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<td>Conceptualized Box Model for Intersegment Exchange Calculations</td>
</tr>
</tbody>
</table>
1.0 INTRODUCTION

1.1 PROJECT BACKGROUND
In March 2009, total maximum daily loads (TMDLs) were finalized for nine water body segments (WBIDs) within the Indian River Lagoon (IRL), starting north of Fort Pierce Inlet up to the Northern IRL, and including four WBID segments within the Banana River Lagoon (BRL). Figures 1-1a and 1-1b outline the WBIDs for which the TMDLs were developed. Table 1-1 identifies the various WBIDs and their basis for impairment.

<table>
<thead>
<tr>
<th>WBID</th>
<th>WBID Name</th>
<th>Impairment</th>
</tr>
</thead>
<tbody>
<tr>
<td>3044A</td>
<td>Newfound Harbor</td>
<td>Nutrients (Seagrass)</td>
</tr>
<tr>
<td>3057A</td>
<td>Banana River below Mathers</td>
<td>Nutrients (Seagrass)</td>
</tr>
<tr>
<td>3057B</td>
<td>Banana River above 520 Causeway</td>
<td>Nutrients (Seagrass)</td>
</tr>
<tr>
<td>3057C</td>
<td>Banana River above Barge Canal</td>
<td>Nutrients (Seagrass)</td>
</tr>
<tr>
<td>2963A</td>
<td>Indian River above Sebastian Inlet</td>
<td>Nutrients (Seagrass)</td>
</tr>
<tr>
<td>2963B</td>
<td>Indian River above Melbourne Causeway</td>
<td>Nutrients (Seagrass), Nutrients (Chlorophyll a)</td>
</tr>
<tr>
<td>2963C</td>
<td>Indian River above Melbourne Causeway</td>
<td>Nutrients (Seagrass)</td>
</tr>
<tr>
<td>2963D</td>
<td>Indian River above 520 Causeway</td>
<td>Nutrients (Seagrass) and DO</td>
</tr>
<tr>
<td>2963E</td>
<td>Indian River above NASA Causeway</td>
<td>Nutrients (Seagrass)</td>
</tr>
<tr>
<td>2963F</td>
<td>Indian River above Brewer Causeway</td>
<td>Nutrients (Seagrass), Nutrients (Chlorophyll a), and DO</td>
</tr>
<tr>
<td>5003B</td>
<td>South Indian River</td>
<td>Nutrients (Seagrass)</td>
</tr>
<tr>
<td>5003C</td>
<td>South Indian River</td>
<td>Nutrients (Seagrass)</td>
</tr>
<tr>
<td>5003D</td>
<td>South Indian River</td>
<td>Nutrients (Seagrass)</td>
</tr>
</tbody>
</table>
Figure 1-1b. IRL Central Basin Segments and TMDL WBIDs.
A group of local Stakeholders conducted an extensive review of the methodologies, assumptions, and models utilized in the development of the TMDLs, along with analyses of recent seagrass mapping from the area. This evaluation identified several potential problems with the TMDLs and concluded that they needed to be re-evaluated. The local Stakeholders identified the need to update and revise the TMDLs, utilizing more recent data, and alternate approaches.

To complete this effort, the Stakeholders have retained a team of consultants to assist with the process. Of this group, Janicki Environmental, Inc., and Applied Technology and Management, Inc. (ATM) were engaged to complete the Data Compilation, Assessment and TMDL Approach Development (Phase 1). Phase 1 has four tasks:

- Task 1.A - Compilation of Available Data, Literature, and Models
- Task 1.B - Development of Loading Estimates
- Task 1.C - Development of Understanding of IRL Physical/Chemical/Biological Response Processes
- Task 1.D - Development of Technical Approach Document

This Technical Approach Document provides the deliverable under Task 1.D. The goal is to outline the approach to be utilized in the development of the TMDL for the WBID segments, and numeric nutrient criteria (NNC) for the Indian River Lagoon North (IRL North), Indian River Lagoon Central (IRL Central), and the Banana River Lagoon (BRL).

### 1.2 LAGOON SEGMENTATION

For the receiving water analyses discussed in the previous deliverable, and herein, two segmentation levels are used. The first are the three primary “basins” or waterbody areas outlined in Figures 1-1a and 1-1b. These are the IRL North, IRL Central, and the BRL. The second level, referred to as seagrass segments, are shown in Figures 1-2a and 1-2b. The analyses used in the previous reports and this report are based upon averages of the data within the boundaries of these basin level and seagrass segment level areas. This segmentation is consistent with that utilized by the St. Johns River Water Management District (SJRWMD) and the Florida Department of Environmental Protection (FDEP) in the previously developed TMDLs.
Figure 1-2b. IRL Central Seagrass Segments
1.3 REPORT OUTLINE

The technical approach utilized for the development of the TMDLs and the NNCs builds upon analyses conducted under Tasks 1.B and 1.C, the development of the runoff and baseflow loads from the watershed completed under a separate task, and additional analyses conducted following receipt of the final watershed loads. Appendices A through D provide the detailed reports for the previous work. While the details of the analyses are presented in the individual reports, the key findings that support the technical approach outlined in Section 4 are presented herein.

Section 2 provides a summary of the work conducted to develop the total loadings of total nitrogen (TN) and total phosphorus (TP) to the various IRL segments. This includes the load from direct stormwater runoff, baseflow, point sources, and atmospheric deposition. The deliverables for the watershed modeling (Appendices A and B) provide the details on the development of the stormwater runoff and baseflow loads. The Task 1.B deliverable (Appendix C) provides a detailed discussion of the development of the point source, atmospheric loads, and the total loads.

Section 3 summarizes the results from the waterbody characterization and the work to develop relationships between the loads and receiving water responses. This includes the data and analyses presented for the Task 1.C report (Appendix D), which focused on the water quality and biological characteristics of the receiving water prior to receipt of the final loadings. Following calculation of the total loads of TN and TP, analyses were conducted to define potential relationships between the loads of TN and TP and the receiving water responses. These are presented at the end of Section 3.

Section 4 utilizes the findings from Section 3 to provide the technical approach that will be utilized to define the TMDLs and NNCs for the lagoon basin segments. This approach is put before FDEP for review prior to completion of the development of the updated TMDLs and NNCs.
2.0 LOAD DEVELOPMENT

To assess the relationships between TN and TP loads and the water quality responses of the receiving waters of the IRL, total loads were developed that accounted for direct stormwater runoff, baseflow, point sources, and atmospheric loads. Monthly hydrologic, TN and TP loads were calculated into each of the seagrass segments as outlined in Figures 1-2a and 1-2b. Monthly loads were calculated from 1995 through 2010. Appendices A and B present the details of how the loads from direct runoff and baseflow were developed. Appendix C presents the details of how the atmospheric and point source loads were calculated as well as results for all of the loads added together. The following summarizes the total loads as used in the analyses in Section 3.

Utilizing the baseflow and stormwater runoff from the watershed modeling work, along with the atmospheric and point source loads, monthly total loads were developed by seagrass segment. Annual total loads were developed by summing the monthly loads, and basin level loads were developed by combining the seagrass segment loadings into the three primary basins, IRL North, IRL Central, and BRL. The annual loads are provided for presentation purposes and to visualize trends and magnitudes, but all analyses presented within this report utilized the monthly loads.

Figures 2-1 through 2-3 present the annual hydrologic loads to the three primary basins. The results are presented for the baseflow, stormwater runoff and atmospheric load. The point source flow values (hydrologic load) are insignificant in comparison to the other contributions; therefore, these were not included. The plots show the difference in the relative contribution of each of the sources between the basins.

Figures 2-4 through 2-6 present the annual TN loads to the three primary basins. The results are presented for the baseflow, stormwater runoff, atmospheric load, and point source loads. The plots show the difference in the relative contribution of each of the sources between the basins. Table 2-1 presents the average percent contribution for each over the full period from 1995 to 2010.
Figure 2-1. Annual Hydrologic Loads by Source for BRL (1995-2010)

Figure 2-2. Annual Hydrologic Loads by Source for IRL North (1995-2010)
Figure 2-3. Annual Hydrologic Loads by Source for IRL Central (1995-2010)

Figure 2-4. Annual Total Nitrogen Loads by Source for BRL (1995-2010)
Figure 2-5. Annual Total Nitrogen Loads by Source for IRL North (1995-2010)

Figure 2-6. Annual Total Nitrogen Loads by Source for IRL Central (1995-2010)
Table 2-1. Relative Contribution of Nutrient Loads to Indian River Lagoon North, Indian River Lagoon Central, and Banana River Lagoon

<table>
<thead>
<tr>
<th>Location</th>
<th>Baseflow TN</th>
<th>Baseflow TP</th>
<th>Runoff TN</th>
<th>Runoff TP</th>
<th>Atmospheric TN</th>
<th>Atmospheric TP</th>
<th>Point Sources TN</th>
<th>Point Sources TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana River</td>
<td>44%</td>
<td>51%</td>
<td>18%</td>
<td>32%</td>
<td>34%</td>
<td>8%</td>
<td>4%</td>
<td>9%</td>
</tr>
<tr>
<td>IRL North</td>
<td>52%</td>
<td>54%</td>
<td>23%</td>
<td>40%</td>
<td>24%</td>
<td>5%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>IRL Central</td>
<td>60%</td>
<td>53%</td>
<td>31%</td>
<td>44%</td>
<td>6%</td>
<td>1%</td>
<td>2%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Figures 2-7 through 2-9 present the annual TP loads to the three primary basins. The results are presented for the baseflow, stormwater runoff, atmospheric load, and point source loads. The plots show the difference in the relative contribution of each of the sources between the basins. Table 2-1 presents the average percent contribution for each over the full period from 1995 to 2010.
Figure 2-8. Annual Total Phosphorus Loads by Source for IRL North (1995-2010)

Figure 2-9. Annual Total Phosphorus Loads by Source for IRL Central (1995-2010)
Examination of the results shows that the relative contributions of the watershed (baseflow and runoff) load versus the atmospheric load varies considerably by basin. The atmospheric load plays the greatest role in the TN loads, with up to a 34 percent contribution, on average, in the Banana River versus less than 10 percent in the IRL Central. Atmospheric deposition of TP, in contrast, plays less than a 10 percent role in any basin, with near a 1 percent contribution in the IRL Central.

Appendix E provides a complete set of the hydrologic, TN, and TP load plots for the annual and monthly timeframes by both seagrass and basin level segments. Once again, as stated earlier, the monthly loads were used in all of the subsequent analyses.
3.0 WATERBODY CHARACTERIZATION AND LOAD RELATIONSHIPS

The goal of the Water Body Characterization Report (Task 1.C) was to provide an assessment of the condition and biochemical interactions of the IRL receiving waters. A conceptual model, to characterize the key ecosystem processes that affect seagrass growth and reproduction, was established and provided the basis for the analyses. Data analyses conducted as part of Task 1.C included:

- Time-series plots of long-term data (1996 to present 2009)
- Non-parametric trend tests to assess changes in relevant constituents
- Box plots to assess spatial variation within basin areas and between seagrass segments
- Regression analyses to assess the relationships among various constituents

The basis for the technical approach comes from the findings of the waterbody characterization along with analyses conducted to assess the relationship between the total loads (summarized in Section 2) and the receiving water quality response. The following sections summarize results from the Task 1.C report along with a detailed presentation of the results from the load/response analyses.

3.1 DATA UTILIZED

The IRL/BRL system is a relatively data rich estuary. Many years of discrete water quality sampling are available. The forethought and insight of local scientists and resource managers in these estuaries has allowed for analysts to have available to them a wealth of empirical information from which to consider stressor-response relationships as part of the development process for NNC and TMDLs.

Numerous ambient water quality sampling programs were identified in Task 1.A (ATM and JEI, 2011a). From these data, a subset of these sampling stations that have representative long-term records and are representative of the lagoon were selected. In addition, seagrass acreage estimates have been determined via aerial photography and bathymetry by SJRWMD, along with transect data that provided direct measurements of key components of seagrass extents, such as distance to the edge of canopy, maximum depth, percent cover, and other parameters.
Long-term SJRWMD stations were chosen for the receiving water quality analyses. Figures 3-1a, 3-1b, and 3-1c provide the locations of the long-term stations within the IRL North, BRL, and IRL Central respectively. Table 3-1 presents a summary of the data by each of the primary basin areas including the number of stations, the number of total observations, the period of record, and the frequency. For the waterbody characterization work, only long-term stations with continuous monthly data were utilized. The goal was to assure that the results were not skewed by the absence of data from one station for a particular period. It was deemed that the temporal coverage through the full data assessment period had priority over the use of more temporally sparse spatially distributed data.

### Table 3-1. Summary of Water Quality Data

<table>
<thead>
<tr>
<th>Segment</th>
<th>No. of Stations</th>
<th>No. of Observations</th>
<th>Period of Record</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRL</td>
<td>5</td>
<td>1,448</td>
<td>Jan. 1996 – Present</td>
<td>Monthly</td>
</tr>
<tr>
<td>IRL North</td>
<td>10</td>
<td>2,338</td>
<td>Jan. 1996 – Present</td>
<td>Monthly</td>
</tr>
<tr>
<td>IRL Central</td>
<td>11</td>
<td>2,864</td>
<td>Jan. 1996 – Present</td>
<td>Monthly</td>
</tr>
</tbody>
</table>

### 3.2 CONCEPTUAL MODEL

In Task 1.C (ATM and JEI, 2011b), a conceptual model was developed to identify the pathway for the nutrient loads to impact ecological resources within the IRL, with the primary focus upon seagrass restoration. While the model also included dissolved oxygen, findings from Task 1.C showed that dissolved oxygen impairments were primarily a function of inclusion of inappropriate data within specific WBIDs and that the system overall is not impaired for dissolved oxygen. As such, the conceptual model outlined herein focuses upon the direct impacts of nutrients (and nutrient loading) on seagrasses.

The conceptual model utilized to support the technical approach identifies the potential for excess nutrient loads to lead to increases in chlorophyll concentrations (Figure 3-2). The increased Chl a levels then negatively impact the ability of light to penetrate through the water column. This reduced water clarity can limit the potential bottom area where seagrasses can grow and reproduce. Thus, controlling excess nutrient loads can reduce chlorophyll and light attenuation, which can lead to restoration and preservation of seagrass meadows.
Figure 3-1a. IRL North Data Station Locations
Figure 3-1b. BRL Data Station Locations
Figure 3-1c. IRL Central Data Station Locations
It is important to note that within the IRL there are a number of other constituents [total suspended solids (TSS), color, turbidity] that can impact light attenuation and, ultimately, the extent of seagrass. These factors, while considered in the analyses, are not directly influenced by nutrients levels, so for determination of NNC or nutrient TMDLs, they are not considered directly in the cause/effect pathway.

This conceptual model provides a framework of understanding for the paradigm considered for the data analyses conducted and the development of load/response relationships. This conceptual model has been established as the paradigm under which subsequent analyses will take place.

For the TMDLs developed previously, the linkage identified was the impact of nutrient loading directly upon the depth limitation of seagrass growth. The analyses developed direct correlations between annual TN and TP loads and the resultant deep edge of seagrasses in that year. Depth limit targets were established through analyses of all available seagrass data and the maximum depth to which seagrasses were found. Depth limitation by definition is an assessment of water clarity. While the model used in the previous TMDLs provided a direct link from TN and TP loads to resultant depth targets, it is inherent in the model that the only impact that reductions in TN and TP loads can have directly upon depth limits, or light limitation, is through changes in Chl a.

In the proposal for the update of the TMDL, it was identified that the goal would be to assess the relationship between the loading of TN and TP directly to the response variable of concern, Chl a. The TMDLs and resultant NNCs determined are defined, therefore, based
upon targeting of a specified Chl a level that will support seagrass recovery. This is the conceptual model utilized herein and the basis for the technical approach.

3.3 SPATIAL VARIABILITY AND SEGMENTATION

To define the spatial scale utilized in the development of the load-response relationships, an assessment of the spatial variability of the key parameters within each of the three basin areas was performed in Task 1.C. Figures 3-3 through 3-5 present box and whisker plots for Chl a, TN and TP. The data are presented by seagrass segment for the entire study area including the BRL, IRL North, and IRL Central basins. The plots present the mean values (blue dot), median values (line), 25th/75th percentiles (edges of boxes), and the 10th and 90th percentiles (upper and lower bounds).

![Box and Whisker Plots of Chl a by Seagrass Segment and by Basin Area](image)

Figure 3-3. Box and Whisker Plots of Chl a by Seagrass Segment and by Basin Area
Figure 3-4. Box and Whisker Plots of TN by Seagrass Segment and by Basin Area

Figure 3-5. Box and Whisker Plots of TP by Seagrass Segment and by Basin Area
Examination of the Chl a data (Figure 3-3) shows that while there is some spatial variation, overall the characteristics and the ranges are similar between the individual seagrass segments and even to some extent across the basin areas. Within the BRL, all of the segments show similar Chl a distributions, with the same general skewness in the higher levels in comparison to the mean and median. A similar difference between the mean and median exists throughout, indicating the same general distribution. One pattern to note is that in both the BRL and the IRL Central, the Chl a levels appear to decrease somewhat moving south, which is somewhat counter intuitive since the levels of exchange or flushing are reduced in the northern areas of each of these segments (see flushing analyses Task 1.C Appendix D). In addition, the BRL7 segment is very similar in characteristics to the IR9-11 segment, which is as expected, given the adjacent and direct connected nature of these two segments.

Examination of the plots for TN (Figure 3-4) shows that, overall, the data exhibit a more normal distribution with the means and medians at the same levels. There is an overall decreasing trend moving from north to south, with the highest levels in the BRL, somewhat lower levels within IRL North, and the lowest levels within IRL Central. Within the basin areas, results are similar with some exceptions. As was found in the Chl a results, BRL7 segment is more indicative of conditions in the lower end of IRL North, with lower overall TN levels. There is a somewhat significant breakpoint at the boundary of the IRL North/BRL basin with the IRL Central indicating that the location of the boundary is appropriate relative to TN. Table 3-2 presents the means and standard deviations for the various segments within the larger basin areas. The results show that the standard deviations between the various stations are not large and, generally, the conditions are statistically similar across segments.

<table>
<thead>
<tr>
<th>Segment</th>
<th>TN Mean (mg/L)</th>
<th>Stnd Dev (mg/L)</th>
<th>TP Mean (mg/L)</th>
<th>Stnd Dev (mg/L)</th>
</tr>
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<tbody>
<tr>
<td>BRL</td>
<td>1.5</td>
<td>0.12</td>
<td>0.05</td>
<td>0.01</td>
</tr>
<tr>
<td>IRL North</td>
<td>1.3</td>
<td>0.09</td>
<td>0.05</td>
<td>0.01</td>
</tr>
<tr>
<td>IRL Central</td>
<td>0.9</td>
<td>0.15</td>
<td>0.06</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Examination of the plots for TP shows relatively similar conditions throughout the system, other than in the lower end of IRL Central. As was seen for TN, TP concentrations are
relatively normally distributed, with nearly identical means and medians. The results show a somewhat elevated level of TP in the IRL Central, but those elevations are primarily the result of the conditions at the lower end of the basin. Ignoring these data, TP concentrations in the IRL Central are similar to those found in IRL North and the BRL. As was found for TN, the TP levels in BRL7 are similar to those in IRL9-11 and are somewhat different from those in the upper BRL segments. The TP also appears to have an overall opposite trend than the TN data moving from north to south. This trend is more in line with the spatial pattern seen in the Chl a data.

Based upon the spatial analyses performed under Task 1.C and summarized above, it was determined that assessment of the waterbody characteristics and load response relationships at the basin level is a reasonable scale for the system. This is supported by the assessment of exchange between the systems outlined in Section 5 and also by the level of available management that should, at a minimum, focus at the basin level.

3.4 BLOOM EVENT EXCLUSION

In 2010, 2011, and into 2012, a significant bloom event occurred throughout the IRL. This event has continued through the present and is the subject of extensive ongoing study efforts by the Indian River Lagoon National Estuary Program (IRLNEP) and SJRWMD. This event occurred during periods of low rainfall, and initial assessments of the causes of the bloom have indicated that this was not the direct result of watershed loading, but rather by other potential factors.

Analyses of the Chl a data in the three primary basins indicated that under this event, a significant shift in the characteristics of Chl a levels occurred in comparison to the conditions that existed for the 1996 through 2009 period. This was especially true within the BRL and IRL North areas. Figures 3-6 and 3-7 present plots of the measured Chl a through 2010 for the BRL and IRL North areas. The data show that this shift began in and around mid-2009.
Figure 3-6. Banana River Measured Chl a from 1996 to 2010.

Figure 3-7. IRL North Measured Chl a from 1996 to 2010.
In a meeting with representatives from the SJRWMD and FDEP, it was determined that for the analyses conducted under this study, in order to develop regression relationships between the loads and receiving water response, the data during the period of the bloom would be excluded. As such, the analyses and results presented below reflect conditions from 1996 through the end of 2008.

3.5 NUTRIENT LIMITATION

Marine systems, including estuaries, are generally considered nitrogen limited (Thomas, 1970a,b; Ryther and Dunstan, 1971; Boynton et al., 1982; Smith, 1984; Howarth, 1988, 2008; Howarth et al., 1988a,b; Nixon et al., 1996; Howarth and Marino, 2006; Chapra, 1997; National Research Council, 2000), although there may be times and locations when phosphorus limitation may occur (Conley, 2000; Conley et al., 2009; Malone et al., 1996).

According to FDEP guidelines, receiving waters with TN:TP ratios less than 10:1 (molar) are considered nitrogen limited. Ratios of greater than 30:1 (molar) indicate phosphorus limitation, and ratios of 10-30:1 (molar) indicate co-limitation (FDEP, 2002). To assess the nutrient limitation conditions in the IRL North, IRL Central and the BRL, the full data sets were analyzed and the molar TN:TP ratios calculated. Figure 3-8 presents box and whisker plots of the data for each of the three waterbodies. Based on the TN:TP ratios found in the IRL, both Banana River and IRL North are phosphorus limited, while IRL Central is at the upper end of nitrogen and phosphorous co-limitation. This is consistent with findings from past studies (Steward et al., 2010). Additionally, this is consistent with some of the findings from Section 3.3 that showed that Chl a spatial patterns matched more closely with TP levels than TN levels.
3.6 TRENDS ANALYSIS

Under Task 1.C extensive analyses of the water quality data were conducted to determine overall trends within the system for the key parameters of interest, TN, TP, and Chl \( a \). Additionally, trends in the seagrass conditions were also assessed in relation to the water quality trends. The following sections summarize those results.

3.6.1 NUTRIENTS AND CHL \( a \)

Non-parametric (seasonal Kendall-Tau) trend tests were conducted for Chl \( a \), TN, and TP for the period 1996 through 2008 in each of the three lagoon segments (IRL Central, IRL North, and Banana River) to assess inter-annual differences and trends. In all three lagoon segments, Chl \( a \), TN, and TP exhibited statistically significant decreasing trends for the period 1996 through 2008.

The following figures present the plots of the monthly values by the three basin segments along with the statistical coefficients from the analyses. For each plot, the Kendal Tau Slope Coefficient, the Test Statistic, and the p-value are presented. The Kendal Tau Slope
Coefficient quantifies the slope of the line with units of milligrams per liter (mg/L) per year (for TN and TP) or micrograms per liter (μg/L) per year (for Chl a). A negative value indicates a decreasing trend. The Test Statistic provides a measure of the increase or decrease in water quality constituent over time, based on comparison of adjacent in time observations. Finally, the p-value represents the statistical significance of the trend line. For these analyses the p-value cutoff to define statistical significance is 0.05, therefore, if the p-value is less than 0.05, the trend is deemed statistically significant.

Figures 3-9 through 3-11 present the results for TN. All three basins show statistically significant decreasing trends, with the lowest p-value found for the IRL Central segment. The slopes of the lines are similar between the three analyses, indicating that for TN, the changes appear to be similar between the three segments. The slopes show that over the period of the analyses, the decreasing trends represent an overall 22 to 35 percent reduction in TN concentrations.

Figure 3-9. Banana River Lagoon Monthly Total Nitrogen Trend Plot with Statistics
Figure 3-10. IRL North Monthly Total Nitrogen Trend Plot with Statistics

Figure 3-11. IRL Central Monthly Total Nitrogen Trend Plot with Statistics
Figures 3-12 through 3-14 present the results for TP. All three basins show statistically significant decreasing trends, with the lowest p-values found in the IRL North and IRL Central basin segments. The slopes of the lines are similar in the IRL North and BRL segments. The IRL Central Segment shows the steepest slope. For the IRL North and BRL segments, this slope represents a 22 to 52 percent overall reduction in TP concentrations.

Figures 3-15 through 3-17 present the results for Chl a. All three basin segments show statistically significant decreasing trends with the lowest p-values in the IRL North. The slopes of the lines are similar between the basin segments and these represent slightly above a 50% reduction in the Chl a concentrations overall in all of the basin segments.
Figure 3-13.  IRL North Monthly Total Phosphorus Trend Plot with Statistics

Figure 3-14.  IRL Central Monthly Total Phosphorus Trend Plot with Statistics
Figure 3-15. *Banana River Lagoon Monthly Chl a Trend Plot with Statistics*

Figure 3-16. *IRL North Monthly Chl a Trend Plot with Statistics*
3.6.2 SEAGRASS
In the Task 1.C report, annual measurements of seagrass metrics were presented, including acreage, edge of canopy species, percent cover of seagrass, maximum depth, and macroalgal cover. The acreage data were based upon interpretation of aerial photography at intervals of approximately 2 years, while the remaining data were based upon transect observations taken annually.

Figures 3-18 through 3-20 present plots of the acreages from 1986 through 2009, Figures 3-21 through 3-23 present the edge of canopy data, Figures 3-24 through 3-26 present box and whisker plots of the transect measured maximum depths. The remaining plots are provided within the Task 1.C report (Appendix D). All of the seagrass data presented show improving trends for the period of the analyses presented in Section 3.6.1. The data show that, in conjunction with the decreasing trends in nutrient concentrations and Chl a, seagrasses showed net improvement in all areas.
Figure 3-18. Banana River Lagoon Seagrass Acreages

Figure 3-19. IRL North Seagrass Acreages
Figure 3-20.  IRL Central Seagrass Acreages

Figure 3-21.  Banana River Lagoon Seagrass Transect Edge of Canopy
Figure 3-22. IRL North Seagrass Transect Edge of Canopy

Figure 3-23. IRL Central Seagrass Transect Edge of Canopy
Figure 3-24. Banana River Lagoon Seagrass Transect Maximum Depth

Figure 3-25. IRL North Seagrass Transect Maximum Depth
NNC recommendations were completed and submitted to FDEP and the U.S. Environmental Protection Agency (EPA) for the following estuarine waterbodies: Tampa Bay (Janicki 2011a), Clearwater Harbor and St. Joseph Sound (Janicki 2011b), and Sarasota Bay (Janicki 2011c). For these waterbodies, the estuary water quality goals were established to ensure that water quality conditions in the estuary are protective of seagrasses. Based upon the determination that seagrasses were improving in each of these waterbodies, it was concluded that water quality conditions during the period of improvement, were sufficient to maintain full aquatic life uses in the estuary. Therefore, a reference period approach was used to establish management targets and thresholds for each of these systems.

Based upon the available seagrass data and the coincident water quality data, the conditions within the IRL during the period of the assessments presented herein are sufficient to allow seagrass recovery and therefore define levels protective of designated uses. This concept will be a portion of the basis for the Technical Approach in Section 4.
3.7 DEVELOPMENT OF LOAD RESPONSE RELATIONSHIPS

In keeping with the conceptual model defining relationships between nutrients and the primary response variable, Chl a, evaluation of data has been directed at developing these relationships to assist in determining nutrient loadings commensurate with desirable water quality conditions. Previous studies of the IRL and BRL (Steward et al., 2010), along with analyses presented in the Task 1.C report (Appendix C) and Section 3.5, have determined that the IRL North and Banana River Lagoon are primarily phosphorus limited, while the IRL Central shows signs of co-limitation. Therefore, for the following analyses, both TN and TP are evaluated as potential causative variables in the system.

The stressor-response approach consists of developing relationships between nutrient concentrations or loads and biological responses. The biological responses relate to the “designated use of a waterbody (e.g., a biological index or recreational use measure) either directly or indirectly, but ideally quantitatively” (EPA, 2009). After development of quantitative relationships and the identification of appropriate targets, the nutrient loads and resultant criteria protective of the specific designated uses can be determined.

EPA (2009) has provided guidance on the development of stressor-response relationships using empirical data analysis approaches. A review of these approaches by the Science Advisory Board (SAB, 2010) has provided additional insights as to how evidence of stressor-response relationships may be used in establishing NNCs and TMDLs.

Linear regression is a parametric statistical technique used to explore the relationship between two or more variables. In univariate ordinary linear regression, the relationship between the response variable (y-axis) and explanatory variable (x-axis) is quantified by fitting a straight line through the set of points such that the sum of squared residuals of the model is as small as possible. That is to say, the vertical distances between the individual points and the fitted line are minimized. Ordinary linear regression is a well established method for the development of load response relationships.

In linear regression, the assumption is made that the data are independent from the population. For example, if one is developing a relationship between Chl a and TP concentrations for the BRL, the data should come from samples that are representative of the spatial and temporal variability of the system. Another important assumption of linear
regression is that the error term of the model is normally distributed and has constant variance. Often times, one or more of the variables exhibits a non-linear relationship with the other variables. While there are non-linear regression techniques available, one should first try transforming the data. Ordinary linear regressions can often be developed using transformed data. These models will satisfy the assumptions of linear regression.

Diagnostic statistics and plots are commonly used to determine if the regression model meets the assumptions of linear regression. The most commonly used statistics are the statistical significance of the model coefficients and the coefficient of determination ($r^2$). The statistical significance of the model coefficients tests whether the slope and intercept of the model are significantly different from zero. The coefficient of determination is a measure of the variance in the dependent variable that is explained by the model. A plot of the residuals versus the independent variable can be used to judge if the assumption of constant variance is met. Additional plots of residuals versus other variables can also be instructive. For example, a time-series plot of the residuals can be used to assess whether or not the residuals vary seasonally. Additional diagnostics can be run to identify outliers and test for leverage or influential points. Data points that are identified by these additional diagnostics can be further investigated to determine if they are the result of a data entry error or other problem that merits removing them from the analysis.

A graphical example of linear regression is presented in Figure 3-27. The relationship of TP concentrations to Chl $a$ was investigated for the BRL in the Task 1.C report. Preliminary analyses between Chl $a$ and various water quality constituents revealed a correlation between Chl $a$ and TP concentration. As anticipated, Chl $a$ concentrations increase with increasing TP concentrations, though the relationship is non-linear at lower TP concentrations. Therefore, the Chl $a$ concentrations were log transformed and the fit of the model was improved (Figure 3-27). Though the amount of variation explained by the model was less than 50 percent, the coefficients were highly significant. Obviously, a large portion of the variation in Chl $a$ is explained by other variables that are not included in the model, suggesting the model could be improved with the addition of relevant variables and possibly interaction terms.
In previous work for the IRL and BRL (EPA, 2007; FDEP 2009), regression relationships between seagrass depth limits and unit area nutrient loads were used to develop TMDLs. For the analyses herein, the relationship is limited to assessment of nutrient impacts either as concentrations or loads to the primary response parameter, Chl a.

Evaluations of relationships between Chl a and TN and TP concentrations or loads were completed. Initial evaluations examined the relationship between Chl a and the same-month TN and TP concentrations, as well as 2- and 3-month average TN and TP concentrations. The same-month relationships are provided graphically in Figures 3-28 and 3-29, and the relationships between Chl a and the 3-month average TN and TP concentrations are provided in Figures 3-30 and 3-31. The relationships in all three segments were significant (p-values<0.0001), but did not explain a large portion of the variation in Chl a, as evidenced by the relatively low $r^2$ values.
Figure 3-28. Relationships between Chlorophyll a and Same-Month TN Concentrations

Figure 3-29. Relationships between Chlorophyll a and Same-Month TP Concentrations
Figure 3-30. Relationships between Chlorophyll a and 3-Month Average TN Concentrations

Figure 3-31. Relationships between Chlorophyll a and 3-Month Average TP Concentrations
The next step in the process was to evaluate other factors potentially impacting the relationships between Chl $a$ and TN and TP concentrations. Based on the findings from a residuals analysis, a term for season (wet or dry) was added to the linear regression. This resulted in some improvement in the relationships, as provided in Figures 3-32 and 3-33, but still explained only 31 to 43 percent of the variation in Chl $a$.

The relationships between Chl $a$ and TN and TP loadings were then evaluated, utilizing same-month and 2- and 3-month cumulative loadings. As for concentrations, the best relationship for each segment was selected, and then subjected to residuals analysis to identify other factors that should be included to improve the predictability of the model. The 3-month cumulative loads for both TN and TP were the most appropriate loading metric to use, and a term for season (wet or dry) was included as well. Utilizing the output from these relationships, further residuals analysis identified a signal related to the year during which the Chl $a$ data were collected, so an additional term was added to the relationship to account for this variability. The final selected relationships related monthly Chl $a$ to 3-month cumulative loads with seasonal and year terms, for both TN and TP loads (Figures 3-34 and 3-35).

The predictive equations are of the form:

$$\ln(\text{chl}_t,s) = a_s + b_s L_{t,s} + c_s \text{Season} + \text{error}$$

where,

- $\text{chl}_t,s$ = average Chl $a$ concentration at month $t$ and segment $s$ ($\mu g/L$),
- $L_{t,s}$ = cumulative 3-month load (TN or TP) at month $t$ and segment $s$ (kg),
- Season = 1 (wet, months 7-10) or 0 (dry)
- $a_s$, $b_s$, and $c_s$ = regression parameters.

The year term absorbs variability in the model associated with individual years of the model period but is only relevant to estimating the confidence intervals associated with the prediction for future years. The regression parameter estimates used for the predictive equation for each segment are specified in Table 3-3. Appendix F contains the full regression model output.
Figure 3-32.  Best Relationships between Chlorophyll a and TN Concentrations and Season

Figure 3-33.  Best Relationships between Chlorophyll a and TP Concentrations and Season
Figure 3-34. Best Relationships between Chlorophyll a and TN Loads (3-Month Cumulative)

Figure 3-35. Best Relationships between Chlorophyll a and TP Loads (3-Month Cumulative)
Table 3-3. Regression Parameter Estimates for Predictive Equations

<table>
<thead>
<tr>
<th>Segment</th>
<th>Nutrient Load</th>
<th>$a_s$</th>
<th>$b_s$</th>
<th>$c_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRL North</td>
<td>TN</td>
<td>-3.15442</td>
<td>0.14679</td>
<td>0.32677</td>
</tr>
<tr>
<td>IRL North</td>
<td>TP</td>
<td>-1.27422</td>
<td>0.10926</td>
<td>0.43879</td>
</tr>
<tr>
<td>Banana River</td>
<td>TN</td>
<td>-1.26159</td>
<td>0.09328</td>
<td>-0.06861</td>
</tr>
<tr>
<td>Banana River</td>
<td>TP</td>
<td>-1.27870</td>
<td>0.12443</td>
<td>-0.05369</td>
</tr>
<tr>
<td>IRL Central</td>
<td>TN</td>
<td>-4.82113</td>
<td>0.17907</td>
<td>0.31272</td>
</tr>
<tr>
<td>IRL Central</td>
<td>TP</td>
<td>-3.60288</td>
<td>0.17491</td>
<td>0.33261</td>
</tr>
</tbody>
</table>

It should be noted that TN and TP loads are highly correlated in the Indian River Lagoon and Banana River, with coefficients of correlation ($r^2$) of the monthly loads of 0.84 (Banana River), 0.91 (IRL North) and 0.99 (IRL Central). It is not surprising, then, that the relationships between Chl $a$ and loadings within a segment are very similar, whether the load being utilized is TN or TP. Inclusion of both TN and TP loads in the same regression results in no improvement in relationships in the IRL North and IRL Central segments. It only results in small improvements within the Banana River, where the $r^2$ value of 0.49, when using only the 3-month cumulative TP load (Figure 3-35), only increases to 0.52 when using both the 3-month TP and TN loads.

Previous TMLD efforts (FDEP, 2009) provided both TN and TP load limits, in recognition of the fact that portions of the lagoon are likely phosphorus limited while other portions show signs of co-limitation. The relationships provided here, with Chl $a$ as a function of TN and TP loads, provides the basis for the development of loads commensurate with Chl $a$ targets selected for the system.
4.0 TECHNICAL APPROACH

4.1 BACKGROUND
FDEP and EPA have identified three analytical approaches for the development of nutrient criteria or TMDLs:

- The reference condition approach
- Stressor-response analysis
- Mechanistic modeling

The reference condition approach is divided into two different methods, the historical and comparative reference approaches. The historical reference approach is a strong candidate if sufficient data are available for the waterbody of interest during a period when the desired designated use is achieved. If sufficient data are not available for the waterbody for a minimally impacted reference period, it is possible to use the comparative reference approach. The comparative reference approach is based on determining criteria based on a group of reference waterbodies. The reference waterbodies are selected from among a group of like waterbodies (e.g., the same class of waterbodies) that represent minimally disturbed conditions.

The stressor-response approach consists of developing relationships between nutrient concentrations or loads and biological responses (i.e., Chl a). The biological responses should be related to the “designated use of a waterbody (e.g., a biological index or recreational use measure) either directly or indirectly, but ideally quantitatively” (EPA, 2009). After quantitative relationships have been developed, the NNC or TMDL that is protective of the specific designated uses can be determined.

The mechanistic modeling approach is used to simulate specific constituents based on a series of equations and algorithms that represent physical, chemical, biological, and ecological processes. Mechanistic models include a wide variety of water quality models, some of which were briefly described in previous EPA nutrient criteria guidance documents (EPA 2000a, 2000b).
In addition to these individual approaches, a hybrid (or weight of evidence) approach that utilizes portions of each can be utilized.

4.2 APPROACH

In the initial proposal, and as described in the Conceptual Model in Section 3.2, the goal of this effort was to establish stressor-response relationships that provide a direct link between nutrient loads/concentrations and the response of Chl \(a\). Based on these relationships and the determination of an appropriate Chl \(a\) target level, the NNC and TMDLs would be determined.

In 2011, FDEP proposed NNC rules for various waterbodies along the Florida Gulf Coast. This work included Sarasota Bay, Tampa Bay, Clearwater Harbor and St. Joseph Sound (Janicki 2011a, Janicki 2011b, Janicki 2011c). For these waterbodies, the goal was to “manage nutrients in surface (and groundwater) at loadings or concentrations that result in protection and maintenance of healthy, well-balanced aquatic communities.” The approaches taken looked to establish quantifiable linkages between anthropogenic nutrient enrichment and a biological response (such as seagrass growth). This determination then is used to numerically interpret the narrative nutrient criteria. For this type of process, there is value in knowing whether nutrient concentrations are potentially elevated to environmentally harmful levels, but it is also important to identify adverse biological effects and determine if they are linked to nutrients before deciding that nutrient reductions should be pursued.

For each of the waterbodies listed, the goal was the protection of seagrasses. Additionally, each of the waterbodies had demonstrated periods where the data showed recovery of the seagrass communities along with commensurate improvements in water quality (nutrients and Chl \(a\)). Based upon these determinations, target Chl \(a\) levels were identified that were representative of the period where seagrass recovery occurred and the Chl \(a\) levels were linked to either loads or concentrations through empirically derived relationships (stressor-response). This represents a hybrid approach that utilizes both a stressor response combined with a reference period.

For the IRL TMDLs and NNCs, this hybrid approach will be utilized. Section 3 presented data showing periods of seagrass recovery, along with improving water quality in all three basin segments. This will allow the determination of appropriate Chl \(a\) targets and
thresholds. Additionally, statistically significant load/response relationships were developed between TN and TP loads and the receiving water Chl a levels to allow linkage of loads to the proposed targets. The following sections describe the work to be performed under each step along with how the TMDL/NNCs will be implemented.

4.2.1 CHL A TARGETS AND THRESHOLDS

Based upon the analyses provided in Section 3, the reference period for the determination of the target Chl a levels will be 2001-2008. For each of the basin segments, the annual geometric mean Chl a levels will be determined over the full period of reference. The resultant geometric mean Chl a concentrations from this overall period will be established as the targets for each basin segment.

As part of this analysis, it is recognized that there may be years in which these targets may be exceeded without causing significant reductions in seagrass cover. This means that there is some allowable amount of variation that should not elicit a significant degradation in water quality and, therefore, seagrass coverage. For the work conducted in the west coast embayments, this level of variation was defined as the standard deviation around the geometric mean annual Chl a concentrations in each segment for the entire period of record. Therefore, this approach makes a distinction between a target, i.e., a desired Chl a concentration, and a threshold, i.e., a Chl a concentration above which undesirable Chl a concentrations exist. The Chl a threshold for each segment will then be determined as the sum of the target and the standard deviation around the geometric-mean annual Chl a concentrations in each basin segment.

4.2.2 NNC AND TMDL DEVELOPMENT

In Section 4.2.1, the method for the development of the target and threshold Chl a concentrations was outlined. For the determination of the NNCs and TMDLs, the threshold is coupled with the stressor response relationships outlined in Section 3 to link the threshold with the appropriate nutrient concentrations and loads. This approach involves the using the quantitative relationship (i.e., model) between a Chl a and nutrient loads or concentrations. For the IRL basin segments, the independent variables used in the model-building process included loadings, concentrations, and various additional variables such as season and year. The loadings data included monthly hydrologic, TN, and TP loads, as well as cumulative total loads extending over a 3-month period. As with the Chl a levels, the loads
will be assessed based upon both target and threshold levels and will provide allowance for the variations in hydrologic conditions during the reference period.

### 4.2.3 IMPLEMENTATION

For the NNC values, it will be necessary to define the strategy for the determination of compliance. Once again, following the methodologies established for the Gulf Coast waterbodies, the proposed compliance assessment strategy involves two steps. The initial step is the comparison of the geometric mean annual Chl \( a \) concentrations in each bay segment to the established Chl \( a \) thresholds. Compliance is achieved if the threshold is met in that year. If the Chl \( a \) threshold is exceeded in more than 2 years during any 5-year period, the second step would be an assessment of nitrogen concentrations. The justification for the “2-in-5 year” compliance assessment is well documented in FDEP publications on NNC.

Additionally, FDEP has identified in its recent NNC development for Gulf Coast waterbodies approaches to define the targets based upon the availability of data and its level of representation of the waterbody. This work will be utilized to define both the Chl \( a \) targets and the TN and TP targets that are appropriate given available data.
5.0 TRANSPORT ISSUES AND LOAD DISTRIBUTION

In the approach described in Section 4, the relationships are based upon assessment of loads coming into the basin level segments and does not consider inter-basin transport of loads. As part of the approach, various data sets will be utilized to assess the potential inter-basin load transport and the relationships may be adjusted based upon these assessments. Additionally, this assessment will aide in the assignment of loads impacting the basins and the relative contribution of loads to local water quality conditions.

The following sections provide a brief discussion of the overall transport in the system based upon analyses of available data and literature. These results serve to support the use of basin level segmentation for the analyses versus seagrass level segmentation. Following that description, an approach is outlined to utilize various data sets and box modeling to assess the net transport impacts and potential alternations in the load response relationships. These analyses/data will be utilized in the development of the final load assessments for the TMDL.

5.1 IRL TRANSPORT CONDITIONS AND NET EXCHANGE

Due to the isolated nature of most of the areas being considered relative to ocean exchange and tidal forcing and the narrow constricted nature of the inlets that do connect to water bodies outside the three basins, the transport within the system is primarily governed by sub-tidal conditions. In an assessment of hydrodynamics in the IRL the SJRWMD stated (SJRWMD, 2005):

"Transport of pollutants within the IRL primarily occurs over sub-tidal time scales and is primarily governed by the wind. Smith (1993b) states: “Even in the southern sub-basin where tidal and non-tidal water level variations are similar in magnitude, the wind-driven circulation dominates tide-induced residual flow over time scales in excess of a few days.” The dependence of sub-tidal transport on wind causes seasonal shifts in the direction of net displacement throughout the IRL, although wind effects can be modified by sub-tidal water level and freshwater inflows."

The U.S. Geological Survey (USGS) has been monitoring flows within Haulover Canal using acoustic Doppler current profiler (ADCP) technology since 1996. Figure 5-1 shows the
location of Haulover Canal relative to the IRL North Segment 1-3. These data provide a good long-term record of flow conditions into out and of the northern portion of the IRL and also provide quantification of the magnitudes of the sub-tidal flows between Sebastian Inlet and Haulover Canal. Figure 5-2 presents a plot of the 30-day averaged flows through Haulover Canal. The units presented are million gallons per day. The plots reflect the seasonal wind patterns with generally negative net flows (flow into IRL North from Mosquito Lagoon) during the winter and positive net flows (out of IRL North into Mosquito Lagoon) during the summer months. This agrees with findings of analyses done by SJRWMD that state "Longitudinal wind run indicates that net winds were generally from the north in late fall and winter (October–February) and from the south in early spring and summer (March–September)".

Figure 5-1. Location of Haulover Canal in Relation to the Northern IRL
To put these flows into context, the total annual hydrologic load for the entire IRL North Basin, including direct precipitation, stormwater runoff and baseflow as presented in Appendix C, ranges from 120,000 million gallons up to 250,000 million gallons. Examination of the data presented in Figure 5-2 shows that during certain periods, net flows on the order of 500 million gallons per day can extend up to 200 days, in essence providing net transport on the same order of magnitude as the hydrologic load. Further comparison with the segment volumes shows that the net transport can provide full exchange on some segments between Haulover Canal and Sebastian inlet within a 15-day period, while other larger segments exchange over larger time scales. Similar analyses done of the areas south of Sebastian Inlet also show a long-term net residual pattern moving southward toward Ft. Pierce inlet (Smith, 2001) with magnitudes on the order of 200 million gallons per day as an annual average. A point to note is that for the areas north of Sebastian Inlet, the residual flow patterns are northward from March to September, which are the primary wet periods. As such, there would be a northward flowing transport of loads coming in during this period. Clearly, when dealing with loads on an annual basis, the residual transport may play a role in the distribution of loads throughout the system and, therefore, including transport aspects
into the load relationships provided may improve further the relationships found tying loads to Chl a response.

In contrast to the IRL North and IRL Central, the BRL system is a truly closed-end system, with the single opening located at its southern boundary where it meets the IRL North and IRL Central basin areas. Therefore, residual circulation in this system would be reduced in comparison to those shown for the IRL North and Central areas.

5.2 APPROACH TO ASSESS INTERBASIN AND INTERSEGMENT TRANSPORT IMPACTS ON LOAD/RESPONSE RELATIONSHIPS

In order to assess the interbasin and intersegment transport within the IRL, simplified box models will be developed. For the IRL work, two potential box model representations will be used. Figures 5-3a and 5-3b provide conceptualized views of the two levels of detail with the inflows, outflows, and areas of exchange coefficients. The conceptual level provided in Figure 5-3a represents interbasin exchange evaluation, while the level in Figure 5-3b represents intersegment exchange.

The method used in this effort is predicated on a well-defined flow path for freshwater beginning at the head of an estuary. For a lagoonal system such as the IRL, it is necessary to define the flow path for freshwater entering the estuary at a given point. For each of the segments in these groupings, non-advective transports are estimated based on observed salinity. Exchange coefficients for non-advective transport are estimated using mean water column salinity data. The algorithm for exchange coefficients estimation will be based on the salinity mass balance equations developed for each segment of the system.

Recently, the project team has received model output from the IRL Hydrodynamic Model developed by SJRWMD (SJRWMD, 2005). The model simulations run from January 1, 1997 to January 1, 2000. These data will be analyzed to develop the levels of exchange during the period of the simulations at the same time scale as the box modeling. The results will be utilized to calibrate the exchange coefficients determined from the salinity data and, for the final box models, the revised coefficients will be utilized to assess the net transport. Based upon the determination of the interbasin and intersegment exchange levels, the loads utilized in the empirical analyses presented in Section 3 may be modified, the determination of the need to modify
Figure 5-3a. Conceptualized Box Model for Interbasin Exchange Calculations

Figure 5-3b. Conceptualized Box Model for Intersegment Exchange Calculations
6.0 REFERENCES


