Appendix G

Methods for the Estimation of Nutrient and Hydrologic Loadings to the Clearwater Harbor and St. Joseph Sound Estuaries

1.0 Estimation of Nutrient and Hydrologic Loadings for the St. Joseph Sound / Clearwater Harbor Watershed

Nutrient and hydrologic loads were estimated for the period 1985-2008 for the three bay segments within the greater St. Joseph Sound / Clearwater Harborwatershed. Drainage basins forSt. Joseph Sound, Clearwater Harbor North and South were delineated based on drainage boundaries used by Pinellas County's Ambient Water Quality Monitoring Program. To develop non-point source loading estimates, we included the Anclote River watershed which extends north and east into Pasco and Hillsborough counties. Our estimates of nutrient loading were comprised of loads derived from atmospheric deposition, non-point source and point source from domestic wastewater treatment facilities, including surface water discharges and land application of reclaimed water. Estimates were made for hydrologic load, total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS) and biochemical oxygen demand (BOD) for each of the 13 drainage basins which consisted of the major basins along the eastern shoreline of the estuary as well as the coastal zones inclusive of barrier islands and spoil islands.

1.1 Atmospheric Deposition

Total atmospheric deposition is defined as the sum of wet deposition (rainfall) and dry deposition (gaseous constituent interaction and dust fallout) directly to the surface of the bay. Deposition of pollutants to the watershed of the bay is incorporated into non-point source loading estimates.

Three types of data were used to estimate total atmospheric deposition:

- an estimate of the hydrologic load directly to the surface of the bay via precipitation;
- an estimate of the pollutant concentration in that precipitation; and
- an estimate of dry deposition, either from empirical data or model-based estimates.

Precipitation-derived hydrologic loads to the bay surface were estimated as the total monthly rainfall using the rainfall dataset used to generate hydrologic loads to the watershed (described above).

Mean monthly pollutant concentrations for TN in rainfallwere obtained from the National Atmospheric Deposition Program (NADP) Verna Wellfield site in Sarasota County. This site represents the nearest long-term site measuring precipitation concentration data. TN loadings from precipitation were estimated by multiplying the monthly precipitation-weighted mean TN concentrations from the Verna site and the monthly bay surface hydrologic loads to estimate monthly wet TN loads to the bay. Estimates of wet deposition for nitrogen were calculated as follows:

$$Nwet_m = [N]_m * H_m,$$

where:

$Nwet_m$ = wet deposition of nitrogen (kg/month) for each month *m*,

$[N]_m$ = mean precipitation-weighted nitrogen concentration (g/m^3) in the rainfall measured at the Verna Wellfield for each month *m*, and

H_m = estimated hydrologic load (m^3/month) from rainfall for each month *m*to the bay surface.

Concentrations for TP in rainfall were unavailable from the Verna site and had to be estimated from a relationship betweenrainfall concentrations of nitrogen and phosphorus which were based ondata collected by the Tampa Bay Atmospheric Deposition Study (TBADS) were utilized (Poor, 2000). This program, running from 1996 to 2006, included sampling elements for both wet and dry deposition at an intensive monitoring site located on the Gandy Bridge Causeway. The data available from TBADS include concentrations fornitrogen and phosphorous, wet and dry deposition rates, and an estimate of the ratio of dry:wet deposition, and have been used to estimate atmospheric deposition to Tampa Bay (Pribble et al., 2001).

Estimates of dry deposition for both nitrogen and phosphorus were based on data collected at the TBADS site. Dry deposition was estimated using the TBADS-derived seasonal dry:wet deposition ratio, which was 1.05 for the dry season (months 1-6 and 11-12) and 0.66 for the wet season (months 7-10), as follows:

$Ndry_m =$ Seasonal Deposition Ratio * $Nwet_m$,

where:

$Ndry_m$ = dry deposition of nitrogen (kg/month) for each month *m*, and

$Nwet_m$ = wet deposition of nitrogen (kg/month) for each month *m*.

Total atmospheric deposition to a surface of the bay was given as the sum of the wet and dry deposition, as follows:

$Ntot_m = Nwet_m + Ndry_m$,

where:

$Ntot_m$ = total atmospheric deposition of nitrogen (kg/month) for each month *m*to the surface of the bay.

1.2 Point Source Loads

Point sources of flow and pollutant loadings are defined as discharges that originate at adiscrete location, such as from a pipe or a small, definable land area (such as for landapplication of treated wastewater effluent). Point sources include publicly andprivately owned wastewater treatment plants.

The estimated pollutant loadings from domestic point sources were derived using the samemethods as used in previous loading estimates (Pribble et al. 2001, Zarbock et al., 1994;1996; Poe et al., 2005). Point sources identified for use in estimation of 1989-2008 loadings areshown in Table 1-1, and include all direct surface discharges and all land applicationwith an annual average daily flow (ADF) of 0.1 mgd or greater.Point sources were identified by reviewing FDEP point source dischargelocations in relation to the Clearwater Harbor/St. Joseph Sound watershed. This list of point sources was then confirmed with the assistance of FDEP Tampa office staff.Data sources used to estimate domestic point source discharge and concentration data for Clearwater Harbor/St. Joseph Sound1989-2008 are as follows:

- Florida Department of Environmental Protection's Alchemy database;
- Pinellas County Utilities (for the William E. Dunn Advanced Wastewater Treatment Plant);
- City of Clearwater Utilities (for the City of Clearwater Master Urban Reuse facility and the City of Clearwater Marshall Street facility).

A database of point source discharge information was developed, listing monthly discharge rates and TN, TP, TSS, and BOD concentration data. Both surface water dischargers and facilities with land application of effluent were included. Monthly data from a total of 8 major point source dischargers (Table 1-1) were included.

Table 1-1 - Domestic wastewater treatment facilities used to estimate point source loadings to Clearwater Harbor and St. Joseph Sound for the period 1989-2008.

Facility Name	Bay Segment	Sub-basin
Mid-County	St. Joseph Sound	Curlew Creek
William E. Dunn*	St. Joseph Sound	Klosterman Bayou
Coca-Cola/Minute Maid	Clearwater Harbor North	Coastal Zone
Dunedin-Mainland	Clearwater Harbor North	Coastal Zone
City of Clearwater - Marshall Street	Clearwater Harbor North	Stevenson's Creek
Tarpon Springs	Clearwater Harbor North	Anclote River
City of Clearwater - Master Reuse**	Clearwater Harbor North	Stevenson's Creek
Town of Belleair	Clearwater Harbor South	Coastal Zone

*Data were unavailable for the period prior to 1995 before this facility assumed treatment of loads from smaller package plants in the surrounding area.

**Plant began service to areas with the watershed in 1998.

The database was subjected to quality control measures to ensure that the most accurateflows and concentrations obtainable were used in the loading estimates. The entries werescanned for incongruous data points andobvious outliers were removed from therecord. Complete records existed for most domestic wastewater treatment plants, withfacilities reporting flow rate and concentrations for TN, TP, TSS, and BOD on a monthlybasis. Attempts were made to locate sources of valid data to replace missing or invalidvalues, contacting facility personnel directly when necessary.

When actual recorded monthly data were not available, we used measured proxies (maximum or monthly average total Kjeldahl nitrogen for TN, monthly average orthophosphate for TP). When proxy values were not recorded, we used one of two methods:

- If fewer than 4 consecutive months of data were missing, discharge and/or pollutant concentrations were set to the average of the previous and following month.
- If data from 4 or more consecutive months were missing, discharge and/or pollutant concentrations were set to the monthly averages for at least 3 consecutive years of recorded data.

Data for the William E. Dunn facility were unavailable prior to 1995. Differences in plant capacity (i.e., the incorporation of several additional facilities and increased plant capacity from 1989-1995) and the more recent period prevented averaging of the available data. Therefore, loads were estimated beginning in 1995for the Dunn facility.

The above methods of estimating monthly input data was chosen as an alternative toshowing missing data for loads from major point sources. The percentage of data records for which data were estimated based on previous months records was approximately 4%for flow data and approximately 9% for water quality data.

Surface Discharge

Many of the inventoried domestic facilities utilize direct surface discharge for effluentdisposal. Surface water inputs from domestic point sources were estimated for each of the basins receiving surface discharge, expressed as a volume per unit time (i.e., million gallons per day, mgd). Flows from each point source were assigned to thebasin that receives the discharge, allowing the aggregation of point source flows for all three bay segments. All of the effluent released via surfacedischarge was assumed to reach the waters of Clearwater Harbor and St Joseph Sound. Estimates of point source pollutant loading for surface water discharges were obtained bymultiplying the reported mean monthly concentration of the pollutant of concern and themean monthly discharge volume. With appropriate conversion factors, this calculationyields a mass per unit time, such as tons per year of pollutant for TN, TP, TSS and BOD.

Land Application

Treated effluent from domestic facilities is frequently discharged onto the land, most commonly for reuse by spray irrigation or into percolation ponds. The applied effluent evaporates, is taken up by vegetation, becomes surface runoff (generally a very small component of the total volume), or infiltrates to the water table. Therefore, pollutant loadings from this source that reach the bay generally do so via groundwater. In this loading analysis, land application effluent loads are calculated separately from groundwater loads. Land application loadings were estimated using recorded effluent quality data from specific facilities, with "typical" reduction rates applied to the nitrogen and phosphorus once in the environment. These reduction rates are the same as those used previously for loading estimations from Pinellas County to Tampa Bay (Pribble et al. 2001, Zarbock et al., 1994; 1996; 2005), and account for attenuation of pollutants in the environment prior to the effluent flow reaching the receiving waters of the estuary. Pollutant loading reductions applied to loads discharged to land were 95% reduction for TN, TP, TSS and BOD from spray irrigation. We assumed that 100% of monthly reuse volumes from treatment facilities were used for land application and apportioned these volumes to each basin as a percentage of the facility's service area contained within the basin.

1.3 Non-point Source Loads

Non-point source pollutant loadings are a result of stormwater runoff from the watershed surrounding St. Joseph Sound and Clearwater Harboras well as base flow from the Anclote River and smaller tidal tributaries draining to the estuary. We estimated non-point source loadings for TN, TP, TSS, and BOD for the 1985--2008 period using the same methods as those used to establish loading estimates for the Tampa Bay estuary (Poe et al.2005). Basin boundaries were obtained from the Pinellas County Department of Environmental Management. Land use coverages classified according to the Florida Land Use and Cover Classification System (FDOT, 1985) were obtained for 1990 and 2005from SWFWMD and wereusedto estimate non-point source loadings for the 1985-1995 and the 1996-2008, respectively.Soil data were also acquired from SWFWMD and were produced by the United States Department of Agriculture/Natural Resource Conservation Service. Rainfall data were obtained from the National ClimaticData Center of the National Weather Service for the ten rain gauges located within a 35-mile radius of the watershed. Streamflow data were obtained from the USGeological Survey for the Anclote River gauge station at Perrine Ranch Road in Elfers, FL.

We estimated non-point source loadings for the majority of the watershed (with the exception of the gauged Anclote River basin) as a function of calculated streamflows using the empirical model with NWS rainfall data, GIS coverages for 1990 and 2005 land use, soils, and basin boundaries, seasonal land use-specific runoff coefficients, and land use-specific water quality concentrations. Land uses were aggregated from FDOT FLUCCS codes into 21 coastal land use categories (Appendix 2) following the same convention used in the previous loading estimates for Tampa Bay (Pribble et al., 2001; Zarbock et al., 1994; 1996; Poe et al., 2005). For each land use category (i), specific water quality concentrations (WQi′) were obtained from the literature (Appendix 3). Runoff (Qi′) from each land use category was estimated by the empirical model. The product of the literature-based land use-specific water quality concentrations and the estimated runoff from each land use category is summed over each basin to provide the pollutant loadings from each basin.

We provide here, a summary of the empirical model for estimating non-point source hydrologic and nutrient loads to the Clearwater Harbor and St. Joseph Sound estuaries. A complete description of the development and testingof the empirical model is provided by Poe et al. (2005).

The empirical model is a relatively simple statistical regression model which predicts total monthly runoff for each ungauged basin as a non-linear function of rainfall and land use. Land use is aggregated into four classes: urban, agricultural, forest/undisturbed, and wetland/water which are included in the model as a percentage of the entire basin.The use of the percent coverage of these four classes in the hydrology model was found to improve the fit of the rainfall/runoff relationships without compromising the predictive capability of the model. We also included in the model, two variables representing one and two months lagged rainfall based on a relationship between the existing month's streamflow and the previous months′ rain, as suggested from earlier work by Dames & Moore (1992). This relationship may be due to the lag in release of rainfall stored in wetlands and surface water bodies, groundwater interflow, or other factors. Aspointed out in the Dames & Moore work, flows are often observed during months with little or no rainfall. Thus, it was concluded that a non-zero intercept for a model which relates flow to rainfall was appropriate.To further improve runoff estimates, we used four separate rainfall/runoff relationships, varying with season and basin land use characteristics.

The four cases were:
1) wet season, “more urban” basin;
2) dryseason, “more urban” basin;
3) wet season, “less urban” basin;
4) dry season, “less urban” basin.

Based on long-term rainfall records for the watershed, the wet season was defined as July through October, and the dry season was November through June. Although long-term rainfall data from Tampa International Airport suggests a June-September wet season, the July-October period accounted for approximately 55% of the annual precipitation on a watershed-wide basis.

"More urban" basins were defined as having greater than 19% urban land use, and "less urban" basins had less than 19% urban land use. The selection of the 19% level was based on an investigation of the distribution of urban land cover and the goodness of fit of the rainfall/runoff relationships for the Tampa Bay watershed.

We apportioned total estimated runoff in a basin to constituent land uses,based on their relative frequency of occurrence in the basin through the use of landuse-specific runoff coefficients. These coefficients allocated fractions of total streamflow to individual land uses based on the extent of their coverage and the literature values of land use-specific runoff coefficients (Appendix 3).The land use composition of each basin was included through an adjustment factor **(a).**

Monthly non-point source flows for each basin were calculated as a log-linear function of rainfall, land use and land-use specific runoff coefficients using this model:

$$\mathbf{FLOW = \exp\,[a + (b0 * RAIN0 + b1*RAIN1 + b2*RAIN2)]} \quad \text{(Equation 1)}$$

and,

$$\mathbf{a = (c1*L1) + (C2*L2) + (C3*L3) + (C4*L4)}$$

Where:

FLOW = non-point source flow (meters per month) for a given basin, year and month,
RAIN = rainfall (meters per month) in the month,
RAIN1 = rainfall (meters per month) in the month before the present month,
RAIN2 = rainfall (meters per month) two months before the present month,
L1 = the fraction of the basin acreage in the URBAN land use category,
L2 = the fraction of the basin acreage in the AGRICULTURAL land use category,
L3 = the fraction of the basin acreage in the WETLANDS land use category, and
L4 = the fraction of the basin acreage in the FOREST land use category, and

c1, c2, c3, c4, b0, b1, and **b2** are parameters to be estimated.

Flow is expressed as a volume of water with an area equal to the land area, and the depth in meters. Although the unit is listed as depth, the volume is implicitly accounted for in the land area. For rainfall, m/mo represents the depth of rainfall over the land area during the monthly time period, although it may also be expressed as a volume, such as cubic meters/month, acre-feet/month, etc.

A least squares regression with no intercept was used to estimate the seven parameters in Equation (1) after taking the natural logarithm of both sides of the equation:

$$\mathbf{Log\,(FLOW) = (c1*L1) + (c2+L2) + (c3*L3) + (C4*L4) + (b0*RAIN0 + b1*RAIN1 + b2*RAIN2)} \quad \text{(Equation 2)}$$

Flow was then apportioned among the constituent land use categories within each basin as follows:

$$\mathbf{FLOW_i = \frac{FLOW * A_i * R_i}{\sum A_i * R_i}} \quad \text{(Equation 3)}$$

Where:

$\mathbf{FLOW_i}$ **=** the total non-point source flow (cubic meters per month) from Land use category i,

FLOW = the total non-point source flow (cubic meters per month) from thebasin,

$\mathbf{A_i}$ **=** area (acres) in land use category i, and

$\mathbf{R_i}$ **=** the runoff coefficient (fraction of rainfall that runs off) for land use category i.

Loading estimates for the gauged Anclote River basin

For the gaugedportion of the Anclote River basin, we used measured streamflows and estimated water quality data to calculatenon-point source loadings. Runoff from each land use category was estimated by apportioning the non-point source streamflowamong the constituent land use categories in the basin using land-use specific runoff coefficients (Appendix 4) as follows:

$$Q_i' = \frac{Q_n * A_i * R_i}{\sum A_i * R_i} \qquad \text{(Equation 4)}$$

where:

Q_i' = total non-point source flow (m3/month) from land use category *i*,

Q_n = total non-point source flow (m3/month) from the gauged basin,

A_i = area of land use category *i* in gauged basin, and

R_i = runoff coefficient for land use category *i* for the month, representing fraction of rainfall that runs off of the land.

The product of the literature-based land use-specific water quality concentrations and the estimated runoff from each land use category is summed over each basin to provide the pollutant loadings for the gauged Anclote River basin.

1.4 Loads from Springs

There are three significant sources of groundwater loads originating as springs within theSt. Joseph Sound and Clearwater Harbor North bay segments. Tarpon Spring is located within Spring Bayou approximately 6 km from the mouth of the Anclote River. Tarpon Spring has reportedly not flowed since the connection to Lake Tarpon Sink was disrupted by the construction of a ring dike around the sink in the 1970's. There have been unconfirmed reports of other smaller spring vents in Spring Bayou, but there have been no data collected from those springs (pers. comm. David Dewitt, SWFWMD).There are two springs, Wall Spring (sometimes also referred to as Health Spring), which is a 3rdmagnitude spring,and Crystal Beach Spring, which is a 2ndmagnitude spring, that are located in close proximity to one another (4 km) within the coastal zone of Clearwater Harbor North. The most recent flow measurements available for Wall Spring are from 1946-1949 when flows were measured at 0-16.5 cfs (Florida Geological Survey, Bulletin No. 66, rev 1977). More recent flow estimates of 19.8 cfs (12.8 mgd) and 22.7 cfs (14.7 mgd) were derived for Crystal Beach Spring in September 2003 and June 2004 (Karst Environmental Services, 2003, 2004). Because of the limited availability of flow data and the lack of water quality data for these springs, we were unable to estimate loadings for these sources, however, the contribution of nutrient and hydrologic loads from the aquifer via springs may be significant and deserves consideration.