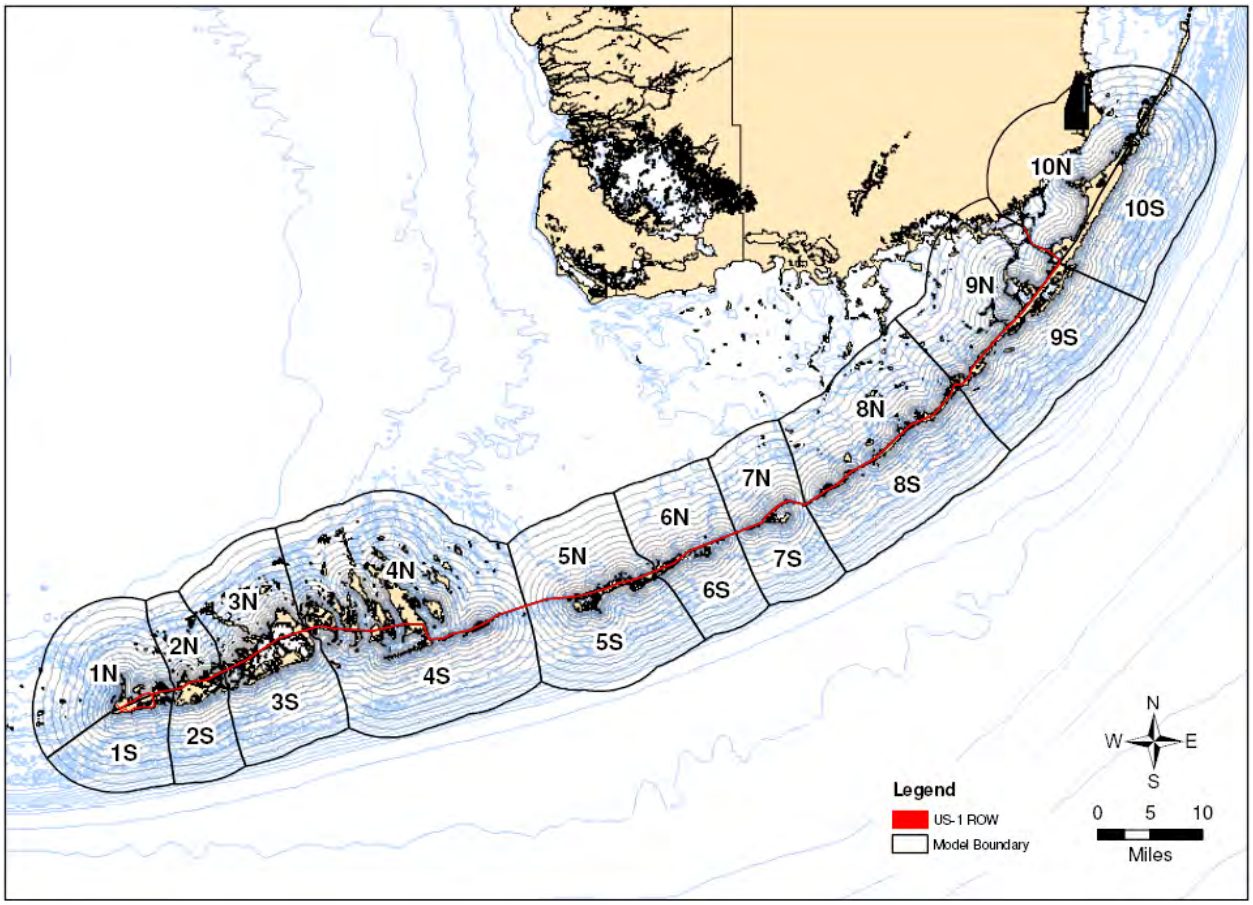
FLORIDA KEYS REASONABLE ASSURANCE DOCUMENT

WBID TIDAL FLUSHING MODEL



Final Report

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1 BACKGROUND AND OVERVIEW

This report describes the development, testing and subsequent use of a relatively simple, comparative analysis tool for evaluating the relative impacts of wastewater effluents and stormwater discharges in the near-shore waters of the Florida Keys. The analysis tool was created to support the development of Reasonable Assurance Documents (RADs) within the Florida Keys. Designed around the tidal flushing models previously developed for a selected number of residential canals during the Florida Keys Carrying Capacity Study (FKCCS), the WBID Tidal Flushing Model (WTFM) is a larger scale application of the algorithms from the canal models.

In addition, the previous canal models were updated to include the revised load projections for the scenarios prepared in this work, and to use the WTFM predicted results as boundary conditions.

1.1 Overview of Work

The process of developing the WTFM was conducted to enable the stakeholders in the Florida Keys to understand and evaluate the relative impacts of wastewater and stormwater management decisions on nutrient concentrations in the nearshore WBIDs within the Florida Keys. This work included the following:

- Review and assess selected physical and water quality data
- Develop a tidal characteristics database
- Develop an ambient nearshore water quality database
- Define model boundaries and model cells
- Define the contributing wastewater and stormwater loads under various scenarios
- Develop a simplified tidal flushing model
- Apply the tidal flushing model to various load scenarios
- Prepare a summary report

These work efforts produced a model that is responsive to the stakeholders need to estimate relative impacts within the nearshore WBIDs.

2 DATA COLLECTION, REVIEW & DEVELOPMENT

The objective of this section is to review and discuss the results of a narrowly focused literature search and data acquisition effort which was undertaken to acquire, review and assess physical and water quality data related to the nearshore WBIDs, and site-specific waste load data (both stormwater and wastewater) in the Florida Keys. This investigative effort provides the basis for an understanding of the available data, their limitations and constraints, and enables beneficial use of these available data.

In some cases, the data (as retrieved) was not suitable for direct use in the development of the WTFM and required some manipulation to develop useful databases for implementation of the model. This included a database to represent tides and their characteristics throughout the Keys, and one to represent the nearshore water quality that would feed into the model during flood tides.

2.1 Focused Literature Review

The literature review conducted in the Keys was very narrowly focused upon investigations of the near-shore waters immediately to the Keys. Seven studies were identified and reviewed, as summarized in the following paragraphs:

- Proposed Designation of the Waters of the Florida Keys as Outstanding Florida Waters. FDER, March 1985. A total of 165 stations were sampled for a limited amount of parameters from Key Largo to Key West from January 8, 1985 to February 20, 1985. Background stations at ¼ mile offshore show no violations of dissolved oxygen standards, while one to seven ocean side stations and one to five bayside stations violated the standard as well as showed higher levels of nitrogen and phosphorous.
- Water Quality Assessment of Five Selected Pollutant Sources in Marathon, Florida Keys. FDER. Heatwole, July 1987. The study measured 32 water quality parameters at twelve nearshore sites in Marathon during 1984. Five primary sampling sites were located in canals and marina basins with a representative pollution source, five secondary sampling sites were located in areas adjacent to these primary sites to monitor the pollutant dilution, and two stations were located as background stations. Results varied by pollution source, and by seasonal changes in weather and population densities.
- Boot Key Harbor Study. FDER, December 1990. Fourteen stations located in canals and the harbor basin were monitored during a year in Boot Key Harbor. Low dissolved oxygen levels in the canals were attributed to poor flushing characteristics that resulted in them serving as sinks for organic matter.
- Florida Bay Watch Annual Reports. The Nature Conservancy, 1995 –2001. The reports summarized the data collected during the sample year and it presented monthly means for certain parameters over the entire data collection history. Data results varied among stations because of the location differences between sampling sites.
- Effects of Stormwater Nutrient Discharges on Eutrophication Processes in Nearshore Waters of the Florida Keys. LaPointe & Matzie, June 1996. Stormwater discharges were characterized by continuously sampling (30 minutes interval) water quality parameters along an offshore eutrophication gradient prior to and following heavy rainfall during the 1992 rainfall season. The gradient included a station in a developed canal system on Big Pine Key (Port Pine Heights).
- Nutrient Inputs from the Watershed and Coastal Eutrophication in the Florida Keys. LaPointe & Clark, December 1992. 30 stations throughout inner-shelf waters (<10 m depth) were measured for water quality parameters during summer and winter. Sampling at each site was done along an onshore-offshore transect. They found a gradient in nutrients from inshore to offshore and concluded that the widespread use of septic tanks increases the nutrient concentrations of limestone groundwaters that discharge into shallow nearshore waters, resulting in coastal eutrophication.

- Water Quality Concerns in the Florida Keys: Sources, Effects and Solutions. USEPA, Kruczynski, 1999. The report references several previous published studies and reports in the study area. This report did not include comprehensive data itself.

2.2 Existing Data Acquisition

Existing data sources were inventoried for use with this study. Available data that was acquired includes the following:

- FKNMS Water Quality Protection Program data. 155 fixed stations were monitored for water quality parameters for the period of record of March 1995 to December 2001.
- Village of Islamorada, Periodic water quality sampling program data. 24 Stations were sampled for the period of record of April 2001 to April 2002.
- The Florida Bay Watch ambient water quality program data, the Nature Conservancy. 101 stations were monitored for water quality parameters for the period of record of November 1994 to December 2001.
- The Little Venice Canals water quality monitoring data, USEPA. 9 stations were sampled for the period of record of May 2001 to January 2002.

2.3 Tidal Database

Development of a simplified nearshore model based on tidal flushing requires information on the tidal fluctuations (driving function) that would be expected within the Florida Keys. The Florida Keys covers more than 100 miles and considerable variations in tidal fluctuations occur throughout their range. The current NOAA tide gauge network consists of more than 150 tidal stations in the vicinity of the Florida Keys. The variation in daily tidal range among these stations varies from as little as 4-inches (Upper Sugarloaf Sound - North Harris Channel) to nearly 3-feet (Content Keys, Content Passage).

In addition to tidal fluctuations, simulation of water quality characteristics within the nearshore waters requires information on the quality of water introduced into these waters over each tidal cycle. A water quality database was needed to provide information regarding the input of the selected model pollutants (Total Nitrogen [TN] and Total Phosphorous [TP]) from sources outside of the nearshore WBIDs.

2.3.1 NOAA Tide Gage Network

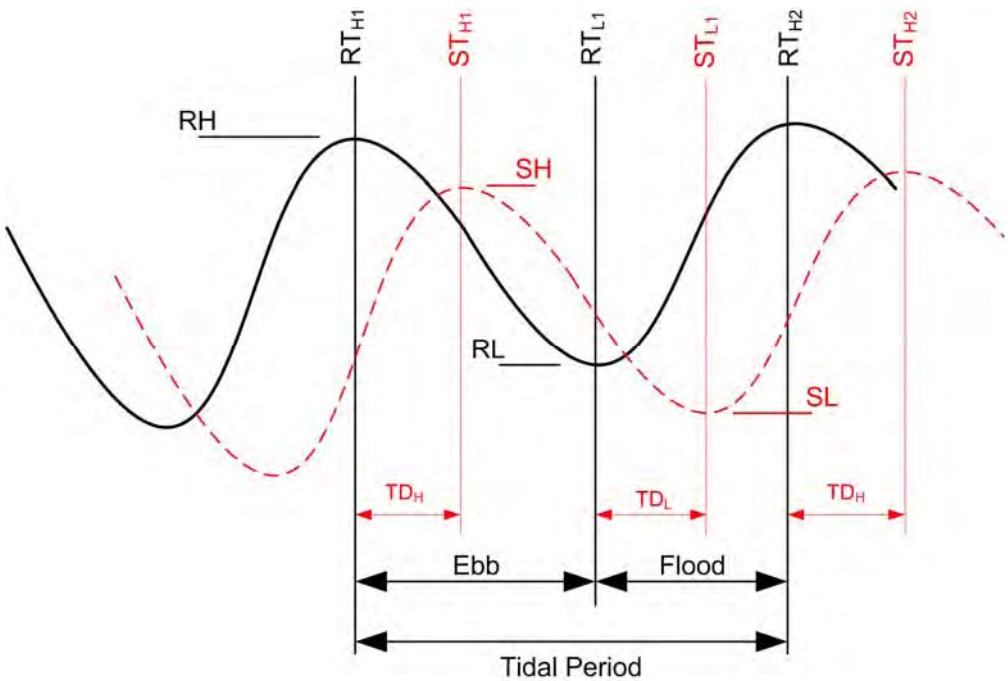
An inventory of tide stations for the Florida Keys was collected from the Center for Operational Oceanographic Products and Services (CO-OPS) web site. CO-OPS resides within NOAA's National Ocean Service. The inventory consists of 172 stations from Virginia Key to the Dry Tortugas. Appendix B lists the tide stations and inventory data that were retrieved from the CO-OPs site. This information is stored in the Microsoft Access database as a table [TIDE_TABLE].

The tide station inventory collected from CO-OPS also included location data for each station in the form of latitude and longitude. This location data was used to develop a GIS coverage of the tide stations and imported into the CCIAM as a data layer.

2.3.2 Tidal Characteristics

The list of tide stations Appendix B shows the mean tide range and level, the time and height adjustment factors for the high and low tides and the reference station to which the adjustment factors are applied for each station. A graphical representation of the adjustment factors is shown in Figure 1. The mean tide range is the mean difference between the high and low tidal levels at the station while the mean tide level is the arithmetic mean of the high and low tidal levels.

Figure 1
SECONDARY TIDAL STATION ADJUSTMENTS



Reference Stations

The time and height adjustments from Appendix B are applied to the reference station (also listed in Appendix A) to predict the time and height of the high and low tides at the selected subordinate station. Of the 172 tide stations in the Keys, only three are reference stations. The remaining 169 are subordinate stations that rely on one of the reference stations for tidal predictions. The three reference stations are Miami Harbor Entrance, Vaca Key and Key West. The Miami Harbor Entrance station acts as a reference station for 45 subordinate tide stations in the Upper Keys region. Vaca Key is not used as a reference by any subordinate station. Key West represents most of the tide stations in the Keys with 124 subordinate tidal stations using it as a reference.

High/Low Tide Time Adjustments

To determine the time of high tide (ST_H) or low tide (ST_L) at a subordinate station, the appropriate time adjustment value (TD_H or TD_L) is added to the time of the high (RT_H) or low tide (RT_L) for the reference station. The equations used to compute these time values at a secondary station are as follows:

$ST_H = RT_H + TD_H$ (Time of high tide at secondary station)
or: $ST_L = RT_L + TD_L$ (Time of low tide at secondary station)

Positive time adjustment values indicate that the tide at the subordinate station occurs later than at the reference station, negative values indicate that the tide occurs earlier.

High/Low Tide Height Adjustments

Height adjustments are applied to the reference station as multiplicative factors. To compute the high (SH) or low tide (SL) elevations at the subordinate station, the high (RH) or low (RL) tide elevation at the reference station is multiplied by the appropriate adjustment factor (H_{adj}/L_{adj}). The equations used to compute tide elevation values at a secondary station are as follows:

$SH = RH \times H_{adj}$ (High tide elevation at secondary station)
or: $SL = RL \times L_{adj}$ (Low tide elevation at secondary station)

Tide Cycle Durations

The ebb tide cycle (Ebb) is the time required to move from high tide to low tide. The flood tide cycle (Flood) is just the opposite - the time required to move from low tide to high tide. A tidal period (Period) is the duration of any two consecutive tide cycles. The equations used to compute these durations, expressed in hours, at a reference station are as follows:

$Ebb_{ref} = RT_{L1} - RT_{H1}$ (Duration from high to low tide)

$Flood_{ref} = RT_{H2} - RT_{L1}$ (Duration from low to high tide)

$Period = RT_{H2} - RT_{H1}$ (Duration from high to high tide)
or: $Period = RT_{L2} - RT_{L1}$ (Duration from low to low tide)
or: $Period = Ebb_{ref} + Flood_{ref}$

At secondary stations, the Ebb and Flood durations can be computed directly from the adjustment factors from Appendix B. The equations used to compute these durations, expressed in hours, at a secondary station are as follows:

$Ebb_{sec} = Ebb_{ref} + TD_L - TD_H$ (Duration from high to low tide)

$Flood_{sec} = Flood_{ref} + TD_H - TD_L$ (Duration from low to high tide)

$$Period_{sec} = Ebb_{sec} + Flood_{sec}$$ (Duration from high to high or low to low tide)

Data regarding the tidal periods and the duration of ebb and flood tides was not available on the CO-OPs site. To estimate these values, a year of daily predicted tidal data values were downloaded for each of the three reference stations. These values were assessed to determine the range and average duration for the tidal period (high to high or low to low), ebb tide (high to low) and flood tide (low to high). The results of this assessment are shown in Table 1.

Table 1
REFERENCE STATION TIDE CYCLE DURATIONS

	Miami Harbor Entrance			Vaca Key			Key West		
	Min	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**
Ebb Tide (hrs)	5.4	6.5	6.2	0.8	12.3	4.7	3.2	7.9	5.8
Flood Tide (hrs)	5.8	6.9	6.2	2.3	19.1	8.7	5.8	7.4	6.7
Tidal Period (hrs)	11.9	13.1	12.4	3.4	27.7	13.3	10.2	15.3	12.4

2.4 Water Quality Database

The data used to compile the ambient nearshore water quality were provided by the Southeast Environmental Research Center - Florida International University (SERC-FIU) Water Quality Monitoring Network (WQMN) which is supported by SFWMD/SERC Cooperative Agreements #C-10244 and #C-13178 as well as EPA Agreement #X994621-94-0. The monitoring program is administered by Dr. Ron Jones and Dr. Joe Boyer of the Southeastern Research Center at Florida International University. These time series data have been collected since 1995 at stations distributed throughout the Florida Keys and Florida Bay. Additional information regarding these data can be found at http://www.serc.fiu.edu.

This data is stored in two tables in the Access database. An index of monitoring stations is stored in the [FKNMS Stations] table. The individual water quality records are stored in the [TN_TP Data] table.

3 GEODATABASE DEVELOPMENT

This section describes the development of the GIS datasets used to support the MS Access database and MS Excel spreadsheets for simulation of the tidal flow and pollutant concentrations due to stormwater and wastewater discharges driven by tidal exchange.

3.1 Model Boundary and Cell Definition

Nearshore WBID boundaries were adopted as the internal model boundary. In general, these boundary lines were approximately 100 meters offshore from the shoreline. The water area/volume

between the shoreline and the WBID boundary make up the initial model cell (Cell 0), which is the receiving cell for land based discharges of stormwater and wastewater.

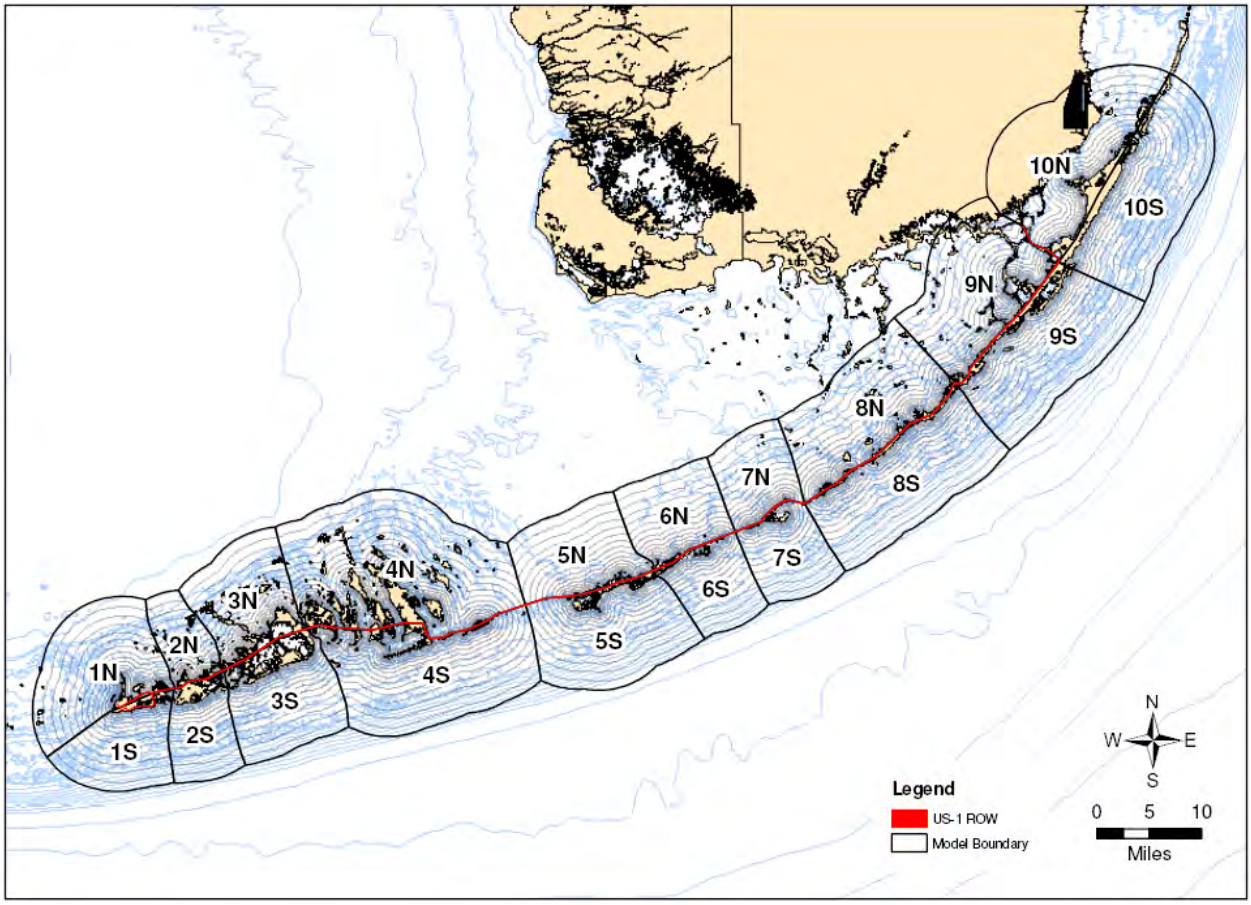
Model cells were developed by offsets of the nearshore WBID lines. The first model cell was defined using a 100 meter offset, which each subsequent cell defined by increasing the offset an additional 100 meters. A total of fifteen (15) offsets were made, creating sixteen (16) model cells, including Cell 0. Each model cell was identified by its offset number, from 0 to 15. Table 2 lists the model cells, widths and distance from the original WBID line to their outer boundary.

Table 2
WTFM CELL DEFINITIONS

Model Cell	Cell Width (meters)	Outer Distance from WBID (meters)
0	100	0
1	100	100
2	200	300
3	300	600
4	400	1,000
5	500	1,500
6	600	2,100
7	700	2,800
8	800	3,600
9	900	4,500
10	1,000	5,500
11	1,100	6,600
12	1,200	7,800
13	1,300	9,100
14	1,400	10,500
15	1,500	12,000

The resulting model cell coverage was then divided into 10 models (1 through 10) from Key West to Ocean Reef Club, with each model further divided into a north and south zone using US-1 as the division between them. Model Zones were identified by both their model number and their north/south zone, i.e. 10N. Each Model Zone is independent of the others and no cross-zone influences are considered in the WTFM algorithms. Figure 2 shows the resulting model boundaries, zones and cells.

Figure 2
WTFM DOMAIN



3.2 Model Bathymetry/Volume Data

Model bathymetry was created through the development of an elevation model based on the bathymetry line file GIS coverage from FGDL (http://www.geoplan.ufl.edu). Overlaying the model cell and land coverages allowed the cell water surface area and water volumes to be computed for each model cell. A detailed explanation of the GIS process used in the development of the bathymetry and volume coverages is included in Appendix C. Table 3 shows a summary of the model zone water surface areas and volumes. Detailed data for each model cell is also included in Appendix C. This information is stored in the Access database as a table [M_CELL].

Table 3
SUMMARY OF MODEL ZONE AREAS/VOLUMES

Model	Zone	Water Volume (ac-ft)	Water Area (acres)
1	N	829,000	75,878

	S	2,334,731	46,087
2	N	142,834	21,323
	S	2,153,787	32,232
3	N	432,667	46,915
	S	2,145,265	53,693
4	N	682,970	121,007
	S	6,175,346	107,100
5	N	346,577	56,472
	S	7,861,141	79,305
6	N	278,760	47,391
	S	2,570,590	38,320
7	N	200,828	38,443
	S	3,102,693	39,869
8	N	396,035	83,284
	S	9,100,418	94,022
9	N	251,701	74,086
	S	5,087,594	89,047
10	N	240,704	52,337
	S	2,886,521	94,048

3.3 Model Boundary WQ Data

The SERC-FIU data included location information for the monitoring stations and these were used to develop a point coverage of the stations to spatially distribute the water quality data. For many of the surveys (monitoring events) both a surface value and a bottom value were collected and an arithmetic average was computed to represent the event values at each station. Also, since water quality data are generally log-normal distributions, a geometric mean was used to compute the average water quality value for total nitrogen (TN) and total phosphorous (TP) at each monitoring station over a specific time period. A geometric mean was computed for each monitoring station over three different periods:

- June 2000 and earlier
- After June 2000
- Entire period of record (Mar-95 to Sep-06)

The June 2000 date was selected to coincide with the implementation of deep well disposal at the Key West wastewater treatment facility.
The geometric mean values for each of the TN and TP data sets were kriged to produce a GIS grid, or spatial surface, for both parameters throughout the monitoring network. Kriging is a method of interpolation that uses known values and a measure of the degree of spatial dependence between these known values to determine unknown values. Kriging weights the closest measured values with the most influence to predict values between measurements.

Kriging accounts for the spatial arrangement of the input data and results in an interpolated surface GIS coverage. This allowed the best use of the available nearshore water quality data and its spatial variations for input into the outer model boundaries during flood tides. ArcGIS Spatial Analyst was used to krige the water quality measurements from the SERC-FIU point data. The resulting grids, or spatial surfaces, represent the predicted values between those measured points. The kriged surfaces were used to develop concentration estimates for total phosphorous (TP) and total nitrogen (TN) in each cell of each Model Zone. This information is included in the [Cell_zone_vol_mass] table in the Access database. The initial concentrations of the outermost cell (Cell 15) of each Model Zone were used as boundary conditions in the WTFM. Table 4 lists these values for each of the three time periods. Details regarding the kriging process are included in Appendix C.

Table 4
MODEL ZONE BOUNDARY CONDITIONS
(Cell 15)

Model	Zone	Pre June 2000		Post June 2000		All Data	
		Avg TN (µg/l)	Avg TP (µg/l)	Avg TN (µg/l)	Avg TP (µg/l)	Avg TN (µg/l)	Avg TP (µg/l)
1	N	168	9	223	9	198	9
	S	130	6	199	6	168	6
2	N	194	10	219	10	205	10
	S	123	5	181	7	153	6
3	N	204	10	212	11	202	11
	S	127	6	179	6	147	6
4	N	210	9	219	10	214	10
	S	131	5	177	7	152	6
5	N	215	8	214	8	215	8
	S	125	6	170	7	151	6
6	N	238	8	222	9	225	8
	S	125	5	171	7	143	6
7	N	389	11	297	9	344	10
	S	115	5	174	6	139	6
8	N	754	9	438	8	599	9
	S	114	6	179	6	144	6
9	N	729	8	470	8	591	8
	S	112	5	169	7	141	6
10	N	321	6	216	6	308	6
	S	116	6	152	6	138	6

3.4 Wastewater Data

Wastewater inputs were developed using the equivalent dwelling unit (EDU) coverage from the FKCCS which was based on a parcel coverage. That coverage included data related to the number of EDUs and type of wastewater treatment for each parcel within the Keys. Table 5 lists the various

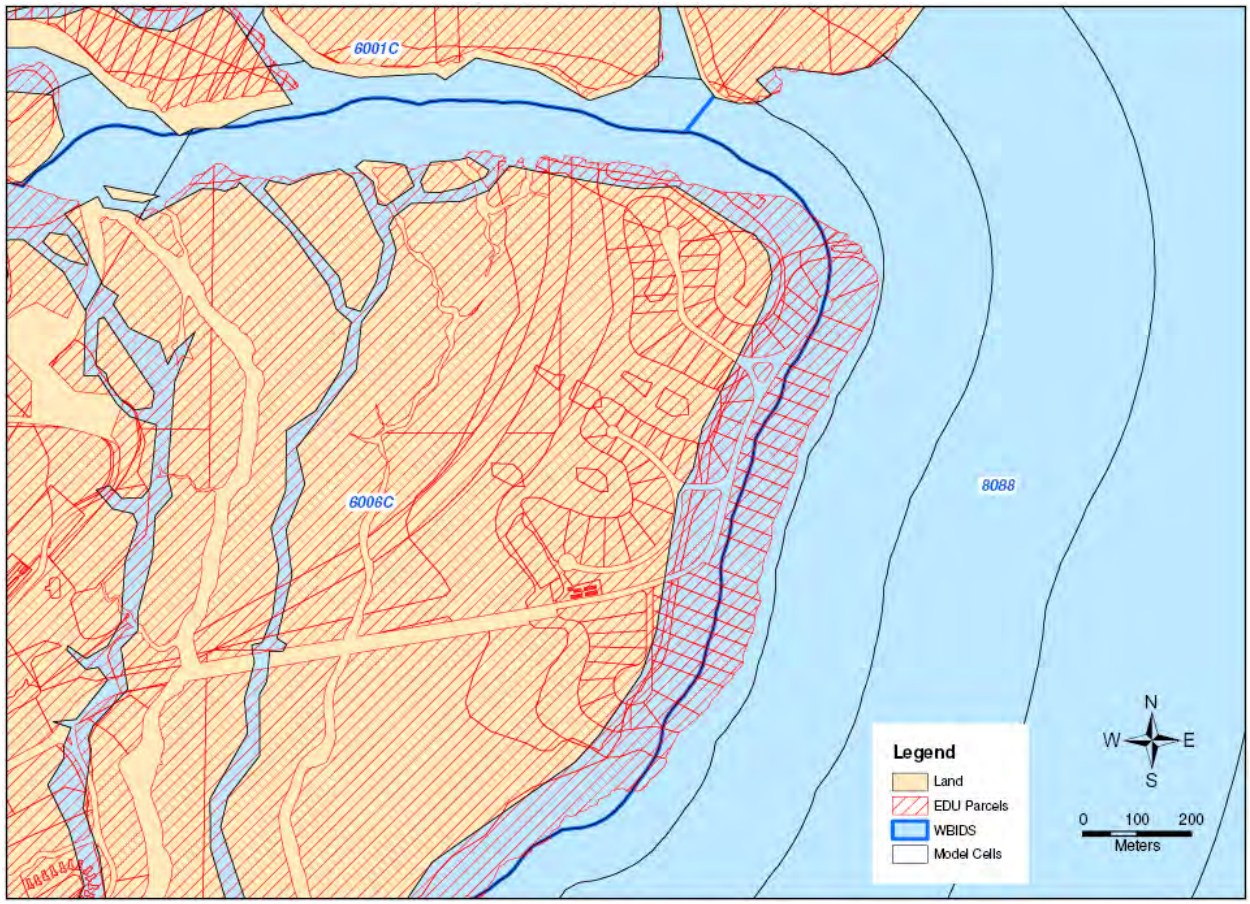
types of wastewater treatment types and their associated effluent quality found within the FKCCS EDU/parcel coverage, including additional types used to represent proposed wastewater facilities. The FLOW field was used to eliminate volumes from contributing to loads for deep well facilities. This information is stored in the Access database as a table [WWT_EFFLUENT].

Table 5
FKCCS WASTEWATER TREATMENT DATA

WWT	WWT_METHOD	FLOW	TN (mg/l)	TP (mg/l)
<blank>	assumed cesspool	1	30	6
ATU	ATU/Drainfield	1	20	6
AWT DEEP	AWT	0	3	1
AWT SHALLOW	AWT	1	3	1
BAT	BAT	1	10	1
CESSPOOL	Cesspool	1	30	6
FDEP ADVSEC	Advance Secondary	1	10	6
FDEP SECOND	Secondary Treatment	1	20	6
IQ/PART II	IQ Part II	1	10	6
IQ/PART III	IQ Part III	1	10	6
NO STRUCTURE	assumed cesspool	1	30	6
not a parcel	assumed cesspool	1	30	6
OWNRS	Onsite OWNRS	1	5	1
SEPTIC TANK	Septic Tank/Drainfield	1	20	6
SUB-STD SEPTIC	Substandard Septic	1	20	6

The initial coverage used in the FKCCS was not correctly projected and resulted in substantial projection errors which increased to the north and east (i.e. not noticeable at Key West, but substantial in Key Largo). As a result, some corrections were necessary to correctly place the subsequent loads from the EDU polygons within the proper Model Zone. Figure 3 shows an example of the parcel registration errors near Ocean Reef Club.

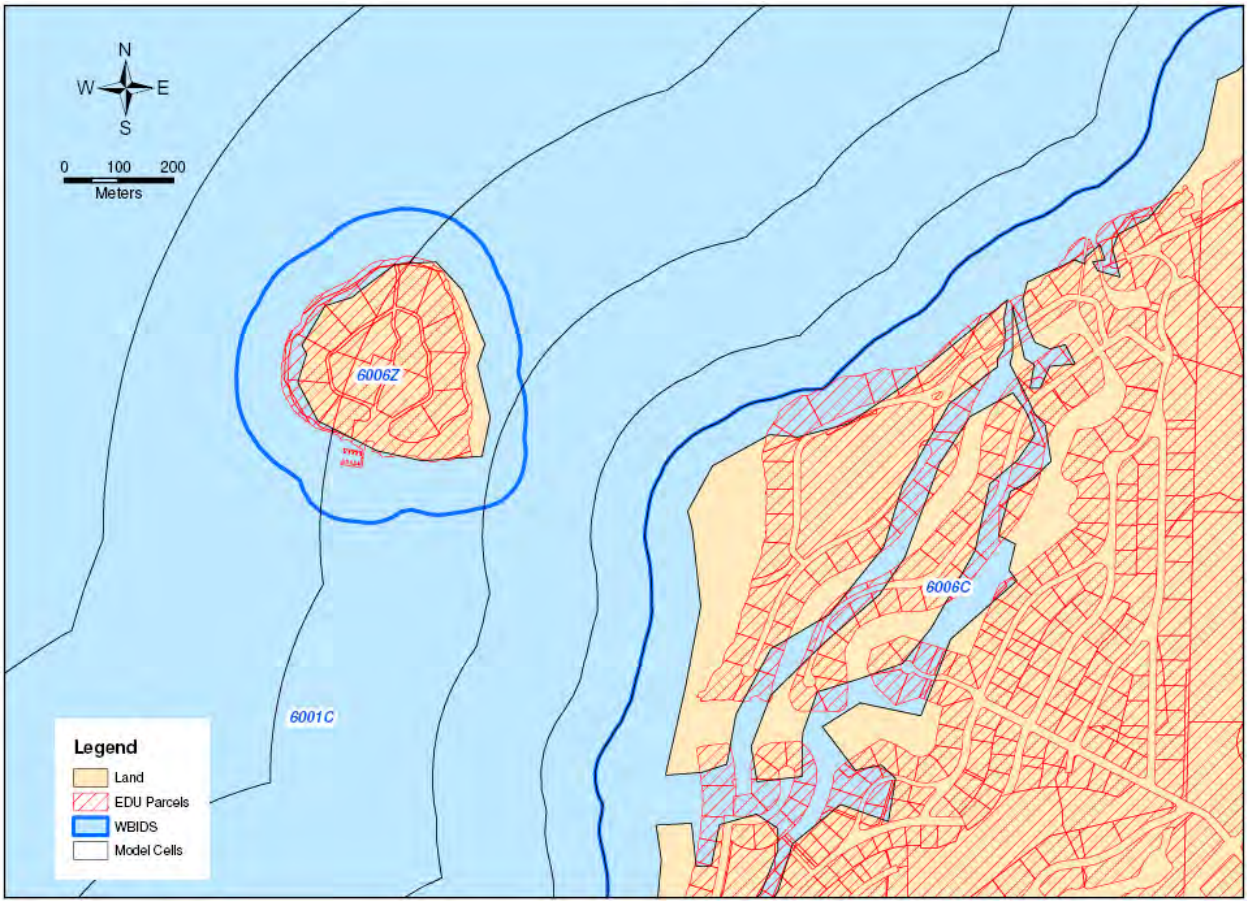
Figure 3
PARCEL REGISTRATION EXAMPLE



To ensure that the entire wastewater load generated by a parcel was correctly placed within each Model Zone, the EDU parcels were intersected with the model cell coverage in GIS. All EDUs were then associated with the Model Zone and assumed to originate from within Cell 0 of that Model Zone, regardless of what cell they actually occupied. As a result, parcel registration errors were insignificant and any wastewater loads from offshore islands were attributed to the land mass within Cell 0 of that Model Zone. Also, wastewater loads from inhabited near-shore islands were associated with the nearby modeled WBID, as the example in Figure 4 shows that the EDUs within WBID 6006Z were placed within Cell 0 of the Model Zone for WBID 6006C.

The EDU parcel data for the entire WTFM domain is included in the Access database as a table [EDU].

Figure 4
OFFSHORE EDU EXAMPLE



3.5 Wastewater Service Areas

Wastewater service areas (WWSA) were used to represent the service area of wastewater treatment plants. These were implemented into the WTFM through the development of polygons in GIS so that the wastewater treatment type (WWT) of each parcel could be readily updated and modified by associating them with specific treatment plants or processes. The inventory of WWSA is stored in the Access database as a table [WWSA].

3.5.1 Key Largo Wastewater Service Areas

Wastewater Service Areas were developed within the GIS system so that the WTFM could account for both current and future wastewater treatment facilities and changes in treatment types and disposal methods. Key Largo Wastewater Service Areas (WWSA) were developed from a CADD file provided by the Key Largo Wastewater Treatment District (KLWTD). The information was imported and projected into ArcGIS to form a GIS WWSA coverage.

Figure 5
KEY LARGO WASTEWATER SERVICE AREAS

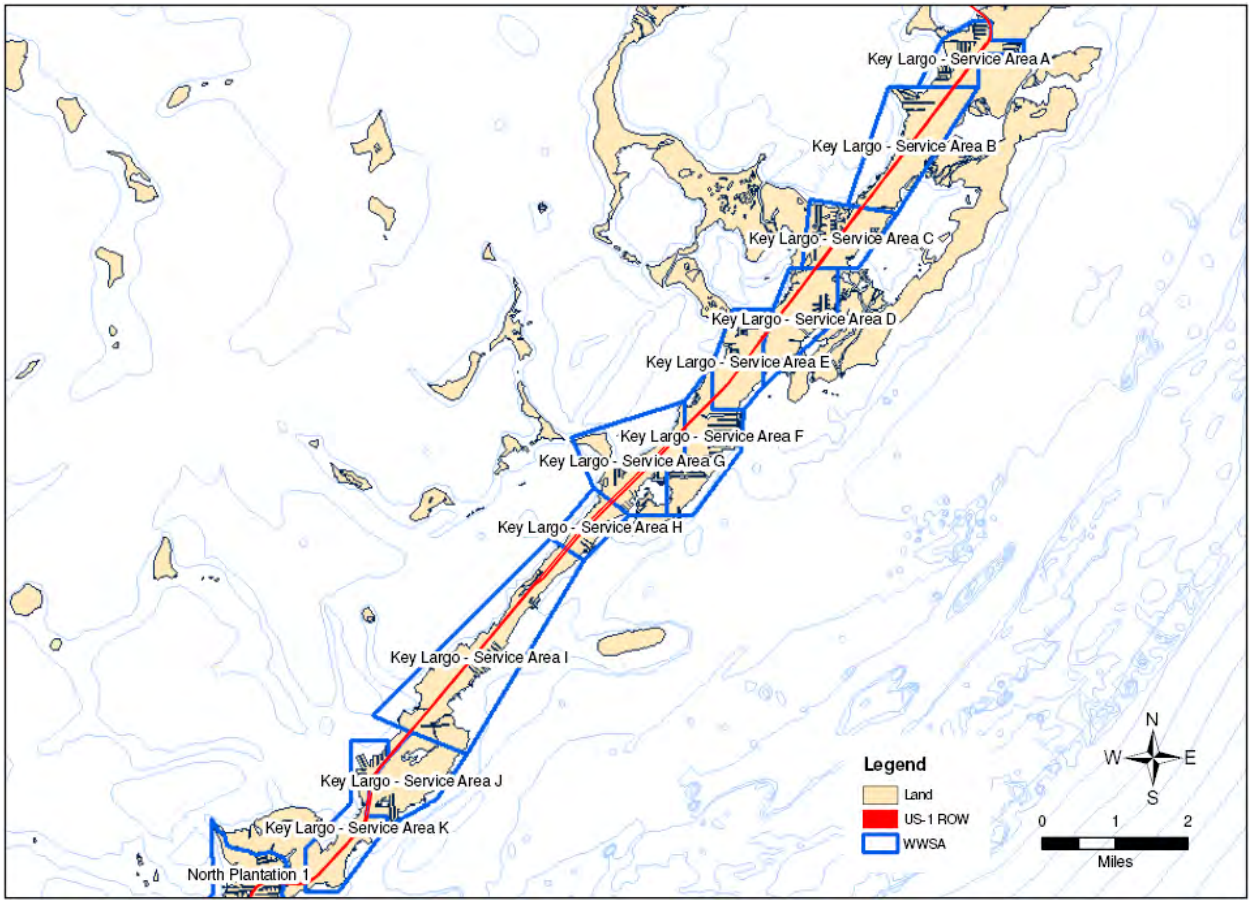


Table 6
KEY LARGO WWSA TABLE

WWSA	2007 WWTT	2010 WWTT	EDUs	AREA (ac)
Key Largo - SA-A		AWT DEEP	1,330.8	135.62
Key Largo - SA-B		AWT DEEP	1,999.8	300.48
Key Largo - SA-C		AWT DEEP	1,206.6	156.85
Key Largo - SA-D		AWT DEEP	2,549.7	195.17
Key Largo - SA-E	AWT SHALLOW	AWT SHALLOW	998.7	114.12
Key Largo - SA-F		AWT DEEP	1,111.3	195.85
Key Largo - SA-G		AWT DEEP	1,625.0	168.02
Key Largo - SA-H		AWT DEEP	736.9	70.86
Key Largo - SA-I		AWT DEEP	1,910.0	218.30
Key Largo - SA-J		AWT DEEP	893.3	105.49
Key Largo - SA-K		AWT DEEP	1,079.7	156.38
Ocean Reef Club		AWT SHALLOW	2,789.0	643.31

3.5.2 Islamorada Wastewater Service Areas

Wastewater Service Areas in Islamorada were developed from generalized descriptions provided by _____. This information was used to develop polygons in ArcGIS and added to the WWSA coverage.

Figure 6
ISLAMORADA WASTEWATER SERVICE AREAS

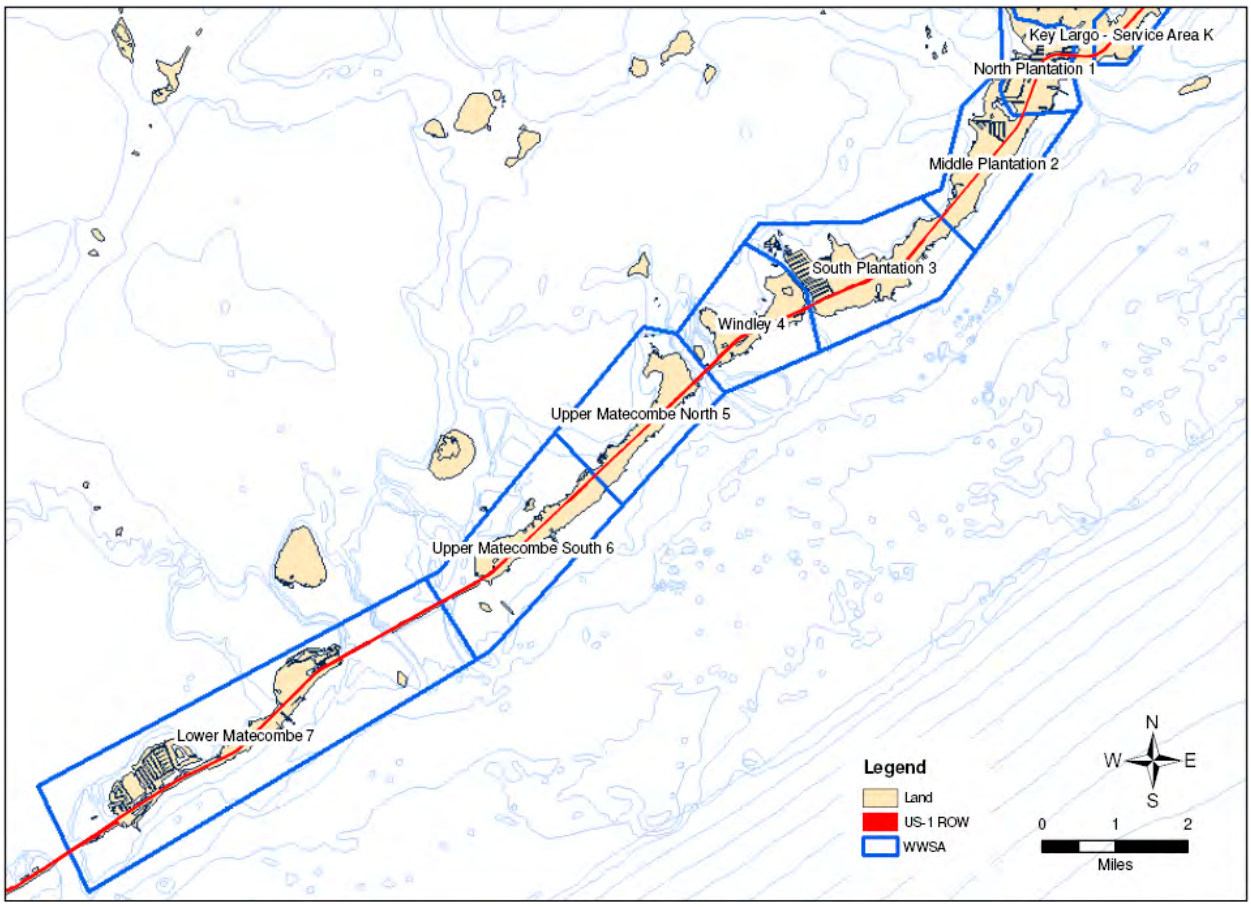


Table 7
ISLAMORADA WWSA TABLE

WWSA	2007 WWTT	2010 WWTT	EDUs	AREA (ac)
North Plantation 1		AWT SHALLOW	2,789.0	643.31
Middle Plantation 2		AWT SHALLOW	1,612.4	201.30
South Plantation 3		AWT SHALLOW	1,476.5	253.86
Windley 4		AWT SHALLOW	1,325.0	225.66
Upper Matecombe North 5		AWT SHALLOW	1,088.0	102.81

Table 7
ISLAMORADA WWSA TABLE

WWSA	2007 WWTT	2010 WWTT	EDUs	AREA (ac)
Upper Matecombe South 6		AWT SHALLOW	1,506.3	343.15
Lower Matecombe 7		AWT SHALLOW	1,289.1	201.13

3.5.3 Long Key Wastewater Service Areas

WWSAs for Long Key were created by attributing all EDU polygons within the City of Layton municipal limits or Long Key State Park to create a LAYTON WWSA. Polygons east of this service area were assumed to be in the Long Key East (KOA) WWSA, while those to the west were assumed to be in the Long Key West WWSA.

Figure 7
LONG KEY WASTEWATER SERVICE AREAS

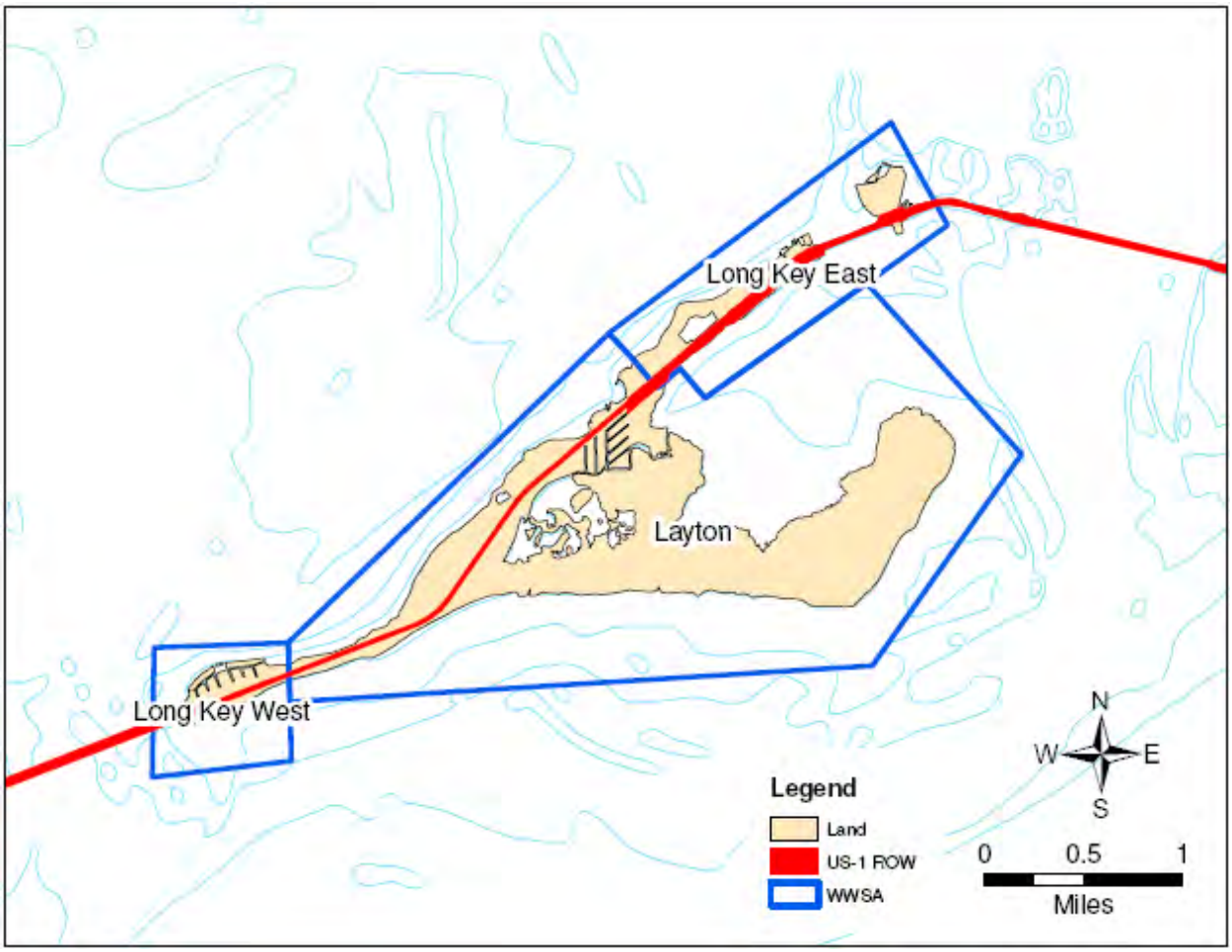


Table 8
LONG KEY WWSA TABLE

WWSA	2007 WWTT	2010 WWTT	EDUs	AREA (ac)
Long Key East (KOA)		BAT	322.0	31.63
Layton	AWT SHALLOW	AWT SHALLOW	204.3	213.04
Long Key West		BAT	394.7	26.73

3.5.4 Marathon Wastewater Service Areas

Wastewater Service Areas in Marathon were developed from generalized descriptions provided by _____. This information was used to develop polygons in ArcGIS and added to the WWSA coverage.

Figure 8
MARATHON WASTEWATER SERVICE AREAS

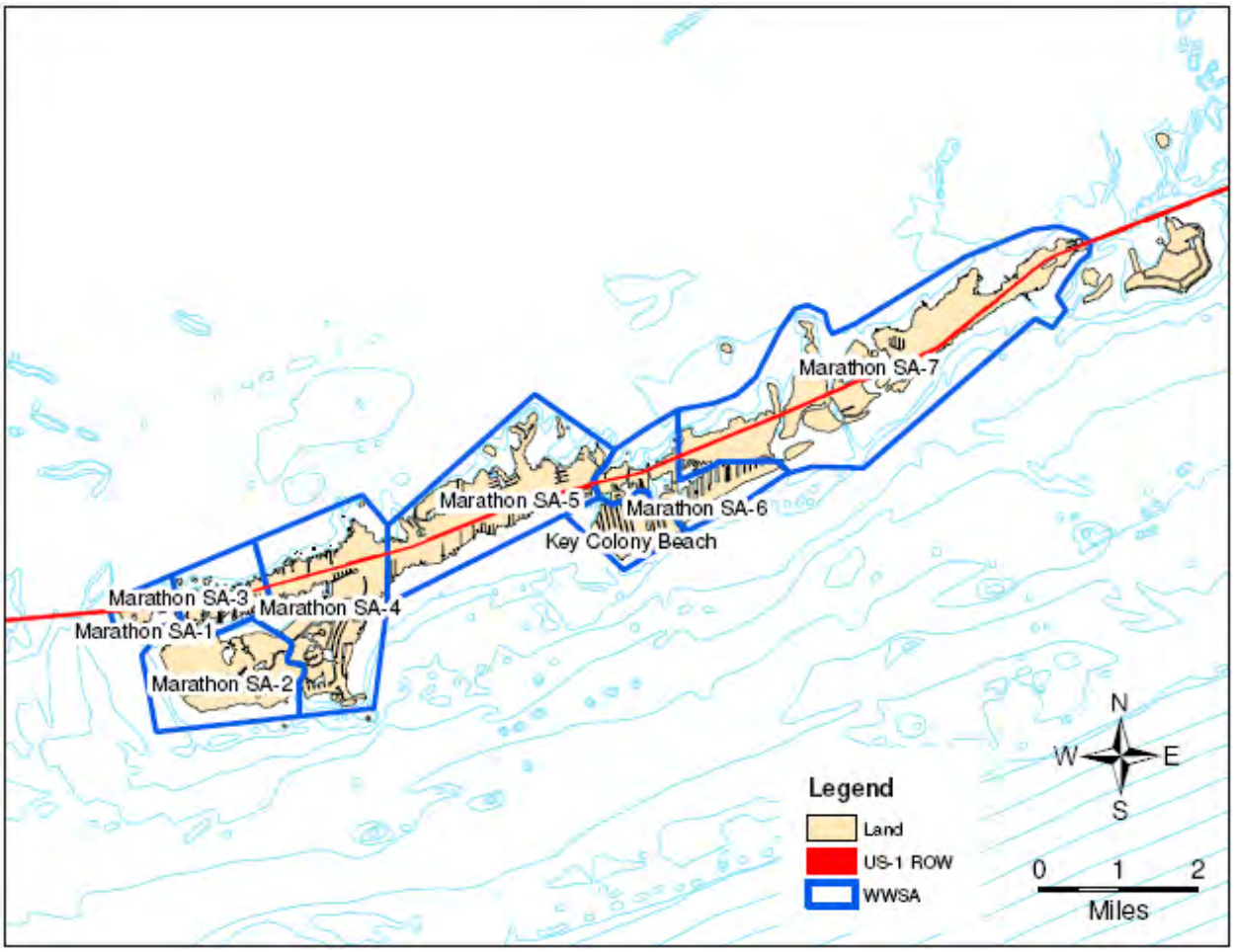


Table 9
MARATHON WWSA TABLE

WWSA	2007 WWTT	2010 WWTT	EDUs	AREA (ac)
Key Colony Beach	BAT	AWT SHALLOW	925.0	104.99
Marathon SA-1		BAT	311.8	37.84
Marathon SA-2		BAT	33.0	9.58
Marathon SA-3		AWT SHALLOW	1,565.0	190.78
Marathon SA-4		AWT SHALLOW	2,282.7	395.88
Marathon SA-5		AWT SHALLOW	2,668.5	500.52
Marathon SA-6		AWT SHALLOW	1,028.0	126.28
Marathon SA-7		BAT	1,597.0	274.49

3.5.5 Key West Wastewater Service Areas

Wastewater Service Areas in Key West were developed from generalized descriptions provided by _____. This information was used to develop polygons in ArcGIS and added to the WWSA coverage.

Figure 9
KEY WEST WASTEWATER SERVICE AREAS

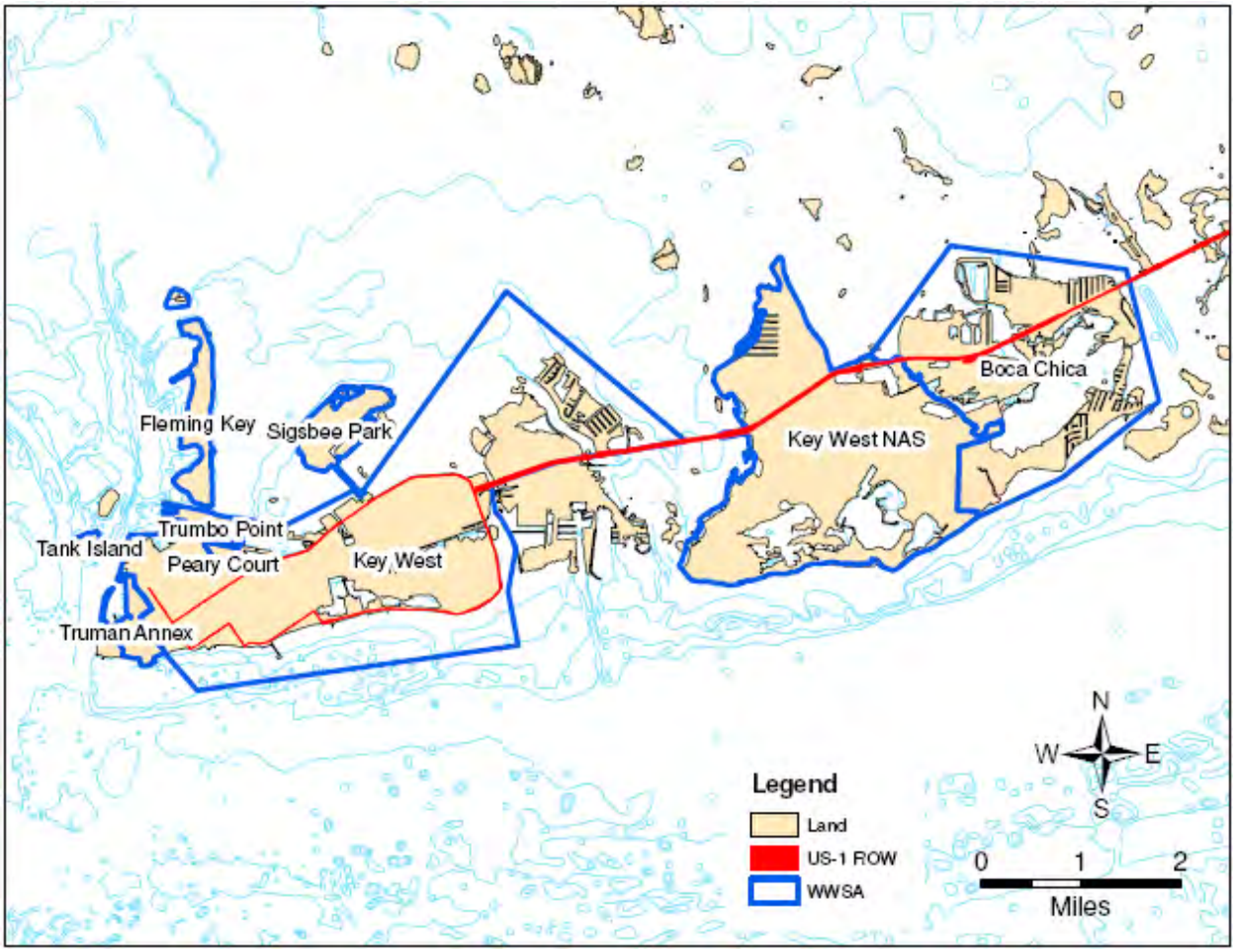


Table 10
KEY WEST WWSA TABLE

WWSA	2007 WWTT	2010 WWTT	EDUs	AREA (ac)
Fleming Key	AWT DEEP	AWT DEEP	1,144.0	68.79
Key West	AWT DEEP	AWT DEEP	3.0	274.65
Key West NAS		AWT SHALLOW	22,226.0	2,025.74
Peary Court	AWT DEEP	AWT DEEP	108.0	24.65
Sigsbee Park	AWT DEEP	AWT DEEP	0.0	0.00
Tank Island	AWT DEEP	AWT DEEP	27.0	2.62
Truman Annex	AWT DEEP	AWT DEEP	312.0	133.71
Trumbo Point	AWT DEEP	AWT DEEP	215.0	86.77

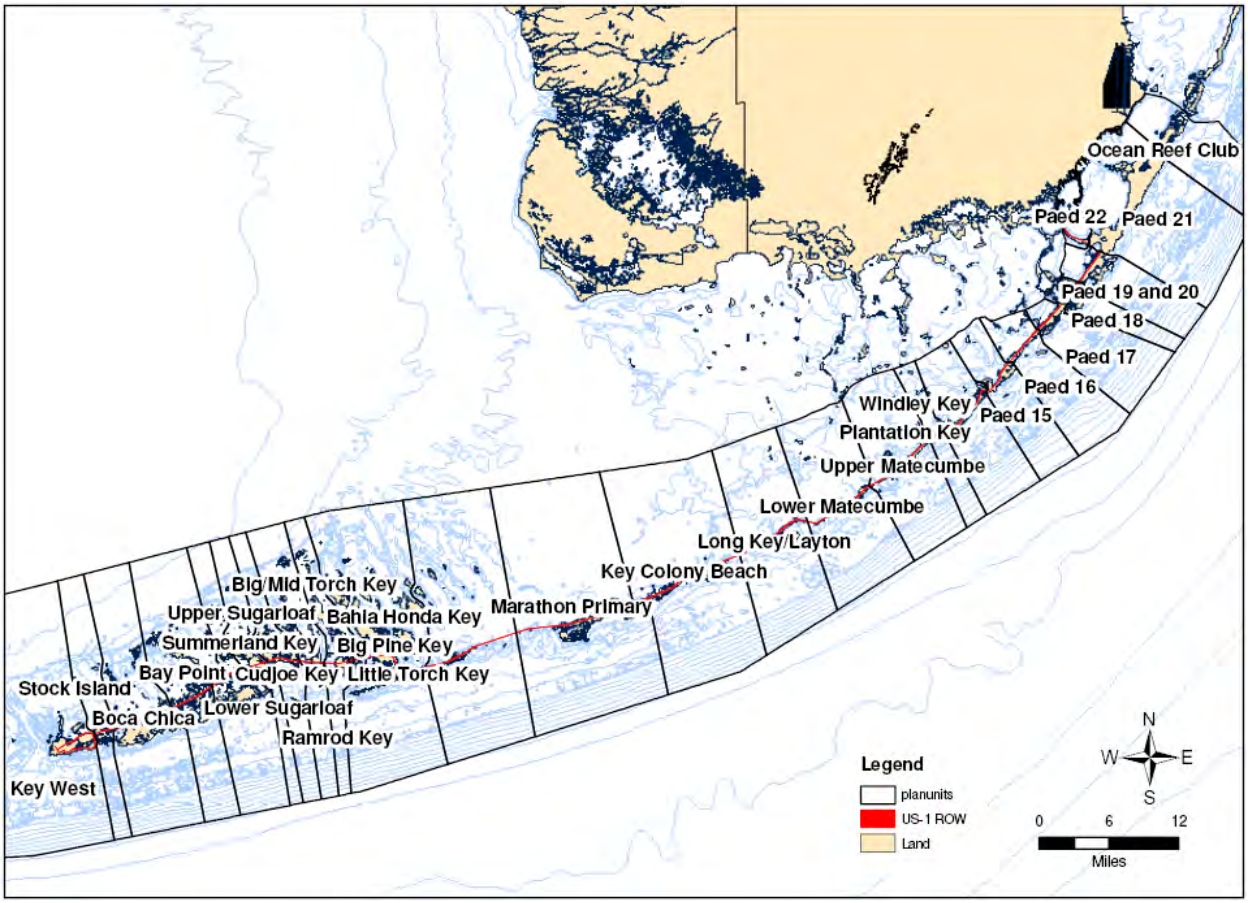
3.6 Wastewater Volumes

Wastewater volumes were developed using data from the FKCCS. That study divided the Keys into 28 planning units and defined a water use value related to the number of EDUs on a parcel. These values varied somewhat through the Keys and were adopted in the WTFM as the wastewater flow volume, which was assigned to each EDU polygon based on the study area in which it fell. Table 11 lists the flow assigned to each planning unit in gallons per day per EDU. Figure 10 shows the general location of the planning units. This information is stored in the Access database as a table [GPD_EDU].

Table 11
WASTEWATER FLOWS

Planning Unit	GPD per EDU	Planning Unit	GPD per EDU
Key West	132	Marathon Secondary	172
Stock Island	168	Long Key/Layton	116
Boca Chica	149	Lower Matecumbe	151
Bay Point	119	Upper Matecumbe	167
Lower Sugarloaf	181	Windley Key	150
Upper Sugarloaf	156	Plantation Key	158
Cudjoe Key	110	Tavernier, PAED 15	125
Summerland Key	149	Rock Harbor, PAED 16	115
Big Torch/Middle Torch Key	200	PAED 17	155
Ramrod Key	146	PAED 18	134
Little Torch Key	135	PAED 19 & 20	143
Big Pine Key	132	PAED 22	160
Bahia Honda/Ohio Key	160	PAED 21	160
Marathon Primary	160	Ocean Reef Club	112

Figure 10
WASTEWATER FLOW PLANNING UNITS



3.7 Land Use Data

At the time the FKCCS was conducted, the only consistent set of land use data available were the Department of Revenue (DOR) codes from the EDU/parcel database. Since that time GIS coverages using the Florida Land Use and Cover Classification System (FLUCCS) have been developed and were adopted for use in the WTFM. This classification system is used throughout Florida for mapping both land use and cover in a single map layer. FLUCCS was developed by the Florida Department of Transportation (FDOT). It provides a broad range of potential classes in a four level hierarchical structure. The FLUCCS coverage is correctly projected and allows the projection errors found in the EDU/Parcel coverage to be avoided.

Unlike the EDU/Parcel data used to develop wastewater loads, only land coverage that fell within Cell 0 of each Model Zone was considered as a contributing source of stormwater loads. This assumption was made to readily assess only the land area within the Model Zones and to exclude the large areas in Model Zones 9N and 10N that lie outside of the Keys. The minor amount of potential stormwater runoff from the small islands outside of Cell 0 are not expected to be a significant source of nitrogen or phosphorous.

The FLUCCS coverage data has two fields which are used to characterize the land: the land use code (LUCODE) and the land cover code (LCCODE), both defined using Level IV FLUCCS codes. Land use (LUCODE) describes the activities, management, or cultural importance of a given area. The use may extend over most of the area and infer physical features (e.g. cemetery), or it may be based on an abstract property, such as ownership (e.g. institutional). Land cover (LCCODE) describes the features, predominantly vegetation, which exists over most of the unit of area delineated at the time of interpretation. These features are in most cases natural vegetation or lithographic features, but may also be established and maintained artificially, as in the case of pasture lands, pine plantations, or lagoons.

Generally the LUCODE and the LCCODE have the same value, but in some cases are different. This is because land cover and use have an either/or relationship – for each area there is either something growing (cover), or some activity (use). Or, the cover (i.e. pine plantation) is sufficient to describe the use; or vice versa, the use (i.e. residential) is sufficient to describe the cover. For these reasons, FLUCCS defines cover and use with one set of polygons and only one attribute. For each polygon the attribute table has two items or fields – LCCODE for land cover emphasis, and LUCODE for land use emphasis. A problem arises when both land cover and use are present in one location, and one cannot be inferred from the other.

The data set developed for the WTFM created a new field (LULC) which was populated by dividing the LCCODE by 1,000 and adding it to the LUCODE. A summary table of all resulting LULC polygons was prepared and an index table developed which associated each unique LULC with a land use type for modeling purposes (MODEL_LU) and secondary land use type to characterize that land use under pre-developed, or natural conditions (NAT_LU). This information is stored in the Access database as a table [FLUCCS]. A second table [LU] contains the data from the individual FLUCCS polygons for the entire WTFM domain. During the development of the index table, a few FLUCCS codes were identified which were not expected to result in stormwater discharges and were excluded from the WTFM. These are summarized in Table 12.

Table 12
FLUCCS AREAS EXCLUDED FROM WTFM

LULC	Description	Acres
5110	Natural River, Stream, Waterway	71.93
5120	Channelized Waterways, Canals	1,373.92
5410	Embayments Opening Directly to Gulf or Ocean	22,677.72
5420	Embayments Not Opening Directly to Gulf or Ocean	2,096.47
5710	Atlantic Ocean	21,834.65
5720	Gulf of Mexico	459.32
6510	Tidal Flats	3,540.50

A summary of the FLUCCS codes and their associated model land use is shown in Table 13.

Table 13
SUMMARY OF FLUCCS

LULC	Description	Model Land Use	Natural Land Use	Acres
1110	Low Density: Fixed Single Family Units	LDR	VAC	821.66
1120	Low Density: Mobile Home Units	LDR	VAC	61.55
1130	Low Density: Mixed Units, Fixed and Mobile Home Units	LDR	VAC	3.92
1180.31	Rural Residential [Herbaceous (Dry Prairie)]	LDR	VAC	40.51
1180.32	Rural Residential [Upland Shrub and Brush land]	LDR	VAC	39.32
1180.322	Rural Residential [Coastal Scrub]	LDR	VAC	13.05
1180.33	Rural Residential [Mixed Rangeland]	LDR	VAC	17.41
1180.42	Rural Residential [Upland Hardwood Forest]	LDR	VAC	7.48
1210	Medium Density: Fixed Single Family Units	MDR	VAC	6,095.56
1220	Medium Density: Mobile Home Units	MDR	VAC	12.97
1230	Medium Density: Mixed Units, Fixed and Mobile Home Unit	MDR	VAC	0.93
1290	Medium Density: Under construction	MDR	VAC	51.63
1310	High Density: Fixed Single Family Units	HDR	VAC	1,739.18
1320	High Density: Mobile Home Units	HDR	VAC	1,161.53
1330	Multiple Dwelling Units, Low Rise	HDR	VAC	546.07
1340	Multiple Dwelling Units, High Rise	HDR	VAC	272.24
1350	High Density: Mixed Units, Fixed and Mobile Home Units	HDR	VAC	201.80
1390	High Density: Under construction	HDR	VAC	22.99
1400	Commercial and Services	COM	VAC	2,343.84
1411	Shopping Centers	COM	VAC	153.61
1423	Wholesale Sales & Services - Junk Yards	COM	VAC	6.74
1480	Cemeteries	REC	VAC	26.62
1500	Industrial	IND	VAC	9.18
1550	Other light industry	IND	VAC	39.17
1560	Other heavy industrial	IND	VAC	28.15
1600	Extractive	IND	VAC	117.55
1660	Holding ponds	WTR	WTR	37.65
1700	Institutional	INS	VAC	203.12
1710	Educational Facilities	INS	VAC	222.24
1730	Military	LDR	VAC	1,180.66
1730.612	Military [Mangrove swamp]	WTR	WTR	371.23
1800	Recreational	REC	VAC	11.42
1810	Swimming beach	REC	VAC	158.95
1820	Golf course	AGR	VAC	596.13
1840	Marinas and fish camps	MDR	VAC	186.26
1850	Parks and zoos	INS	VAC	237.14
1900.31	Open Land [Herbaceous (Dry Prairie)]	VAC	VAC	128.66
1900.32	Open Land [Upland Shrub and Brush land]	VAC	VAC	111.99
1900.33	Open Land [Mixed Rangeland]	VAC	VAC	30.67
1900.411	Open Land [Pine Flatwoods]	VAC	VAC	14.98
1900.434	Open Land [Hardwood/Conifererous Mixed]	VAC	VAC	22.39
1900.74	Open Land [Disturbed land]	VAC	VAC	70.96
1920.31	Inactive land with street pattern [Herbaceous (Dry Prairie)]	LDR	VAC	36.01
1920.32	Inactive land with street pattern [Upland Shrub and Brush land]	LDR	VAC	449.20
1920.33	Inactive land with street pattern [Mixed Rangeland]	LDR	VAC	60.76
1920.411	Inactive land with street pattern [Pine Flatwoods]	LDR	VAC	550.40

Table 13
SUMMARY OF FLUCCS

LULC	Description	Model Land Use	Natural Land Use	Acres
1920.42	Inactive land with street pattern [Upland Hardwood Forest]	LDR	VAC	15.64
1920.434	Inactive land with street pattern [Hardwood/Conifererous Mixed]	LDR	VAC	21.06
2540	Aquaculture	WTR	WTR	5.49
3100	Herbaceous (Dry Prairie)	VAC	VAC	43.63
3200	Upland Shrub and Brush land	VAC	VAC	1,113.33
3220	Coastal Scrub	VAC	VAC	1,174.16
3300	Mixed Rangeland	VAC	VAC	60.23
4100	Upland Coniferous Forests	VAC	VAC	36.69
4110	Pine Flatwoods	VAC	VAC	1,270.02
4200	Upland Hardwood Forest	VAC	VAC	5,158.48
4340	Hardwood/Conifererous Mixed	VAC	VAC	80.85
4370	Australian Pine	VAC	VAC	116.70
5200	Lakes	WTR	WTR	269.70
5300	Reservoirs	WTR	WTR	428.20
6120	Mangrove swamp	WTR	WTR	26,444.11
6172	Mixed Shrubs	VAC	VAC	26.13
6420	Saltwater Marshes/Halophytic Herbaceous	WTR	WTR	6,094.52
6440	Emergent aquatic vegetation	WTR	WTR	44.99
6500	Non-vegetated Wetland	WTR	WTR	4.75
7200	Sand other than beaches	VAC	VAC	62.29
7300	Exposed Rock	VAC	VAC	15.13
7400	Disturbed land	REC	VAC	211.75
7430	Spoil areas	REC	VAC	97.49
8100	Transportation	HWY	VAC	6.69
8110	Airports	HWY	VAC	1,141.10
8113	Private airports	HWY	VAC	28.01
8115	Grass airports	IND	VAC	18.20
8140	Roads and highways	HWY	VAC	1,734.19
8200	Communications	IND	VAC	50.92
8300	Utilities	IND	VAC	13.80
8310	Electrical power facilities	IND	VAC	13.24
8330	Water supply plants - Including Pumping Stations	IND	VAC	15.78
8340	Sewage treatment	IND	VAC	25.72
8350	Solid waste disposal	IND	VAC	85.07
8350.836	Solid waste disposal [Other Treatment Ponds]	IND	VAC	1.82
			TOTALS:	**64,445.30**

3.8 Rainfall Data

Daily rainfall records for stations in the Florida Keys were downloaded from the South Florida Water Management District (SFWMD) and EarthInfo. These stations were spatially located in ArcGIS and each Model Zone associated with one of the rainfall stations. The period of record was evaluated for each station and an annual average rainfall computed. Rainfall days of less than 0.10-

inches were assumed to contribute no stormwater flow and the WTFM model excludes those rainfall volumes from the runoff calculations. A summary of the rainfall stations and the Model Zones associated with them are shown in Tables 14 and 15. This information is stored in two data tables in the Access database: [RS_TABLE] which includes the inventory of rainfall stations and [RS_Index] which indexes each Model to one of the rainfall stations.

Table 14
SUMMARY OF RAINFALL STATION DATA

Station ID	Station Name	Data Source	Years of Record	% of Wet Days with Rainfall < 0.10”	Average Annual Rainfall (inches)
RS-02	Key West	SFWMD	92	5.30%	38.90
RS-04	Marathon	SFWMD	24	1.88%	37.21
RS-06	Long Key	SFWMD	20	2.03%	41.73
RS-07	Lignumvitae	EarthInfo	35	1.81%	39.77
RS-09	Tavernier	SFWMD	63	1.66%	44.11
RS-10	TPTS	SFWMD	9	1.85%	46.60

Table 15
WTFM ZONE RAINFALL STATIONS

Model	Station ID	Station Name
1	RS-02	Key West
2	RS-02	Key West
3	RS-02	Key West
4	RS-04	Marathon
5	RS-04	Marathon
6	RS-04	Marathon
7	RS-06	Long Key
8	RS-07	Lignumvitae
9	RS-10	TPTS
10	RS-10	TPTS

3.9 Stormwater Load Data

Stormwater loads computed by the WTFM are dependent on rainfall, land cover and land use. The model uses land use categories with associated event mean concentrations (EMCs), depending on the constituents of concern, to simulate annual or seasonal pollutant loads carried in storm water runoff. The algorithms used by the WTFM were adopted from the Watershed Management Model originally developed by Camp Dresser and McKee (CDM). A final land use index table, relating the

model land use to runoff coefficients and EMC was developed from the Monroe County Stormwater Management Master Plan prepared by CDM. Table 16 shows the data taken from that study and adopted for the WTFM. This information is stored in the Access database as a table [EMC].

Table 16
WTFM LAND USE, RUNOFF COEFFICIENT AND EMC

Model Land Use	Description	DCIA	CI	CP	TP (mg/l)	TN (mg/l)
AGR	Agriculture, Golf Course	0.5%	0.95	0.10	0.34	2.32
COM	Commercial	90%	0.95	0.10	0.21	1.82
HDR	High Density Residential	50%	0.95	0.10	0.27	1.64
HWY	Roadways	90%	0.95	0.10	0.40	1.85
IND	Industrial	70%	0.95	0.10	0.28	1.87
INS	Public Facilities	70%	0.95	0.10	0.20	2.29
LDR	Low Density Residential	10%	0.95	0.10	0.35	1.97
MDR	Medium Density Residential	30%	0.95	0.10	0.30	2.01
REC	Urban Open	0.5%	0.95	0.10	0.13	1.58
VAC	Forest, Open, Park	0.5%	0.95	0.10	0.22	1.24
WTR	Waterbodies & Watercourses	25%	0.95	0.10	0.16	0.98

3.10 Stakeholder Development

A number of stakeholders are involved in the development of the FKRAD. It was important that the WTFM be able to properly recognize and attribute loads and reductions to the appropriate stakeholders. To do this, a stakeholder GIS coverage was developed to include the following stakeholders:

- Florida State Parks
- Incorporated Municipalities
- FDOT
- U.S. Navy

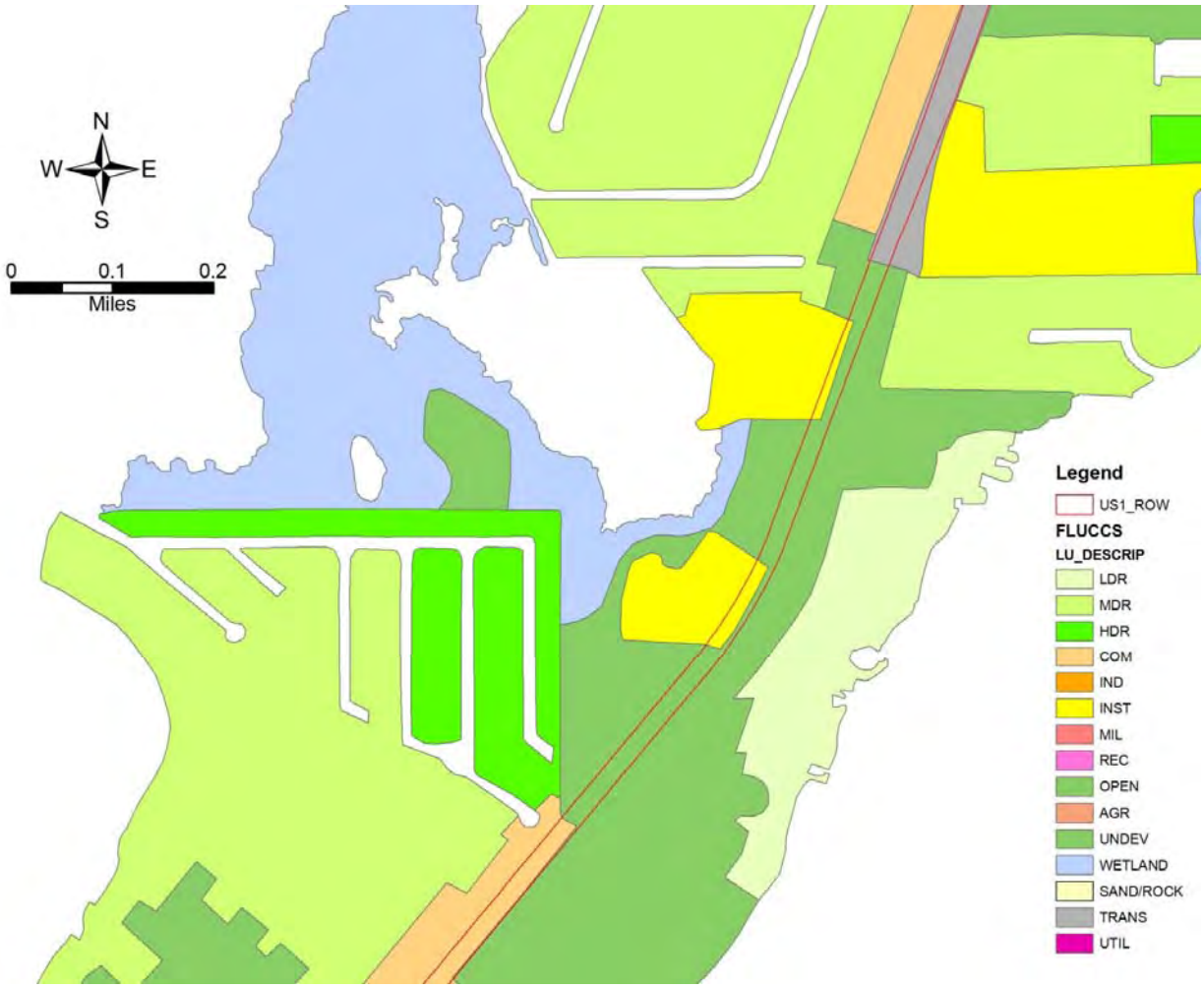
Areas within the WTFM domain that were not identified as falling within one of these stakeholder polygons were assumed to be in unincorporated Monroe County.

3.11 US-1 Corridor

Examination of the model land use codes, when projected and displayed in ArcGIS found some obvious inconsistencies in regards to the US-1 corridor through the Keys. As a stakeholder in the development of FKRAD, it was important to identify and include the contribution from FDOT. A US-1 corridor was developed from US-1 centerline and the open areas from parcel boundaries. Bridges were included using aerial photographs and digitizing their boundaries. Since the parcel boundaries have registration errors, as discussed previously, the parcel areas associated with US-1

were moved to the centerline to correct their location in regards to FLUCCS (land use) and the land use within the US1 corridor was modified to "HWY". Figure 11 illustrates an example of this process and the errors that were corrected in FLUCCS coding for US-1.

Figure 11
US-1 CORRIDOR EXAMPLE – FLUCCS ERRORS



The stakeholder coverage was overlaid on the land use coverage and each land use polygon attributed with a stakeholder. The stakeholder coverage was also overlaid on the EDU coverage and each EDU polygon attributed with a stakeholder. A summary of EDUs and land area for each stakeholder is provided in Table 17.

Table 17
SUMMARY OF STAKEHOLDER EDU/LAND AREA

Stakeholder	EDUs	Acres
FDOT	0.0	1,495.84
Islamorada	9,038.7	3,593.88
Key Colony Beach	859.6	262.65
Key West	21,666.5	2,596.89
Layton	130.7	88.39
Marathon	9,008.9	4,401.04
U.S. Navy	1,799.8	3,313.22
State Parks	1,138.6	7,850.64
Bahia Honda	*82.1*	*302.72*
Curry Hammock	*72.7*	*566.80*
Dagny Johnson	*94.8*	*2,493.96*
Fort Zachary Taylor	*7.5*	*38.31*
Indian Key	*15.5*	*5.03*
John Pennekamp	*784.70*	*3,360.43*
Lignumvitae	*9.80*	*306.02*
Long Key	*32.9*	*748.94*
Windley Key	*38.7*	*28.43*
Unincorporated County	34,150.9	40,683.02
TOTAL:	**77,793.8**	**64,285.58**

3.12 Canals

The residential canals that were previously modeled in the FKCCS project in 2002 were revised to incorporate the newer data and results from the WTFM. This included the following ten canals scattered throughout the Keys:

- 50 Key Largo
- 69 Rock Harbor
- 70 Rock Harbor
- 117 Plantation Key
- 152 Lower Matecumbe Key
- 204 Marathon
- 208 Marathon
- 246 Marathon
- 288 Big Pine Key
- 339 Little Torch Key

In the FKCCS work, canal segments were defined for each canal based upon geometry, connectivity and tidal connection. Canals were attempted to be divided into segments of approximately equal length (roughly 150 feet, more or less), but segment lengths were varied to accommodate canal geometry, branches and turns.

Canal segment drainage areas were delineated based on the previously defined canal segments overlaid on the 1999 digital orthographic quarter-quads (DOQQs) aerials. Roads were frequently

used to delineate drainage divides and the proximity of adjacent canals or other water bodies were often used to estimate split areas between the canal of interest and the adjacent canal/water body.

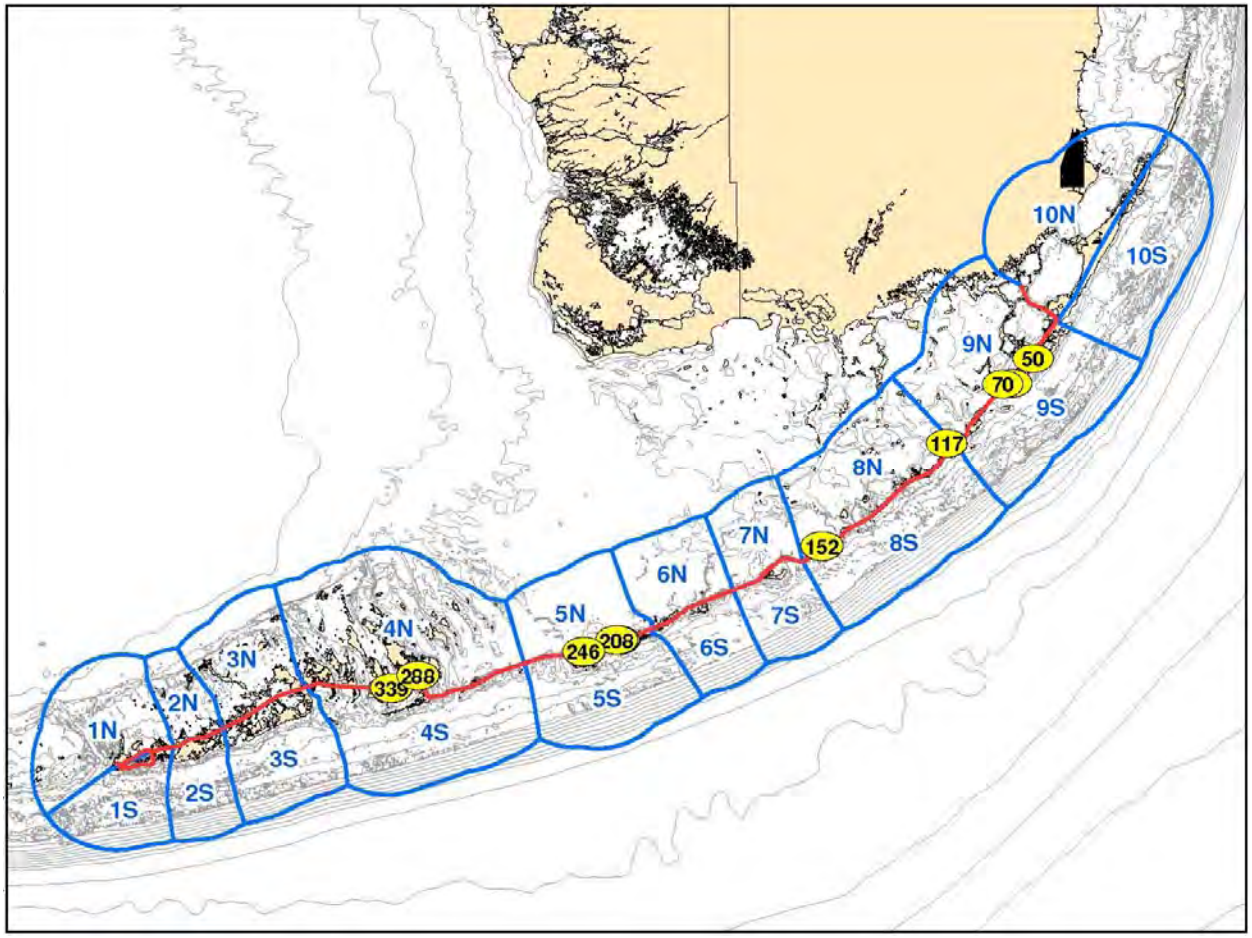
Unfortunately, the original delineations had been developed using the GIS parcel coverage which suffers from projection errors as discussed earlier in this report. The original delineations could still be used for the wastewater load assessment and are stored in the Access database as a table [Canal_EDU]. A second set of delineations was developed based on the FLUCCS coverage and aerials for land use/stormwater loading assessment and is stored in the Access database as a table [Canal_LU].

In the FKCCS project, receiving water discharge zone segments (mixing zones) were defined for each of the 10 representative canals. Those discharge zones were developed using a 250-foot radial distance from the outlet of each canal. The radial line was trimmed where it intersected the shoreline or other obstruction and was used to represent the boundary between the nearshore water and the end of the discharge zone associated with the canal. It was assumed that the canal would not affect water quality beyond 250 feet from its outlet. The water quality at that boundary (Cell 0 of the large scale model) was used to characterize the quality of the source water during flood tides. The nearshore values for TN and TP were selected for each canal by taking the value computed by the large scale model for Cell 0 of the appropriate Model Zone. Table 18 below lists the modeled canals and their associated Model Zone from the large scale model. Figure 12 shows the general locations of the modeled canals.

Table 18
MODELED CANALS AND MODEL ZONES

Canal ID	Canal Location	Model Zone
50	Key Largo	9S
69	Rock Harbor	9S
70	Rock Harbor	9N
117	Plantation Key	8N
152	Lower Matecumbe Key	8N
204	Marathon	5S
208	Marathon	5S
246	Marathon	5S
288	Big Pine Key	4N
339	Little Torch K	4S

Figure 12
MODELED CANAL LOCATIONS



4 MODEL DEVELOPMENT

This section describes the development of the WTFM to simulate flow and pollutant concentrations through the model cells based on stormwater and wastewater discharges and tidal exchange, and estimate relative pollutant concentrations in each cell based upon the waste loads and ambient water quality at the outer model boundary.

4.1 Model Objectives

The objective was to create a tool that could be rapidly developed and applied to the Florida Keys to simulate the dilution of stormwater and wastewater pollutant loads into the nearshore waters. Given the size of the various data tables involved, the tool was developed using both a database (load projections) and a spreadsheet (tidal flushing simulation) with appropriate macros to aid in estimating a pollutant concentration for each model cell under specific scenarios. Variables included in the algorithms were tidal fluctuation, nearshore water quality, stormwater loads (affected by land use and any best management practices, or BMPs) and wastewater loads (affected by the type of wastewater treatment and disposal method).

4.2 Wastewater Load Computations (MS Access Database)

Wastewater load computations were carried out within the Access Database developed for the WTFM. Data tables included:

- [EDU] table of polygons from GIS EDU coverage (large scale model)
- [Canal_EDU] table of polygons from GIS EDU coverage (canal scale models)
- [GPD_EDU] wastewater volume table (associate to EDU by planning unit)
- [WWT_EFFLUENT] wastewater treatment table (associate to EDU by treatment type)
- [Parcel_Summary] summary query (associate to EDU by Parcel ID)

A series of queries were developed within Access to develop wastewater loading tables for each Model Zone and modeled canal under a number of different scenarios. This included the following queries:

- Baseline WW Loads (Model)
- 2007 WW Loads
- Proposed WW Loads
- 1999 Canal WW Loads
- 2007 Canal WW Loads
- 2010 Canal WW Loads

4.2.1 Conceptual Basis

Wastewater loads are estimated at the EDU polygon level for the aggregated flows being treated by either onsite wastewater technology or wastewater treatment plants Effluent characteristics for each polygon are associated with the type of treatment [WWT_EFFLUENT] and the volume is based on potable water flow [GPD_EDU].

4.2.2 Computational Algorithms

Since the original parcel coverage had been split among the various stakeholders, planning units and model cells, the number of EDUs attributed to each EDU polygon was computed as the area of the polygon times the number of EDUs assigned to the original parcel and divided by the area of the parcel. This resulted in an area weighted EDU value for each EDU polygon, the sum of which equaled the original EDUs assigned to the parcel.

$$M_EDU = \frac{[Shape_Area]*[Parcel_EDU]}{[Parcel_Area]}$$

The wastewater flow contributed by each EDU polygon was computed as the area weighted EDU value times the gallon/day/EDU assigned based on the planning unit the EDU fell in. The annual wastewater volume was computed as the flow times 365 days/year divided and the units converted to acre-feet.

$$GPD = [M_EDU] * [GPD_EDU]$$

$$VOL_AF = \frac{[GPD] * (365\ days/yr)}{(7.48\ gal/cf) * (43{,}560\ sf/acre)}$$

Wastewater loads were computed using the effluent concentrations from the wastewater treatment table. The effective wastewater volume was assumed to be 0 for treatment types with deep well disposal. Load units were converted to pounds.

$$LOAD_LB = \frac{[GPD] * CONC_{(mg/l)} * (365\ days/yr) * (3.78754\ l/gal) * 2.20462\ (lb/kg)}{(1{,}000{,}000\ mg/kg)}$$

4.3 Stormwater Load Computations (MS Access Database)

Stormwater load computations were carried out within the Access Database developed for the WTFM. Data tables included:

- [LU] table of polygons from GIS EDU coverage (large scale model)
- [Canal_LU] table of polygons from GIS EDU coverage (canal scale model)
- [RS_Index] associate rainfall stations to LU by model zone
- [RS_TABLE] associate rainfall data to LU by RS_ID
- [FLUCCS] associate model land use (Model_LU) by LULC_Code
- [EMC] associate runoff characteristics by Model_LU

A series of queries were developed within Access to develop stormwater loading tables for each Model Zone and modeled canal under a number of different scenarios. This included the following queries:

- Baseline SW Loads
- Baseline SW (developed land only)
- Baseline SW (natural land only)
- 1999 Canal SW Loads

4.3.1 Conceptual Basis

Nonpoint pollution loading factors (lbs/acre/year) for different land use categories are based upon annual runoff volumes and event mean concentrations (EMCs) for different pollutants. The EMC is defined as the average of individual measurements of storm pollutant mass loading divided by the storm runoff volume and the values used in the WTFM were taken from the Monroe County Stormwater Management Master Plan. In order to calculate annual runoff volumes for each Model Zone, the pervious and impervious fractions of each land use category are used as the basis for determining rainfall/runoff relationships. For rural/agricultural (nonurban) land uses, the pervious fraction represents the major source of runoff or stream flow, while impervious areas are the predominant contributor for most urban land uses.

The WTFM calculates annual runoff volumes for the pervious/impervious areas of each land use polygon, multiplying the average annual rainfall volume by a runoff coefficient. Based on the data from the Monroe County Stormwater Management Master Plan, a runoff coefficient of 0.95 was used for impervious areas (i.e., 95% of the rainfall is assumed to be converted to runoff from the impervious fraction of each land use) and a pervious area runoff coefficient of 0.10 was used. The total average annual surface runoff from land use L was calculated by weighting the impervious and pervious area runoff factors for each land use.

4.3.2 Computational Algorithms

Drainage areas within each Model Zone were limited to the LU polygons that fell within Cell 0. This assumption was made to readily assess only the land area within the Model Zones and to exclude the large areas in Model Zones 9N and 10N that lie outside of the Keys. The minor amount of potential stormwater runoff from the small islands outside of Cell 0 are not expected to be a significant source of nitrogen or phosphorous. For each LU polygon within Cell 0, the impervious (AI) and pervious (AP) portions were computed in units of acres as follows:

$$AI = \frac{[ShapeArea]*[DCIA]}{(43{,}560\ sf\ /\ ac)}$$

$$AP = \frac{[ShapeArea]}{(43{,}560\ sf\ /\ ac)} - [AI]$$

The runoff volume from each LU polygon was computed as the sum of the annual runoff expected from the impervious and pervious area within each polygon. The average annual rainfall varied depending on the rainfall station associated with the Model Zone the polygon fell in. These volumes were then converted to acre-feet.

$$R_VOL_AF = \frac{[R_AVG]}{(12\ in\ /\ ft)} * ([CI]*[AI] + [CP]*[AP])$$

Stormwater loads were computed using the EMC concentrations from the Model Land Use table. Load units were converted to pounds.

$$LOAD_LB = \frac{[R_VOL_AF] * CONC_{(mg/l)} * (43{,}560\ sf/ac) * (2.20462\ lb/kg) * (28.3168\ l/cf)}{(1{,}000{,}000\ mg/kg)}$$

4.4 Tidal Flush Computations (MS Excel Spreadsheet)

A set of queries were developed in MS Access to summarize the loads and volumes for each Model Zone. Different queries are used to represent different scenarios such as the pre-development scenario (all natural land use), the baseline scenario (June 2000), and the 2010 scenario (improved wastewater/stormwater BMPs). The final query creates a table of stormwater and wastewater loads for the scenario which is pasted directly into the spreadsheet model (Model_Loads tab).

The tidal flushing model was developed using MS Excel with Visual Basic (VB) macros which iteratively run the algorithms until the maximum change in any model cell between iterations reaches a tolerance value (concentration) set by the user. All model runs used in the study adopted a tolerance of 0.001mg/l. The large scale flushing model of the 20 large scale Model Zones was developed using a single spreadsheet. However, due to their unique geometry, the ten canals were each modeled as an independent spreadsheet.

4.4.1 Conceptual Basis

The model was developed using a two-step (flood and ebb) tidal flushing algorithm, based upon the following concepts:

- Fully mixed exchange between the defined cells (radially)
- One-dimensional, bi-directional flow within the model cells
- Defined and constant boundary conditions at the outer boundary of the model

4.4.2 Enabling Assumptions

To allow for the development of a tool that can reflect the impacts of various land use and wastewater treatment scenarios, yet be accomplished within the confines of a spreadsheet and be readily applied to the Model Zones, a number of enabling assumptions were necessary. These included:

- Tidal flows are idealized as a single time-steps from low tide directly to high tide and vice-versa
- Each Model Zone is independent, i.e. there is no interchange of flow or pollutants between them
- US-1 acts as a barrier to flow. Tidal interchange through bridges and passes are not simulated by the model

- Flows and their associated pollutant loads passed between segments are assumed to be completely mixed with the fluid volume and pollutant load of the receiving segment prior to being passed to subsequent canal/discharge zone segments
- The selected pollutants (TN and TP) are idealized as conservative, uniformly mixed, neutrally buoyant particles that do not volatilize or settle out of the water column.
- Nutrient uptake and sediment interactions are ignored.
- The only forcing function recognized is tidal fluctuation. Wind, temperature, stormwater flow, wastewater flow and other potential driving factors are not considered
- Utilize a steady-state approach (i.e. annual averages for input values), rather than event simulations
- The model is a comparative tool (i.e. results compared between two scenarios) rather than predictive

An example model zone is illustrated in Figure 13 with a detailed close up shown in Figure 14. That figure shows a plan view of the example model zone (5S) divided into the model cells. The overview illustration shows:

- the ID of the example model zone (5S)
- the source land mass (Marathon)
- the bathymetric contours
- the coastal WBID boundary (WBID 6011A)
- Model Cell 0 (WBID 6011A)
- the concentric model cells from the coastal WBID boundary (1 through 15)
- Model cell width (cell # * 100 m)
- the offshore WBID boundary (WBID 8081)
- the outer model boundary (12,000 m)

Figure 13
EXAMPLE LARGE SCALE MODEL ILLUSTRATION

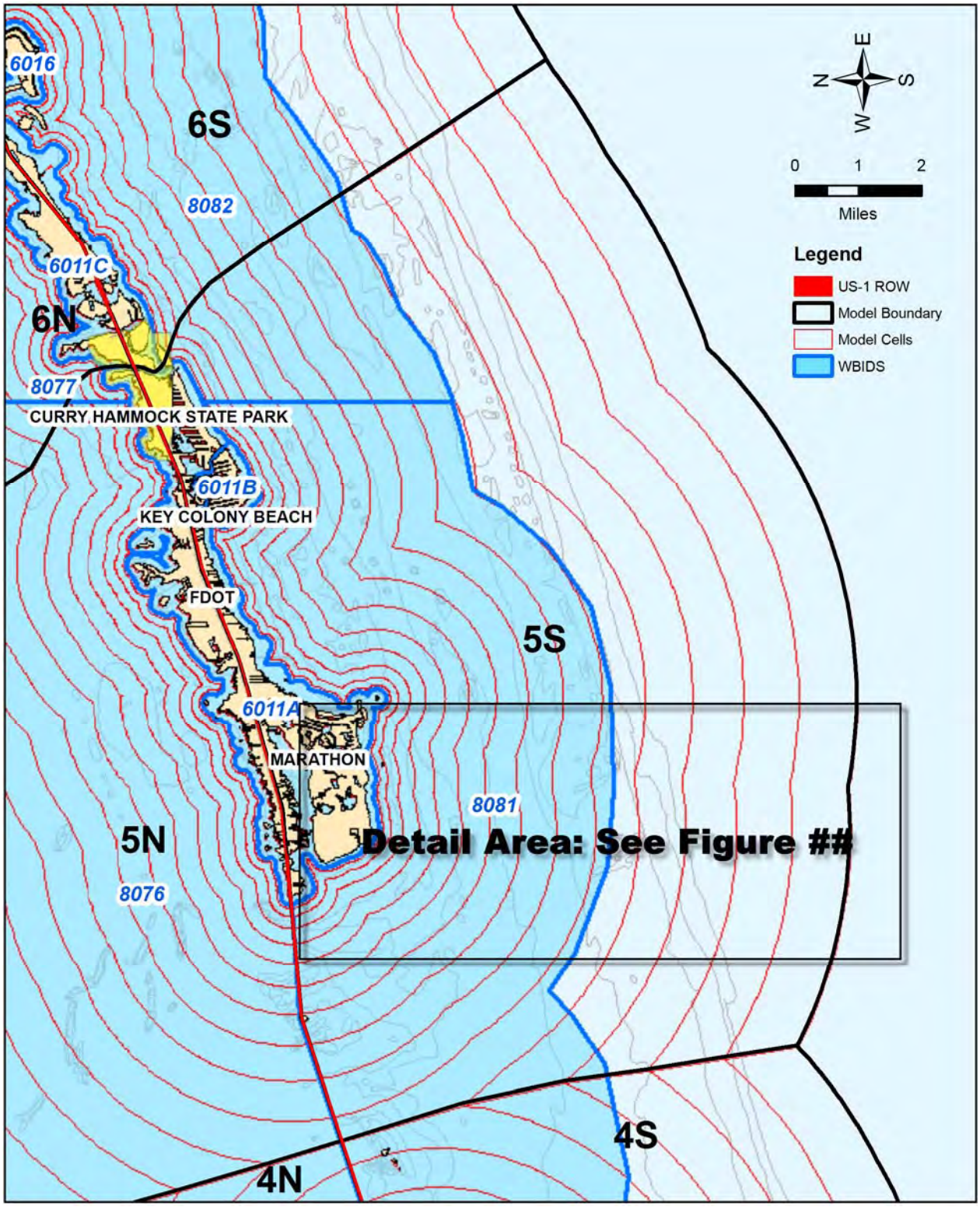
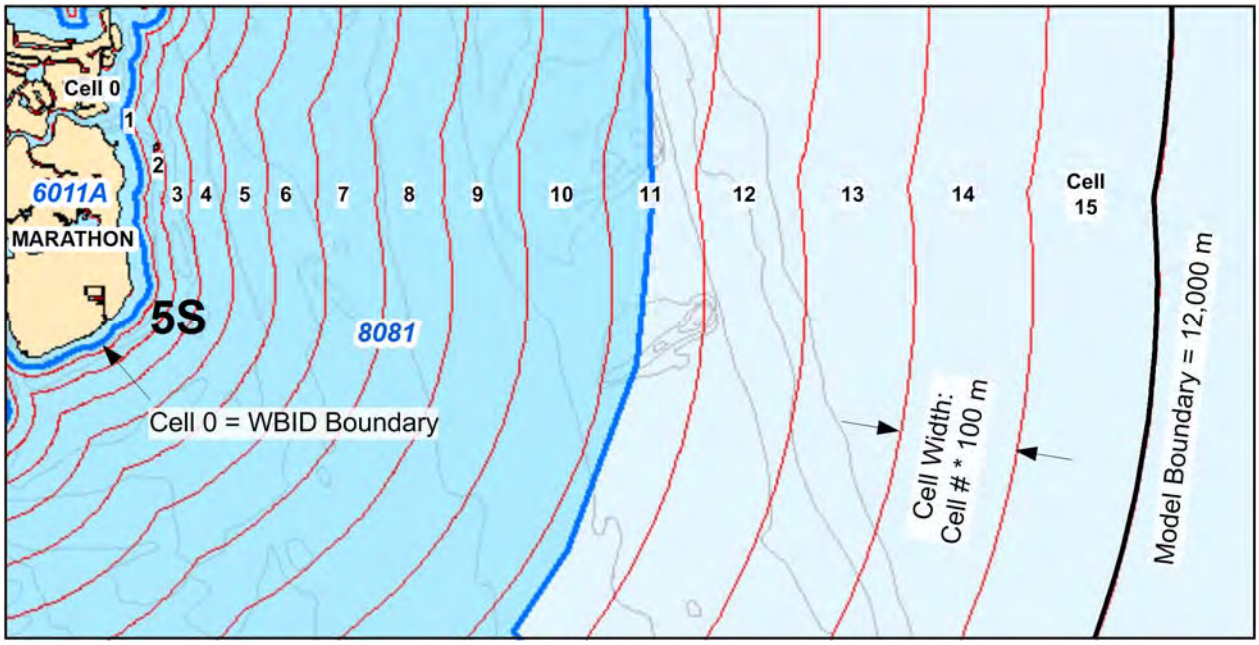


Figure 14
EXAMPLE LARGE SCALE MODEL DETAIL AREA

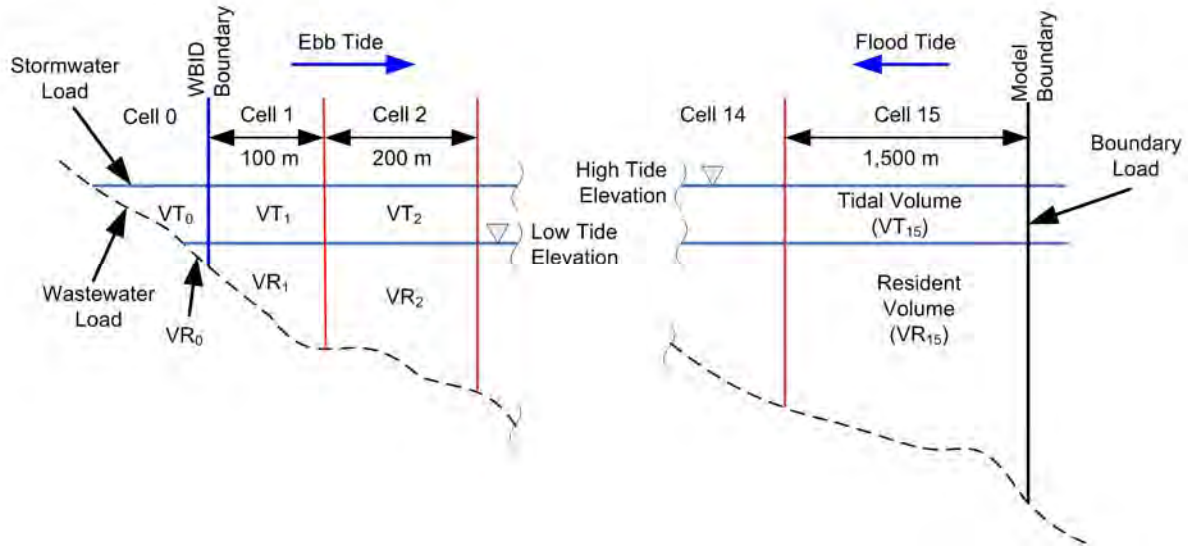


The model for each zone uses the intersection of the model boundary for that zone with the offshore kriged water quality surface discussed previously to establish a boundary condition water quality value. Each model cell in that zone has its initial water quality value set to that value. The initial water quality values are actually irrelevant to the values the model will compute under a given load scenario, but serve as a realistic starting point for model iterations.

For the purposes of modeling definitions, model segments are numbered in an offshore order, with model cell 0 defined as the volume between the land interface and the coastal WBID boundary. Flood tides are shown in the profile illustration as entering the outer model cell (15) and discharged into the next inshore model cell (14). Ebb tides are just the opposite, initiating at Cell 0 and discharged into the next offshore model cell (1).

The profile illustration in Figure 15 shows a section of a typical model. Several variables are shown in the profile illustration. Stormwater and wastewater loads from the land based areas are shown discharging into Cell 0 (both ebb and flood tide). The boundary load from the offshore waters is shown discharging into Cell 15 (flood tide only). The tidal volume (VT) is shown as the volume in the model cell between low and high tide. The resident volume (VR) is shown as the volume in the model cell between low tide and the sea floor. VT and VR are the volumes considered by the model for mixing, or for computing pollutant mass/concentration in a segment at any time.

Figure 15
EXAMPLE TIDAL FLUSH MODEL PROFILE



Canals were modeled with the same algorithm, and were taken from the FKCCS project essentially unaltered with the exception of the loading data which was updated based on the Access database load projections. The predicted concentrations from the large scale model for Cell 0 were used as the boundary concentrations at the edge of the mixing zone for each canal model. An example of a modeled canal is shown in Figure 16.

Figure 16
EXAMPLE CANAL MODEL

4.4.3 Time Steps and Iterations

The model uses a time step of one tide period. As shown previously in Figure 1, this is the duration from high tide to high tide, or low tide to low tide. With the exception of the Vaca Key tide station at 13.32 hours, tidal periods in the Keys average 12.42 hours at all tide stations. There is however, substantial variation in the durations of average flood and ebb tides among the Keys tide stations. Average flood tide durations range from 3.87 hours (Upper Sugarloaf Sound - Perky) to 8.65 hours (Vaca Key, USCG Station, Florida Bay). Average ebb tide durations range from 4.50 hours (East Bahia Honda Key, south end, Florida Bay) to 8.55 hours (Upper Sugarloaf Sound - Perky). This is important since the model computes flood tides and ebb tides separately for each iteration (tidal period).

Although a daily average load (based on an annual load computation) is used as the model input, it is reduced to an average hourly rate and then low and high tide components computed based on tide

cycle duration. Thus different loads (L), load volumes (LV) and load mass (LM) are used by the model for ebb and flood tides.

4.4.4 Flood Tide Algorithms

To simulate a flood (incoming) tide, the initial volume (IV) in each model cell is set as the volume at low tide. This is computed as the resident volume (VR), which is the volume at mean sea level (MSL) plus any additional volume based on the predicted low tide elevation. The additional volume at low tide is computed as the water surface area (WSA) of the cell times the low tide elevation (LTE). The model tracks volume in units of acre-feet (ac-ft). The equation used to compute this value for each model cell (i) is as follows:

$$IV(f)_i = VR_i = V_{MSL} + WSA_i * LTE$$

Note that (f) indicates a flood tide value.

The volume of water that flows into a model cell (VI) is equal to the tidal volume (VT) of the model cell plus the VT of the model cells in the model zone that are inshore of that cell. The VT of each cell is the volume change in the cell between the predicted high and low tides. This is computed as the water surface area (WSA) of the cell times the difference of the high tide elevation (HTE) and the low tide elevation (LTE) for the model zone. The equation used to compute this value for each model cell (i) is as follows:

$$VI(f)_i = \sum_0^i VT_i = \sum_0^i \left[WSA_i * (HTE_Z - LTE_Z)\right]$$

Note that Z indicates the model zone. Each model zone was assigned an average low and high tide elevation based on tidal data for NOAA tide stations within that model zone.

The volume of water that flows out of a model cell (VO) is equal to the tidal volume (VT) of all cells in the model zone that are inshore of that cell. The equation used to compute this value for each model cell (i) is as follows:

$$VO(f)_i = \sum_0^{i-1} VT_i = \sum_0^{i-1} \left[WSA_i * (HTE_Z - LTE_Z)\right]$$

Note that for cell 0, VO = 0.

The final volume (FV) in a model cell is computed as the initial volume (IV) plus the volume in (VI) minus the volume out (VO). The equation used to compute this value for each model cell (i) is as follows:

$$FV(f)_i = IV(f)_i + VI(f)_i - VO(f)_i$$

The total volume used in the mixing calculation (MV) for a model cell is the initial volume (IV) plus the volume in (VI). The equation used to compute this value for each model cell (i) is as follows:

$$MV(f)_i = IV(f)_i + VI(f)_i$$

The initial mass of a pollutant in a model cell is computed as the resident volume (VR) of the cell times the concentration (C) of the pollutant. The model tracks mass in units of tons and concentration in units of milligrams per liter (mg/l). The equation used to compute this value for each model cell (i) is as follows:

$$IM(f)_i = VR_i * C_i * \frac{[(43{,}560\ sf/ac)*(28.3168\ l/cf)*(2.20462\ lb/cf)]}{[(1{,}000{,}000\ mg/kg)*(2{,}000\ lb/ton)]}$$

The mass of a pollutant discharged into a model cell (MI) is computed as the mass out of the cell immediately offshore from it (MO_{i+1}) in the model zone (see the definition of $MO(f)$ below). The equation used to compute this value for each model cell (i) is as follows:

$$MI(f)_i = MO(f)_{i+1}$$

Note that for cell 0, the stormwater mass (SWLOAD) and wastewater mass (WWLOAD) loads discharged from the land source are added to this term. Thus:

$$MI(f)_o = MO(f)_1 + SWLOAD + WWLOAD$$

Note that for cell 15, the mass in $MI(f)_{15}$ is determined by the boundary concentration for that model zone (C_z) times the total tidal incoming tidal volume (VT) for that model zone. Thus:

$$MI(f)_{15} = VI(f)_{15} * C_Z * \frac{[(2.20462\ lb/kg)*(43{,}560\ sf/ac)*(28.3168\ l/cf)]}{[(2{,}000\ lb/ton)*(1{,}000{,}000\ mg/kg)]}$$

The mass used in the mixing calculation (MM) is the initial mass (IM) plus the mass in (MI). The equation used to compute this value for each model cell (i) is as follows:

$$MM(f)_i = IM(f)_i + MI(f)_i$$

The mixed pollutant concentration (MC) is the mixed mass (MM) divided by the mixing volume (MV). The equation used to compute this value for each model cell (i) is as follows:

$$MC(f)_i = \frac{MM(f)_i * [(2{,}000\ lb/ton)*(1{,}000{,}000\ mg/kg)]}{MV(f)_i * [(2.20462\ lb/kg)*(43{,}560\ sf/ac)*(28.3168\ l/cf)]}$$

The mass discharged out (MO) is the mixed concentration (MC) times the volume out (VO). The equation used to compute this value for each model cell (i) is as follows:

$$MO(f)_i = MC(f)_i * VO(f)_i * \frac{[(2.20462\ lb/kg)*(43{,}560\ sf/ac)*(28.3168\ l/cf)]}{[(2{,}000\ lb/ton)*(1{,}000{,}000\ mg/kg)]}$$

Note that for cell 0, MO = 0.

The final mass (FM) in a model cell is computed as the initial mass (IM) plus the mass in (MI) minus the mass out (MO). The equation used to compute this value for each model cell (i) is as follows:

$$FM(f)_i = IM(f)_i + MI(f)_i - MO(f)_i$$

4.4.5 Ebb Tide Algorithms

Ebb (outgoing) tide algorithms are essentially the same as those for flood tide, but the flow directions are reversed. To simulate an ebb tide, the initial volume (IV) in a model cell is set as the volume at high tide. This was computed earlier in the flood tide computations as $FV(f)$ and this value is carried down to represent the initial volume for the ebb tide computations. Thus:

$$IV(e)_i = FV(f)_i$$

Note that (e) indicates an ebb tide value.

The volume of water that flows into a model cell (VI) is equal to the tidal volume (VT) of all the model cells in the model zone that are inshore of that cell. The equation used to compute this value for each model cell (i) is as follows:

$$VI(e)_i = \sum_0^i VT_{i-1} = \sum_0^i \left[WSA_{i-1} * (HTE_Z - LTE_Z)\right]$$

Note that for cell 0, VI = 0. The minor volumes attributable to stormwater and wastewater discharges are considered negligible and are ignored (i.e. they will not increase tidal elevations).

The volume of water that flows out of a model cell (VO) is equal to the tidal volume (VT) of the model cell plus the VT of all the model cells in the model zone that are inshore of that cell. The equation used to compute this value for each model cell (i) is as follows:

$$VO(e)_i = \sum_0^i VT_i = \sum_0^i \left[WSA_i * (HTE_Z - LTE_Z)\right]$$

The final volume (FV) in a model cell is computed as the initial volume (IV) plus the volume in (VI) minus the volume out (VO). This is also equal to the IV value for that cell from the flood tide calculations. The equation used to compute this value at each model cell (i) is as follows:

$$FV(e)_i = IV(e)_i + VI(e)_i - VO(e)_i = IV(f)_i$$

The total volume used in the mixing calculation (MV) for a model cell is the initial volume (IV) plus the volume in (VI). The equation used to compute this value for each model cell (i) is as follows:

$$MV(e)_i = IV(e)_i + VI(e)_i$$

Similar to the initial volume, the initial mass of a pollutant in a model cell for ebb tide calculations was computed earlier in the flood tide computations as $FM(f)$ and this value is carried down to represent the initial mass for the ebb tide computations. Thus:

$$IM(e)_i = FM(f)_i$$

The mass of a pollutant discharged into a model cell (MI) is computed as the mass out of the cell immediately inshore from it (MO_{i+1}) in that model zone (see the definition of $MO(e)$ below). The equation used to compute this value for each model cell (i) is as follows:

$$MI(e)_i = MO(e)_{i+1}$$

Note that for cell 0, there are no cells inshore from it. The stormwater mass (SWLOAD) and wastewater mass (WWLOAD) loads discharged from the land source are the only source of mass to this cell during the ebb tide calculations. Thus:

$$MI(e)_o = SWLOAD + WWLOAD$$

The mass used in the mixing calculation (MM) is the initial mass (IM) plus the mass in (MI). The equation used to compute this value for each model cell (i) is as follows:

$$MM(e)_i = IM(e)_i + MI(e)_i$$

The mixed pollutant concentration (MC) is the mixed mass (MM) divided by the mixing volume (MV). The equation used to compute this value for each model cell (i) is as follows:

$$MC(e)_i = \frac{MM(e)_i * \left[(2{,}000\ lb/ton) * (1{,}000{,}000\ mg/kg)\right]}{MV(e)_i * \left[(2.20462\ lb/kg) * (43{,}560\ sf/ac) * (28.3168\ l/cf)\right]}$$

The mass discharged out (MO) is the mixed concentration (MC) times the volume out (VO). The equation used to compute this value for each model cell (i) is as follows:

$$MO(e)_i = MC(e)_i * VO(e)_i * \frac{\left[(2.20462\ lb/kg) * (43{,}560\ sf/ac) * (28.3168\ l/cf)\right]}{\left[(2{,}000\ lb/ton) * (1{,}000{,}000\ mg/kg)\right]}$$

The final mass (FM) in a model cell is computed as the initial mass (IM) plus the mass in (MI) minus the mass out (MO). The equation used to compute this value for each model cell (i) is as follows:

$$FM(e)_i = IM(e)_i + MI(e)_i - MO(e)_i$$

4.5 WTFM Application

The WTFM consists of a single spreadsheet with four computational tabs: Loads, Model, Results and Summary. In its current version, loads must be entered by the user from queries to the Access database. The Access database is used to compile the loads and flows for specific scenarios.

- Loads Tab: This tab is where the user should paste the values from the MS Access model load query into Cell A1. No other changes should be made to this tab.
- Model Tab: The Model tab is the heart of the flushing model. The user can select the boundary conditions (pre-2000, post 2000 or All) using the radio buttons in the upper left. The Tolerance value (mg/l) is in Cell A5 and can be modified by the user, though 0.0001

mg/l is generally acceptable for most scenarios. This is the precision to which the computations will be run. Once a model iteration fails to have any parameter change by more than the Tolerance value, the model assumes steady-state has been reached and proceeds to the next Model Zone. Two buttons, RESET and RUN, are the only other user input areas within this tab. RESET will reset the model to pre-run condition, RUN will start the iterative process to estimate pollutant concentrations in each model cell. Since the name of this tab is hard coded in the macros, **it must not be renamed**.

- Results Tab: This tab is used as to check for model convergence against the tolerance value throughout the model runs. It only contains the results for the last Model Zone. Since the name of this tab is hard coded in the macros, **it must not be renamed**.
- Summary Tab: This tab is the output table for the model. Once the tolerance value has been satisfied, the values from the Results Tab are pasted into this tab along with model run statistics. The values in this table are used in the Profiles Tab (see below) for the solid heavy line in the charts. Since the name of this tab is hard coded in the macros, **it must not be renamed**.

There are also data tabs which should not be altered by the casual user. These are: Model_Data, Cells, T_Sta and Conversion.

- Model_Data Tab: This tab is used to reformat and apply the model data for use in the Model Tab. All values are linked and updated as needed No changes should be made to this tab.
- Cells Tab: The Cells Tab contains the cell volume and surface area data from the GIS coverage. It also forms a searchable index used to set up the model runs. No changes should be made to this tab.
- T_Sta Tab: This tab contains the data for the various tide stations in the Keys, grouped by Model Zone. The Models Tab references this sheet to pull the data needed for the tidal flushing values and boundary conditions. No changes should be made to this tab.
- Conversion Tab. All units conversion values are stored and named in this tab.

Finally two additional tabs are used to view and compare the results from model runs. These are Comparison Data and Profiles.

- Comparison Data Tab: This tab is used in the Profiles tab to plot the thin dashed line. The data in this tab is the Summary tab from any model runs the user desires. The values are simply pasted from other models.
- Profiles Tab: This tab is a series of charts for each Model Zone. It shows the current model results as a heavy solid line and the comparison results as a thin dashed line.

4.6 WTFM Constraints and Limitations

The WTFM is a simplified model, based on the previously described enabling assumptions and the conceptual basis of the model. In its current configuration, it assumes a long-term steady-state influx

of pollutant loads and volumes. It does not include or account for a number of variables that may have a significant impact on observed canal water quality. Some of these potential factors include:

- Interchange between the north/south (N/S) Model Zones along US-1
- water column stratification
- wind effects
- thermal gradients
- surge tides associated with tropical storms or hurricanes
- interactions between the benthic/sediment zone and the active water column
- nutrient uptake/release by marine plants
- washed in seagrasses and similar sources
- direct input of water volumes and pollutant loads attributable to precipitation or atmospheric dryfall deposition
- water volume losses attributable to evaporation or transpiration
- direct pollutant inputs related to marine vessel discharges and illicit discharges

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Appendix A
CONVERSION FACTORS

43,560.....square-feet/acre
365.....days/year
24.....hours/day
7.48.....gallons/cubic-foot
3.7854.....liters/gallon
28.3168.....liters/cubic-foot
2.20462.....pounds/kilogram
1,000,000.....milligram/kilogram
2,000.....pounds/ton (US)

Appendix B
NOAA TIDE STATION INVENTORY – FLORIDA KEYS

Sta. #	Station Name	Mean Tide (feet)		Time Difference (hrs) (TD_H/TD_L)		Height Adjustments (H_{adj}/L_{adj})		Ref. Station
		Range	Level	High	Low	High	Low	
1	Bear Cut, Virginia Key	2.05	1.16	0.817	0.867	0.82	0.82	Miami Harbor Entrance
2	Key Biscayne Yacht Club, Biscayne Bay	2.00	1.13	1.117	1.583	0.80	0.81	Miami Harbor Entrance
3	Coral Shoal, Biscayne Channel	2.05	1.15	0.567	0.683	0.82	0.81	Miami Harbor Entrance
4	Cutler, Biscayne Bay	1.98	1.13	1.383	2.000	0.79	0.88	Miami Harbor Entrance
5	Soldier Key	1.90	1.00	0.883	1.333	0.74	0.75	Miami Harbor Entrance
6	Fowey Rocks	2.40	1.40	0.017	0.050	0.97	0.94	Miami Harbor Entrance
7	Ragged Keys, Biscayne Bay	1.65	0.95	1.117	1.417	0.66	0.66	Miami Harbor Entrance
8	Boca Chita Key, Biscayne Bay	1.57	0.94	1.400	1.717	0.63	0.63	Miami Harbor Entrance
9	Sands Key, northwest point, Biscayne Bay	1.46	0.82	1.800	2.500	0.58	0.56	Miami Harbor Entrance
10	Coon Point, Elliott Key, Biscayne Bay	1.44	0.82	2.300	3.000	0.57	0.57	Miami Harbor Entrance
11	Elliott Key Harbor, Elliott Key, Biscayne Bay	1.48	0.83	2.317	3.067	0.59	0.56	Miami Harbor Entrance
12	Turkey Point, Biscayne Bay	1.64	0.94	2.550	3.417	0.65	0.65	Miami Harbor Entrance
13	Billys Point, south of, Elliott Key, Biscayne Bay	1.46	0.82	2.517	3.400	0.58	0.56	Miami Harbor Entrance
14	Sea Grape Point, Elliott Key	2.30	1.39	0.633	0.650	0.92	0.92	Miami Harbor Entrance
15	Christmas Point, Elliott Key	1.82	1.06	0.600	0.683	0.73	0.73	Miami Harbor Entrance
16	Adams Key, south end, Biscayne Bay	1.52	0.90	1.400	1.200	0.61	0.61	Miami Harbor Entrance
17	Totten Key, west side, Biscayne Bay	1.26	0.71	2.700	3.417	0.50	0.50	Miami Harbor Entrance
18	East Arsenicker, Card Sound	0.91	0.54	2.817	3.217	0.36	0.36	Miami Harbor Entrance
19	Card Sound, western side	0.68	0.40	3.233	3.733	0.27	0.27	Miami Harbor Entrance
20	Pumpkin Key, south end, Card Sound	0.63	0.43	2.967	2.933	0.25	0.25	Miami Harbor Entrance
21	Wednesday Point, Key Largo, Card Sound	0.77	0.46	3.017	3.567	0.31	0.31	Miami Harbor Entrance
22	Cormorant Point, Key Largo, Card Sound	0.73	0.43	3.133	3.083	0.29	0.29	Miami Harbor Entrance
23	Little Card Sound bridge	0.53	0.32	3.850	4.267	0.21	0.21	Miami Harbor Entrance
24	Ocean Reef Harbor, Key Largo	2.33	1.37	0.217	0.300	0.93	0.93	Miami Harbor Entrance
25	Main Key, Barnes Sound	0.41	0.26	5.450	6.333	0.16	0.16	Miami Harbor Entrance
26	Manatee Creek, Manatee Bay, Barnes Sound	0.39	0.25	5.617	6.400	0.16	0.16	Miami Harbor Entrance
27	Carysfort Reef	2.34	1.36	0.700	0.717	0.93	0.93	Miami Harbor Entrance
28	Garden Cove, Key Largo	2.16	1.24	0.367	0.483	0.86	0.86	Miami Harbor Entrance
29	Largo Sound, Key Largo	0.80	0.47	2.600	3.117	0.32	0.32	Miami Harbor Entrance
30	Key Largo, South Sound, Key Largo	1.55	0.85	0.767	1.883	0.61	0.56	Miami Harbor Entrance
31	Rock Harbor, Key Largo	2.10	1.23	0.717	0.683	0.84	0.84	Miami Harbor Entrance
32	Rock Harbor, Key Largo	2.14	1.24	0.750	0.667	0.85	0.85	Miami Harbor Entrance
33	Mosquito Bank	2.20	1.20	0.367	0.517	0.85	0.88	Miami Harbor Entrance
34	Molasses Reef	2.20	1.20	0.233	0.200	0.88	0.88	Miami Harbor Entrance
35	Tavernier Harbor, Hawk Channel	2.09	1.23	0.517	0.483	0.83	0.83	Miami Harbor Entrance
36	Tavernier Creek, Hwy. 1 bridge, Hawk Channel	1.32	0.81	0.800	0.933	0.53	0.53	Miami Harbor Entrance
37	Crane Keys, north side, Florida Bay	0.40	0.24	3.317	4.667	0.16	0.16	Miami Harbor Entrance
38	East Key, southern end, Florida Bay	0.52	0.28	3.100	4.167	0.21	0.21	Miami Harbor Entrance
39	Plantation Key, Hawk Channel	2.20	1.27	0.467	0.267	0.88	0.88	Miami Harbor Entrance
40	Yacht Harbor, Cowpens Anchorage, Plantation Key	0.53	0.31	3.133	4.067	0.21	0.21	Miami Harbor Entrance
41	Snake Creek, Hwy. 1 bridge, Windley Key	1.07	0.61	1.200	1.000	0.43	0.43	Miami Harbor Entrance
42	Snake Creek, USCG Station, Plantation Key	0.82	0.48	1.517	2.000	0.33	0.33	Miami Harbor Entrance
43	Whale Harbor, Windley Key, Hawk Channel	1.56	0.83	0.500	0.917	0.62	0.62	Miami Harbor Entrance
44	Whale Harbor Channel, Hwy. 1 bridge, Windley Key	1.36	0.78	0.650	1.067	0.54	0.54	Miami Harbor Entrance
45	Upper Matecumbe Key, Hawk Channel	1.98	1.16	0.950	0.883	0.79	0.79	Miami Harbor Entrance
46	Alligator Reef, Hawk Channel	1.93	1.15	0.517	0.467	0.77	0.77	Miami Harbor Entrance

Sta. #	Station Name	Mean Tide (feet)		Time Difference (hrs) (TD_H/TD_L)		Height Adjustments (H_{adj}/L_{adj})		Ref. Station
		Range	Level	High	Low	High	Low	
47	Flamingo, Florida Bay	2.02	1.27	5.467	7.333	1.47	1.08	Key West
48	Upper Matecumbe Key, west end, Hawk Channel	1.44	0.80	-1.000	0.233	0.98	0.33	Key West
49	Indian Key, Hawk Channel	1.84	1.09	-0.300	0.083	1.30	0.71	Key West
50	Shell Key Channel, Florida Bay	1.02	0.58	0.333	0.750	0.78	0.78	Key West
51	Lignumvitae Key, NE side, Florida Bay	0.68	0.37	0.150	1.517	0.52	0.52	Key West
52	Lignumvitae Key, west side, Florida Bay	0.62	0.35	0.533	1.900	0.47	0.47	Key West
53	Little Basin, Upper Matecumbe Key, Florida Bay	0.80	0.40	0.133	1.250	0.61	0.61	Key West
54	Shell Key, northwest side, Lignumvitae Basin	0.60	0.33	0.517	1.950	0.46	0.46	Key West
55	Islamorada, Upper Matecumbe Key, Florida Bay	0.49	0.30	0.650	2.117	0.37	0.37	Key West
56	Indian Key Anchorage, Lower Matecumbe Key	1.94	1.20	-0.783	-0.250	1.40	0.96	Key West
57	Matecumbe Bight, Lower Matecumbe Key, Fla. Bay	0.77	0.48	0.417	0.583	0.55	0.38	Key West
58	Matecumbe Harbor, Lower Matecumbe Key, Fla. Bay	0.83	0.50	0.250	0.383	0.59	0.33	Key West
59	Channel Two, east, Lower Matecumbe Key, Fla. Bay	1.18	0.72	-0.150	-0.033	0.85	0.54	Key West
60	Channel Two, west side, Hawk Channel	1.55	0.96	-0.433	-0.233	1.12	0.75	Key West
61	Channel Five, east side, Hawk Channel	1.25	0.77	-0.233	-0.033	0.90	0.58	Key West
62	Channel Five, west side, Hawk Channel	1.39	0.85	-0.300	-0.017	1.00	0.67	Key West
63	Jewfish Hole, Long Key, Florida Bay	0.56	0.37	0.483	1.533	0.42	0.38	Key West
64	Long Key Bight, Long Key	1.44	0.87	-0.317	-0.050	1.03	0.62	Key West
65	Long Key Lake, Long Key	0.85	0.53	0.550	0.950	0.62	0.46	Key West
66	Long Key, western end	1.19	0.67	-0.350	-0.233	0.82	0.33	Key West
67	Conch Key, eastern end	1.18	0.72	-0.483	-0.083	0.85	0.54	Key West
68	Toms Harbor Cut	0.48	0.33	-0.650	0.167	0.37	0.38	Key West
69	Duck Key, Hawk Channel	1.37	0.81	-0.517	0.000	0.96	0.50	Key West
70	Toms Harbor Channel, Hwy. 1 bridge	0.50	0.45	5.117	4.817	0.38	0.38	Key West
71	Grassy Key, north side, Florida Bay	0.87	0.70	5.683	6.817	0.66	0.66	Key West
72	Grassy Key, south side, Hawk Channel	1.72	1.03	-0.200	0.233	1.22	0.71	Key West
73	Fat Deer Key, Florida Bay	1.14	0.82	5.150	6.433	0.87	0.87	Key West
74	Vaca Key-Fat Deer Key bridge	1.31	0.83	-0.517	0.067	0.95	0.71	Key West
75	Key Colony Beach	1.69	1.05	-0.617	-0.217	1.22	0.83	Key West
76	VACA KEY, USCG STATION, FLORIDA BAY	0.75	0.52	0.000	0.000	1.00	1.00	Vaca Key
77	Boot Key Harbor bridge, Boot Key	1.57	0.96	-0.383	0.050	1.13	0.75	Key West
78	Sombrero Key, Hawk Channel	1.64	1.01	-0.383	0.017	1.18	0.79	Key West
79	Knight Key Channel, Knight Key, Florida Bay	0.72	0.48	0.633	0.367	0.54	0.50	Key West
80	Pigeon Key, south side, Hawk Channel	1.14	0.69	-0.250	0.233	0.81	0.50	Key West
81	Pigeon Key, north side, Florida Bay	0.60	0.44	0.500	0.750	0.46	0.46	Key West
82	Molasses Key Channel, Molasses Keys	1.10	0.67	-0.267	0.400	0.79	0.50	Key West
83	Money Key	0.76	0.54	0.050	1.283	0.58	0.58	Key West
84	Little Duck Key, east end, Hawk Channel	0.88	0.60	-0.150	0.083	0.67	0.67	Key West
85	East Bahia Honda Key, south end, Florida Bay	0.90	0.77	4.067	2.817	0.69	0.69	Key West
86	Cocoanut Key, Florida Bay	0.72	0.66	3.867	2.833	0.55	0.55	Key West
87	West Bahia Honda Key	1.27	0.88	3.983	4.017	0.97	1.00	Key West
88	Horseshoe Keys, south end	1.09	0.79	3.900	3.150	0.86	1.00	Key West
89	Johnson Keys, south end	0.88	0.67	3.600	2.550	0.72	0.96	Key West
90	Johnson Keys, north end	1.70	1.18	3.583	4.367	1.31	1.38	Key West
91	Missouri Key-Little Duck Key Channel	0.98	0.60	-0.200	0.600	0.70	0.46	Key West
92	Missouri Key-Ohio Key Channel, west side	1.08	0.66	-0.117	0.300	0.77	0.50	Key West
93	Ohio Key-Bahia Honda Key Channel, west side	1.10	0.70	-0.283	0.433	0.81	0.62	Key West
94	Bahia Honda Key, Bahia Honda Channel	1.19	0.74	-0.083	0.217	0.86	0.62	Key West
95	Big Pine Key, Spanish Harbor	1.07	0.64	-0.067	0.617	0.75	0.42	Key West
96	Big Pine Key, Doctors Arm, Bogie Channel	0.80	0.57	0.683	1.783	0.63	0.71	Key West

Sta. #	Station Name	Mean Tide (feet)		Time Difference (hrs) (TD_H/TD_L)		Height Adjustments (H_{adj}/L_{adj})		Ref. Station
		Range	Level	High	Low	High	Low	
97	Big Pine Key, Bogie Channel Bridge	0.80	0.60	2.167	2.183	0.65	0.83	Key West
98	No Name Key, east side, Bahia Honda Channel	0.70	0.55	1.583	1.550	0.58	0.83	Key West
99	Little Pine Key, south end	0.68	0.53	1.117	1.117	0.56	0.79	Key West
100	Porpoise Key, Big Spanish Channel	0.88	0.68	3.383	2.483	0.72	1.00	Key West
101	Water Key, west end, Big Spanish Channel	1.00	0.75	3.383	2.617	0.81	1.04	Key West
102	Mayo Key, Big Spanish Channel	1.17	0.85	3.583	3.017	0.92	1.08	Key West
103	Little Pine Key, north end	1.33	0.96	3.633	3.467	1.05	1.21	Key West
104	Big Pine Key, northeast shore	1.08	0.80	3.317	2.500	0.86	1.08	Key West
105	Crawl Key, Big Spanish Channel	1.74	1.19	3.567	4.217	1.33	1.33	Key West
106	Big Pine Key, north end	1.29	0.85	4.400	5.933	0.96	0.83	Key West
107	Annette Key, north end, Big Spanish Channel	1.92	1.27	3.500	4.550	1.44	1.29	Key West
108	Little Spanish Key, Spanish Banks	2.30	1.54	3.417	4.500	1.74	1.62	Key West
109	Big Spanish Key	2.69	1.71	3.317	4.483	1.97	1.50	Key West
110	Munson Island, Newfound Harbor Channel	1.36	0.84	0.000	0.467	0.98	0.67	Key West
111	Ramrod Key, Newfound Harbor	1.28	0.76	-0.017	0.083	0.90	0.50	Key West
112	Middle Torch Key, Torch Ramrod Channel	0.98	0.58	0.400	1.483	0.69	0.38	Key West
113	Little Torch Key, Torch Channel	0.80	0.48	0.183	1.750	0.57	0.33	Key West
114	Big Pine Key, Newfound Harbor Channel	1.16	0.69	0.517	0.733	0.82	0.46	Key West
115	Big Pine Key, Coupon Bight	1.22	0.74	0.333	0.817	0.87	0.54	Key West
116	Little Torch Key, Pine Channel Bridge, south side	0.97	0.56	0.417	0.950	0.68	0.33	Key West
117	Little Torch Key, Pine Channel Bridge, south side	0.98	0.58	0.450	0.900	0.69	0.38	Key West
118	Big Pine Key, Pine Channel Bridge, south side	0.96	0.56	0.450	1.050	0.67	0.33	Key West
119	Big Pine Key, Pine Channel Bridge, north side	0.81	0.49	0.050	1.733	0.57	0.33	Key West
120	Big Pine Key, west side, Pine Channel	0.71	0.45	0.350	1.867	0.52	0.42	Key West
121	Howe Key, south end, Harbor Channel	0.96	0.63	4.717	4.817	0.72	0.62	Key West
122	Big Torch Key, Harbor Channel	2.14	1.38	3.783	5.850	1.58	1.29	Key West
123	Water Keys, south end, Harbor Channel	2.11	1.29	3.700	5.683	1.52	1.00	Key West
124	Howe Key, northwest end	2.28	1.46	3.483	5.367	1.68	1.33	Key West
125	Summerland Key, Niles Channel South	1.14	0.74	0.067	0.183	0.85	0.71	Key West
126	Summerland Key, Niles Channel Bridge	0.90	0.59	0.500	0.933	0.67	0.58	Key West
127	Ramrod Key, Niles Channel Bridge	0.93	0.58	0.450	1.200	0.67	0.46	Key West
128	Big Torch Key, Niles Channel	0.77	0.56	3.250	2.083	0.61	0.71	Key West
129	Knockemdown Key, north end	1.80	1.19	3.500	4.900	1.35	1.21	Key West
130	Raccoon Key, east side	2.04	1.31	3.333	5.150	1.50	1.21	Key West
131	Content Keys, Content Passage	2.86	1.87	2.783	3.833	2.13	1.83	Key West
132	Key Lois, southeast end	1.46	0.91	-0.583	-0.083	1.06	0.75	Key West
133	Sugarloaf Key, east side, Tarpon Creek	1.24	0.76	-0.017	0.250	0.89	0.58	Key West
134	Gopher Key, Cudjoe Bay	1.22	0.78	-0.100	0.283	0.90	0.71	Key West
135	Sugarloaf Key, Pirates Cove	0.74	0.55	-0.133	1.683	0.59	0.75	Key West
136	Cudjoe Key, Cudjoe Bay	1.18	0.76	0.033	0.683	0.87	0.71	Key West
137	Summerland Key, southwest side, Kemp Channel	1.12	0.69	0.233	0.833	0.81	0.54	Key West
138	Cudjoe Key, north end, Kemp Channel	2.17	1.43	3.533	4.667	1.63	1.46	Key West
139	Sugarloaf Key, northeast side, Bow Channel	1.40	0.87	3.783	3.400	1.01	0.71	Key West
140	Cudjoe Key, Pirates Cove	1.01	0.69	3.833	2.917	0.77	0.79	Key West
141	Sugarloaf Key, north end, Bow Channel	1.82	1.09	3.617	5.333	1.29	0.75	Key West
142	Pumpkin Key, Bow Channel	2.14	1.35	3.283	4.650	1.56	1.17	Key West
143	Sawyer Key, outside, Cudjoe Channel	2.32	1.28	2.750	5.400	1.57	0.50	Key West
144	Sawyer Key, inside, Cudjoe Channel	2.10	1.17	2.617	5.317	1.43	0.50	Key West
145	Johnston Key, southwest end, Turkey Basin	1.59	0.92	3.433	5.633	1.10	0.50	Key West
146	Upper Sugarloaf Sound - Perky	0.42	0.23	5.617	8.417	0.28	0.08	Key West

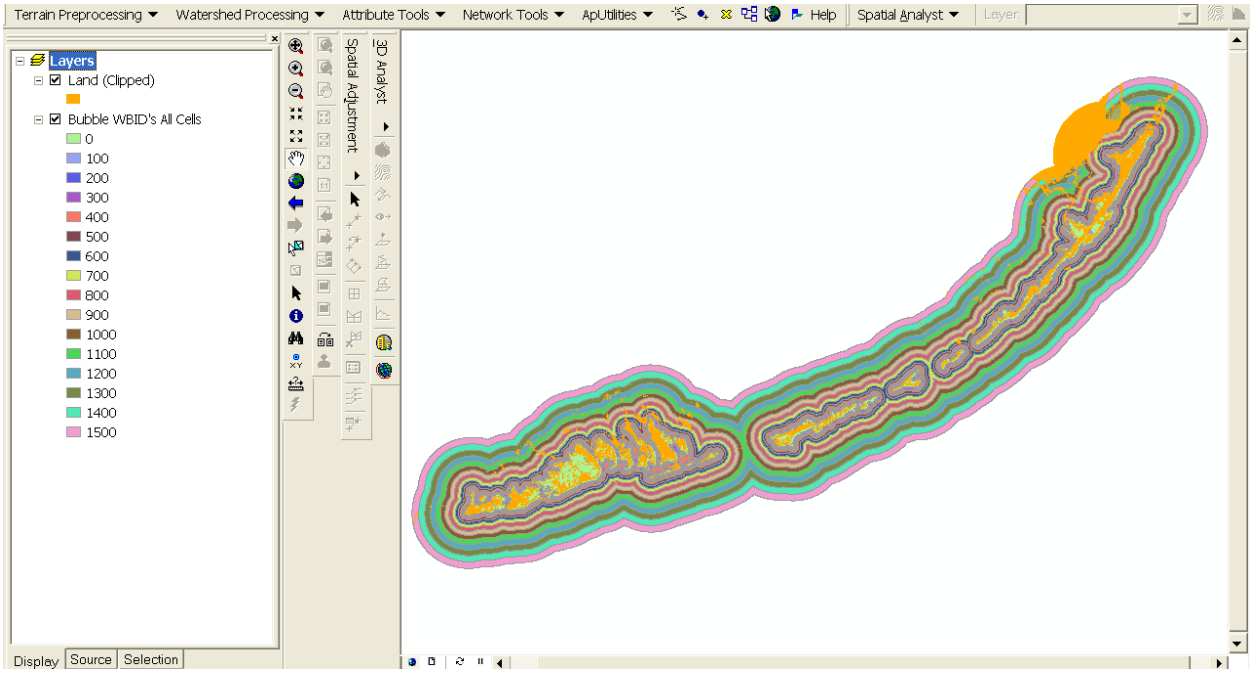
Sta. #	Station Name	Mean Tide (feet)		Time Difference (hrs) (TD_H/TD_L)		Height Adjustments (H_{adj}/L_{adj})		Ref. Station
		Range	Level	High	Low	High	Low	
147	Upper Sugarloaf Sound - Park Channel Bridge	0.34	0.24	5.783	8.550	0.26	0.29	Key West
148	Upper Sugarloaf Sound - North Harris Channel	0.33	0.22	5.533	8.067	0.25	0.25	Key West
149	Upper Sugarloaf Sound - Tarpon Creek	0.46	0.32	0.183	0.283	0.35	0.38	Key West
150	Snipe Keys, southeast end, Inner Narrows	1.79	1.10	3.417	5.650	1.28	0.83	Key West
151	Snipe Keys, Middle Narrows	1.42	0.87	3.733	5.900	1.02	0.67	Key West
152	Snipe Keys, Snipe Point	2.31	1.47	2.250	3.550	1.69	1.29	Key West
153	Waltz Key, Waltz Key Basin	1.36	0.91	3.883	5.550	1.03	0.96	Key West
154	Duck Key Point, Duck Key, Waltz Key Basin	1.61	1.03	3.450	4.950	1.19	0.96	Key West
155	O'Hara Key, north end, Waltz Key Basin	1.40	0.90	3.883	5.650	1.03	0.83	Key West
156	Saddlebunch Keys, Channel No. 5	0.76	0.65	4.533	6.967	0.66	1.12	Key West
157	Saddlebunch Keys, Channel No. 4	0.76	0.45	4.583	5.600	0.54	0.29	Key West
158	Saddlebunch Keys, Channel No. 3	0.62	0.36	1.733	0.500	0.43	0.21	Key West
159	Bird Key, Similar Sound	0.82	0.51	0.317	1.050	0.59	0.42	Key West
160	Shark Key, southeast end, Similar Sound	0.70	0.46	0.300	1.850	0.52	0.46	Key West
161	Saddlebunch Keys, Similar Sound	0.52	0.31	0.650	2.683	0.37	0.21	Key West
162	Big Coppitt Key, northeast side, Waltz Key Basin	1.22	0.69	4.350	6.900	0.84	0.33	Key West
163	Rockland Key, Rockland Channel Bridge	0.97	0.69	5.033	6.100	0.76	0.88	Key West
164	Boca Chica Key, Long Point	1.28	0.81	3.900	5.367	0.94	0.71	Key West
165	Channel Key, west side	0.91	0.62	3.150	3.117	0.70	0.71	Key West
166	Boca Chica Channel Bridge	0.72	0.52	1.383	1.483	0.57	0.67	Key West
167	Key Haven - Stock Island Channel	0.94	0.66	2.417	2.950	0.73	0.79	Key West
168	Sigsbee Park, Garrison Bight Channel	1.04	0.73	1.983	2.100	0.81	0.88	Key West
169	Key West, south side, Hawk Channel	1.44	0.94	-0.200	0.167	1.07	0.92	Key West
170	KEY WEST	1.31	0.90	0.000	0.000	1.00	1.00	Key West
171	Sand Key Lighthouse, Sand Key Channel	1.26	0.82	-0.383	0.017	0.94	0.79	Key West
172	Garden Key, Dry Tortugas	1.14	0.89	0.483	0.550	0.94	1.33	Key West

Source: http://www.co-ops.nos.noaa.gov/tides

Appendix C
GIS PROCEDURES

The following steps were taken to derive the water volume data for each model cell. This and all source datasets were projected to the Florida State Plane Coordinate System, East Zone, NAD83, U.S. Survey Feet. All feature classes reside within the **water_volume** geodatabase.

- Downloaded the most recent WBID layer from FDEP's geospatial data portal (http://www.dep.state.fl.us/gis/datadir.htm).
- After reviewing FDEP's WBID's layer for relevancy, minor adjustments to the geometry of certain polygons were deemed necessary. Most of the original WBID polygons remained unaltered; however, others were modified to account for localized conditions. The final version of the WBID layer was saved as **wbids** and stored in the **water_volume** geodatabase.
- To analyze variability of nearshore conditions, it was determined that the **wbids** layer should be buffered with 15 concentric rings, or cells, extending to the outermost point 12,000 meters offshore. The ArcGIS *Buffer* routine was invoked and each WBID polygon was buffered each of the 15 predefined distances. The result was saved as **bubble_wbids_all_cells** and stored in the **water_volume** geodatabase. The feature attribute field BUFF_DIST was created to store the values of the desired buffer distances and identify each buffer cell accordingly. Note: BUFF_DIST = 0 simply represents an unbuffered WBID.
- Dissolved all interior boundaries of **bubble_wbids_all_cells** and saved the layer as **bubble_wbids_cell15**. This layer represents the study area limits and was used to clip other source datasets to ensure a common extent among layers.
- Downloaded the **countyshore_areas.shp** (land) polygon file from FDEP, clipped it to the study limits, and saved it as **land** in the geodatabase.
- Using the ArcGIS *Erase* routine, eliminated land areas from the **bubble_wbids_all_cells** layer so land areas would not be accounted for in the water volume calculations. The resulting layer was saved in the **water_volume** geodatabase as **bubble_wbids_cells_no_land**.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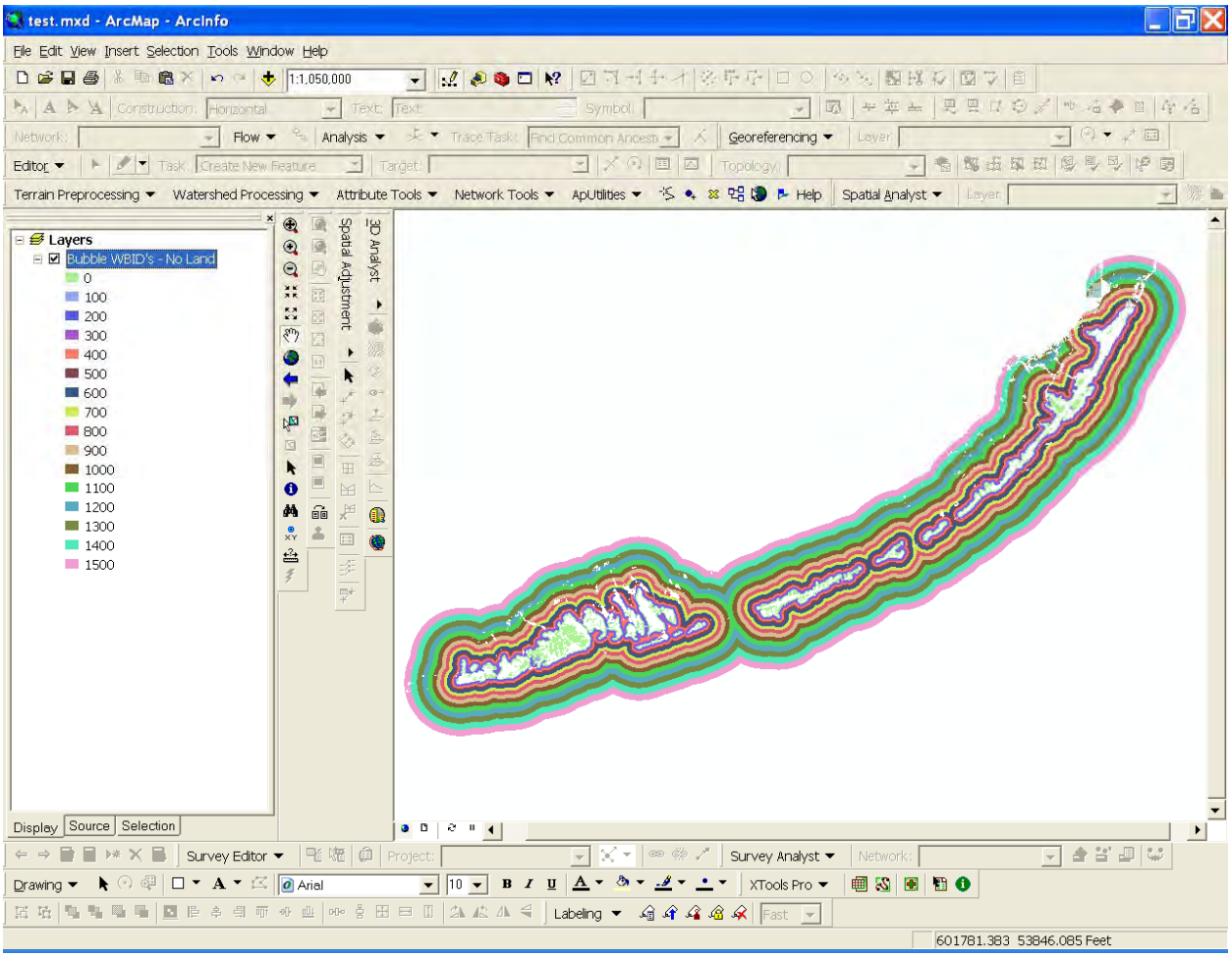
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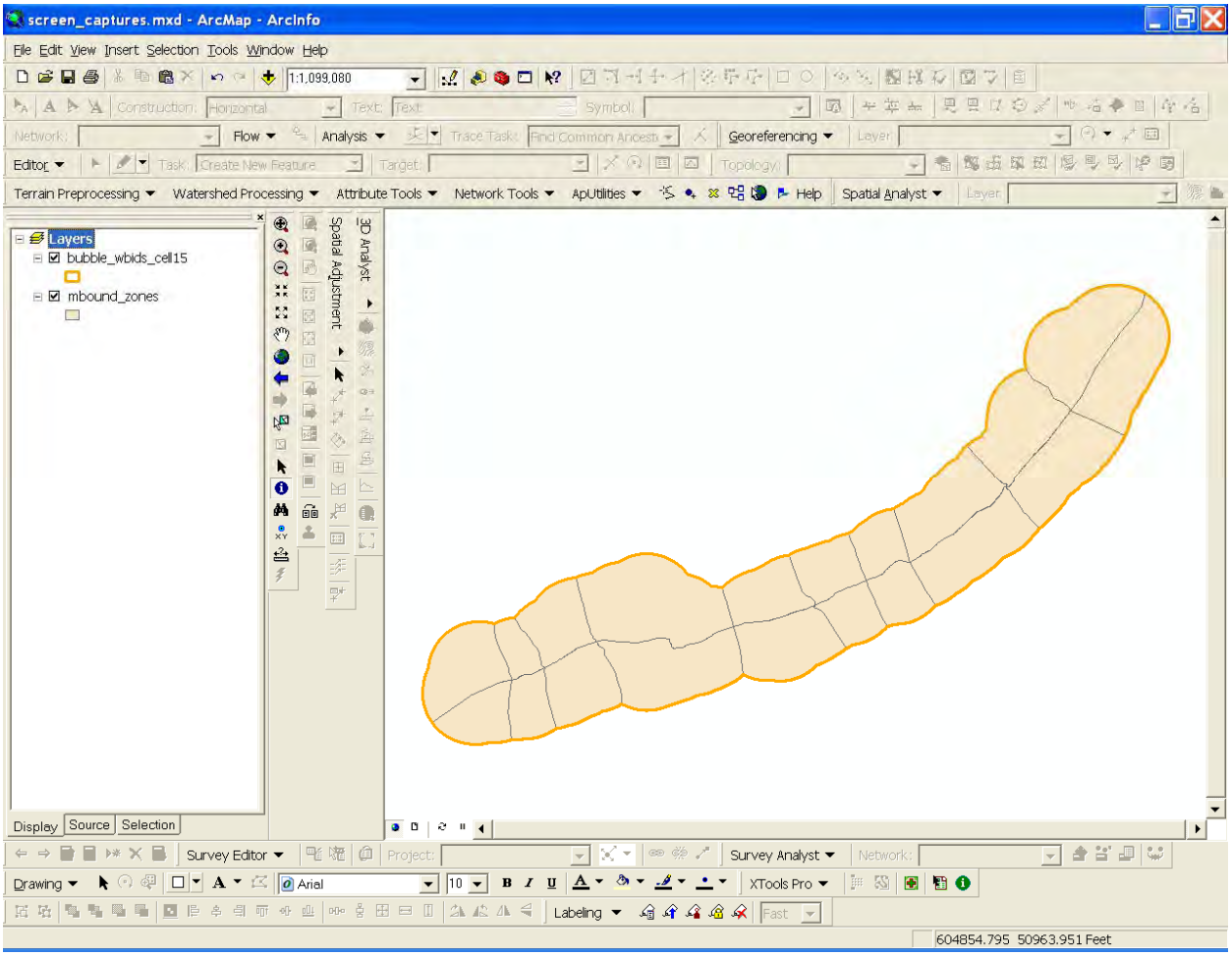
601781.383 53846.085 Feet

The **bubble_wbids_cells_no_land** layer was subdivided into 20 North/South zones with US 1 as the dividing line.

- Created a line file representing zone divisions and saved it as **model_linework.shp**.
- Converted the **model_linework.shp** file to a temporary polygon layer, clipped it to the study limits, and saved the result as **mbound_zones** in the **water_volume** geodatabase.



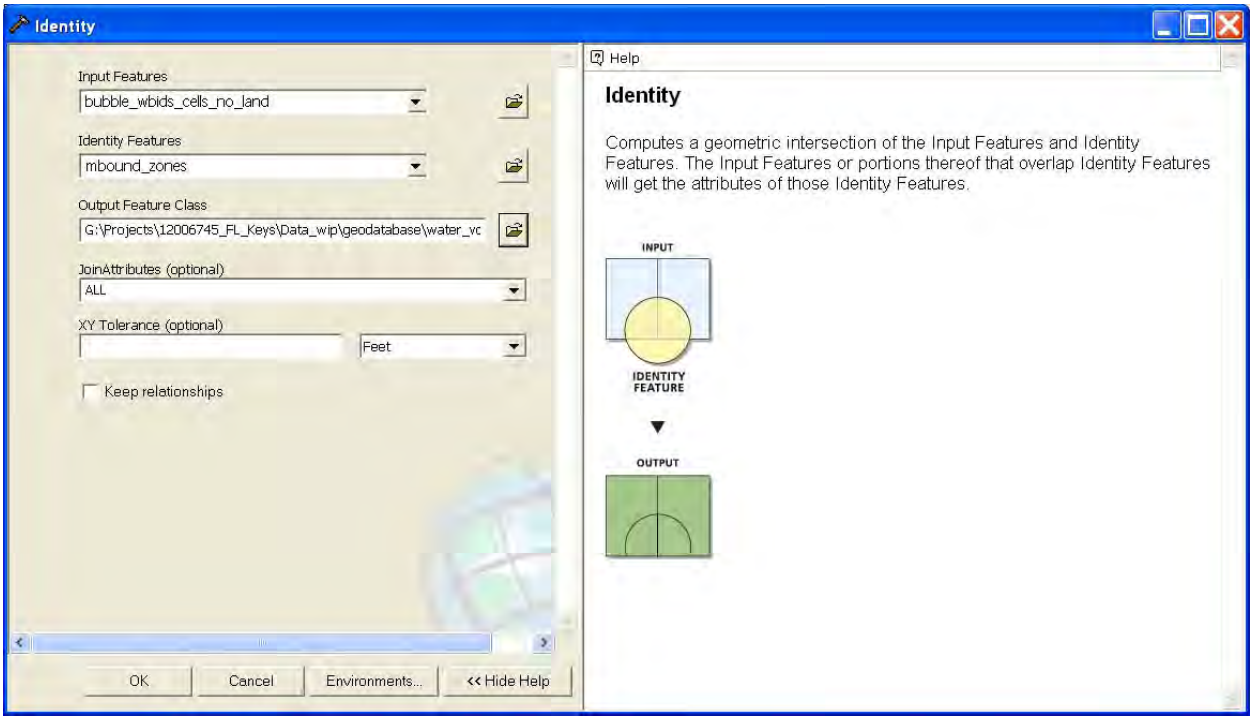
- Created a ZONE field in the **mbound_zones** feature attribute table and attributed each feature with its respective zone number (e.g., 1N, 3S, etc.)

Attributes of mbound_zones

OBJECTID *	Shape *	Shape_Length	Shape_Area	Zone
1	Polygon M	191248.890447	2082478333.11827	1S
2	Polygon M	164058.115805	1612897750.35614	2S
3	Polygon M	208635.308604	2895485619.91563	3S
4	Polygon M	317567.019008	4879033488.85478	4S
5	Polygon M	240993.974868	3605999541.64563	5S
6	Polygon M	168168.654365	1718078184.87816	6S
7	Polygon M	239520.981207	3464069623.83188	1N
8	Polygon M	163767.651173	1780574264.70164	7S
9	Polygon M	140182.655	1142413440.73648	2N
10	Polygon M	208267.521319	2620259355.90253	3N
11	Polygon M	334085.703101	6681462233.24585	4N
12	Polygon M	206882.563248	2530379635.89848	5N
13	Polygon M	287662.937206	4161542843.50555	8S
14	Polygon M	183436.730037	2106685441.23482	6N
15	Polygon M	166709.298502	1690309259.91151	7N
16	Polygon M	271794.157055	3862995817.9929	8N
17	Polygon M	274460.463427	4176771871.75666	9S
18	Polygon M	262528.474848	3973003918.21887	9N
19	Polygon M	287987.005444	4170385830.48761	10S
20	Polygon M	296628.327635	5009487170.08515	10N

Record: 1 Show: All Selected Records (0 out

- Using the ArcGIS *Identity* routine, overlaid the **mbound_zones** layer and the **bubble_wbids_cells_no_land** layer, with **bubble_wbids_cells_no_land** as the input layer and **mbound_zones** as the identity layer. This was necessary to merge the geometry and attributes of these layers while preserving the spatial extent of **bubble_wbids_cells_no_land** in the output.



- The result was saved in the **water_volume** geodatabase as **bubble_wbids_cells_w_zones**. The combination of unique cell and zone polygons results in 320 distinct features.
- Created the field UNIQUE_ID and populated it with a unique identifier for each of the 320 feature polygons.

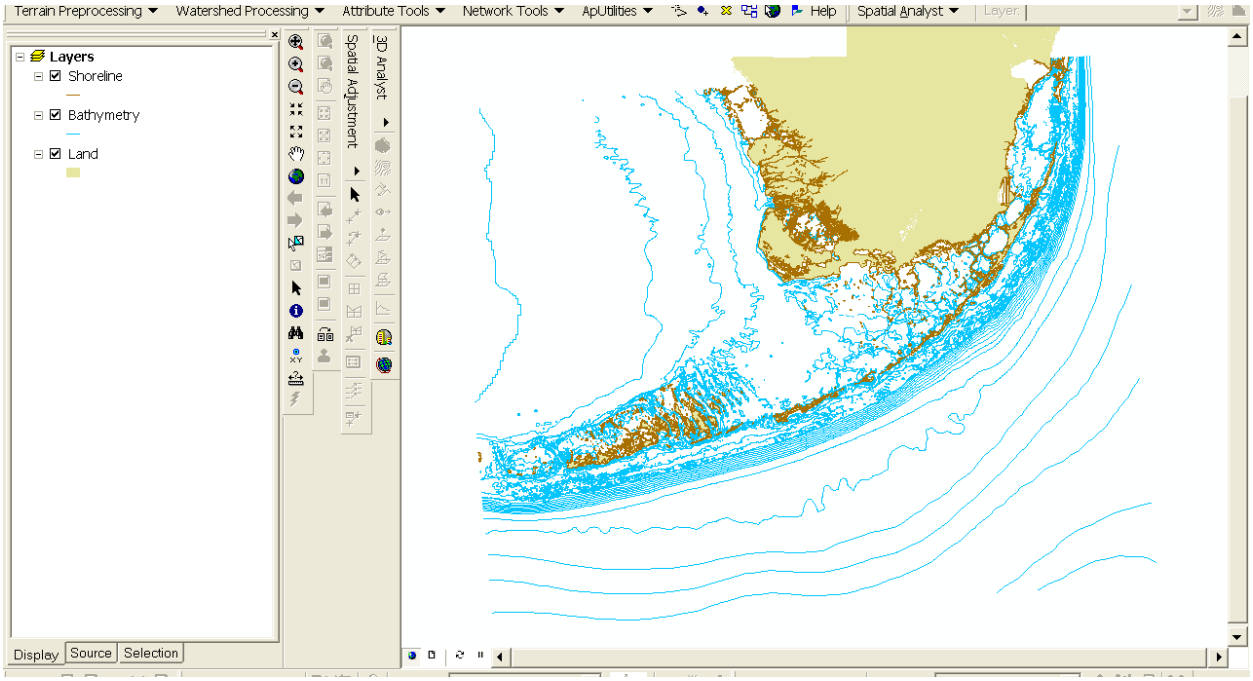
Attributes of bubble_wbids_cells_w_zones

OBJECTID *	Shape *	BUFF_DIST	Zone	Unique_ID	Shape_Length	Shape_Area
72	Polygon M	300	4N	72	568289.104885	255753439.958392
73	Polygon M	300	6N	73	98541.193191	47070498.027357
74	Polygon M	300	7N	74	70627.670538	33754548.68646
75	Polygon M	300	8S	75	193544.414756	90144810.264658
76	Polygon M	300	8N	76	220934.503602	105725840.466109
77	Polygon M	300	9S	77	191385.501661	91386056.485327
78	Polygon M	300	9N	78	264288.085354	117605358.377911
79	Polygon M	300	10S	79	172767.038867	80602281.791467
80	Polygon M	300	10N	80	204519.881938	92435442.492432
81	Polygon M	400	1S	81	72535.662761	45735765.515103
82	Polygon M	400	2S	82	71424.460923	43415696.40844
83	Polygon M	400	3S	83	130205.835549	81204638.68482
84	Polygon M	400	4S	84	315646.495116	213746655.189907
85	Polygon M	400	1N	85	121605.243921	76385336.734215
86	Polygon M	400	2N	86	86825.539798	46453746.6686

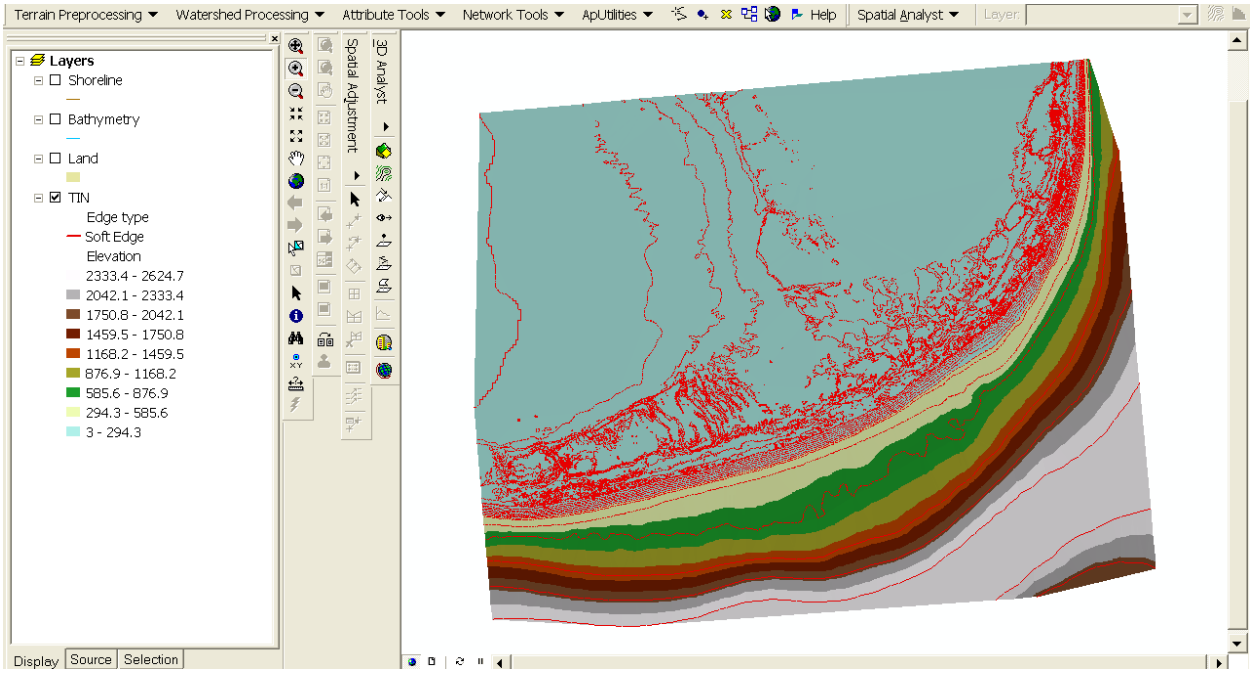
Record: 1 Show: All Selected Records (0 out of 320 Selected)

Following are the steps that were taken to create a Water Volume layer:

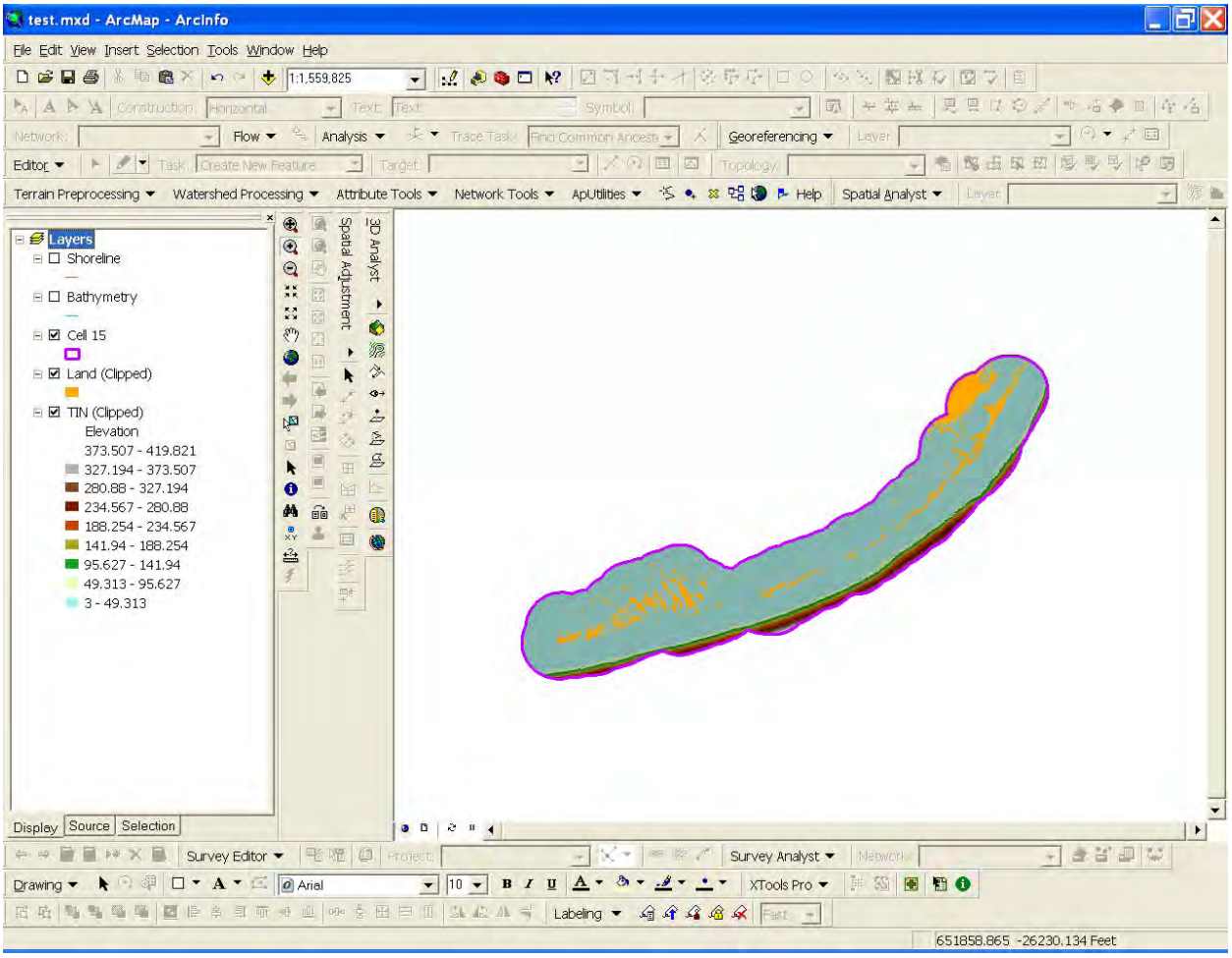
- Downloaded the **bathym.shp** (bathymetry) line file from the FGDL (http://www.geoplan.ufl.edu). Selected a subset of features and saved the layer as **bathymetry** in the **water_volume** geodatabase.
- Downloaded the **countyshore_lines.shp** (shoreline) line file from FDEP and filtered for shoreline arcs. Saved the layer as **shoreline** in the **water_volume** geodatabase.



- Created a DEPTH_FT field in the shoreline attribute table to match that of the bathymetry attribute table. Attributed all values in the shoreline DEPTH_FT field with a value of '0.'
- Updated the **bathymetry** layer with the **shoreline** layer.
- Created a temporary elevation model (TIN) from the **bathymetry** layer using values in the DEPTH_FT field.



- Used the **bubble_wbids_cell15** feature class to clip the TIN to the extent of the study area. Saved the TIN as **wbid_bathy**.



Following are the steps that were taken to extract water volume information from the **wbid_bathy** TIN:

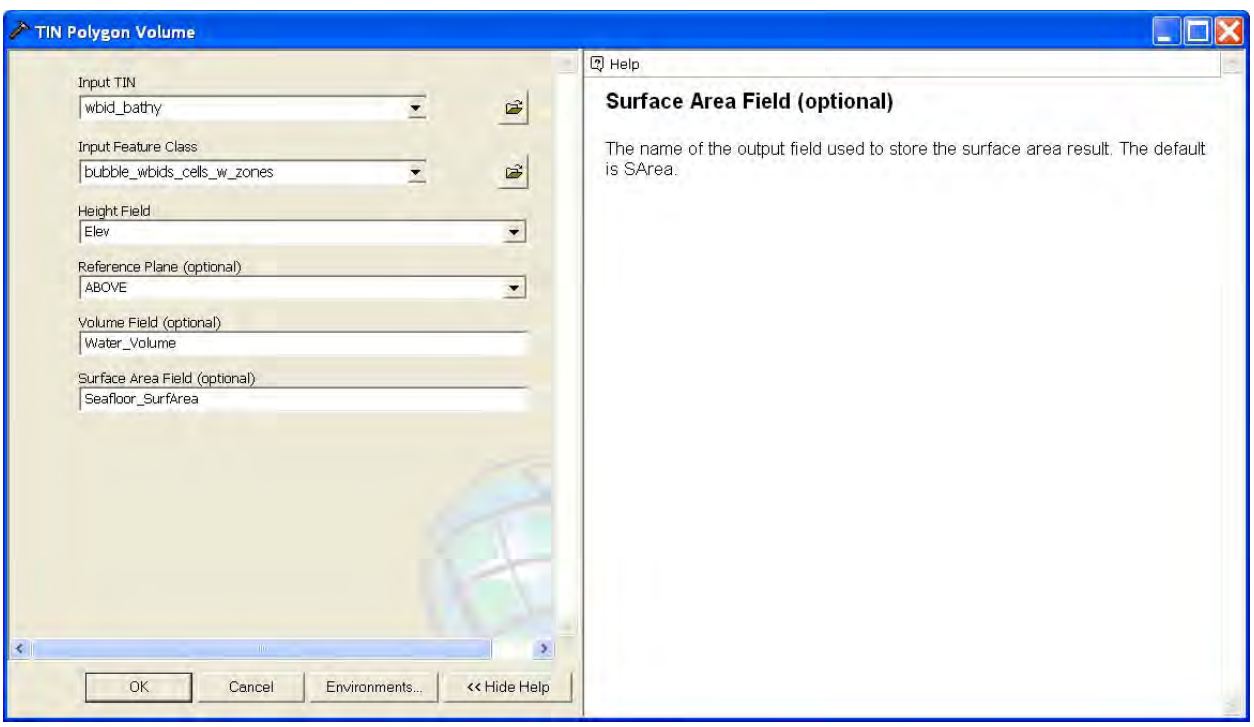
- Created a field called ELEV in the **bubble_wbids_cells_w_zones** layer and attributed it as '0' for all records. The *TIN Polygon Volume* routine requires a HEIGHT field in the polygon layer, which serves as the horizontal plane, above or below which volumes are calculated for each polygon. In this case, all polygons in the **bubble_wbids_cells_w_zones** layer are assumed to be at sea level, or elevation 0.

Attributes of bubble_wbids_cells_w_zones

OBJECTID *	Shape *	BUFF_DIST	Elev	Zone	Unique_ID	Shape_Length	Shape_Area
72	Polygon M	300	0	4N	72	568289.104885	255753439.958392
73	Polygon M	300	0	6N	73	98541.193191	47070498.027357
74	Polygon M	300	0	7N	74	70627.670538	33754548.68646
75	Polygon M	300	0	8S	75	193544.414756	90144810.264658
76	Polygon M	300	0	8N	76	220934.503602	105725840.466109
77	Polygon M	300	0	9S	77	191385.501661	91386056.485327
78	Polygon M	300	0	9N	78	264288.085354	117605358.377911
79	Polygon M	300	0	10S	79	172767.038867	80602281.791467
80	Polygon M	300	0	10N	80	204519.881938	92435442.492432
81	Polygon M	400	0	1S	81	72535.662761	45735765.515103
82	Polygon M	400	0	2S	82	71424.460923	43415696.40844
83	Polygon M	400	0	3S	83	130205.835549	81204638.68482
84	Polygon M	400	0	4S	84	315646.495116	213746655.189907
85	Polygon M	400	0	1N	85	121605.243921	76385336.734215
86	Polygon M	400	0	2N	86	86825.539798	46453746.6686

Record: 1 Show: All Selected Records (0 out of 320 Selected) Options

- Using the 3D Analyst *TIN Polygon Volume* routine, extracted Water Volume and Sea Floor Surface Area from the **wbid_bathy** TIN for each polygon in the **bubble_wbids_cells_w_zones** layer.



- Though the result of the *TIN Polygon Volume* routine does not create a new layer, the **bubble_wbids_cells_w_zones** layer was saved as the **bubble_wbids_cells_w_zones_vol** feature class specifically to store the calculations and provide clarity.

Attributes of bubble_wbids_cells_w_zones_vol

OBJECTID *	Shape *	BUFF_DIST	Elev	Zone	Unique_ID	Shape_Length	Shape_Area	Water_Volume	SeaFloor_SurfArea
83	Polygon M	400	0	3S	83	130205.835549	81204638.68482	538178697.871894	80338725.626404
84	Polygon M	400	0	4S	84	315646.495116	213746655.189907	1315283669.15931	212320231.971275
85	Polygon M	400	0	1N	85	121605.243921	76385336.734215	520720800.841235	76387708.180372
86	Polygon M	400	0	2N	86	86825.539798	46453746.6686	54005454.439503	31410355.735815
87	Polygon M	400	0	5S	87	144861.988533	92911441.182846	934238052.133671	92912094.41416
88	Polygon M	400	0	6S	88	95912.084513	60188266.613315	622031316.874771	60188513.238579
89	Polygon M	400	0	3N	89	133891.26746	78889711.02448	68352298.213384	58889777.472264
90	Polygon M	400	0	7S	90	83644.895331	52687155.223626	354644377.811977	52688055.937058
91	Polygon M	400	0	5N	91	115557.415912	72842901.208602	422752608.753165	72842988.930375
92	Polygon M	400	0	4N	92	473614.887851	269478823.5346	1043986845.4566	215149445.373753
93	Polygon M	400	0	6N	93	100692.17567	63930856.57406	368251342.908421	63931106.395462
94	Polygon M	400	0	7N	94	79623.274919	50441016.134719	286459902.705956	50441229.60372
95	Polygon M	400	0	8S	95	200949.491154	127869451.020377	747027130.855222	127871471.19803
96	Polygon M	400	0	8N	96	224020.709984	142043069.429859	637510783.433874	141977985.179762
97	Polygon M	400	0	9S	97	186230.26083	120191965.78577	835556076.341886	120192228.935441

Record: 2 Show: All Selected Records (0 out of 320 Selected) Options

- Resulting model cell data was used by the WTF model, as well as pollutant kriging calculations (below)

MODEL CELL DATA

Model	Zone	Cell	Volume (ac-ft)	Water Area (acres)
1	N	0	6,628	1,210
1	N	1	4,048	527
1	N	2	8,557	1,105
1	N	3	10,392	1,573
1	N	4	11,954	1,754
1	N	5	15,375	2,173
1	N	6	19,503	2,689
1	N	7	20,834	3,282
1	N	8	23,191	3,972
1	N	9	26,169	4,728
1	N	10	35,164	5,503
1	N	11	49,656	6,742
1	N	12	77,432	7,862
1	N	13	121,366	9,299
1	N	14	172,565	10,926
1	N	15	226,167	12,535
2	N	0	85	137
2	N	1	107	99
2	N	2	353	283

Model	Zone	Cell	Volume (ac-ft)	Water Area (acres)
2	N	3	755	507
2	N	4	1,240	721
2	N	5	2,089	929
2	N	6	3,133	1,338
2	N	7	3,435	1,513
2	N	8	4,304	1,717
2	N	9	5,977	1,694
2	N	10	7,935	1,918
2	N	11	8,963	2,069
2	N	12	5,601	1,952
2	N	13	19,452	2,171
2	N	14	38,486	2,202
2	N	15	40,920	2,073
3	N	0	1,373	1,204
3	N	1	382	277
3	N	2	699	570
3	N	3	1,072	972
3	N	4	1,569	1,352
3	N	5	2,413	1,795
3	N	6	3,665	2,237
3	N	7	4,984	2,562
3	N	8	6,280	2,450
3	N	9	10,729	3,085
3	N	10	13,345	3,743
3	N	11	11,279	4,082
3	N	12	20,392	4,195
3	N	13	76,852	5,530
3	N	14	122,461	6,147
3	N	15	155,174	6,714
4	N	0	4,770	3,025
4	N	1	5,251	1,774
4	N	2	12,584	3,426
4	N	3	20,633	4,722
4	N	4	23,967	4,939
4	N	5	23,066	4,506
4	N	6	27,496	5,530
4	N	7	27,635	6,129
4	N	8	29,111	6,700
4	N	9	28,955	7,770
4	N	10	38,989	9,670
4	N	11	48,549	10,948
4	N	12	55,095	11,425

Model	Zone	Cell	Volume (ac-ft)	Water Area (acres)
4	N	13	65,141	12,249
4	N	14	121,102	13,690
4	N	15	150,626	14,504
5	N	0	4,026	1,200
5	N	1	2,562	497
5	N	2	4,940	892
5	N	3	7,136	1,278
5	N	4	9,705	1,672
5	N	5	12,404	2,074
5	N	6	14,218	2,487
5	N	7	16,672	2,932
5	N	8	20,184	3,462
5	N	9	25,335	4,114
5	N	10	31,040	4,901
5	N	11	34,754	5,700
5	N	12	36,558	5,848
5	N	13	39,343	6,115
5	N	14	42,714	6,460
5	N	15	44,987	6,838
6	N	0	1,994	687
6	N	1	1,546	361
6	N	2	3,572	736
6	N	3	5,975	1,081
6	N	4	8,454	1,468
6	N	5	11,056	1,918
6	N	6	14,270	2,445
6	N	7	16,494	2,815
6	N	8	18,888	3,220
6	N	9	21,051	3,592
6	N	10	23,047	3,951
6	N	11	24,895	4,311
6	N	12	27,642	4,666
6	N	13	30,296	5,028
6	N	14	33,167	5,382
6	N	15	36,412	5,730
7	N	0	1,686	490
7	N	1	1,270	234
7	N	2	2,716	475
7	N	3	4,463	775
7	N	4	6,576	1,158
7	N	5	9,062	1,648
7	N	6	12,603	2,232

Model	Zone	Cell	Volume (ac-ft)	Water Area (acres)
7	N	7	14,498	2,516
7	N	8	15,308	2,595
7	N	9	16,884	2,864
7	N	10	18,255	3,157
7	N	11	18,063	3,468
7	N	12	17,281	3,777
7	N	13	17,886	4,062
7	N	14	20,538	4,307
7	N	15	23,740	4,685
8	N	0	5,120	2,084
8	N	1	2,981	826
8	N	2	6,592	1,628
8	N	3	10,567	2,424
8	N	4	14,635	3,259
8	N	5	17,475	4,040
8	N	6	20,629	4,666
8	N	7	25,213	5,459
8	N	8	27,660	5,883
8	N	9	29,090	6,337
8	N	10	34,469	6,758
8	N	11	37,778	7,111
8	N	12	41,468	7,668
8	N	13	43,212	8,067
8	N	14	42,066	8,337
8	N	15	37,081	8,738
9	N	0	10,158	3,725
9	N	1	3,808	1,053
9	N	2	7,890	1,965
9	N	3	11,692	2,687
9	N	4	15,187	3,433
9	N	5	17,833	4,051
9	N	6	18,020	4,447
9	N	7	16,813	4,568
9	N	8	19,200	5,369
9	N	9	18,208	5,789
9	N	10	17,672	6,327
9	N	11	20,624	6,871
9	N	12	22,627	6,829
9	N	13	20,976	6,662
9	N	14	15,904	5,128
9	N	15	15,090	5,181
10	N	0	2,389	1,028

Model	Zone	Cell	Volume (ac-ft)	Water Area (acres)
10	N	1	3,171	752
10	N	2	7,630	1,444
10	N	3	11,464	2,107
10	N	4	15,537	2,814
10	N	5	19,351	3,555
10	N	6	23,546	4,307
10	N	7	26,767	4,955
10	N	8	27,460	5,209
10	N	9	22,290	4,738
10	N	10	12,553	3,667
10	N	11	7,904	2,777
10	N	12	10,172	2,961
10	N	13	13,118	3,465
10	N	14	17,379	4,074
10	N	15	19,974	4,482
1	S	0	1,652	656
1	S	1	1,400	326
1	S	2	3,568	617
1	S	3	7,137	851
1	S	4	16,314	1,050
1	S	5	28,649	1,347
1	S	6	43,735	1,675
1	S	7	57,222	2,039
1	S	8	69,573	2,448
1	S	9	83,373	2,917
1	S	10	94,641	3,445
1	S	11	117,328	4,063
1	S	12	129,603	4,799
1	S	13	169,364	5,641
1	S	14	495,480	6,581
1	S	15	1,015,693	7,632
2	S	0	535	622
2	S	1	703	326
2	S	2	1,872	607
2	S	3	3,737	765
2	S	4	11,488	994
2	S	5	21,603	1,227
2	S	6	28,685	1,466
2	S	7	36,530	1,720
2	S	8	43,670	1,990
2	S	9	50,019	2,286
2	S	10	63,191	2,600

Model	Zone	Cell	Volume (ac-ft)	Water Area (acres)
2	S	11	68,963	2,911
2	S	12	63,062	3,200
2	S	13	206,591	3,493
2	S	14	555,266	3,830
2	S	15	997,872	4,195
3	S	0	1,041	926
3	S	1	1,017	504
3	S	2	2,656	1,008
3	S	3	5,563	1,400
3	S	4	12,355	1,844
3	S	5	25,375	2,142
3	S	6	37,146	2,554
3	S	7	46,183	3,007
3	S	8	57,314	3,478
3	S	9	67,105	3,954
3	S	10	81,888	4,424
3	S	11	117,518	4,861
3	S	12	137,711	5,302
3	S	13	160,279	5,758
3	S	14	397,411	6,137
3	S	15	994,705	6,394
4	S	0	3,104	2,497
4	S	1	3,832	1,596
4	S	2	10,852	3,133
4	S	3	20,318	4,447
4	S	4	30,195	4,874
4	S	5	49,257	4,143
4	S	6	73,913	4,932
4	S	7	103,005	5,727
4	S	8	141,026	6,528
4	S	9	189,491	7,584
4	S	10	227,868	8,703
4	S	11	251,741	9,693
4	S	12	265,596	9,946
4	S	13	672,911	10,464
4	S	14	1,531,500	11,069
4	S	15	2,600,737	11,764
5	S	0	2,859	1,743
5	S	1	1,794	554
5	S	2	5,046	1,057
5	S	3	10,863	1,558
5	S	4	21,447	2,133

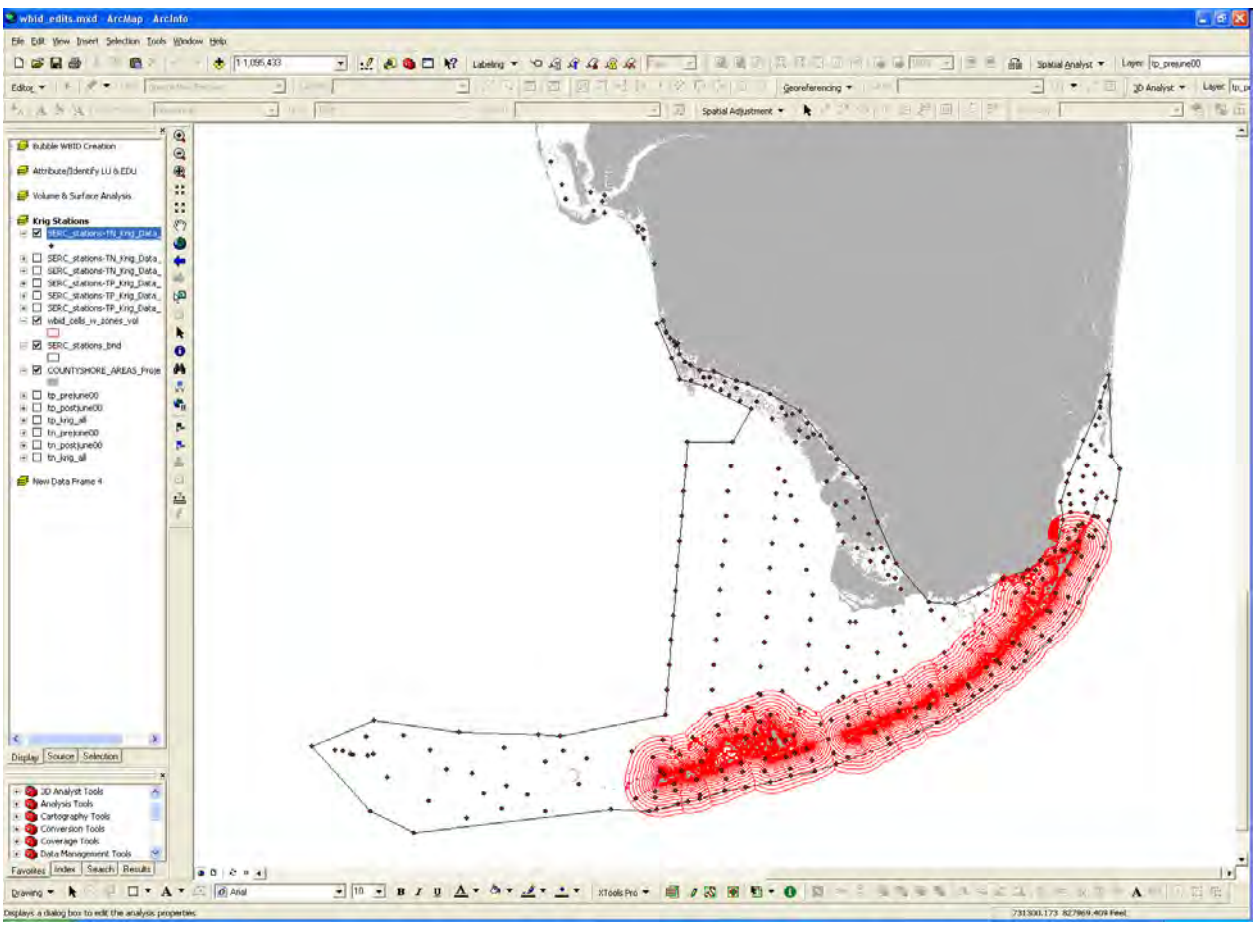
Model	Zone	Cell	Volume (ac-ft)	Water Area (acres)
5	S	5	37,049	2,768
5	S	6	57,661	3,461
5	S	7	88,409	4,228
5	S	8	128,814	5,055
5	S	9	144,775	5,907
5	S	10	154,744	6,920
5	S	11	278,820	7,839
5	S	12	669,565	8,052
5	S	13	1,242,714	8,604
5	S	14	2,001,433	9,316
5	S	15	3,015,149	10,111
6	S	0	2,081	1,192
6	S	1	1,310	439
6	S	2	3,326	812
6	S	3	7,468	1,118
6	S	4	14,280	1,382
6	S	5	22,722	1,734
6	S	6	32,283	2,111
6	S	7	41,174	2,303
6	S	8	53,090	2,549
6	S	9	65,089	2,805
6	S	10	78,162	3,057
6	S	11	70,981	3,295
6	S	12	101,676	3,530
6	S	13	346,880	3,764
6	S	14	678,944	3,992
6	S	15	1,051,125	4,238
7	S	0	886	752
7	S	1	813	346
7	S	2	2,185	693
7	S	3	4,562	992
7	S	4	8,142	1,210
7	S	5	13,747	1,633
7	S	6	22,777	2,106
7	S	7	33,998	2,440
7	S	8	45,510	2,627
7	S	9	51,427	2,884
7	S	10	57,277	3,189
7	S	11	65,947	3,516
7	S	12	165,962	3,853
7	S	13	452,874	4,193
7	S	14	852,860	4,549

Model	Zone	Cell	Volume (ac-ft)	Water Area (acres)
7	S	15	1,323,726	4,886
8	S	0	1,991	1,492
8	S	1	1,683	644
8	S	2	4,383	1,298
8	S	3	8,846	2,065
8	S	4	17,149	2,936
8	S	5	32,851	3,907
8	S	6	56,116	4,791
8	S	7	78,963	5,617
8	S	8	99,771	6,260
8	S	9	112,945	6,954
8	S	10	140,131	7,692
8	S	11	247,169	8,463
8	S	12	756,680	9,262
8	S	13	1,677,635	10,051
8	S	14	2,511,617	10,861
8	S	15	3,352,488	11,729
9	S	0	3,525	2,202
9	S	1	2,214	824
9	S	2	5,749	1,420
9	S	3	11,517	2,091
9	S	4	19,182	2,759
9	S	5	28,645	3,386
9	S	6	39,578	3,961
9	S	7	56,236	4,784
9	S	8	77,214	5,549
9	S	9	92,164	6,333
9	S	10	103,536	7,143
9	S	11	110,430	7,974
9	S	12	175,896	8,814
9	S	13	551,846	9,703
9	S	14	1,457,363	10,595
9	S	15	2,352,498	11,509
10	S	0	737	869
10	S	1	1,060	657
10	S	2	3,716	1,291
10	S	3	9,457	1,841
10	S	4	17,071	2,452
10	S	5	28,898	3,172
10	S	6	40,760	3,790
10	S	7	50,813	4,465
10	S	8	64,237	5,313

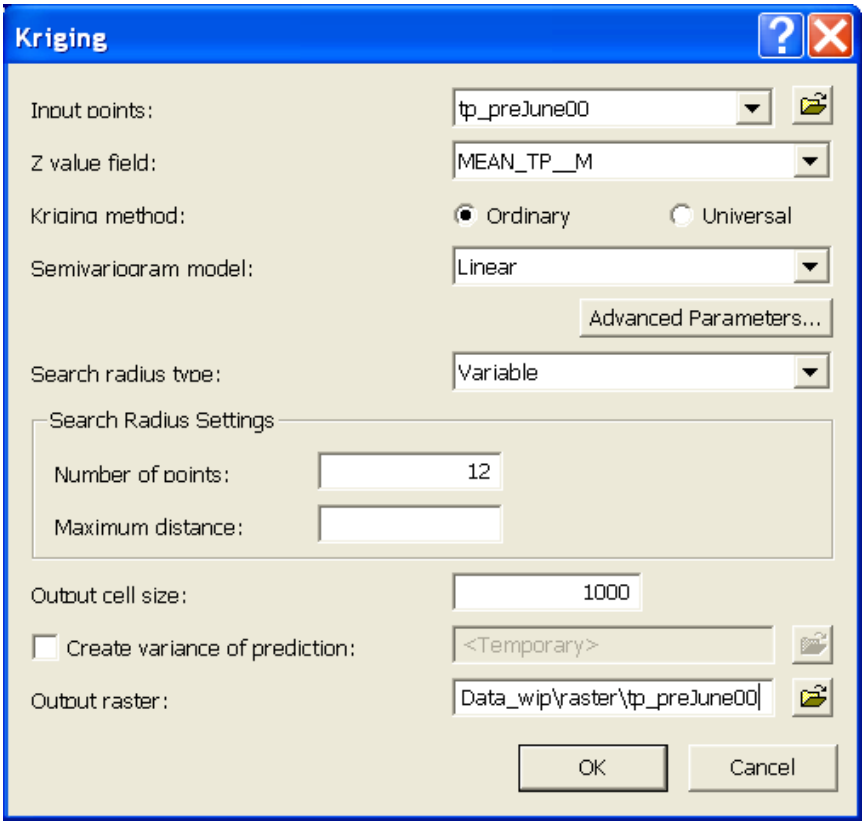
Model	Zone	Cell	Volume (ac-ft)	Water Area (acres)
10	S	9	77,656	6,247
10	S	10	98,736	7,301
10	S	11	120,026	8,540
10	S	12	132,254	9,852
10	S	13	229,212	11,160
10	S	14	495,838	12,693
10	S	15	1,516,050	14,406

Pollutant Kriging Calculations

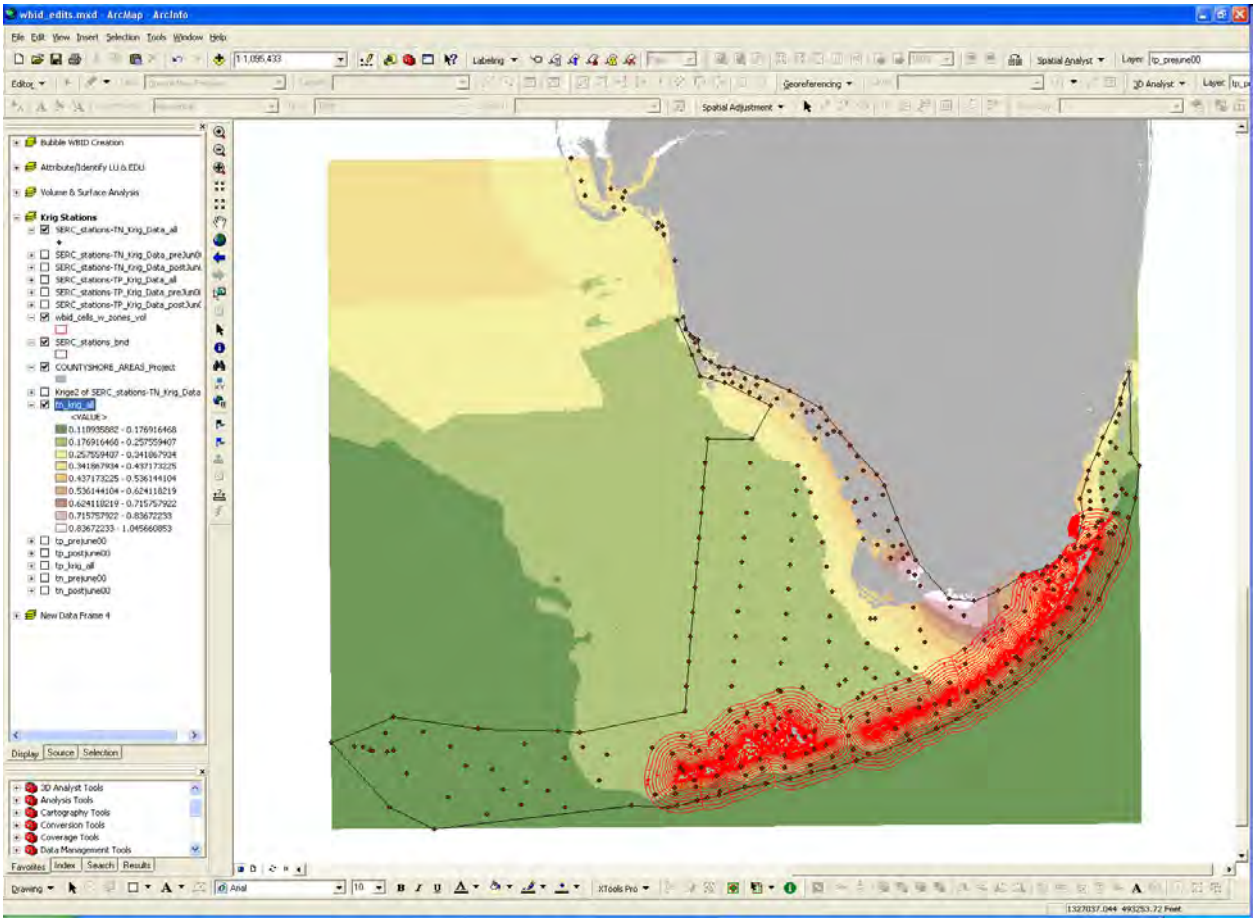
- A table of average values (bottom surface readings) was developed for each station and monitoring event in the water quality database for total phosphorous (TP) and total nitrogen (TN).
- Summarized the values in each table into 3 time periods – pre-June 2000, post-June 2000, and all dates – resulting in six tables for spatial analysis.
- Computed the geometric mean of the pollutant values for each monitoring station over each of the time periods contained in each table and saved the results in the MEAN_* field.
- Geocoded the Latitude and Longitude values of each Station in the tables to establish six Water Quality Monitoring Station GIS point layers. Saved the layers as **tp_preJune00**, **tp_postJune00**, **tp_all_dates**, **tn_preJune00**, **tn_postJune00**, and **tn_all_dates** in the **water_volume** geodatabase.



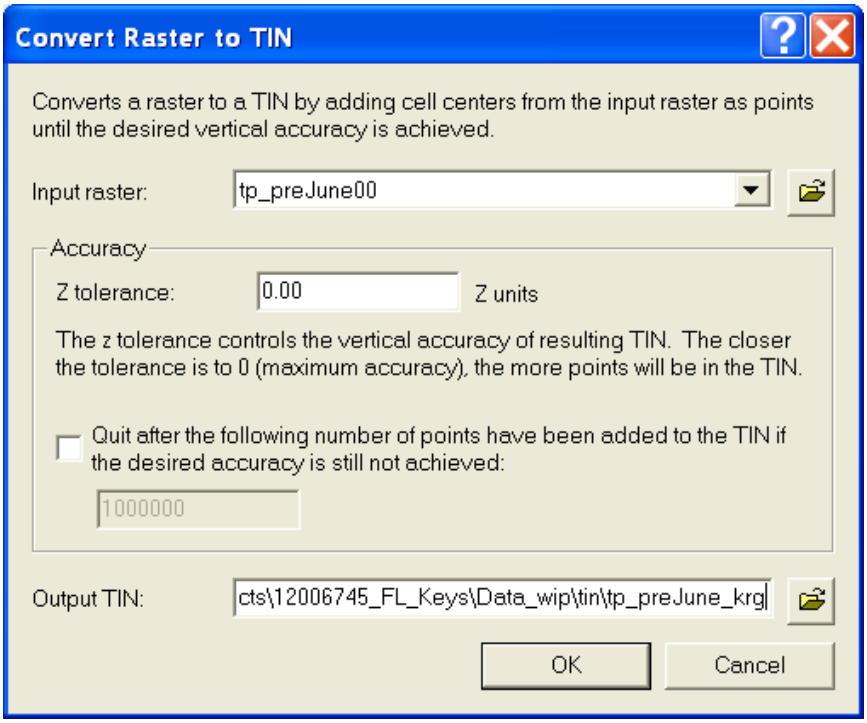
- Using the MEAN values in each Water Quality Monitoring Station layer, created continuous surface pollutant models (rasters) using the ArcGIS *Kriging* routine.
- Z value field: The MEAN field in the attribute table (geometric mean value of TN or TP).
- A Linear Semi-variogram Model was used based on the linear variogram model adopted by Dr. Joe Boyer of the Southeastern Research Center at Florida International University.
- The default values were used for search radius settings & output cell size.



- Saved the six rasters as **tp_preJune00**, **tp_postJune00**, **tp_all_dates**, **tn_preJune00**, **tn_postJune00**, and **tn_all_dates**.



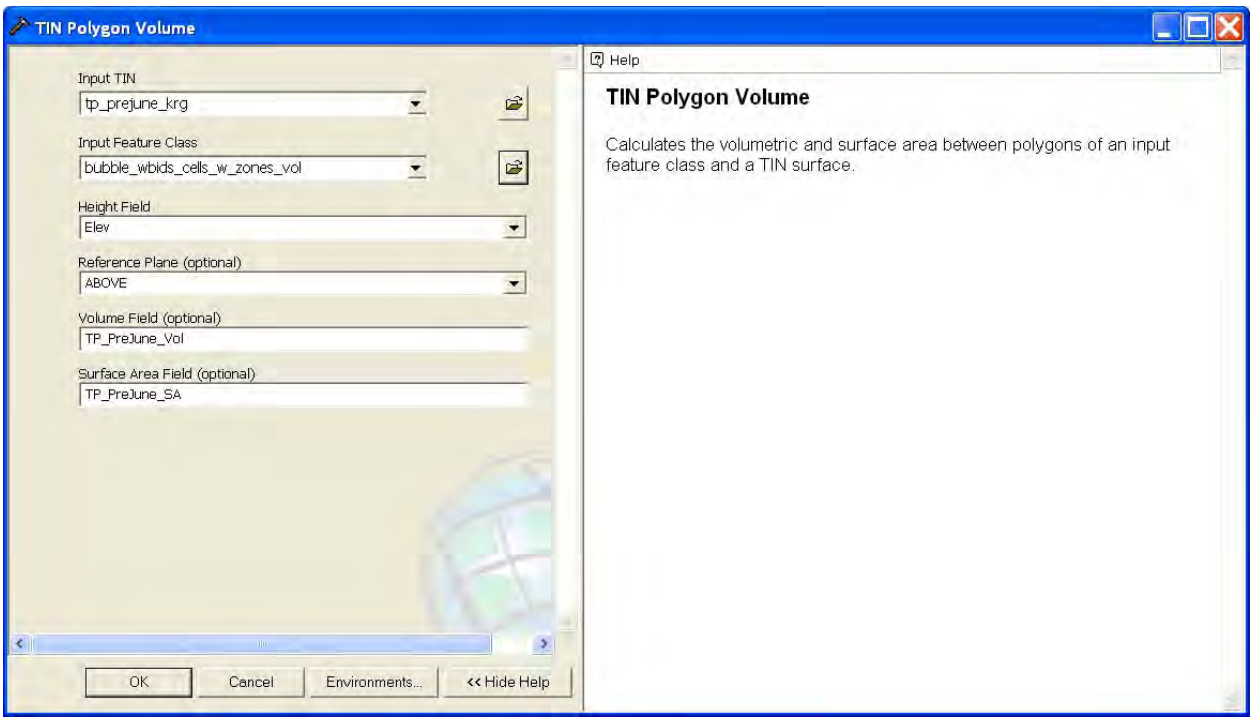
- Converted each kriged surface to a TIN and saved the TINs as **tp_preJune_krg**, **tp_postJune_krg**, **tp_alldates_krg**, **tn_preJune_krg**, **tn_postJune_krg**, and **tn_alldates_krg**.

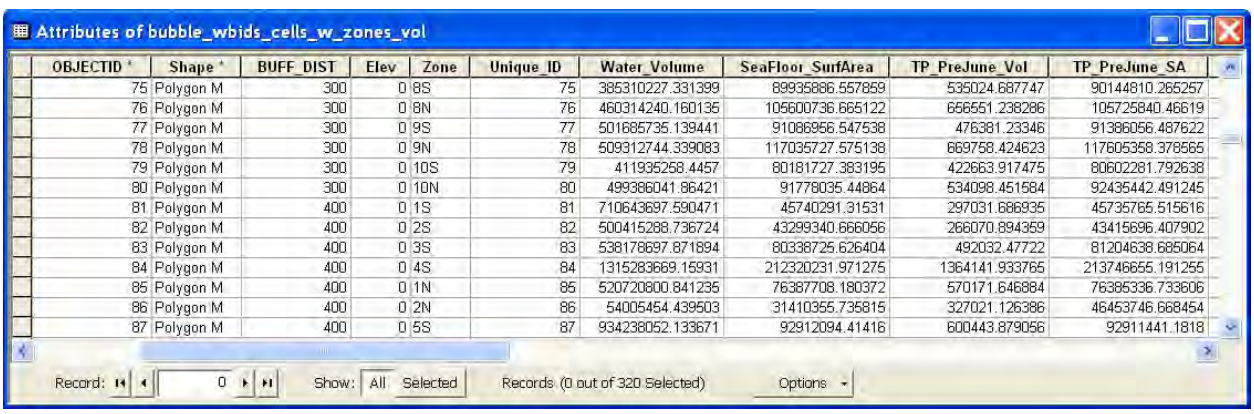


At this point, instead of converting rasters to TINs, the next step would have been to invoke the ArcGIS *Zonal Statistics* routine to capture the values of each pollutant raster into the polygons of the **bubble_wbids_cells_w_zones_vol** layer. However, ESRI has a documented bug in this algorithm, which required converting each surface to a TIN. The potential, minor consequence of this workaround is the difference in precision between the two storage methods. Converting to TIN appears to round the pollutant values to 3 decimal places. At this point, it's not known if the remaining decimal values have been dropped or are stored internally and simply not displayed.

In addition, a TIN is best used as an elevation model, where it can calculate items such as slope, aspect, hillshade, viewshed, cut and fill, and volumes. This is why it was chosen to store water volumes and model the sea floor surface in the study area. The *TIN Polygon Volume* routine, by extension, extracts volumes and surface areas into the overlapping polygons of a vector layer, which is why this was a logical routine for storing water volumes in the cell/zone polygons of the **bubble_wbids_cells_w_zones** layer.

- Used the 3D Analyst *TIN Polygon Volume* routine to extract Volume and Surface Area from each pollutant TIN for each polygon in the **bubble_wbids_cells_w_zones_vol** layer.





OBJECTID *	Shape *	BUFF_DIST	Elev	Zone	Unique_ID	Water_Volume	SeaFloor_SurfArea	TP_PreJune_Vol	TP_PreJune_SA
75	Polygon M	300	0	8S	75	385310227.331399	89935886.557859	535024.687747	90144810.265257
76	Polygon M	300	0	8N	76	460314240.160135	105600736.665122	656551.238286	105725840.46619
77	Polygon M	300	0	9S	77	501685735.139441	91086956.547538	476381.23346	91386056.487622
78	Polygon M	300	0	9N	78	509312744.339083	117035727.575138	669758.424623	117605358.378565
79	Polygon M	300	0	10S	79	411935258.4457	80181727.383195	422663.917475	80602281.792638
80	Polygon M	300	0	10N	80	499386041.86421	91778035.44864	534098.451584	92435442.491245
81	Polygon M	400	0	1S	81	710643697.590471	45740291.31531	297031.686935	45735765.515616
82	Polygon M	400	0	2S	82	500415288.736724	43299340.666056	266070.894359	43415696.407902
83	Polygon M	400	0	3S	83	538178697.871894	80338725.626404	492032.47722	81204638.685064
84	Polygon M	400	0	4S	84	1315283669.15931	212320231.971275	1364141.933765	213746655.191255
85	Polygon M	400	0	1N	85	520720800.841235	76387708.180372	570171.646884	76385336.733606
86	Polygon M	400	0	2N	86	54005454.439503	31410355.735815	327021.126386	46453746.668454
87	Polygon M	400	0	5S	87	934238052.133671	92912094.41416	600443.879056	92911441.1818

Converting the pollutant rasters to TINs and invoking the *TIN Polygon Volume* routine provides somewhat misleading values. In the preceding screen captures, 'TP_PreJune_Vol' and 'TP_PreJune_SA' do not reflect true volumes or surface areas for TP, since these pollutant surfaces are not 3 dimensional. They are simply placeholders for subsequent calculations. To arrive at a pollutant by volume result, an additional calculation is needed. In this example, Total Phosphorous values by cell/zone = (TP_PreJune_Vol / TP_PreJune_SA) * Water_Volume. In the screen capture below, the result is shown in the field TP_PreJune_Total.

Attributes of bubble_wbids_cells_w_zones_vol

BUFF_DIST	Elev	Zone	Unique_ID	Water_Volume	SeaFloor_SurfArea	TP_PreJune_Vol	TP_PreJune_SA	TP_PreJune_Final
300	0	8S	75	385310227.331399	89935886.557859	535024.687747	90144810.265257	2286881.335235
300	0	8N	76	460314240.160135	105600736.665122	656551.238286	105725840.46619	2858524.302526
300	0	9S	77	501685735.139441	91086956.547538	476381.23346	91386056.487622	2615209.349224
300	0	9N	78	509312744.339083	117035727.575138	669758.424623	117605358.378565	2900518.360661
300	0	10S	79	411935258.4457	80181727.383195	422663.917475	80602281.792638	2160114.65443
300	0	10N	80	499386041.86421	91778035.44864	534098.451584	92435442.491245	2885487.476598
400	0	1S	81	710643697.590471	45740291.31531	297031.686935	45735765.515616	4615287.268629
400	0	2S	82	500415288.736724	43299340.666056	266070.894359	43415696.407902	3066769.727104
400	0	3S	83	538178697.871894	80338725.626404	492032.47722	81204638.685064	3260914.674198
400	0	4S	84	1315283669.15931	212320231.971275	1364141.933765	213746655.191255	8394206.713043
400	0	1N	85	520720800.841235	76387708.180372	570171.646884	76385336.733606	3886874.749507
400	0	2N	86	54005454.439503	31410355.735815	327021.126386	46453746.668454	380182.995095
400	0	5S	87	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Record: 6 Show: All Selected Records (0 out of 320 Selected) Options

- Calculated true pollutant volumes by cell/zone for all time periods and stored the values in the *_Final field of the **bubble_wbids_cells_w_zones_vol** layer.