounts of nitrogen and phosphorus both. Used properly reuse water can minimize the amount of fertilizer needed in some landscape applications. Used improperly reuse water can contribute to the nitrogen loading within adjacent waterways. Care must be taken to keep reuse water application within pervious vegetated areas and not used when the soil is already saturated.

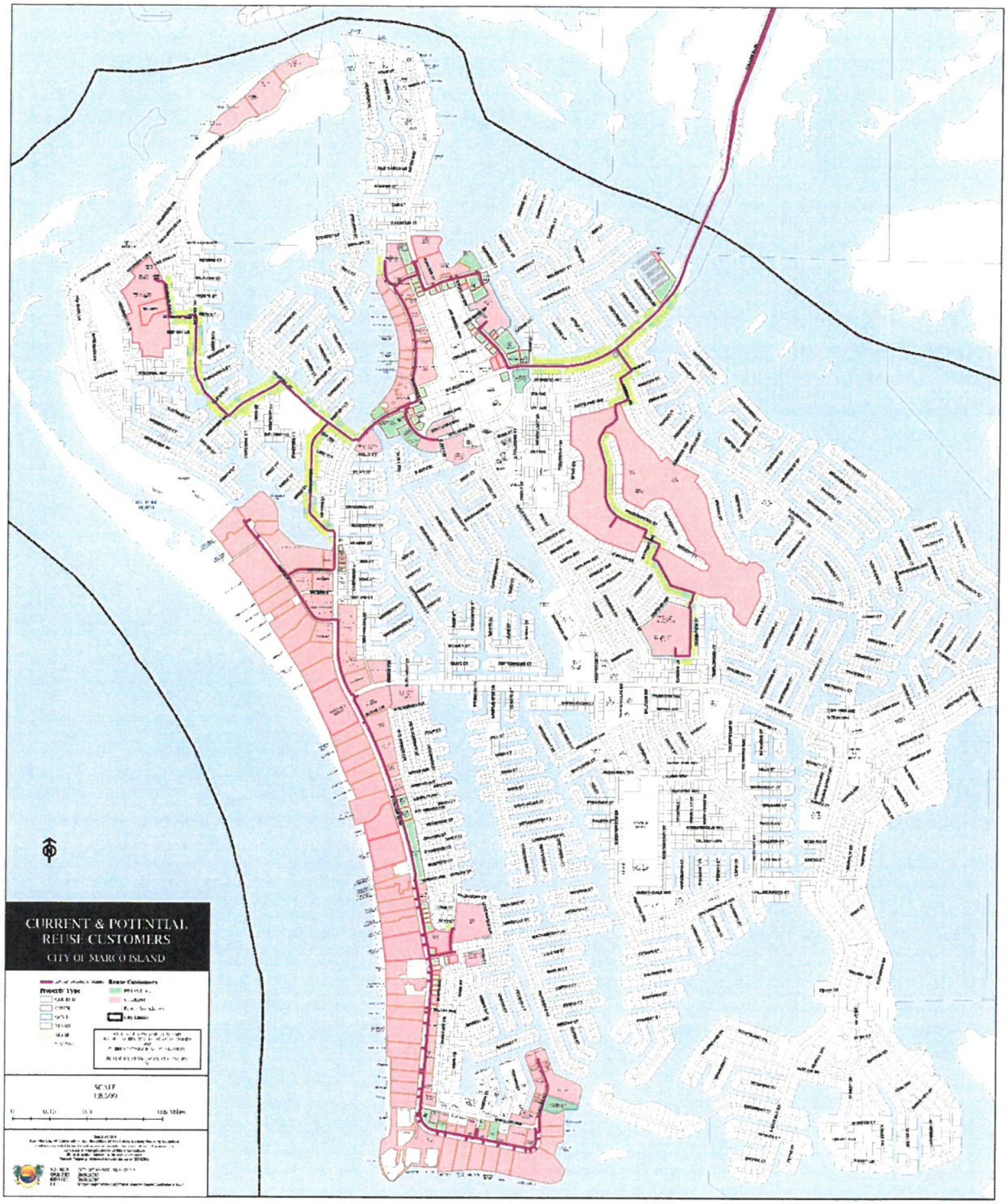


Figure 15: Reuse water availability

FERTILIZERS AND LANDSCAPE PRACTICES

Fertilizers are generally defined as "any material, organic or inorganic, natural or synthetic, which supplies one or more of the chemical elements required for the plant growth". Most fertilizers that are commonly used in landscaping practices contain the three basic plant nutrients: nitrogen, phosphorus, and potassium. Some fertilizers also contain certain "micronutrients," such as zinc and other metals, that are necessary for plant growth. Fertilizers are applied to replace the essential nutrients for plant growth to the soil after they have been depleted.

Excess amounts of fertilizers may enter streams creating sources of nonpoint pollution. Fertilizers most commonly enter water sources by surface runoff and leaching from agricultural lands. Large amounts of nitrogen and phosphorous are present in the runoff. Increased amounts of nitrogen, phosphorous, and other micronutrients can have negative impacts on public health and aquatic ecosystems.

Improper fertilization or utilization of the wrong fertilizers can also contribute nitrogen to local waters. It is important to use fertilizers with only the correct amounts and forms of nitrogen that can be readily used by the plants being fertilized. Fertilizer that are spread or overcast onto impervious surfaces can then be washed directly into the stormwater system and transported to the local waters where they contribute to algal growth and blooms rather than to the landscape plants or grass for which they were intended. Fertilizers that are not incorporated into the soils can also be more susceptible to being washed away into the adjacent waterways.

Figure 16: Fertilizer overcast onto adjacent curb

STORMWATER

Waterways and receiving waters near urban and suburban areas are often adversely affected by urban storm water runoff. The degree and type of impact varies from location to location, but it is often significant relative to other sources of pollution and environmental degradation. Urban storm water runoff affects water quality, water quantity, habitat and biological resources, public health, and the aesthetic appearance of urban waterways. As reported in the National Water Quality Inventory Report to Congress, urban runoff is one of the leading sources of pollutants causing water quality impairment in estuaries across the nation.

Pollutants in stormwater degrade water quality in receiving waters near urban areas, and often contribute to the impairment of use and exceedences of criteria included in State water quality standards. The quantity of these pollutants per unit area delivered to receiving waters tends to increase with the degree of development in urban areas.

Storm water runoff from urbanized areas is generated from a number of sources including residential areas, commercial and industrial areas, roads, highways and bridges. Essentially, any surface which is not able to pond, or infiltrate water will produce runoff during storm events. When a land area is altered from a natural forested ecosystem to an urbanized land use consisting of rooftops, streets and parking lots, the hydrology of the system is significantly altered. Water which was previously ponded on the forest floor, infiltrated into the soil and converted to groundwater, utilized by plants and evaporated or transpired into the atmosphere is now converted directly into surface runoff. An important measure of the degree of urbanization in a watershed is the level of impervious surfaces. As the level of imperviousness increases in a watershed, more rainfall is converted to runoff.

The traditional means of managing storm water runoff in urban areas has been to construct a vast curb-and-gutter, catch basin, and storm drain network to transport this runoff volume quickly and efficiently away from the urbanized area with discharge into receiving waters.

As part of this nitrogen investigation, the land use areas of Marco Island were looked at to determine approximate levels of impervious area associated with the different land uses. Twenty random constructed single family lots were chosen, and an aerial interpretation was done to determine the percentage of the lot that was pervious vs. impervious. Lot coverage varied between the lots chosen from 38% impervious to 74% impervious. The average for residential areas appears to be around 50% pervious/impervious though the trend towards larger homes covering more of the lots appears to be increasing the impervious area associated with the single-family components. Similar exercises were done on the different land use categories to come up with the table below.

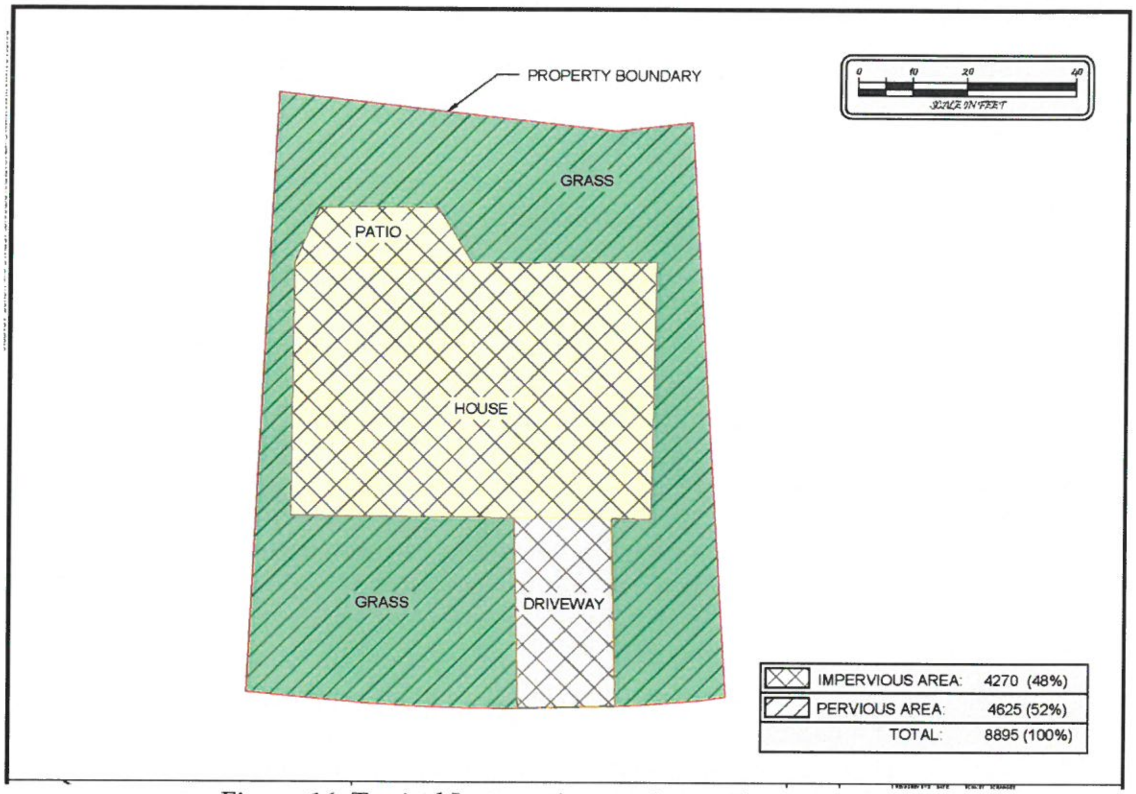


Figure 16: Typical Lot pervious vs impervious estimate.

Table 1. Marco Island Pervious and Impervious Estimates

DECSRIPTION	PARCEL TOTALS (AC)	% PERVIOUS	% IMPERVIOUS	PERVIOUS (AC)	IMPERVIOUS (AC)
CANALS	1514				
ROADS	333	0	100	0	333
VACANT LAND	442	100	0	442	0
SINGLE FAMILY	1987	50	50	993.5	993.5
MULTI FAMILY	635	45	55	285.75	349.25
COMMERCIAL	224	25	75	56	168
GOLF COURSE	183	89	11	162.87	20.13
INSTITUTIONS	180	50	50	90	90
FOREST & CEMETARY	236	95	5	224.2	11.8
TOTALS	**5734**			**2254.32**	**1965.68**

Based on this data, approximately 47% of the developed portions of the island are impervious to infiltration and contribute to the stormwater flows. This means that the run-off of surface water can be 3 to 4 times greater than under natural undeveloped conditions.

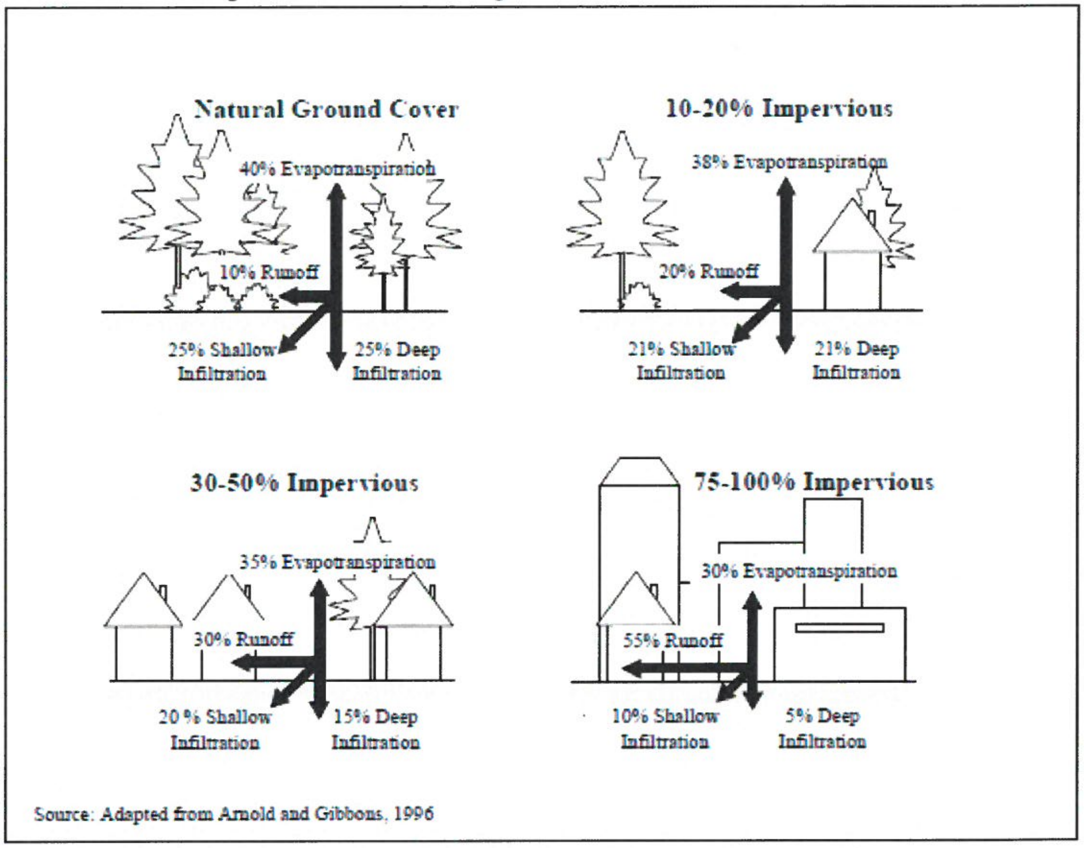


Figure 16: Changes to run-off with increasing impervious area

When the primary concern with stormwater drainage is to limit nuisance and potentially damaging flooding due to the large volumes of storm water runoff, little, if any, thought may go into to the environmental impacts of such practices. As a result, waterways that receive storm water runoff frequently and that cannot convey the large volumes of water generated during runoff events and experience significant degradation. In addition to the problems associated with excess water volume, the levels of toxic or otherwise harmful pollutants in storm water runoff can cause significant water quality problems in receiving waters.

Storm water runoff from a variety of sources such as parking lots, highways, open land, residential areas, and commercial areas can enter waterways directly as sheet flow or as a series of diffuse, discrete flows. Due to the diffuse nature of many storm water discharges, it is difficult to quantify the range of pollutant loadings to receiving waters that are attributable to storm water discharges.

Awareness of the damaging effects storm water runoff is causing to the water quality and aquatic life of receiving waters is a relatively recent development. Storm water management traditionally was, and still is in many cases, a flood control rather than a quality control program. Local governments intending to improve the quality of their runoff need to incorporate best management practices (BMPs) into their drainage programs. BMPs which reduce the volume of runoff discharged, such as minimizing directly connected impervious surfaces, providing on-site storage and infiltration and implementing buffers along adjacent waters can help to prevent further degradation and even result in improvements to receiving waters. However, in many existing urbanized areas, the cost of infrastructure changes necessary to retrofit existing storm water drainage systems with structural BMPs--to provide for storm water quality as well as quantity control--can be prohibitively expensive. In these cases, non-structural BMPs can be implemented to reduce pollutant sources and to reduce the transfer of urban pollutants to runoff, before more expensive, structural controls are instituted.

Figure 17: Parking area draining directly to street gutter

POTENTIAL MEANS TO REDUCE NITROGEN LOADING INTO MARCO ISLAND WATERS

This Section tries to briefly describe options that are available to manage or control nutrient loading into the adjacent waterways. The majority of the options discussed have to do with stormwater management and source control and is by no means comprehensive but is provided to give an idea of the options available as well as some of the pros and cons associated with them.

STORMWATER BMPs

There are a variety of stormwater BMPs available for managing urban runoff. Regardless of the type, stormwater BMPs are most effective when implemented as part of a comprehensive storm water management program that includes proper selection, design, construction, inspection and maintenance. Stormwater BMPs can be grouped into two broad categories: structural and non-structural. Structural BMPs are used to treat the stormwater at either the point of generation or the point of discharge to either the storm sewer system or to receiving waters. Non-structural BMPs include a range of pollution prevention, education, institutional, management and development practices designed to limit the conversion of rainfall to runoff and to prevent pollutants from entering runoff at the source of runoff generation.

Structural BMPs

There are a wide variety of structural BMPs in use for storm water management. Structural BMPs include engineered and constructed systems that are designed to provide for water quantity and/or water quality control of storm water runoff. While the terms "retention" and "detention" are sometimes used interchangeably, they do have distinct meanings. Storm water detention is usually defined as providing temporary storage of a runoff volume for subsequent release.

Examples include detention basins, underground vaults, tanks or pipes, and deep tunnels, as well as temporary detention in parking lots, roof tops, depressed grassy areas, etc. Retention is generally defined as providing storage of storm water runoff without subsequent surface discharge however, retention is also commonly used to describe practices that retain a runoff volume (and hence have a permanent pool) until it is displaced in part or in total by the runoff event from the next storm. Examples include retention ponds, tanks, underground vaults or pipes, and wetland basins.

- Infiltration systems capture a volume of runoff and infiltrate it into the ground. These are not too effective in South Florida due to the high water table and lack of "dry" space with which to accomplish the infiltration. One type of infiltration system that has had some success is porous or pervious pavement systems. Permeable pavement can be used in parking lots, roads and other paved areas and can reduce the amount of runoff and associated pollutants leaving the area. Typically, porous pavement can only be used in areas that are not exposed to high volumes of traffic or heavy equipment. They are particularly useful for driveways and parking areas in commercial areas, especially overflow areas that are not used on a daily basis. They must be installed correctly and require regular maintenance including periodic vacuuming or jet-washing to remove sediments from the pores in order to remain effective.

- Detention systems capture a volume of runoff and temporarily retain that volume for subsequent release. Detention systems to not retain a significant permanent pool of water between runoff events. These systems generally take up a lot of space in order to provide enough storage volume to make them worthwhile.

- Retention systems capture a volume of runoff and retain that volume until it is displaced in part or in total by the next runoff event. Retention systems therefore maintain a significant permanent pool volume of water between runoff events. These systems also take up a lot of space and, if not managed appropriately, can be an additional source of contaminants into adjacent waters. Stormwater ponds are often treated as amenities in most south Florida developments and are managed for aesthetics instead of for nutrient removal. This can lead to herbicide and algaecide application which can contaminate the water and flow out into adjacent waters during rainfall events. Examples of this type of treatment system can be found at Mackle Park, the Villas at Waterside, and within the golf courses on the Island.

- Constructed wetland systems are similar to retention and detention systems, except that a major portion of the water or bottom surface area contains wetland vegetation. These types of systems often generate complaints from residents adjacent to them as "weed infested" or "mosquito havens". They can also take up a lot of space in order to be very effective.

- Biofilters and Bioretention areas are vegetated areas such as roadway medians, swales and filter strips which are designed to convey and treat either shallow flow or sheet flow runoff. Biofilters can also be retention areas which are designed to mimic the functions of a natural ecosystem for treating storm water runoff. Storm water flows into the bioretention area, ponds on the surface, and gradually infiltrates into the soil bed. Pollutants are removed by a number of processes including adsorption, filtration, volatilization, ion exchange and decomposition. Treated water is allowed to infiltrate into the surrounding soil or is collected by an under-drain system and discharged to the stormwater system or directly to receiving waters. In addition to providing for treatment of storm water, bioretention facilities, when properly maintained, can be aesthetically pleasing. Bioretention facilities can be placed in areas such as parking lot islands, in landscaped areas around buildings, the perimeter of parking lots, and in other open spaces.

  The City has a lot of the biofilter type of treatment areas throughout the Island, but most are designed to pass water as quickly as possible rather than trying to retain it at all. Stormwater grates within the swales are placed at the bottom of the swale so during storm events, the water runs out immediately rather than being retained for any time.

Figure 18: Stormwater grate at the low point of the swale.

The City also has several areas where no treatment or retention at all occurs before stormwater flows into the adjacent waterways. Areas such as this should be a priority for modifications to reduce direct flow into the adjacent waters.

Figure 19: Road run-off directed immediately into stormwater grate

Figure 20: Direct run-off from parking lot into the canal.

- Vendor-supplied systems include a variety of proprietary and miscellaneous systems including catch basin inserts, hydrodynamic devices, and filtration devices. The City currently has examples of these inserts scattered around the Island. Some can be very effective but can be expensive to maintain (both from and equipment and a labor aspect), especially if used for direct run-off without settling basins or filtering from biofilters as outlined above. They can also be susceptible to clogging and reduced efficiency when grass and vegetative debris flows into them.

Figure 21: Storm drain insert becoming blocked with vegetative debris

Non-Structural BMPs

Non-structural BMPs include institutional and pollution-prevention type practices designed to prevent pollutants from entering storm water runoff or reduce the volume of storm water requiring management. Non-structural BMPs can be very effective in controlling pollution generation at the source, which in turn can reduce or eliminate the need for costly structural BMPs. Non-structural BMPs discussed in this report include education, source controls, and maintenance practices.

Public education can be an effective means of reducing the amounts of non-point source pollutants entering receiving streams. The public is often unaware that the combined effects of their actions can cause significant non-point source pollution problems. Proper education on day-to-day activities such as recycling of used automotive fluids, household chemical and fertilizer use, animal waste control and other activities can significantly reduce non-point source pollutant loadings to urban streams.

Source reduction is probably the most effective non-structural way of controlling the amounts of pollutants entering storm water runoff. A wide range of pollutants are washed off of impervious surfaces during rainfall events. Removing these contaminants from the urban landscape prior to precipitation can effectively limit the amounts of pollutants contained in the storm water runoff. Source reduction can be accomplished by a number of different processes including: limiting applications of fertilizers, pesticides and herbicides; periodic street sweeping to remove trash, litter and particulates from streets; collection and disposal of lawn debris; periodic cleaning of catch basins; elimination of improper dumping of used oil, antifreeze, household cleaners, paint, etc. into storm drains; and identification and elimination of illicit cross-connections between sanitary sewers and storm sewers.

- Commercial and retail areas can contribute significant pollutant loadings to runoff. The biggest contributor of pollutants is usually impervious surfaces used for vehicle parking, storage and maintenance areas, which can contribute sediment, metals and hydrocarbons. Other sources include raw material and finished product storage areas, pesticides and fertilizers from grounds maintenance, and rooftop runoff. Good housekeeping practices include; cleaning and maintain parking lots and delivery bays; limiting exposure of materials and equipment to rainfall; and spill cleanup, using dry cleanup techniques instead of wet techniques.

- Community Outreach. A main problem associated with identifying and controlling nonpoint source pollution is that the public is generally unaware of the sources and control measures for urban nonpoint source pollutants. Information dissemination is a critical need of most local storm water programs. Information that explains the sources of nonpoint source pollution, control measures available and the steps homeowners and commercial owners can do to reduce impacts of their activities can help to increase the public awareness of the need to control nonpoint source pollution. A few of the techniques available for providing educational materials to the public include television, radio and newspaper announcements, distribution of flyers, community newsletters, workshops and seminars, conducting teacher training programs at schools, and supporting citizen-based watershed stewardship groups and volunteer monitoring programs. Residents are frequently unaware that materials dumped down storm drains may be discharged to a local water body. A simple program of stenciling the inlets can be an effective means of alerting residents of this fact.

Figure 22: Example of basin inlet stencil/plaque

- Pesticide/Herbicide Use. Due to their high aquatic toxicity, pesticides and herbicides can be a significant source of water quality impairment in urban waters. According to the US EPA, home and garden usage accounted for 133 million pounds (11 percent of total usage) in 2000. A significant portion of these applications find their way into storm water runoff and ultimately into receiving streams through spray drift, transport by soils, solubilization by runoff, and by spillage, dumping and improper disposal of containers and residuals. Education on the proper methods of application, application rates and alternatives to pesticides can help to reduce the amount of pesticides that are carried by urban runoff. Alternatives to pesticides, such as in integrated pest management program and pesticide alternatives such as insecticidal soap or natural bacteria, can also reduce the need for pesticides.

- Fertilizer Use. A significant amount of nutrients in urban runoff results from misapplication of fertilizer to the urban landscape. Residential lawn and garden maintenance and maintenance of landscape and turfgrass at golf courses, in road right-of ways, and commercial areas uses significant amounts of fertilizers containing nitrogen and phosphorus. Since most fertilizers are water soluble, over-application or application before rainfall events can allow significant quantities to be carried away by storm water runoff. Education on proper application of fertilizers can help to reduce the quantities of nutrients reaching receiving waters. Ordinances and regulations limiting the use of certain fertilizers or limiting time frames for application can also be effective means of controlling nutrient run-off. Keep in mind though that any ordinance or regulation is only as good as the compliance with said regulations. Without compliance or enforcement for non-compliance, most homeowners remain unaware.

- Lawn Debris Management. Lawn debris such as grass trimmings and leaves require proper management in order to reduce impacts to adjacent waters. Grass trimmings and leaves can be carried away by runoff or wind and can find their way into adjacent waters where they rapidly decompose and release nutrients. Grass trimmings and leaf litter can be controlled by composting lawnmowers, bagging and composting or by community curbside collection programs. Composted yard debris can be an excellent source of mulch for residential landscape and gardens. Use of mulch can greatly reduce the need for inorganic fertilizers, which also helps to keep nutrient loadings to a minimum.

Figure 23: Grass clippings and leaf debris in canal

- Pet Waste Disposal. Pet waste can cause significant loadings of bacteria, nutrients and oxygen demanding substances to urban runoff. Pet waste deposited in yards and street right of ways can be carried by runoff into storm drains. As an example, it is estimated that an average 30 pound dog produces 0.75 pounds of waste daily. This can equate to over 270 pounds of pet waste per year that should not be allowed to flow into adjacent waters.

- Catch Basin Cleaning. Catch basins naturally accumulate sediment and debris such as trash and leaf litter. In order to ensure their continued effectiveness, catch basins need to be periodically cleaned. This can be done by manual means, or by using a vacuum truck.

- Street and Parking Lot Sweeping. Urban streets and parking lots can accumulate large amounts of pollutants that can be washed off during storm events. Streets and parking lots comprise a significant portion of the total impervious area within a developed watershed, and a large percentage, if not the entire area, of streets and parking lots are usually directly connected to the storm drain system.

Other Potential Means of Reducing Nutrient Levels in Waterways

Background nitrogen levels were mentioned earlier in this summary as already being elevated. The BMPs addressed above are designed to minimize additional input into the system but do not have any effect on what is already there. Two means of potentially improving water quality and decreasing nutrient levels within the canals and waterways of Marco Island would be to increase the filtering capacity within the waterways and to increase the flushing capacity within the canals.

FLUSHING CAPACITY IMPROVEMENTS

As part of the site investigations associated with this summary, the flow of water within the different basins was observed. A more formal flushing study was not done but observations were made to get a general idea of how water moved (or did not move) within the different basins. Tidal lag varied from 15 minutes to almost 40 minutes on the different days observed. Tidal lag is the time difference between when high tide is observed in the Gulf to when high tide is observed at the end of a canal. In general, the further the waterway was from the "exit" out into gulf or bay waters, the less movement was observed.

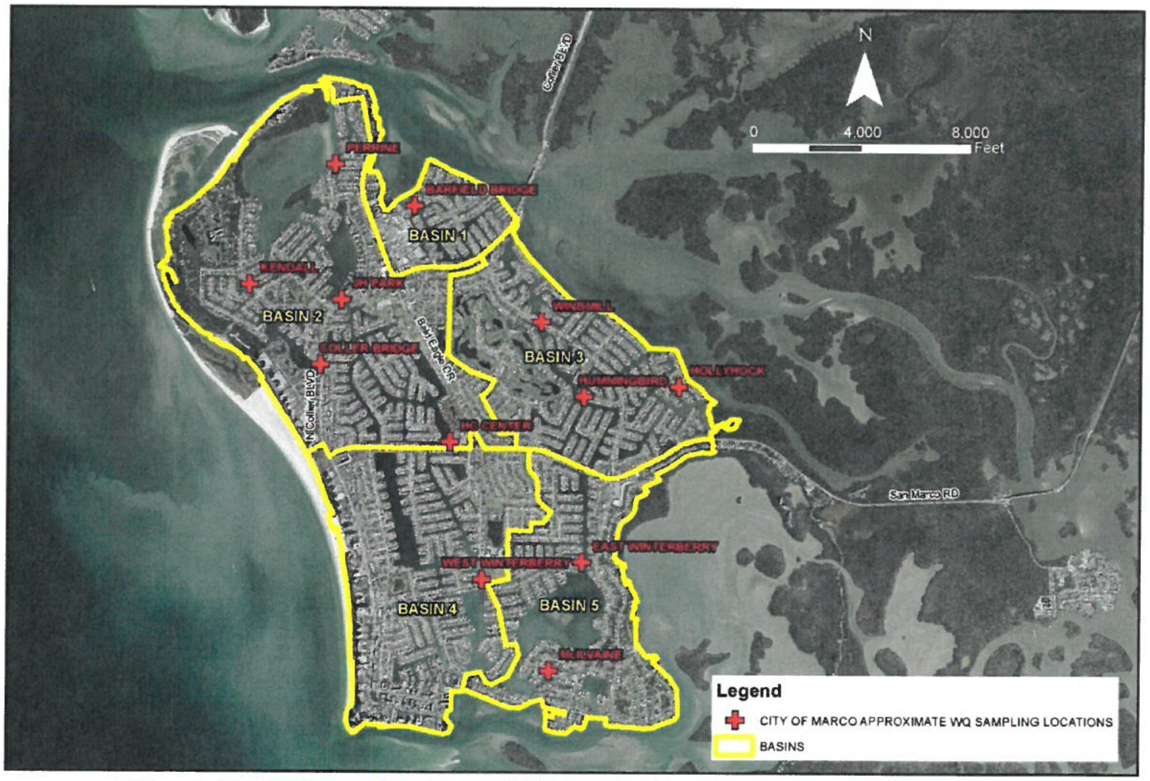


Figure 24: Drainage Basins and Water Quality Monitoring Locations

One notable exception to this was the waterway in Basin 2 next to the Health Center at San Marco Road and Bald Eagle Drive. This location was the furthest from the outfall yet had flows better than many of the closer canals. This is most likely due to the connected canal system facilitating some wind driven current that combined with tidal flow and resulted in more water flow. The higher flows were measured on the outgoing tides and approached 3 knots at a couple of the bridges.

San Marco Road splits Basins 2 and 3 from Basins 4 and 5. Debris buildup and lower flows was the most noticeable at the ends of the waterways between Basins 5 and Basin 3 where San Marco Road separates them. Lower flows were also observed in the large bay in Basin 4 next to San Marco Road. Investigating connections under San Marco Road is something that the City has looked at in the past and may want to consider in the future to increase flow and flushing capacities throughout the center of the island. Creating conditions whereby water could flow from north to south through the island would increase flushing and help to alleviate some of the lower flow areas in the longer dead-end canals. A more thorough flushing study should be undertaken to determine the amount of improvement that could be realized and determine if the expense would be worth the improvement.

SEAWALL IMPROVEMENTS / MODIFICATIONS

When Marco Island was originally constructed, the entire waterway system was lined with vertical seawalls. Many of these seawalls are still present today but are approaching the end of their lifespan. Many have also been replaced but still with vertical walls.

Figure 25: Canal ringed with vertical seawalls

Vertical walls provide the minimum surface area for filter feeding organisms such as oysters, tunicates, and others to colonize. The vertical surfaces of seawalls also act as mirrors for boat wakes and waves and this refraction can result in higher turbulence and lower visibility within the canals. All of the docks located within the canals do provide some structure and can help break up wave energy but most are treated to prevent or discourage growth of organisms on the pilings. Consideration should be given to providing more places for filter feeding organisms which can help to clean the water and could be a way to ameliorate background nutrients that are flowing into and out of the canals on every tidal cycle. Living shorelines, rip rap, and mangrove islands could all provide additional surface area for colonization, but all come with challenges that would have to be considered. Any changes to waterways would require permitting from state and federal agencies. While seawall replacement is an exempt activity, the placement of rip-rap in front of the wall is fill which requires federal permitting and would make seawall replacement a bit more complicated and potentially costlier. The benefits could be substantially more area for colonization by benthic organisms, relief from wave refraction, and the resultant improvements to water quality.

Figure 26: Older seawall with rip rap showing substantial benthic growth

CONCLUSIONS

It is easy to see from the water quality data being collected that nutrient levels, specifically total nitrogen, have increased within the Marco Island waterways over the past four years. Based on the preliminary work done in conjunction with this report, there is no "smoking gun" reason found that would explain this increase. It appears that an array of factors could be contributing to the increases observed.

Nitrogen levels within the waters surrounding the Island have also increased in the past five years. The water bodies to the south and west of the island exceeded the impaired waters criteria according to the most recent Impaired Waters Run so the waters flowing into the Marco waterways via tidal exchange may already be problematic before it enters the canals.

There are several potential loading sources or issues identified on and around the Island that can be contributing additional nutrients into the waterways and accounting for the increasing nitrogen levels. Finding ways to reduce the upland sources of nitrogen, coupled with increasing the time it takes stormwater to enter the canal system would help to reduce the nitrogen loading coming from the Island land uses.

Water quality testing should continue at all of the currently monitored sampling stations. Two of the drainage basins only have a single monitoring point. Basin 1 is relatively small and has multiple connections to the background waters, so a single sampling point is sufficient. Basin 4 is a larger basin and currently only has a single monitoring station at the West Winterberry Bridge. Since the other basin stations are generally located to collect at the entrance and "back" of the waterways within them, consideration should be given to adding one or two additional monitoring points within this basin.

Questions about trends and influences (such as rainfall and other environmental events) on the testing results are difficult to answer with quarterly testing. The City has conducted monthly and bi-monthly testing in the past and should consider monthly testing in order to collect sufficient data to answer many of the questions being asked. Periodic testing of the stormwater prior to entry into the waterways would also provide information on potential loading coming directly from the stormwater system.

Some consideration may also be given to looking at ways to help treat or deal with the nutrient levels once they get into the canal system. Increasing habitat for benthic organisms, especially filter feeders could help to cycle nutrients out of the water column and would help with both Island generated and background levels.