Technical Memorandum

To: Mac Hatcher, PM Collier County

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Date: November 23, 2010

Re: Watershed Model Update and Plan Development
Contract 08-5122, PO 4500106318
Element 2, Task 1: Volume and Timing of Freshwater Inflows
Element 3, Task 2: Freshwater Discharge to Estuaries

1.0 Objective

Historic fresh water flow patterns in Collier County have changed over the years due to increased development. The changes in flow have impacted the environmental integrity of many of the County's estuaries due to changes in salinity patterns (Browder et al. 1998, Shirley et al. 2005). In addition, the changes in flow patterns have resulted in the introduction into some estuaries of large quantities of organic-rich sediment from accelerated rates of freshwater inflow (Locker 2005). In fact, much of the scientific literature conducted in the Ten Thousand Islands estuary has focused primarily on the issue of altered hydrology and the need for a more natural pattern of freshwater inflow (e.g., Browder et al. 1988, Shirley et al. 2005).

As watershed restoration activities must consider the restoration of historic flows, it was necessary as part of this project to assess existing conditions in the volume and timing of fresh water discharges to each estuary system from the contributing watersheds by comparing them to a baseline, which in this case is represented by the predevelopment condition.

The methodology consisted of comparing the results of the MIKE She MIKE 11 Existing Conditions model (ECM) to those of the Natural Systems Model (NSM) to define the monthly water surplus or deficit that should be targeted for restoration purposes. The ECM is the model updated specifically for this project to support preparation of the County's Watershed Management Plans, whereas the NSM, or pre-development model, was developed as part of the USCOE Southwest Florida Feasibility Study (SWFFS). A full description of the NSM can be found in the report titled "Final Report, Natural Systems Model (NSM) Scenario Southwest Florida Feasibility Study" (SDI, 2007).

As part of the watershed management planning process, it is necessary to establish basis for comparing existing conditions to both the natural system and a master plan conditions. That was achieved through the use of a performance measure, which is a quantitative indicator of the characteristics of the system under a given condition. A numerical scoring methodology was identified to reflect existing and proposed system conditions in terms of volume and timing of

fresh water discharges into the receiving estuaries. This technical memorandum includes a description of the scoring methodology and its results.

2.0 Assessment of Existing Conditions

This section presents descriptions of the hydrologic and hydraulic models used to evaluate system characteristics, as well as the flow estimates for both the natural system and existing conditions. Results are provided for each estuary.

2.1 Description of the Hydrologic / Hydraulic Models

As indicated above, model results from the Natural Systems MIKE SHE model (NSM) were compared to the Existing Conditions MIKE SHE model (ECM). The ECM represents the 2007 land use condition in Collier County and was calibrated against measured flow and stage data in the canal network, as well as measured groundwater head elevation data. The simulation period for this model is 2002 – October 2007. The primary drainage system and most of the secondary drainage system is explicitly represented in the model input.

The NSM was developed as part of the USCOE Southwest Florida Feasibility Study (SWFFS) by modifying the original SFWMD Big Cypress basin (BCB) model in terms of land use and conveyance systems to represent pre-development conditions. The NSM simulation period extended from 1976 to 1986.

It should be noted that the ECM and NSM computer models provide an estimate of the simulated conditions. However, comparisons must consider differences in model characteristics including:

a) The ECM model domain includes the area within Collier County west of, and including, the Okaloacoochee-S.R. 29 basins, and all the way to the coastline. The NSM encompasses the entire SWFFS area, including the Caloosahatchee and Estero River Basins.

b) The ECM includes all the entire main conveyance system, as well as the main secondary canals. In the Collier County portion of the NSM, flow to the estuarine systems is predicted as overland flow. Natural drainage systems such as the Gordon River and Henderson Creek are not explicitly represented.

c) The ECM and NSM simulation periods are not the same. As indicated above, the ECM was used to conduct simulations from 2002 – October 2007, whereas the NSM simulation period extended from 1976 to 1986.

d) The input data, particularly the topographic data source, for the ECM and NSM are not the same and differences in terrain elevations are noticeable.

In spite of the model differences, it was determined that the comparisons between the two models provide valid information to setup flow restoration targets because a) flow estimates for comparison were obtained at specific locations within each watershed, which minimized the effect of differences in the extent of the model domain, and b) both models included simulation periods that on the average can be considered representative of hydrologic conditions.

To further validate the model comparisons results, it was considered necessary to compare them to those from an alternative methodology. As such, they were compared to those from the salinity analysis described in a technical memorandum previously prepared as part of this project. Results of those comparisons are also described later in this report.

2.2 Flow Estimation Methodology

This section describes the methodology used to calculate the total water discharged to each estuary system from the Natural Systems Model (NSM) and the Existing Conditions Model (ECM).

2.2.1 Natural Systems Model (NSM) Flow Estimates

The NSM uses overland flow to predict the movement of water across the ground surface and into the estuaries. In order to extract overland flow results from specific locations in the model, a tool was developed to extract the required information. This tool, called FlowthruLine, was used to extract a time series of flow data from one set of cells to an adjacent set of cells along a line. **Figures 1 through 4** show the locations of the "Flow through" lines specified for each watershed. These lines are generally drawn along the US 41 corridor and it is assumed that all water that flows across this line will enter the downstream estuary.

The tool was applied to each of the six watersheds. The calculated times series of flow for each watershed was then converted to daily discharge volume and summed by month for the period of the simulation (1976 – 1986). The monthly values generated for each year were then averaged to estimate the period of record average monthly flow volume from each watershed. The flows from the Faka Union, Fakahatchee, and Okaloacoochee-SR29 watersheds were combined to estimate total flows into the Ten Thousand Islands estuary.

Figure 1
NSM Flow Through Line and ECM Flow Data Points
Cocohatchee – Corkscrew Watershed

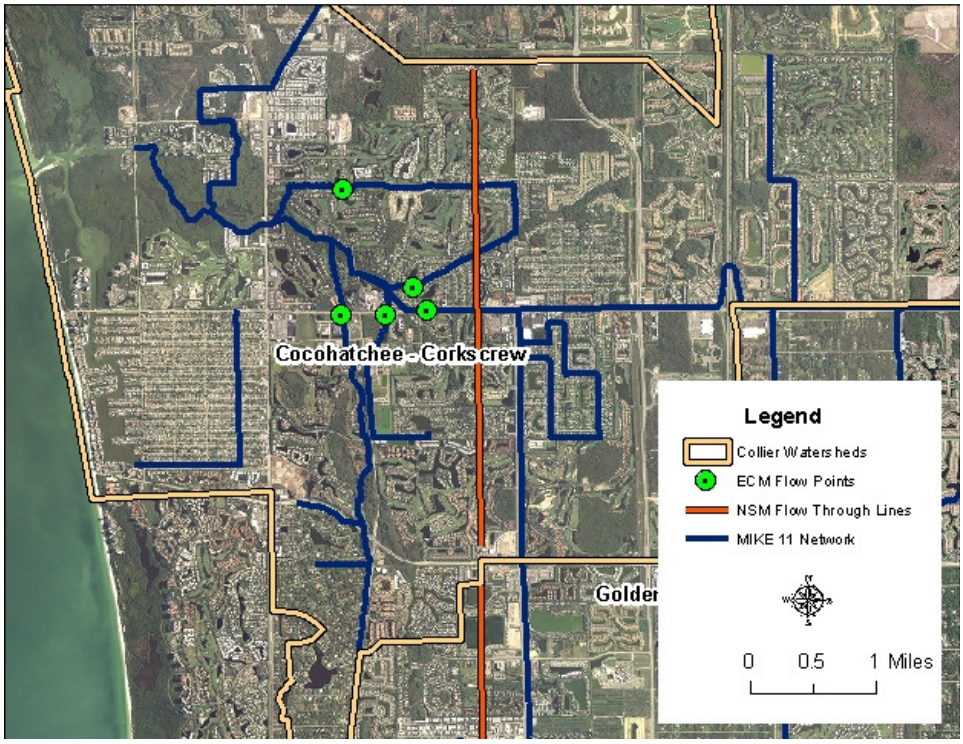


Figure 2
NSM Flow Through Line and ECM Flow Data Points
Golden Gate – Naples Bay Watershed

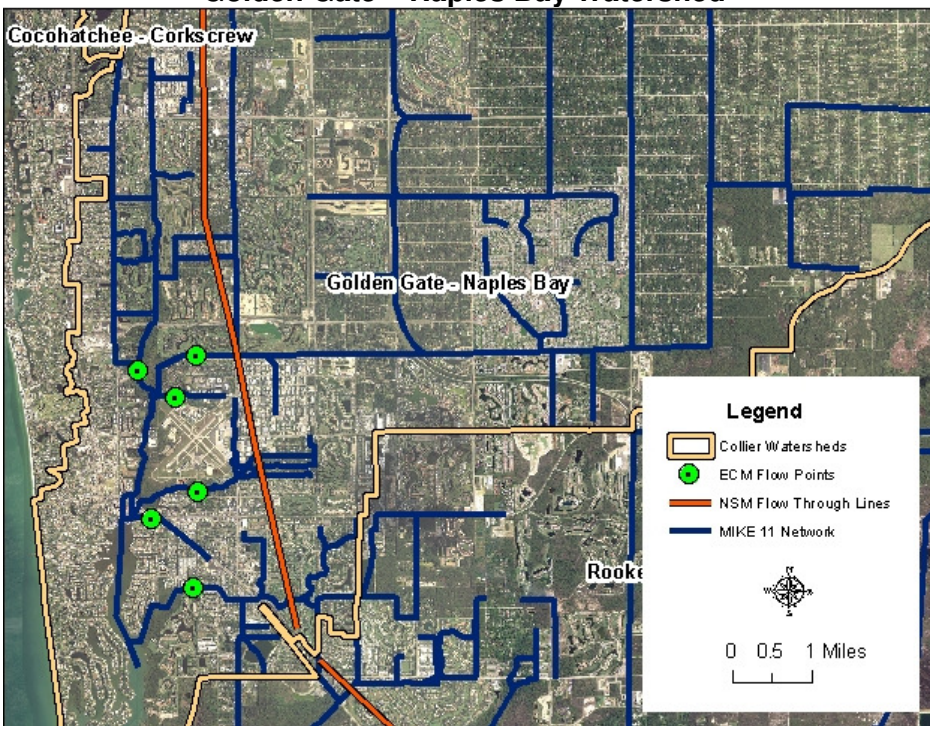


Figure 3
NSM Flow Through Line and ECM Flow Data Points
Rookery Bay Watershed

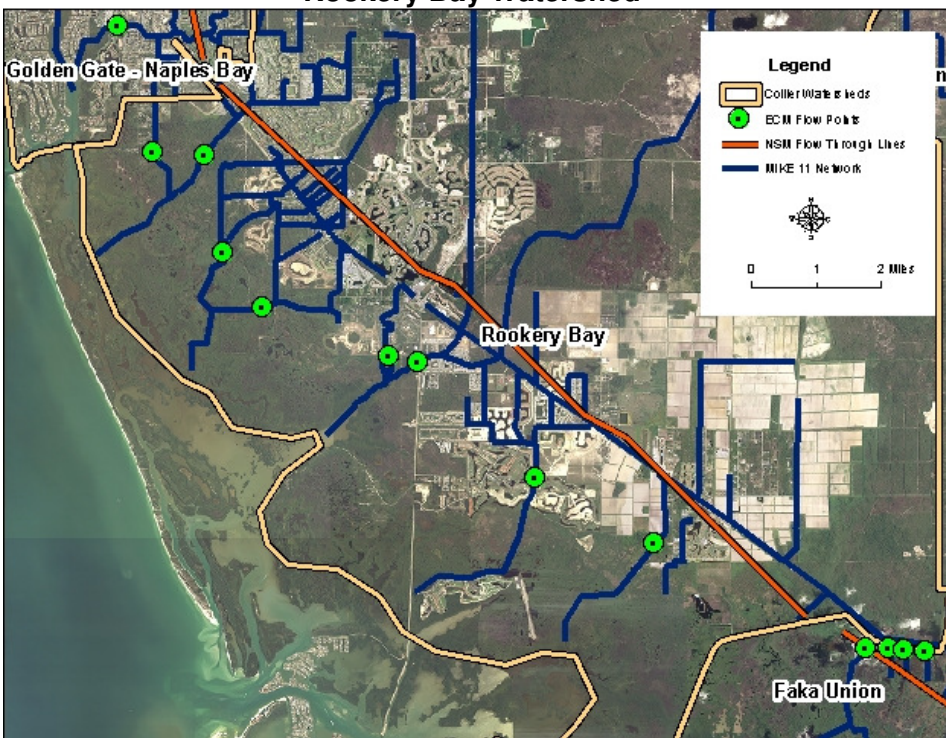
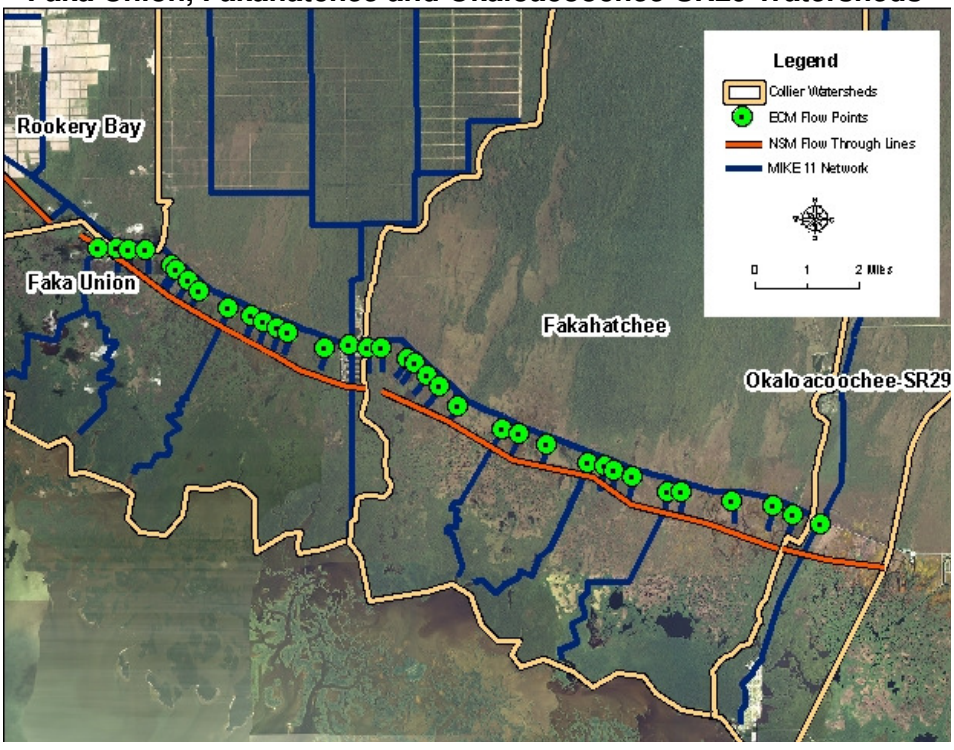


Figure 4
NSM Flow Through Line and ECM Flow Data Points
Faka Union, Fakahatchee and Okaloacoochee-SR29 Watersheds



2.2.2 Existing Conditions Model (ECM) Flow Estimates

The ECM utilizes both channel and overland flow to predict total watershed discharge. However, in Collier County US 41 generally restricts overland flow before it can reach the estuaries and flow is routed through a series of culverts, bridges, or control structures. Therefore, only flows in the conveyance system were used in the calculations.

Discharge to the estuaries was measured by extracting time series of flow data from specified locations in the MIKE 11 river network. These locations are also shown in **Figures 1 through 4**. The flow data from each station was converted from discharge rate (cubic feet per second) to discharge volume (inches) for each time step. Flow data was extracted every three hours for the duration of the simulation. As indicated previously, the simulation covers the period from January 1, 2002 – October 31, 2007.

The following steps were used to calculate the seasonal fresh water discharges for each watershed.

1) The individual times series of discharge for each watershed were summed to estimate the total volume to the estuary for each time step.

2) The volumes for each time step were then summed by month and by year. The results for the Faka Union, Fakahatchee, and Okaloacoochee-SR29 watersheds were consolidated to represent the total flow to the Ten Thousand Islands Estuary. This resulted in a table of monthly volume by year for the period of the simulation. An example calculated for the Wiggins Pass Estuary is shown in Table 1.

3) The monthly values generated for each year were then averaged to estimate a period of simulation average monthly water volume discharged from each watershed.

4) The monthly average values were then consolidated by season to arrive at predicted wet season and dry season discharges into each of the receiving estuaries.

Table 1
Calculated ECM Fresh Water Discharge to the Wiggins Bay Estuary from the Cocohatchee-Corkscrew Watershed

Discharge to Wiggins Bay Estuary (inches)							
Month	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**Average Month**
January	0.02	0.17	0.10	0.05	0.12	0.03	0.08
February	0.01	0.10	0.11	0.04	0.08	0.02	0.06
March	0.01	0.06	0.12	0.11	0.07	0.01	0.06
April	0.01	0.04	0.07	0.07	0.02	0.01	0.03
May	0.01	0.03	0.06	0.05	0.01	0.01	0.03
June	0.03	0.65	0.03	1.12	-0.10	0.01	0.29
July	0.10	0.66	0.12	1.59	0.20	0.01	0.44
August	0.09	1.44	2.21	1.04	0.61	0.01	0.90
September	0.54	1.75	1.72	0.50	1.52	0.06	1.02
October	0.22	0.73	0.45	1.36	0.20	0.13	0.51
November	0.13	0.21	0.07	0.48	0.04		0.19
December	0.15	0.15	0.06	0.21	0.03		0.12
Annual Total	1.32	5.98	5.11	6.61	2.79		3.73

3.0 Fresh Water Discharge Comparison

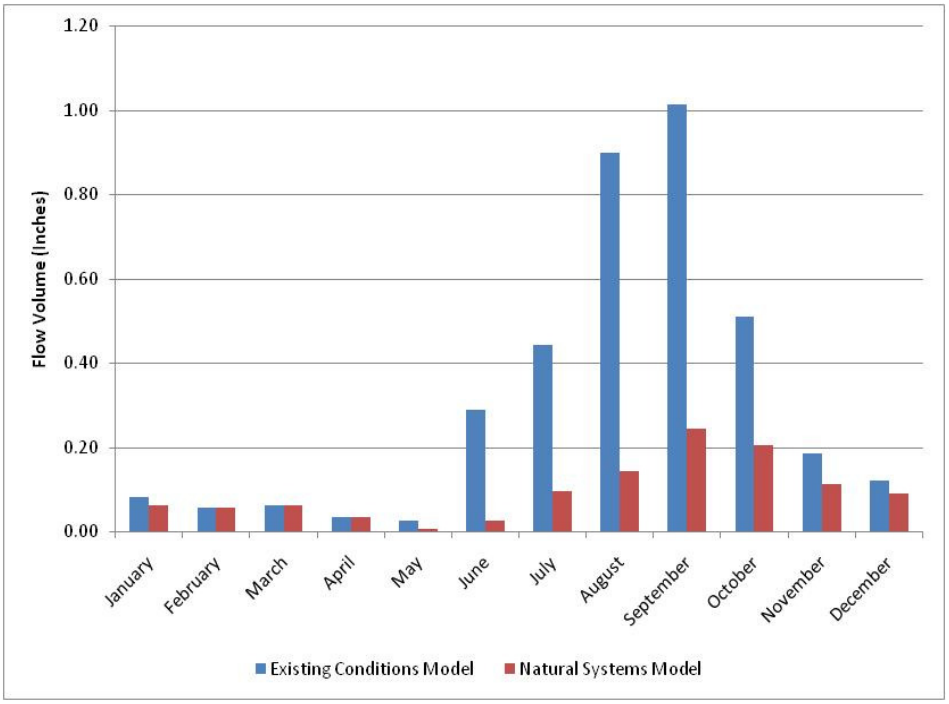
For each of the four estuaries in Collier County, the predicted fresh water discharges from the NSM was compared to those predicted from the ECM. This was completed by subtracting the average monthly flows over the simulation period. Below is a description of the results for each of the estuaries.

3.1 Wiggins Pass Estuary

As shown in **Figure 5**, results indicate that the total fresh water discharges into Wiggins Pass have increased from pre-development conditions, particularly in the wet season. In addition, flow increases start earlier in the year and continue longer than in the NSM conditions. The difference in total fresh water volume discharged in the wet season (July – October) was expected, as were the comparable discharges for most of the dry season.

The relative large discharge increase in June was unexpected and suggests a change in the timing of flows to the estuary. This increase may also be attributable to the rainfall volume difference in the simulation periods for each model for the month of June. The surplus flow in November and December are likely associated with groundwater recharge to the canal system and delayed runoff from above average rainfall in 2003 and 2005.

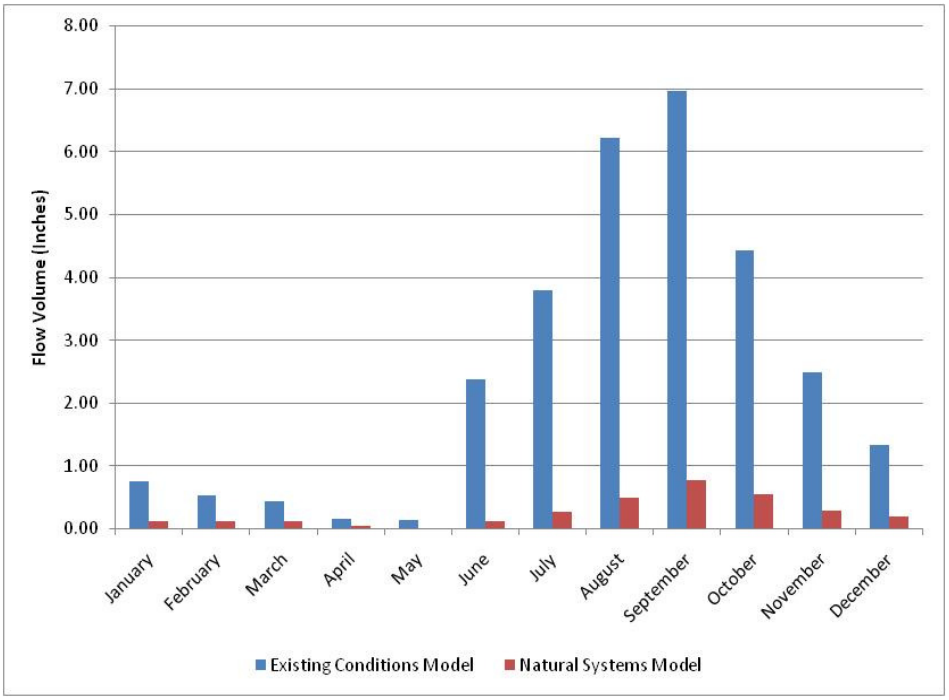
Figure 5
Comparison of the NSM vs. ECM Average Monthly Discharge
Cocohatchee-Corkscrew Watershed to Wiggins Pass Estuary



3.2 Naples Bay Estuary

Figure 6 shows a comparison of the period of simulation average monthly volume of fresh water discharge to the Naples Bay Estuary from the Golden Gate – Naples Bay watershed. The results indicate a year-round increase in the magnitude of water volume released to the estuary. The results do not indicate a significant change in the timing of discharges. These results were expected and consistent with previous studies (Black, Crow, and Eidsness, 1974; SFWMD, 2007). The increased discharges are attributed to construction of the Golden Gate Main Canal that resulted in effectively increasing the extent of the watershed's drainage area from approximately 50 square miles to approximately 135 square miles.

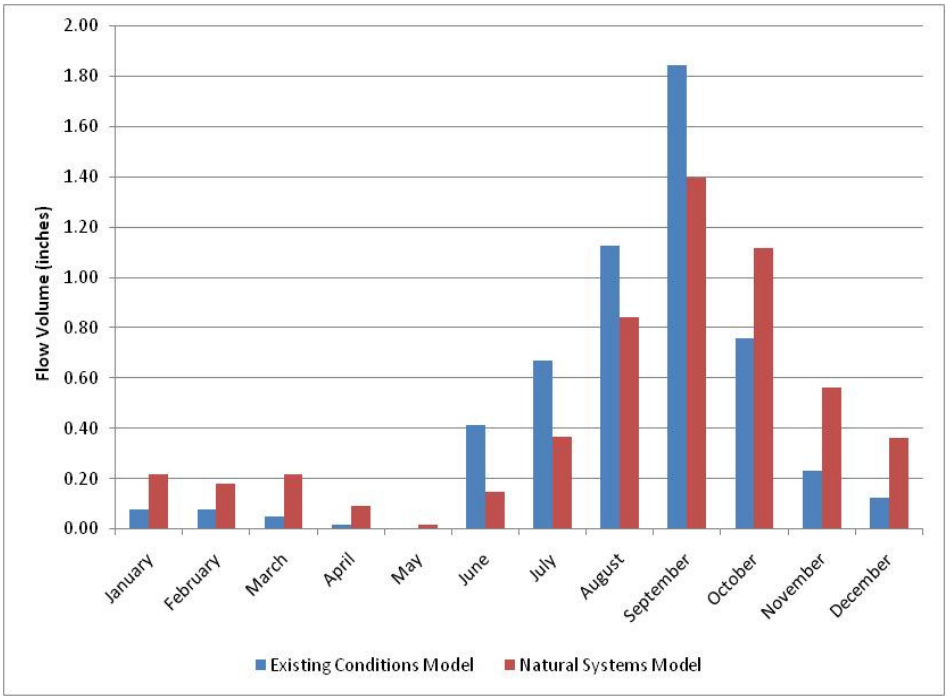
Figure 6
Comparison of the NSM vs. ECM Average Monthly Discharge
Golden Gate – Naples Bay Watershed to Naples Bay Estuary



3.3 Rookery Bay Estuary

The period of simulation average monthly comparison results for the NSM vs. ECM predicted fresh water discharges into the Rookery Bay estuary is shown in **Figure 7**. These results show a flow deficit during the months of October through May, and a flow surplus during the months of June through September. The total average annual predicted volume discharged to the estuary is very similar for both models, indicating that the primary challenge in this estuary is related to the timing of discharges.

Figure 7
Comparison of the NSM vs. ECM Average Monthly Discharge
Rookery Bay Watershed to the Rookery Bay Estuary



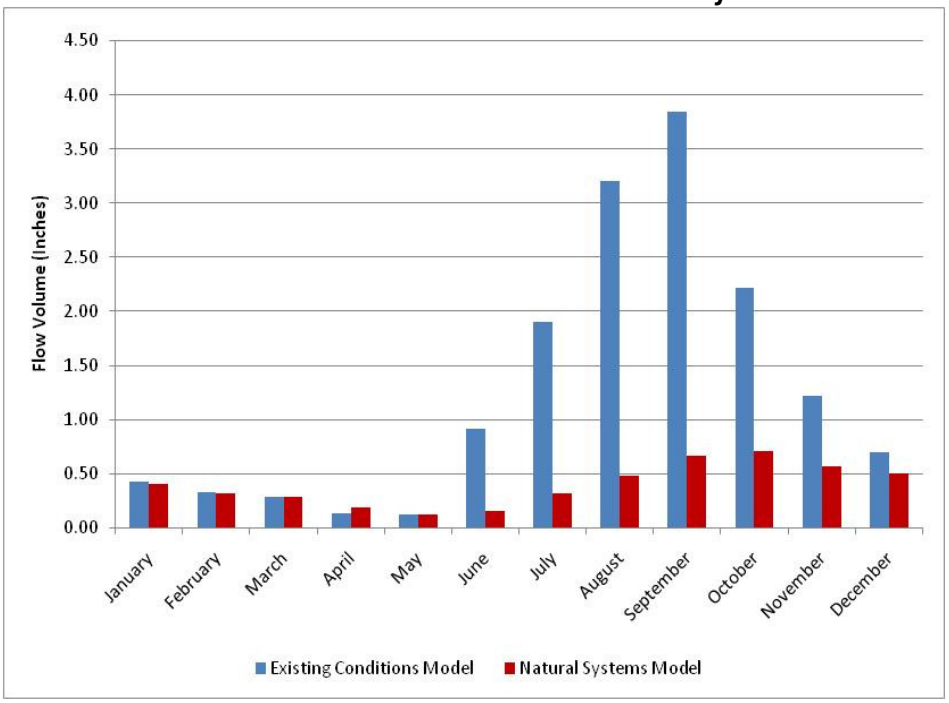
3.4 Ten Thousand Islands Estuary

The Ten Thousand Islands Estuary receives fresh water discharge from three watersheds; Faka Union, Fakahatchee, and Okaloacoochee-SR29. Control structures are used to manage discharge from the Faka Union and SR29 canals into the estuary system. The results in **Figure 8** indicate that excess fresh water discharge to the estuary occurs primarily during the wet season. The volume of wet season excess discharge is approximately 10 inches. The data suggests that the wet season excess flow contribution comes primarily from the Faka Union watershed that is drained by Miller, Faka Union and Merritt Canals.

The southern portion of the Faka Union watershed is the location of the Picayune Strand Restoration Project. This project will remove the road system and install ditch blocks throughout the canal network. The project is expected to provide wet season storage, restore wetlands, and decrease the volume of discharge to the estuary, which is consistent with estuary restoration goals.

Predicted dry season discharges from the watersheds are essentially equal for the ECM and NSM during the months of January through May. Excess flows in November and December are likely the result of delayed runoff during 2003 and 2005. The average runoff volume is 1.97 inches in November 2003 and November 2005. The average runoff volume is 0.70 in the other years of the ECM simulation, which compares favorably with the average NSM November discharge of 0.6 inches.

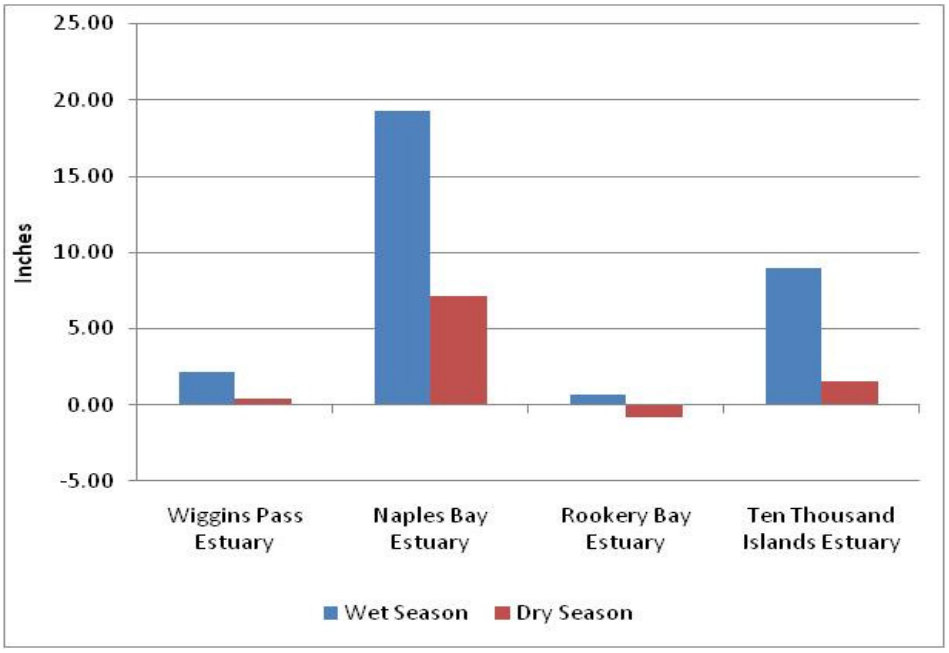
Figure 8
Comparison of the NSM vs. ECM Average Monthly Discharge
Faka Union, Fakahatchee and Okaloacoochee Watersheds
to the Ten Thousand Islands Estuary



3.5 Seasonal Discharge Comparison Summary

Figure 9 shows the seasonal fresh water deficit or surplus estimated by subtracting NSM predicted discharges from ECM predicted discharges. As shown, pre-development water discharges during the wet season have increased for all estuaries due to the construction of drainage canals as well as the increased impervious areas associated with urban development. During the dry season, discharges have increased to all estuaries, except Rookery Bay, which has experienced a fresh water flow reduction because of the re-routing of watershed discharges into the Golden Gate Canal.

Figure 9
Seasonal Fresh Water Surplus and Deficit by Estuary



4.0 Results Validation with Salinity Analysis

The salinity:flow analysis methodology is described in detail in the Technical Memorandum submitted for Phase 1, Element 4, Task 2. The analytical method was applied to areas drained by the four primary canals listed below that discharge to the County estuaries. The location of those canals is shown in **Figure 10**.

- The Cocohatchee Canal that discharges to the Wiggins Pass Estuary,
- The Golden Gate Main Canal that discharges to the Naples Bay Estuary,
- The Henderson Creek Canal that discharges to the Rookery Bay Estuary, and
- The Faka Union Canal that discharges to the Ten Thousand Islands Estuary

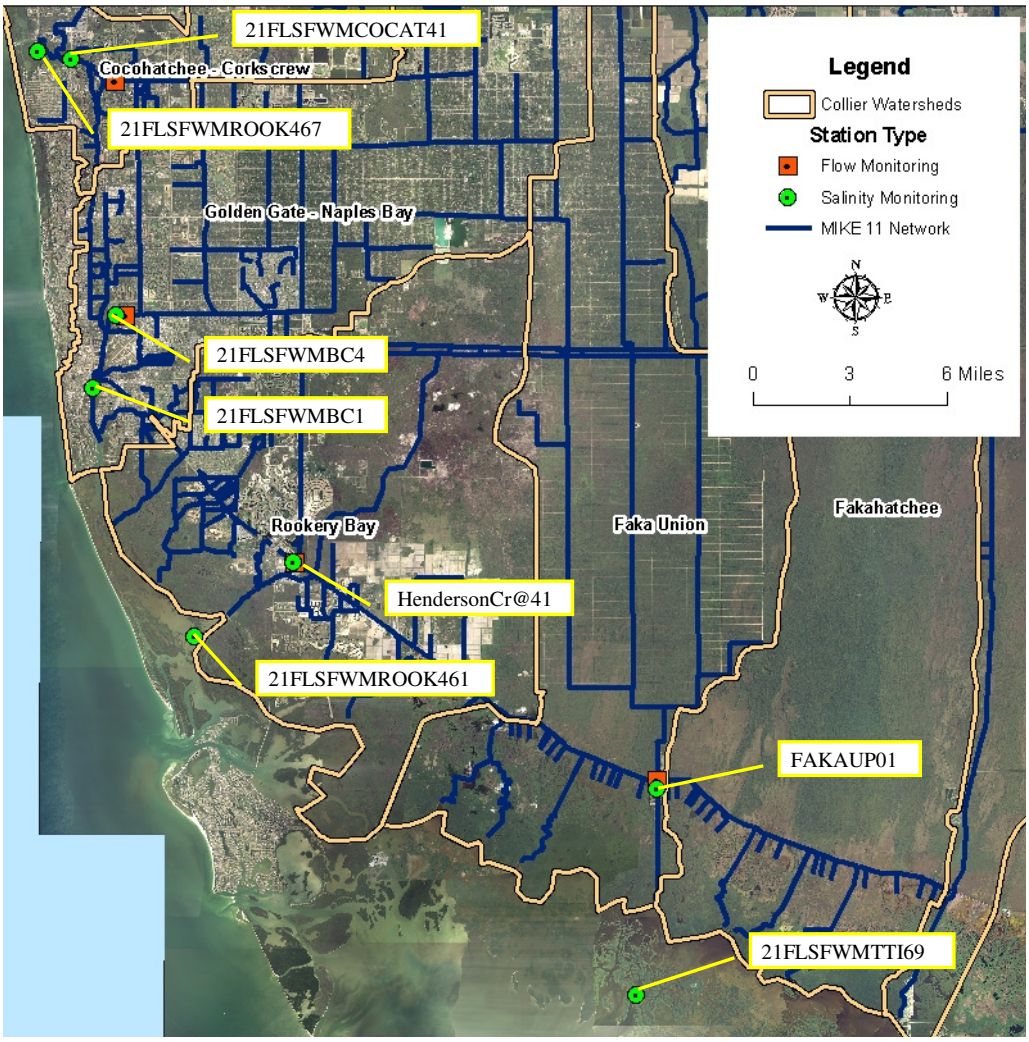
The analysis included the following steps:

- Obtain estimates of salinity at an estuarine area that can be considered unaffected by changes in fresh water discharge patterns due to development. This salinity value was assumed to be the target representing restored conditions at other locations.

- Based on available salinity and flow data, develop salinity:flow relationships representing conditions at the four estuaries of concern for this study, Wiggins Pass, Naples Bay, Rookery Bay, and Ten Thousand Islands. The location of the salinity and flow stations used in the analysis are also shown in **Figure 10**.

- Estimate the flow deficit or surplus at each of the monitoring stations that is required to reach the salinity target.

Figure 10
Monitoring Stations Considered in the Salinity:Flow Analysis



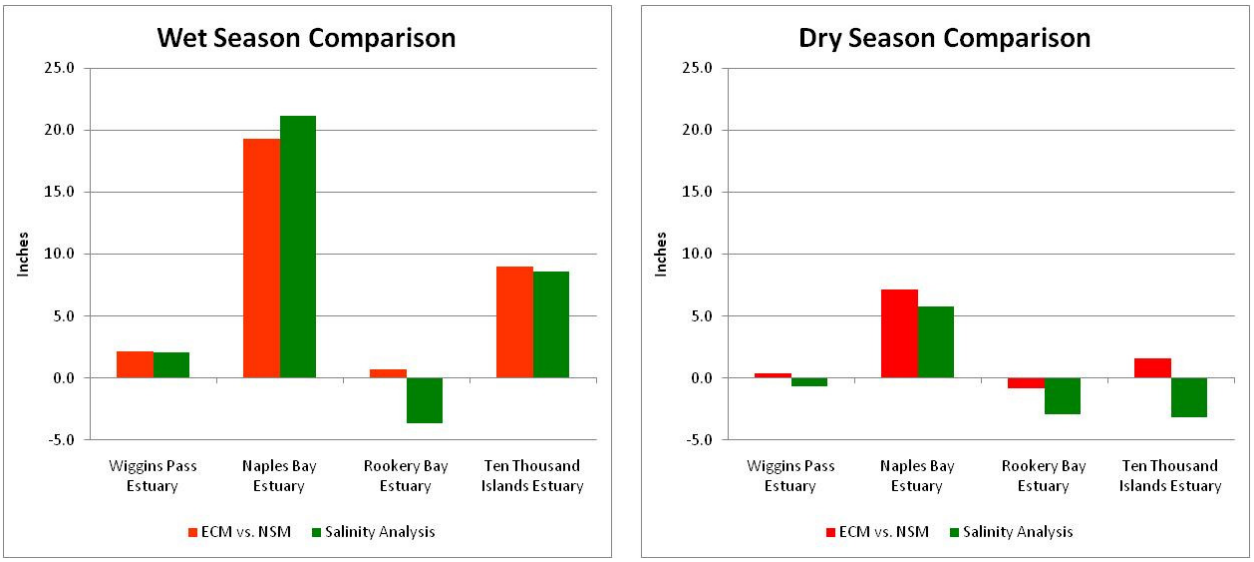
It must be noted that flow estimates in the salinity analysis are based solely on a single point of discharge to each estuary. In some watersheds, such as Rookery Bay, additional fresh water flows enter the estuaries through other canals that are not monitored for flow or salinity and could not be included in the analysis.

Figure 11 shows results of the model comparison and salinity analysis methods for the wet and dry seasons, respectively. During the wet season, the predicted excess flow to the Wiggins Pass and Naples Bay estuaries are very similar in both methods. This indicates that wet season flows to the estuary are dominated by discharge from the Cocohatchee and Golden Gate Main Canals to the Wiggins Pass and Naples Bay estuaries; respectively.

Both methods also predict similar discharge to the Ten Thousand Islands Estuary during the wet season. The salinity analysis uses only measured flows from the Faka Union watershed. The similarity of the ECM vs. NSM results suggest that the excess wet season flow to the Ten

Thousand Islands estuary is dominated by discharges from the largely impacted Faka Union watershed and not from the Fakahatchee and Okaloacoochee/SR 29 watersheds, which have been impacted by development to a much small degree.

Figure 11
Results of the Model Comparison and Salinity Analysis Methods



For the Rookery Bay estuary, the Salinity Analysis indicates a wet season deficit from the Henderson Creek Canal to the estuary. The ECM vs. NSM comparison indicates a wet season surplus. The difference is that the Salinity Analysis only considers flows from the Henderson Creek Canal that drains approximately 40 percent of the watershed. The ECM vs. NSM analysis considers flows from the entire watershed and includes the urbanized Lely Area in the western portion of the watershed and the agricultural areas in the southeastern portion of the watershed.

During the dry season, the Salinity Analysis indicates that there is a flow deficit from the primary canals to the Wiggins Pass, Rookery Bay, and Ten Thousand Islands estuaries. This is expected since the most downstream control structures in the Cocohatchee, Henderson Creek, and Faka Union Canals often prevent flow from occurring during the dry season. In the ECM vs. NSM results, a flow surplus, or a smaller flow deficit, can be attributed to the flow contributions from the secondary and uncontrolled releases to the estuary systems.

In the Naples Bay Estuary, the dry season results indicate a surplus using both calculation methods. This indicates that the Golden Gate Main Canal remains the primary source of discharge to the estuary; however, it is likely that flows from the smaller tributaries make up a larger percentage of the total flow to the estuary during the dry season.

5.0 Conclusions on the Application of the Analysis Methodology

The following conclusions can be drawn from the results of this analysis:

1. In spite of the limitations of both methods applied to define fresh water discharge targets for the Collier County estuaries, the runoff surplus or deficit results are comparable. This validates the use of the ECM to evaluate potential proposed projects that will be incorporated in the Watershed Management Plans.

2. The primary environmental protection issue associated with the Wiggins Pass, Naples Bay, and Ten Thousand Islands estuaries is excess runoff during the wet season.

3. For the Rookery Bay Estuary, the primary issue appears to be the timing of flow to the estuary. The system receives too much water during the wet season and too little water during the dry season.

6.0 Development of Performance Measures

This section summarizes the methodology that was used to assign a Discharge to Estuary score for each watershed based on a comparison to the pre-development condition. As indicated previously, the scoring methodology is defined as the Performance Measure and is used to assign a score to the characteristics of the system under existing conditions. It will also be used to benefits of alternative improvement projects that are being proposed for each watershed.

6.1 Scoring Methodology

Scoring is based by comparing the timing and volume of discharge from the Natural Systems Model (NSM) developed by for the Southwest Florida Feasibility Study (SDI, 2007) to the Existing Conditions Model (ECM) and each alternative scenario. As described previously, average monthly discharge volumes from the NSM and ECM models were used to define the baseline distribution and total volume of flow from each watershed. The alternative scenarios will be scored in the same fashion as the ECM.

The scoring process consisted of the following steps.

1. The monthly discharge from each watershed from the NSM model is considered the baseline condition. The NSM volume of flow for each month is assigned a score of 10.
2. Each monthly discharge from the ECM is assigned a score from one (1) to 10. The monthly score is calculated by dividing the NSM volume by the ECM volume and multiplying by 10.
3. In the event that the NSM volume is larger than the ECM volume, the monthly score is calculated by dividing the ECM volume by the NSM volume and multiplying by 10.
4. The average of the monthly scores determines the watershed score relative to the NSM.

6.2 Example

The following example illustrates the scoring process. It was applied to the Golden Gate – Naples Bay watershed using data extracted from the ECM. The data is shown in **Table 2**.

Step 1. Calculate the absolute difference between the ECM volume and the NSM volume. The result of this calculation is shown in Column 4.

Step 2 Calculate the score for each month. For the month of January, the score would equal to two (2) based on the following equation:

Calculated Score = (NSM volume/ECM volume)*10)

The calculated score is rounded to the nearest whole number.

Step 4 Average the monthly scores to determine the watershed score for the annual and seasonal conditions relative to the NSM.

Table 2
Golden Gate – Naples Bay Watershed Scoring Summary

	Monthly Average NSM Volume (inches)	Monthly Average ECM Volume (inches)	Flow Deficit/Surplus (inches)	Calculated Score
January	0.12	0.76	0.64	2
February	0.12	0.53	0.41	2
March	0.13	0.44	0.31	3
April	0.06	0.15	0.09	4
May	0.02	0.14	0.12	1
June	0.13	2.38	2.25	1
July	0.27	3.80	3.54	1
August	0.50	6.22	5.72	1
September	0.78	6.97	6.19	1
October	0.55	4.43	3.88	1
November	0.30	2.49	2.19	1
December	0.20	1.33	1.13	1
			Annual Score	1.6
			Dry Season Score:	1.9
			Wet Season Score:	1.0

6.3 Existing Conditions Scores for the Watersheds

Tables 3 through 5 provide the scoring matrices showing the score for each of the other watersheds. Of the four watersheds, the Golden Gate – Naples Bay watershed received the lowest annual score of 1.6. The score is indicative of the year round flow surplus discharging into Naples Bay.

The scores for the Rookery Bay watershed indicate that the primary impairment occurs during the dry season due to freshwater deficits. This is likely due to the reduced size of the watershed caused by construction of the Golden Gate Main Canal. The observed wet season surplus is likely due to stormwater runoff from the Lely area and from the agricultural lands in the southeast portion of the watershed.

In the Cocohatchee-Corkscrew, and Eastern (Faka Union, Fakahatchee, and Okalocoochee-SR 29) watersheds, the scoring results indicate that the operational controls that are used to manage dry season flows are reasonably effective at matching pre-development flow conditions. This contributes to the higher monthly scores observed during the dry season. However, the wet season scores are low for all watersheds. This provides an indication of the effect of development on the natural drainage system.

Table 3
Cocohatchee – Corkscrew Watershed Scoring Summary

	Monthly Average NSM Volume (inches)	Monthly Average ECM Volume (inches)	Flow Deficit/Surplus (inches)	Calculated Score
January	0.06	0.08	0.02	8
February	0.06	0.06	0.00	10
March	0.06	0.06	0.00	10
April	0.03	0.03	0.00	10
May	0.01	0.03	0.02	3
June	0.03	0.29	0.26	1
July	0.10	0.44	0.35	2
August	0.14	0.90	0.76	2
September	0.24	1.02	0.77	2
October	0.21	0.51	0.31	4
November	0.11	0.19	0.08	6
December	0.09	0.12	0.03	7
			Annual Score	5.4
			Dry Season Score:	6.9
			Wet Season Score:	2.5

Table 4
Rookery Bay Watershed Scoring Summary

	Monthly Average NSM Volume (inches)	Monthly Average ECM Volume (inches)	Flow Deficit/Surplus (inches)	Calculated Score
January	0.22	0.08	-0.14	4
February	0.18	0.08	-0.10	4
March	0.22	0.05	-0.16	2
April	0.09	0.02	-0.08	2
May	0.01	0.00	-0.01	2
June	0.15	0.41	0.26	4
July	0.37	0.67	0.30	5
August	0.84	1.13	0.28	7
September	1.40	1.84	0.45	8
October	1.12	0.76	-0.36	7
November	0.56	0.23	-0.33	4
December	0.36	0.12	-0.24	3
			Annual Score	4.3
			Dry Season Score:	3.1
			Wet Season Score:	6.8

Table 5
Faka Union, Fakahatchee, Okaloacoochee–SR 29 Watershed Scoring Summary

	Monthly Average NSM Volume (inches)	Monthly Average ECM Volume (inches)	Flow Deficit/Surplus (inches)	Calculated Score
January	0.40	0.43	0.02	9
February	0.31	0.33	0.02	9
March	0.29	0.29	0.00	10
April	0.19	0.14	-0.05	7
May	0.12	0.12	0.00	10
June	0.16	0.91	0.75	2
July	0.32	1.90	1.59	2
August	0.48	3.20	2.72	1
September	0.67	3.85	3.18	2
October	0.71	2.22	1.51	3
November	0.56	1.21	0.65	5
December	0.50	0.69	0.20	7
			Annual Score	5.6
			Dry Season Score:	7.4
			Wet Season Score:	2.0

7.0 Scoring Methodology for the Evaluation of Alternatives

In order to evaluate the alternative scenarios, a similar scoring methodology will be used. The calculated monthly flows for each scenario will be compared to the NSM calculated monthly flows.

For instance, for a project implemented in the Golden Gate Naples Bay watershed that leads to a reduction in flow to the estuary, the calculated monthly flow for September might be 5.0 inches. In the ECM, the score for September is one (1), but for the alterative, the score would be two (2):

$$(0.78/5.0)*10 = 2$$

Where:

0.78 = the NSM monthly flow for September, and
5.0 = the Alternative monthly flow for September

8.0 References

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