SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Final Peer Review Report

South Florida Water Management Model

Version 5.5

October 2005

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The South Florida Water Management Model, Version 5.5

Review of the SFWMM Adequacy as a Tool for Addressing Water Resources Issues

Final Panel Report
October 28, 2005

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Executive Summary

Panel Task

On August 1 2005 the South Florida Water Management District convened a panel of experts to perform a review of the South Florida Water Management Model (SFWMM), version 5.5, as described on the Documentation of the South Florida Water management Model, Version 5.5, Final Draft, August 2005.

The essence of the Panel's task was "To conduct an independent and objective review of the adequacy of the SFWMM [South Florida Water Management Model] as a regional modeling tool for addressing water resources issues in South Florida. The review shall rely on the latest documentation of the model as the primary source of information about the model." The panel interpreted the mandate broadly, seeking to judge the adequacy of the model for its stated objectives and judging whether the written documentation articulates sufficiently well the capabilities of the model. It should be noted that the Panel could not, nor attempted to judge the accuracy of the coding of the model nor did it perform quality control exercises to vouch that it is error free. The Panel judged intended functionality and performance based only on the material provided and hence the accuracy of the model over its whole range of operations cannot be ascertained, except by written and oral assurances of the SFWMD staff and other users.

General Findings

1. The SFWMM is an appropriate model for planning and operational planning for the South Florida system.
2. It is clear from the documentation and the workshop presentations that the model performs satisfactorily and is quite robust.
3. The Panel did not find glaringly missing processes or elements of the system.
4. There is some unevenness in the model's representation of the hydrologic processes.
5. The model is a reasonably complete representation of the district's operational and management system.
6. The description of the operation and management element of the model suffers from the 'forest-from-the-trees' syndrome. Too much detail is provided on specific elements/components, while lacking sufficient overview discussions.
7. The sensitivity and uncertainty analyses that have been reported are inadequate.
8. The District should be more explicit about the precision of calibrated parameters, and the impact of such uncertainty on the values of simulated metrics of systems performance in the SFWMM.
9. There are changes that should be implemented in a completely new version of this model, an effort that the Panel encourages.

Major Recommendations

1. The Panel strongly urges the SFWMD to clarify the model objectives with concise statements in the first chapter of the document.
2. A more rigorous discussion and justification of the level of complexity chosen for each process in each region should be included in the written documentation.
3. Chapter 3 on Policy and System Management Components is possibly the most important chapter in the document. The Panel recommends that Chapter 3 include more discussions of how the whole system operates, before discussing details of specific elements and components.
4. The Panel recommends that water budgets be specifically recognized as key hydrologic performance metrics, and should be both shown and discussed.
5. Automatic optimization search techniques should be considered for parameter calibration. This is important for investigating model behavior as related to establishing parameter values. The Panel recommends that parameter precision be quantified.
6. The Panel recommends that concepts of precision be integrated from the initial calibration process on through the sensitivity and uncertainty analyses that are conducted on the model parameters as well as the performance measures.
7. The Panel suspects that the sensitivity and uncertainty analyses that have been conducted are inadequate. However the Panel is certain that the documentation of the calibration, sensitivity analysis and uncertainty analysis efforts are unclear. It is recommended that efforts on appropriate sensitivity and uncertainty analysis be redoubled and documented appropriately.
8. The Panel recommends an additional chapter to summarize the objectives and capabilities of the model. It should state its limitations as well as appropriate uses, possibly illustrated with experiences with the model. Finally it should speak to the future developments of the model, its useful life and plans for a <u>Next Generation Regional Model</u>.

Summary of Responses to District Questions

A. Clarity and Appropriateness: Are the objectives of the documentation clear? Are the objectives met?

   1. This is overall a complete and readable document. The introduction and initial description of the system is a good one. There is some lack of uniformity apparent in the presentation.
   2. Nowhere can the reader find a concise statement of model goals, objectives and intended use. Nowhere does the documentation state clearly that the model is intended for planning and operations planning, or describe the meaning of those terms. The stated purposes of the model largely address simulation ability without discussing the nature and use of those simulations, possibly by example.

B. Based on the documentation and presentations provided by the District, are the modeling techniques and methodologies used in the SFWMM appropriate for the temporal and spatial scale of the model?

    1. All model processes and techniques are defensible, none of them can be found incorrect or unexplainable. That does not imply that there may not be better ways to represent processes or to model the system. The SFWMM is a result of over 20 years of development. As is commonly the case in this type of a model, it reflects "patchiness"; unevenness in process representation; and solutions that are less than ideal or forced to fit an existing structure. That does not imply that anything is wrong or inappropriate but it is a reflection of legacy and changing times and technologies.

C. Physical and Hydrologic Processes: Does the SFWMM include all the important physical and hydrological processes necessary to address regional-scale water resource issues in South Florida?

    1. All significant processes that describe the regional hydrology of South Florida are represented in the SFWMM. The methodologies used to represent these processes range from quite empirical (e.g., the treatment of the unsaturated zone and evapotranspiration) to more physically-based (e.g., groundwater flow and overland flow in the natural areas). Decisions regarding the level of sophistication required for modeling different hydrologic processes in different regions seem to have been made, based on intuition, experience and data availability, to improve computational efficiency, or to improve model calibration. While the panel respects and accepts the judgment of the modelers at the SFWMD, a more rigorous discussion and justification of the level of complexity chosen for each process in each region should be included in the written documentation.

D. Does the SFWMM include all the important structural and operational rules to address regional-scale water resource issues in South Florida? Are the structural features and operational rules addressed adequately?

    1. As far as the Panel can ascertain, given the limitations of the review process, the SFWMM tries to represent all the important structural and operational rules of the system. This assessment is largely founded on the testimony of the district staff. Nevertheless, the documentation of the operational rules suffers from the 'forest-from-the-trees' syndrome. Too much detail is provided on specific elements/components, while lacking sufficient overview discussions to allow the reader a clearer image of how the whole system operates as an aggregation of its components. Starting with an overview discussion would help clarify how the component information later in the chapter fits into the overall model.
    2. There is no clear distinction on where the model representation ends and actual operating rules and regulations begin. The presentations made it clear that the model is not used for actual operations, but the link between the model and field operations/actions is not clear. The Panel recommends

that the relationship between the model and field operations be discussed and clarified.

E. Calibration and Validation: Is the model calibration process adequate for a predictive model in water resources management? Based on available tools, procedures, and data, is the model validation/verification procedure conducted in an appropriate manner?
   1. The SFWMM is a regional scale hydrology model and is primarily used as a planning and management tool to assist with environmental management, water supply and regional flood control. It is not a research model. When judged against this backdrop, the model calibration and verification was probably satisfactory.
   2. An unanswered question is**:** What is the level of model accuracy needed for appropriate model uses? This has direct bearing on model calibration and verification. A discussion of this issue is important for model calibration and verification.

F. Overall appropriateness of model comparable to others outside South Florida
   1. There is no other existing model that can do what the SFWMM does in South Florida. The value of the SFWMM is that it provides an integrated description of this unique, large, and complicated system. It would be wrong to think of this model or any other future model as a generic hydrologic tool. For the foreseeable, SFWMD needs a customized tool, one that is appropriate for the unique environment it needs to represent.

1.0 Introduction

On August 1 2005 the South Florida Water Management District convened a panel of experts to perform a review of the South Florida Water Management Model (SFWMM), version 5.5 (as described in Documentation of the South Florida Water Management Model, Version 5.5, August 2005, Final Draft). Relevant elements of the Statement of Work are attached in Appendix E. Members of the Panel were Prof. Rafael L. Bras (Chair), Mr. Anthony Donigian, Prof. Wendy Graham, Prof. Vijay Singh and Prof. Jery Stedinger.

The essence of the Panel's task was "To conduct an independent and objective review of the adequacy of the SFWMM as a regional modeling tool for addressing water resources issues in South Florida. The review shall rely on the latest documentation of the model as the primary source of information about the model." The SFWMM is a complicated representation of a complicated system. *While relying heavily on the "Final Draft - Documentation of the South Florida Water Management Model, Version 5.5, August 2005" the Panel also formed its opinion using the responses to our written and oral questions during the two workshops of September 8-9 and October 13-14, 2005 and the written responses to our written questions (see Appendix F). The panel interpreted the mandate broadly, seeking to judge the adequacy of the model for its stated objectives and judging whether the written documentation articulates sufficiently well the capabilities of the model. It should be noted that the Panel could not, nor attempted, to judge the accuracy of the coding of the model nor did it perform quality control exercises to vouch that it is error free. The Panel judged intended functionality and performance based only on the material provided and hence the accuracy of the model over its whole range of operation cannot be ascertained except by written and oral assurances of the SFWMD staff and other users.*

Although the documentation does not succinctly state it, the panel interprets the SFMWM as a planning and operational planning tool. It is not an operations instrument; it is not a predictive model. Its main goal is to provide a platform to test changes in system configuration and operations. The model describes behavior and trends over fairly long time periods (generally monthly), but it is not intended to be used in a fashion compatible, say, with the hourly operations or even daily operations of the system. *The Panel strongly urges the SFWMD to clarify the model objectives with concise statements in the first chapter of the document. In doing so, objectives and functionality should not be confused. The introductory presentations made during the first workshop are a good example to follow.*

2.0 Clarity and Appropriateness of Documentation

Overall this is a complete and readable document. The introduction and initial description of the system is clear. There is still some lack of uniformity apparent in the presentation. The following will point out areas where style uniformity could be improved. One general criticism is the failure to define terms on the first usage; this is true relative to abbreviations and acronyms. A list of abbreviations and acronyms alone does not substitute for good definitions at the appropriate time and the list provided is not comprehensive. Some repetition, spelling out of meaning, will help readability. The most common stylistic flaw is the slippage, at places, into a "user's manual' approach rather than a general documentation and description. Having said this, it is clear that with the appendices, this document could be used as a user's manual. All the information is indeed available, reflecting that a very large amount of work and thought went into the preparation of the document. During the Workshops the Panel pointed out areas where problems were perceived and the staff either answered or accepted the criticism. Without attempting to reconstruct the extensive discussions of the Workshop (see also Panel questions and Staff answers in Appendix 2), which are otherwise documented, the following will provide some of the important specific comments that may lead to the improvement and appropriateness of the documentation.

As stated above the General Introduction of the documentation is a good one, providing a good overview of the system, giving historical background and discussing model characteristics. *One weakness is that nowhere can the reader find a concise statement of model goals, objectives and intended use.* As mentioned previously in this document, nowhere does the documentation state clearly that the model is intended for planning and operations planning or describe the meaning of those terms. The stated purposes of the model largely address simulation ability without discussing the nature and use of those simulations, possibly by example. Interestingly, the oral "overview" of the model was more illustrative. In revising the Introduction the Panel encourages the use of the presentation as a template. This comment is in fact true for many of the sections and corresponding presentations, although not all. The Panel encourages the liberal use of images and illustrations to help in this and other sections.

Chapter 2 on Physical and Hydrologic Components is comprehensive. *The Panel did not detect major missing elements.* The readability is affected by the use of "pseudo code" in parts and by some unevenness in the treatment of material. The Panel recommends that the use of pseudo code and code variable names be eliminated as much as possible from the general narrative. Furthermore, it is important that there is some consistency in use of variable names. It was apparent that the same variable received different names in this and other chapters of the documentation. From a readability point of view the sections on Overland flow, 2.4, and particularly Subsurface Flow, 2.5.5, stand out for their detailed, "quantitative feel". This certainly calls for editing for style but it also poses the larger and more important question on whether the physical and hydrologic processes are modeled to commensurate detail. This will be further discussed in other sections of this report. *The Panel recommends that the sections dealing with input data (i.e., topography, land use, rainfall) be moved to a separate chapter addressing the nature and quality of* *the various forms of input and calibration/verification data available.* Again, the oral presentation during the first workshop is a good template. We repeat the value of liberal use of figures and schematic illustrations.

Chapter 3 on Policy and System Management Components is the most difficult one to write and to read. *The operations of the system are extremely complicated and it is not easy to capture them concisely. The panel urges the use of schematic diagrams to guide the reader through the many operational issues.* Again, the oral presentations used during the workshop are a good improvement and can be used as a template for improving the written document. Section 3.2.2 is an example of "users manual" style relying on "FORTRAN-like statements" and pseudo code. Good schematic diagrams of the procedure would best serve the section. The section should include an explanation of the goals of the system in simple language. Section 3.4.2.1 also resorts to the confusing use of pseudo-code. There is a striking change of style in this section. The section on Rain-Driven operations in 3.4.2.2 is confusing. Section 3.5.2 reads differently and is confusing. Chapter 3, particularly the section on the Everglades Agricultural Area (section 3.2)**,** delves into descriptions of hydrologic processes that naturally belong in Chapter 2. *The Panel suggests that all physical processes be developed and described in one chapter and that Chapter 3 be limited to narrating how different physical conditions trigger different operating rules that affect the movement of water within the model and the real system. In summary, Chapter 3 is possibly the most important, because of its uniqueness, of the document. It is the one that needs the most clarification and improvement.*

Chapter 4, Calibration and Verification, contained some inconsistencies and misstatements that were pointed out during the workshop. An example is section 4.2.1 where the methodology discussion is not representative of what was actually done; this is in reference to comparisons on "end of week" basis. The chapter is also not completely clear on the years of data used for calibration and verification. Equations 4.1.1.1 and 4.1.1.2 need to be clarified as mutually exclusive situations. Figure 4.1.1.1 needs a better explanation of the unusual May value. The workshop presentation was clearer. Table 4.2.2.1 is very difficult to absorb. It is recommended that some of the figures in Appendix C be moved, as examples of key behaviors, to the main text. The Chapter could use a somewhat more critical analysis of the results. *Much of the model is predicated on appropriate water balances but insufficient evidence is given that water balances are accurately obtained. The Panel strongly recommends that parameter estimates be given with associated measures of precision.*

From the workshop it is clear that the text of Chapter 5, Sensitivity Analysis, needs to be improved in order to explain what was done and the results that were obtained. For example**,** text is needed to explain the results in Figures 5.2.1, 5.2.2, 5.2.3 that were used to derive Table 5.2.1. It is also clear that Figures 5.2.4 through 5.2.10 need to be reformulated to be useful. *After the first workshop the Panel was left with the sense that although a lot of good work has been done on sensitivity analysis and in uncertainty analysis (Chapter 6) the document does not correctly represent the issues or the implications of the issues.*

There were serious questions about methodology and clarity of the results in Chapter 6, Uncertainty Analysis, particularly the use of regression, which seemed more appropriate to the calibration chapter. Chapters 5 and 6 were revised in direct response to the comments of the last review. While applauding the effort, the Panel still feels that these two Chapters and the analysis behind them need a lot of work. Section 6 of this report raises some fundamental questions that should be addressed.

The Panel recommends that an additional chapter, possibly entitled Conclusions and Future Development, be written. This chapter should summarize the objectives and capabilities of the model. It should state its limitations as well as appropriate uses, possibly illustrated with experiences with the model. The chapter should be specific as to the performance measures used to evaluate the success of the model in helping planning and operational planning. Finally it should speak to the future developments of the model (i.e., the implementation and use of position analysis), its useful life, and plans for a Next Generation Regional Model.

3.0. Model Structure

3.1 Appropriateness

The SFWMM is an appropriate model for the stated planning objectives. *It is clear from the documentation and the workshop presentations that the model performs satisfactorily and is quite robust. From a structural perspective, the Panel did not see glaringly missing processes or elements of the system.* The model is a reasonably complete and accurate representation of the district system. As will be clear in section 3.4 and throughout this report, there are changes that should be implemented in a completely new version of this model, but that do not warrant changing in the SFWMM.

3.2 Soundness of Modeling Techniques

All model processes and techniques are defensible. None of them was found incorrect or unexplainable. That does not imply that there may not be better ways to represent some processes and to model the system. The SFWMM is a result of over 20 years of development. As is commonly the case in this type of model, it reflects some "patchiness"; unevenness in process representation; and solutions that are less than ideal or forced to fit an existing structure. That does not imply that anything is wrong or inappropriate; rather it is a reflection of legacy, and changing times and technologies. At some point, all models of this type must be rebuilt, from the beginning, because halfway fixes become too cumbersome or endanger the stability of the model. The Panel believes that the SFWMM is at that stage. It is surprisingly robust; it provides good results; and it works, but improvements on the existing model are not worth the time and money. Investment in a new model that will slowly replace the SFWMM is needed. *The Panel supports the development of the Next Generation Regional Model (RSM).*

3.3 Overall Appropriateness of the Model in Comparison to Others Outside South Florida

There is no other existing model that can do what the SFWMM does in South Florida. The value of the SFWMM is that it provides an integrated description of this unique, large, and complicated system. It would be wrong to think of this model or any other future model as a generic hydrologic tool. For the foreseeable future, SFWMD needs a customized tool, one that is appropriate for the unique environment it needs to represent.

3.4 Future and Recommendations

As stated before, *the Panel supports the investment in the development of a Next Generation Regional Model (RSM) that will gradually supplant this SFWMM.* It will take years to make sure that the new model can operate as robustly as the current SFWMM. The RSM is, or should be, developed considering the following (no priorities implied by the order of items):

1. There should be reasonable consistency in the level of representation of processes given their importance and the availability of data.

2. Sensitivity and uncertainty analysis should be integral to the parameter estimation procedures and model outcome evaluation. The new model calibration should provide information on the precision of parameter estimates. Similarly, performance measures important to model uses should be associated with estimates of uncertainty.
3. The calibration and verification system should be integrated into the model development and codified as much as possible. Automatic procedures should be considered when appropriate and measures of parameters precision should be obtained and provided to the extent possible.
4. All calculations should be integrated into the model; offline preprocessing should be avoided if it neglects important interactions.
5. The best available numerical techniques should be used, with particular focus on the need for stability and convergence of solutions.
6. Serious consideration should be given to the time step used in the numerical algorithms.
7. Parallel processing should be the goal of the new model.
8. The new model needs a good graphic user interface.
9. A new model should be designed keeping in mind that this planning tool can, and should, ultimately evolve to an operational tool that would operate in near real time with near real time inputs.

4.0 Physical and Hydrologic Processes

4.1 General Overview of Completeness of Physical and Hydrologic and Representation

All significant processes that describe the regional hydrology of South Florida are represented in the SFWMM. The methodologies used to represent these processes range from quite empirical (e.g., the treatment of the unsaturated zone and evapotranspiration) to more physically-based (e.g., groundwater flow and overland flow in the natural areas). Decisions regarding the level of sophistication required for modeling different hydrologic processes in different regions seem to have been made, based on intuition, data availability and experience, to improve computational efficiency or to improve model calibration. While the panel respects and accepts the judgment of the modelers at the SFWMD, a more rigorous discussion and justification of the level of complexity chosen for each process in each region should be included in the written documentation.

In addition to describing the physical processes simulated in the model, Chapter 2 presents methodologies used to produce model inputs (topography, land use, rainfall, potential evapotranspiration) and methodologies used to estimate initial and boundary conditions. In the panel's opinion these sections should be separated from the discussion of the physical processes, and put into their own chapter.

4.2 Review of Critical Elements

4.2.1 Topography and Land Use

The District has used a variety of sources of topography data to describe land surface elevations in the modeled region. The resolution and accuracy of these data sets differ based on the technologies used to gather and process the data. *The panel has concerns that this merged data product may not be continuous at the boundaries where the datasets meet.* We encourage the District to plot high-resolution contours of the merged data set carefully examining the boundaries for discontinuities that may cause spurious hydrologic flow patterns.

Representing topography and land use as constant over a 2 mile by 2 mile grid cell is an approximation that has implications for the physical meaning of model parameters such as detention depth, surface roughness, potential ET, maximum infiltration rate. Furthermore this spatial aggregation has different implications in different regions of the modeled domain. For example, in the urban region impervious areas and local detention ponds are not specifically modeled. As a result the detention depth must be set to an artificially high value to prevent overland flow between grid cells and to capture the effect of those ponds. Thus detention depth values are larger in the urban areas than in the natural areas of Everglades National Park, which is counterintuitive. Where this occurs, the panel recommends that the District take care not to use these non-physical parameters later in physically-based equations (see section on subsurface flow below) where they would be inappropriate.

4.2.2 Rainfall

The methods by which rainfall measurements are screened for outliers and interpolated over the modeled domain seem generally appropriate. *However the panel recommends that the District examine the impact that network geometry may be having on the interpolated values, particularly in the southwest portion of the domain.* The panel also recommends that the interpolated rainfall be compared to available NEXRAD data to validate spatial patterns. Furthermore, when sufficiently long temporal records of NEXRAD data are available, the panel recommends the NEXRAD data be formally incorporated into the input rainfall dataset.

4.2.3 Evapotranspiration and Vadose Zone Flow

4.2.3.1 Potential Evapotranspiration

Potential Wet Marsh Evapotranspiration is calculated over the entire simulated domain using a temperature-based adaptation of the Abtew simple method, i.e.

$$Et_p=K_1K_r(T_{max}-T_{min})^{0.5}R_a/\lambda$$

where K_1 and K_r are empirical coefficients, R_a is the extraterrestrial radiation calculated from latitude and time of year, λ is the latent heat of evaporation and T_{max} and T_{min} are the mean daily maximum and minimum temperature**s**. This method was selected because it depends only on temperature measurements; there are insufficient high quality long-term measurements of net solar radiation, wind speed, humidity**,** etc. needed for more complex models. K_r was selected for each of 17 NOAA stations so the long-term average annual potential wet marsh evapotranspiration matched a pre-assumed north to south gradient.

The panel believes that this methodology for calculating wet marsh PET most likely gives adequate results. *However the panel questions whether use of this highly specialized, unfamiliar methodology gives more accurate results than well-known algorithms, such as the Priestly-Taylor method if it was regressed against temperature and calibrated for use in the area.*

4.2.3.2 Actual ET and Vadose Zone Simulation

Different methods of actual ET calculation and vadose zone simulation are used in various portions of the SFWMM domain. Based on the draft documentation provided, it is difficult to grasp what methodology was used where, and why different methodologies were applied. The use of pseudo-code and the inconsistent use of notation in these sections make the presentation difficult to follow. The inclusion of ET computation and vadose zone accounting methods both in Chapter 2 (Physical and Hydrologic Components) and Chapter 3 (Policy and System Management Components) further exacerbates the problem.

The panel recommends that all discussions of ET and vadose zone moisture accounting be removed from Chapter 3 and consolidated into Chapter 2. This would include discussions of the procedures used for Lake Okeechobee, Everglades National Park and other natural areas, EAA, LEC (ET-Recharge), and LOSA (AFSIRS/WATBAL). An exploded figure of the computation domain that shows which methodologies are used in each of the domains would be extremely helpful. A brief summary of the rationale for the varying degrees of complexity chosen in each region (as presented in the Sept 8-9th workshop) should be included. Once the procedures are consolidated and clarified in Chapter 2, Chapter 3 would only have to indicate (where appropriate) that irrigation demands were calculated using procedures outlined in Chapter 2.

None of the ET-vadose zone routines explicitly incorporate interception processes. These and other assumptions and simplifications lead to non-physical meanings for many parameters such as detention depth in the urban areas, soil moisture storage parameters in the EAA, roughness coefficients, and infiltration rates in the natural areas etc. It appears that vadose zone accounting is implemented where it is desired to estimate irrigation demand and predict water shortages. The panel questions whether the variety of algorithms incorporated into the various ET-vadose zone accounting procedures improves model performance. Perhaps a simpler more consistent methodology for estimating irrigation demand, coupled with an "above saturated zone" water volume accounting (not parameterized in terms of soil characteristics) would perform as well.

The panel recommends that the District consider eliminating the pre-processing of the ET-Recharge and AFSIRS/WATBAL models to allow more appropriate coupling between the surface and subsurface hydrologic processes. If this is computationally infeasible then the District should consider adding a first-order correction term to adjust the ET/Recharge values used in the simulation for deviation in groundwater table and depth of surface ponding from assumed values used in the pre-processing algorithm.

4.2.4 Overland Flow

Overland flow is modeled throughout the simulated domain using the diffusion wave model. This mechanism of overland flow is appropriate for the natural areas of Everglades National Park, but inappropriate for the urban areas where sheet flow does not occur due to engineered drainage. As mentioned previously this problem is overcome by setting the surface water detention depth so high in the urban areas that overland flow never occurs. The panel does not recommend this non-physical manipulation of parameters to achieve desired simulation results. *Perhaps an urban surface flow accounting algorithm that more realistically represents the dominant processes should be added to the model to replace the overland flow algorithm in developed areas. This could improve the model's ability to more accurately evaluate the impacts of future urbanization in the region.*

Based on the written documentation, it is the Panel's opinion that under certain conditions there may be problems with the stability and accuracy of the explicit, first-order-in-time, numerical technique used to model overland flow. The Panel questions the way that water movement was arbitrarily limited to maintain stability, since this can impact accuracy. Presentations made during the September 8-9 workshop summarized numerical model verification and error analyses that have been conducted by the District. These results showed that for more or less the same level of computational effort, implicit numerical methods would be just as efficient and yet would avoid stability and convergence problems that an explicit numerical method may suffer from. *Therefore the Panel recommends that the District consider exploring alternative implicit numerical methods in the SFWMM.*

The error analysis based on the spatial discretization and time steps at the September 8-9 workshop indicated significant errors associated with simulating overland flow events of duration shorter than 4 days, and smaller than 10-20 km. It seems that most typical disturbance events would fall within this range, and thus have significant errors associated with predicting them. A discussion of the types of disturbance events that would produce predictions within acceptable error bounds should be included in this section of the model document. Hydrographs showing the duration of actual measured system responses to typical disturbances may be useful in this regard.

The error analysis presented in the workshop results should either be briefly summarized in the documentation, or a reference to the detailed report or journal article should be provided in this section.

4.2.6 Groundwater Flow

Saturated subsurface flow is modeled throughout the simulated domain using the linearized 2-D unconfined aquifer flow model. This is an appropriate level of complexity for the South Florida system. Mechanisms used to model canal-groundwater seepage and levee seepage also seem appropriate. However, the panel recommends that all mention of transmissivity anisotropy be removed from the groundwater modeling discussion since anisotropy is not implemented in the model and it is unlikely that it will be.

The panel questions the validity of modifying the groundwater head to account for ponded water depth when the water table rises above the ground surface, particularly in the urban areas. Given the issues mentioned in section 4.2.1 with the physical meaning of ponding depth incorporated in the model, and the expected small gradient for ponding depth across 2 mile by 2 mile grid cells in natural areas, this added complexity is probably not warranted or more accurate. However modifying the groundwater head to account for water ponded behind levees in the water conservation areas may be important and appropriate.

The panel recommends that the discussion of infiltration and percolation be removed from this section and consolidated in the ET-vadose zone section outlined above. The discussion in this section seems to imply that throughout the domain infiltration is taken to be the minimum of

a. Available water above land surface to infiltrate

b. Infiltration rates multiplied by grid cell area and time step
c. Available soil moisture storage above the water table and below the land surface

It is the panel's understanding that this mechanism only applies in the natural areas.

Furthermore the panel questions whether daily rainfall rates could ever exceed the stated potential infiltration rates (9-100ft/day). If not this mechanism is unnecessary even in the natural areas.

4.2.7 Canal Flow

In the SFWMM, flow routing in canal reaches passing through grid cells employs a water balance approach on a daily basis. The canal reach is considered rectangular with a constant width and a linear slope. The model allows either a constant wedge-shaped longitudinal water surface profile or a dynamic wedge-shaped longitudinal profile. The canal water balance is based on rainfall, ET, overland flow, canal seepage, and structure inflows and outflow. Canals also interact with free water or ponded water within a grid cell.

Although water surface profiles are calculated in a simple manner not accounting for any backwater, the method seems satisfactory for operational purposes on a daily basis. This is because over a 24 hour period, transient dynamic effects in canal reaches will have generally been smoothened out. The model also has provision for canals to respond to flow influences due to actual structure operations.

For canal flow routing initial conditions are defined by stage at the start of simulation. Boundary conditions are prescribed by stage at the downstream node plus offset HDC or stage or headwater at downstream structures.

5.0 Structural Features and Operational Use

This section focuses on the information provided in Chapter 3 of the SFWMM Report, entitled "Policy and System Management Components", and attempts to address the specific Peer Review charge question –

> *Does the SFWMM include all the important structural and operational rules to address regional-scale water resources issues in South Florida?*

This capability of the SFWMM has been highlighted throughout the report and is described as (p. 5):

- "The most unique feature of the SFWMM is the ability to simulate operational scenarios, management options, and define regional water budgets."

- " … there are no other models that have the suite of management options and operational flexibility of the SFWMM for large-scale, system-wide interactions."

Historically, the SFWMM has been used since about 1985 (as shown in Figure 1.2.1 of the Documentation), to evaluate and develop water projects, management alternatives, and operating procedures. The most ambitious application being the Central & South Florida (C&SF) Restudy in 1997. That application helped to develop the Everglades restoration plan approved, in concept, by Congress in 2000. A review of the operational and management components of the SFWMM has not been a major focus of prior model reviews, and therefore is a new area of emphasis for this review.

5.1 Findings of the Panel

Clearly the model has been applied by the SFWMD staff for a variety of projects over the past two decades, and has apparently been used as an effective planning and analysis tool. The Peer Review Panel charge, as shown above, was to assess the utility and completeness of the model as related to its representation of structural and operational features needed for water resources management in SF.

Below are findings and recommendations of the Panel derived from Chapter 3:

Findings:

1. The complexity of the model is derived primarily from its scope and extent of coverage of elements within the South Florida hydrologic system, and not as much from its mathematical representation of processes and structural/operational elements, which is relatively simple.

2. The model is essentially a linked series of buckets, pipes, and junctions/nodes that allow storage capacities, conveyance limits, and pump capacities to be defined. The lack of complexity is acceptable, as long as it doesn't limit the model capabilities to address management issues.

3. Each of the elements is represented within a simple mass-balance, or water balance, framework, and this approach can be entirely adequate for the operational planning and evaluation purposes of the model.

Recommendations:

1. The documentation in Chapter 3 suffers from the 'forest-from-the-trees' syndrome. Too much detail is provided on specific elements/components, while lacking sufficient overview discussions to allow the reader a clearer image of how the whole system operates as an aggregation of its components. Starting with an overview discussion would help to clarify how the component information later in the chapter fits into the overall model. *The Panel recognizes the difficulty the District faces in attempting to document such a complex system, covering an area of more than 10,000 sq mi, and including 1,800 miles of canals and levees, 25 major pumping stations, more than 200 large control structures and 2,000 smaller control structures. However, due to this level of spatial complexity and extent, the Panel recommends that a concise overview be presented early in the Chapter in order to convey the major considerations and issues in the operations of the systems.*

2. Chapter 3 is also confusing in that there is no clear distinction on where the model ends and actual operating rules and regulations begin. Presentations at the First Workshop made it clear that the model is not used for actual operations, but the link between the model and field operations/actions was not clear. Presentations at the Second Workshop clarified how the SFWMM has played a significant role in a range of planning projects and endeavors. *The Panel recommends that the relationship between the model and field operations be discussed and clarified in the report.*

3. Examples of how the SFWMM was used for the various applications were noted early in the report in Chapter 1, but no further elaboration on these applications was provided. This is a common deficiency throughout this section. However, the Second Workshop focused on this issue and the presentations demonstrated the types of information that should be added to this section. *The Panel recommends that Section 3.6 be revised, and possibly renamed 'Applications and Toolbox Capabilities', to include a discussion of how SFWMM was used for the LEC Regional Water Supply Study, the C&SF Restudy, the Modified ENP Water Deliveries, drought/water restriction planning, etc.*

4. The procedure described as 'Position Analysis' is essentially a forecasting procedure to project the uncertainty distribution for the possible state of the

system at some future time (and specific locations) given an initial state. This is an important activity wherein the SFWMM is used for operational planning linked to current system conditions and climate forecasts, as opposed to more general planning applications that are not linked to current conditions. As noted above, the Panel recommends that this section (3.6) be expanded and include discussion of how the systems operations planning and management process would be impacted by the results of these projections.

5.2 Review of Critical Elements

The geographical components of SFWMM include Lake Okeechobee (LOK), the Everglades Agricultural Area (EAA), the LOK Service Area, the Everglades Protection Area (EPA), and the Lower East Coast (LEC). Each of these is discussed in separate sections of Chapter 3. Below we address some of the technical and operational issues related to each of these components as they are represented in the model:

5.2.1 Lake Okeechobee (LOK)

LOK is the centerpiece of the SFWMM, as it is for the SF hydrologic system, since it is the primary source of surface water for each of the other major components. The Panel's conclusions and concerns are as follows:

a. The regulation schedules appear to be reasonably well developed, logical, easy to follow, and well presented in the Chapter. *The missing link for some Panel members was how these schedules relate to actual operation of the system. The Panel recommends that this linkage be clarified in the report, as it was in the Second Workshop, by describing how the model was used to help develop and evaluate the schedules, possibly through actual examples of applications.*
b. The operational decisions trees provide a good presentation of how the model simulates discharges under alternative conditions, but again the link to actual operations is not discussed. The Panel again recommends this be addressed as noted in a. above.
c. The flow charts for the Caloosahatchee and St.Lucie components (Figures 3.1.4.1 and 3.1.4.2 in the Documentation) clearly show the 'bucket and pipe' nature of the system, and give some sense of the complexity due to all the necessary elements included in the model.
d. *Simulating LOK as a lumped system definitely has advantages, but it also has limitations. The Panel recommends that possible limitations be assessed and discussed in the report, and elaborate on the extent to which the spatial issue may be addressed in future model development.*
e. Inflows to LOK as boundary conditions are discussed in Section 2. Section 3 briefly mentions the use of 'non-perfect forecasts of lake inflow' (pg. 110) derived from climate forecasts, but indicates that 'several methodologies' are used. A recent paper by Miralles-Wilhelm et al (ASCE J. WRPM, "Climate-Base Estimation of Hydrologic Inflow into Lake Okeechobee, FL", Sept/Oct 2005, pp 394-401) indicates considerable error is common in predicting lake

inflows from climate forecasts. *The Panel recommends that this should be a topic of continuing work to improve inflow forecasts since they are a critical element of the model when used in this manner.*

5.2.2 Everglades Agricultural Area (EAA)

The EAA is simulated as part of the 2 x 2 grid portion of the LOSA and the major issues addressed in this section of the report are calculation of supplemental irrigation demand and conveyance from LOK to and through the EAA to the WCAs and LEC region. The Panel's conclusions and concerns are as follows:

a. This section is extremely confusing and deals with both ET and irrigation demand calculations, along with structural and operational issues associated with conveyance and irrigation supplies. *As noted earlier, the Panel feels that the ET and irrigation demand discussions (Section 3.2.2) should be included in Chapter 2 (specifically in Section 2.3.3) to be more consistent with the content of that Chapter, and separated from this chapter, which should focus on the operating methods/rules that control movement of water to/through the EAA.*
b. As noted earlier, the use of 'computer code' type presentation of equations is used extensively and should be avoided.
c. The presentation on the ET calculations is a confusing amalgamation of coefficients – theoretical KVEG, adjusted KVEG, KCALIB, KFACT, KMAX – all related to the ET calculation. The Panel recommends that this discussion be revised to be more readable and justify the use each separate coefficient.
d. On page 131-133, percolation is used in 2 different ways: first to represent infiltrating water to the saturated zone, and then as supplemental irrigation to raise the water level to the assumed 1.5 foot depth. The terminology should be revised to be more understandable and consistent.
e. The discussion on 'Canal Conveyance' starting on page 135 is also difficult to follow, and would be helped by including some (not all) of the flowcharts referred to in Appendix F of the Documentation.
f. Figure 3.2.5.2 serves its apparent purpose to impress the reader with the level of complexity that can be represented with the model, but it does little to convey an understanding of the overall system operation. Color-coding of the fluxes (e.g. runoff, irrigation return, irrigation demand/supply, etc.) would improve the figure.
g. *Water budgets have been highlighted as a key capability of the model, but were not shown in the report. The Second Workshop included examples of how water budgets generated by the SFWMM are used in planning efforts. This section would be an ideal place to demonstrate what the model can do in providing that information for the EAA, its separate basins, and under alternative operating conditions. The Panel recommends that water budget information be included in this section.*

5.2.3 Lake Okeechobee Service Area

This section of the Chapter discusses the LOSA basins modeled as lumped basins, as opposed to the gridded representation in the rest of the model. The Panel's conclusions and concerns are as follows:

a. *There is no discussion or rationale as to why some portions of the model are gridded and some are lumped.*
b. As noted for the ET discussion in Section 3.2.2, discussion of the AFSIRS/WATBAL model should be in Section 2, along with the other processes simulated.
c. *There is a concern about the level of 'pre-processing' performed for both the ET calculations and the AFSIRS/WATBAL models of the lumped basins.*
d. Figure 3.2.2.2 seems to show the Non-irrigated Lands providing DR (Field-Scale Drainage) to the Irrigated Lands, before reaching the Local Storage and the Regional System. Does this accurately portray the landscape positioning of these lands? The figure and discussion should be further clarified and possibly revised if needed.
e. What does the 'Monthly 2/10 Demand' noted on page 152 mean? It's not described nor clearly defined anywhere.
f. Section 3.3.8 discussing the SSM plan should be included in Section 3.1 with the LOK operations and release schedules.

5.2.4 Everglades Protection Area

This section describes the operations of the WCAs and ENP to meet flood control, water supply, and environmental demands. The Panel's conclusions and concerns are as follows:

a. This section provides a good discussion of the individual WCAs and the ENP, and the primary water resource management functions of each.
b. On page 165 there should be a discussion of why the modeled areas are different than the actual areas, shown in Table 3.4.2.1. This discrepancy should be discussed in the text.
c. On page 167 the report states "Flood control releases out of WCA-2A and WCA-3A closely follow the schedules prescribed by the Corps (Figures 34.2.3 and 4.3.2.4)." A common issue in this entire chapter is the lack of a clear distinction and clarification of what is in the model, compared to what is in the real world, i.e. how is the actual system operated. The statements like that above imply a close correspondence or equivalence, but others, like STAs are not existing but planned, clearly indicating that the model is representing another reality, or scenario. The Second Workshop helped greatly to clarify this distinction. *The Panel recommends that these distinctions, between the model representation and actual field operations be clarified where possible in the report.*
d. On page 165 the discussion notes that separate water budgets can be prepared for each of the six water management basins, i.e. the 5 WCAs and the ENP. Examples of the water budget displays were provided at the Second

Workshop. *The Panel recommends that these water budgets be included in this chapter, along with a discussion of how these would change under different operating scenarios (or options).* This would help to clarify how the model is representing system changes under 'what-if' conditions, a major use and strength of the model.

e. *The operating rules and schedules appear to be a very reasonable approach to managing a complex infrastructure network of multiple sources and demands, for multiple purposes.* Through the development of the SFWMM, the District staff has clearly demonstrated an innate knowledge and understanding of the complex system they are managing, and the foresight to include the model capabilities needed for future planning and management challenges.

5.2.5 Lower East Coast (LEC)

The main focus of Section 3.5 is water supply to the LEC Service Area, with specific emphasis on how the model represents water demand and water use restrictions. The Panel's conclusions and concerns are as follows:

a. Section 3.5.2 attempts to describe the water supply need calculations using a hypothetical example of interconnected canals and control structures delivering water from a single source, namely LOK. The attempt starts off quite readable but quickly becomes too confusing to easily follow, especially the discussion of 'Surface Water Requirements for a Canal Network' starting on page 190. *A better way to describe the simple water accounting concept, as applied to the complicated interconnected canal/structure network is needed. The Panel suggests a better approach would be to describe how actual pieces of the LEC service zones work, possibly starting with simple sections (e.g. a linear system of a few canals and control structures) and progressing to more complicated ones (e.g. adding a few tributaries to the simple system). Also, using and describing some of the flow charts from Appendix F would help to better organize and focus the presentation.*
b. Section 3.5.2 also suffers from a number of undefined variables and confusing labels and figures, such as:
    i. The 6th column in Table 3.5.2.1: this is the reach upstream of the canal reach, but its label says it is the "Reach to be Maintained". The term 'maintained' was clarified by District staff, but it should also be discussed and clarified in the report
    ii. On page 189 $\boldsymbol{cstage_{j,i}}$ (3rd paragraph) is not defined – is it the same as $\mathbf{cstg_j}$ in Eq. 3.5.2.1?
    iii. Figure 3.5.2.3 is very confusing and difficult to follow.
c. Section 3.5.3 should be included in Section 2 with the other ET process descriptions. The issue of 'pre-processing' irrigation amounts and ET fluxes, which depend on state variables calculated by the model, has been addressed in the review of Section 2.
d. In the second to last paragraph it says "The SFWMM … control surface changes with time." This should be control 'volume'.

e. The discussion of, and reference to, “inefficient” irrigation (last 2 paragraphs on page 193) should be revised and presented in terms of the assumptions used since irrigation efficiency is not explicitly represented in the EAA. The assumption and approach is reasonable, but the discussion should be clarified.
f. *The discussion and presentation of the Water Shortage Plan for the LEC in Section 3.5.4 is sound, readable, and demonstrates a potentially very valuable use of the SFWMM. The Panel suggests that some ‘realism’ be added to the section addressing how the model would respond to historic droughts, how it is used to address drought and water restriction planning currently, and whether it has been successful in these endeavors.*

5.2.6 Storage and Additional Management Options

This section (3.6) is essentially a mixed set of topics that describe different capabilities and uses (e.g. BMPs, ASRs, Positional Analyses) of the model. The Panel recommends that this section be renamed ‘Applications and Toolbox Capabilities’ and supplemented with a focus on specific model applications, performance measures employed, and overall weaknesses/limitations of the model. The example applications presented at the Second Workshop would be good candidates for inclusion in this section.

6. Calibration and Validation

6.1 Calibration Procedure

The SFWMM was calibrated for three different regions: 1) Everglades Agricultural Area (EAA), 2) Everglades and Lower East Coast (LEC), and 3) lumped Lake Okeechobee Service Area (LOSA). Reading of the model documentation indicates that individual model components were not calibrated and validated, but the model as a whole was. The data used for model calibration were primarily stage and discharge, which constituted the model output. Calibration of the SFWMM included data on drainage (runoff volumes) and demand volume (supplemental irrigation requirement) for EAA, water level at observation/monitoring points and structure headwater stages as well as discharge through selected outlet structures for Everglades/LEC; and flow for LOSA. Before calibration and validation, all stage and flow data were subjected to an extensive quality assurance/quality control (QA/QC). This included statistical analyses, comparative analyses, flagging of unusual data, and updating of flow data where stage-flow rating curves were improved.

The calibration procedure entailed the following considerations:

1. Determination of the length of the historical data set for calibration. This depended on the region for which calibration was done. Care was taken to include both dry and wet years in the calibration data set.
2. Inclusion of only reliable data in the calibration data set.
3. Limiting the period of calibration and hence the calibration data set during which no significant changes in operational schemes occurred.
4. Calibration was done on a monthly basis, using monthly total discharges, end-of-month nodal stages, and mean monthly canal stages.
5. Display of calibration results and computation of goodness-of-fit statistics for judging the quality of calibration.

The process of calibration also entailed updating data, updating computer programs, and applying accuracy checks to model algorithms. The model parameters were calibrated such that a reasonable match between model-simulated output values and observed historical values was attained. The model calibration was iterative and manual, not automatic as is becoming more popular in hydrology. The parameters that were calibrated for each region are tabulated in Table 1.

6.1.1 Calibration for EAA

For the EAA basin, model-simulated irrigation requirements (demands) and runoff volumes (drainage) were compared with observed values. The calibration period went from January 1984 to December 1995. Three parameters were calibrated: ET calibration coefficient KCALIB, and dimensionless local soil moisture storage parameters fracdph_min and fracdph_max. These parameters were allowed to vary by month. There were certain rules related to operational policies (see Table 4.1.1.1 on Page 218 of the document) that were considered when adjusting these three parameters. Application of these rules introduced a sense of physical realism to the calibration procedure. Calibrated values of these parameters are given in Tables 4.1.1.2 and 4.1.1.3. The EAA basin contains three sub-basins and the same procedure was followed for each of the sub-basins.

Table 1. Parameters calibrated for each region

EAA
ET calibration coefficients: KCALIB = Spatial / Scale coefficient;
KVEG = Vegetation/crop coefficient
fracdph_min = dimensionless local storage parameter
fracdph_max = dimensionless local storage parameter

LEC
Canal parameters: CHHC= aquifer hydraulic conductivity coefficient; N= Surface water-channel interaction; coefficient for operation of outlet structures
DETEN = Detention depths
ET coefficients: KVEG
DSRZ = depth from land surface to the bottom of shallow root zone
DDRZ = depth from land surface to the bottom of the deep root zone

Everglades (WCAs, ENP, and BCNP)
ET coefficients: KVEG, DSRZ, and DDRZ
N=Effective roughness
Levee seepage coefficients: β_1, β_2, and β_3
DETEN = Detention depths
Canal parameters
Storage Coefficient (only changed on a cell-by cell basis)

LOSA: Caloosahatchee River basin, Brighton Seminole Reservation and Lower Istokpoga basin, Big Cypress Seminole Reservation
EFFI=Irrigation efficiency
STOR1=Local storage depth
CAP1=Drainage capacity
COEFF1=Storage coefficient
Feeder Canal basin PAW= Plant available water capacity
CAP1=Drainable storage capacity
COEF1= Storage coefficient
Total ground water storage
Root zone depth

6.1.2 Calibration for Everglades and LEC

Included in the calibration were the Water Conservation Areas, the Big Cypress Preserve (BCNP), Everglades National Park (ENP), the Holey Land and Rotenberger WCAs, and the Lower East Coast (LEC) Service Areas. The data used in calibration generally included daily water levels, and average weekly canal stages. For certain locations that had sparse or unreliable data, monthly, seasonal and annual data were employed for calibration. All historical data were assumed reliable.

The calibration period included historical data consistent with network of canals and water control structures and constant structure operating rules. The period of record available was 36 years. On account of operational and structural changes in the Central and South Florida Flood Control (C& SF) project around 1990, the calibration period was split into two periods: 1984 to 1990 (using operations for the 1980s), and 1991 to 1995 (with operations for the 1990s). Inclusion of system changes in model calibration is a good way to obtain optimum and physically realistic parameter values.

Calibration of the SFWMM parameters was done in an iterative fashion, that is, parameters were changed until a reasonable match between historical and model-simulated values was obtained. Historical flows at certain structures were used as internal boundary conditions. The number of parameters calibrated for LEC was six plus coefficients for outlet structures; for WCAs, ENP and BCNP, the number of parameters was eight plus canal parameters. During calibration a number of guidelines, based on the characteristics of the model domain, were employed. This permitted inclusion of physical considerations in the calibration procedure.

6.1.3 Calibration for Lumped LOSA

LOSA includes the Caloosahatchee (C-43), St Lucie (C-44), S4, Lower Istokpoga, and North/Northeast Lake Shore basins. These share common land use and land management practices. The Caloosahatchee basin has the most reliable and up-to-date data and was therefore used to calibrate the Agricultural Field Scale Irrigation Requirements Simulation (AFSIRS)/Water balance (WATBAL) model. The calibrated parameter values were then used for other basins in LOSA for regional modeling. Additional calibration was also done for areas that encompassed Seminole Brighton and Seminole Big Cypress Reservation lands in order to ensure that estimated demands were consistent with water rights under Florida state law.

6.1.3.1 Calibration for Caloosahatchee River basin

The period of calibration for this basin was 1991 to 2000. The process of calibration of the AFSIRS/WATBAL model was iterative. Parameters for calibration included two irrigation parameters, five parameters for each of the three types of non-irrigated lands, and monthly Kc parameters for evapotranspiration for each land use. The goodness of fit statistics were used as a basis to adjust model parameters until an acceptable match between simulated demand and runoff and observed flows was achieved. Individual land use performances were also evaluated as a check on the adequacy of model performance.

6.1.3.2 Calibration for Brighton Seminole Reservation and Lower Istokpoga basin

For this basin reliable flow and land use data are limited. Calibration of model parameters was done in an iterative manner. Many of the parameters obtained for the Caloosahatchee were used without any modification. Only two of the parameters, irrigation efficiency EFFI and local storage depth STOR1, were calibrated. The period of calibration was 1995-2000.

6.1.3.3 Calibration for Big Cypress Seminole Reservation (BCR) and Feeder Canal basin

For BCR there were four parameters that were calibrated: irrigation efficiency, local storage depth, drainage capacity, and storage coefficient. These parameters were calibrated in an iterative manner. Land use specific performance was used to check the adequacy of model calibration. For this basin, historical data were lacking; therefore simulated demand was matched with permitted demand. Clearly permitted demand and observed can be far off.

For the Feeder Canal basin, calibration was done using monthly runoff data. The period of calibration was 1991-2000. Only a single snapshot was used. Both irrigated and non-irrigated lands were included. Five parameters were calibrated for each of the three non-irrigated lands. The model simulations were in reasonable agreement with observed values.

6.2 Verification Procedure

For each basin for which the SFWMM was verified, verification was done using calibrated parameter values for the period not included in calibration in three ways: 1) graphical displaying of the time series of model simulated output and the observed time series, 2) plotting model simulated values against historical values, and 3) computing goodness of fit statistics.

6.2.1 EAA

The period of verification spanned two time periods: January 1, 1979 to December 31, 1983; and January 1, 1996 to December 31, 2000. The data for verification included annual volumes, daily flows, and monthly volumes and flows. The model was much better for annual values than for daily values. The scatter on the plot between observed and simulated daily flow values was quite significant. The reasons for discrepancies between simulated and observed values can be attributed to less than optimal parameter values, inadequate model hypotheses, and data errors.

6.2.2 Everglades and LEC

The verification spanned two time periods: January 1, 1981 to December 31, 1983; and January 1, 1996 to December 31, 2000. The model performance was not as good as it was during calibration.

6.3 Quality of Calibration

The quality of model simulation using calibrated parameters was evaluated in three ways: 1) the model-simulated daily and monthly outputs were plotted as time series and so were the corresponding observed time series, 2) the model-simulated output was plotted against observed values on daily and monthly bases and 3) differences between observed and simulated values were noted and goodness-of-fit statistics, including bias, root mean square error, coefficient of determination and the Nash-Sutcliffe efficiency, were computed.

6.3.1 EAA

On a monthly basis the match between model-simulated and observed values was quite good, but in case of daily values there was considerable scatter. Although the model calibration was done in a manner that is commonly done for calibration of watershed hydrology models, certain questions remain. Although the model documentation states that only three parameters were calibrated, effectively there are 36 parameters that were calibrated. On this basis, this model is not parsimonious. Looking at Tables 4.1.1.2 and 4.1.1.3, it becomes apparent that it is possible to take the same parameter values for certain months. Second, it is not clear if the calibrated parameter set is the unique set or globally optimum. Third, for daily values the calibration performance is not as good as it is for monthly values, it is not clear if a higher level of accuracy is needed for practical operational and management decisions. After all this is a planning and operational management model. Fourth, since the calibration period was up to 1995, the underlying hypothesis is that EAA is not undergoing any significant change and hence the calibrated parameter values will hold during subsequent years. In light of looming climate change and intensifying hurricane activity, it may be difficult to justify this assumption.

6.3.2 Everglades and LEC

The quality of model calibration was judged visually as well by computing the coefficient of determination, root mean square error, bias, and the Nash-Sutcliffe efficiency. The model performance was not uniform for all areas within the Everglades and LEC basin. One of the reasons cited for this apparent lack of uniformity in model performance is the variation in the quality of data. In several sub-basins, the quality of data is not what it should be. For several sub-basins the unexplained variance is quite high. The marsh areas tend to be better calibrated than canals.

6.3.3 LOSA

For the Caloosahatchee River basin, there was considerable uncertainty associated with climate, flow and land use data. Nevertheless the model simulations were quite good, especially the patterns of demand and flow.

The calibrated model performance for the Brighton Seminole Reservation and Lower Istokpoga basin was not as good as one would want but was considered acceptable. The model under-predicted demand in earlier years and over-predicted in later years. There were significant differences between simulated and observed demands.

For the Big Cypress Seminole Reservation (BCR) area, historical water use data was lacking. Therefore, the irrigation efficiency had to be lowered by 50% in order to attain a reasonable match between permitted demand and simulated demand. For this area, the quality of calibration is difficult to judge. For the Feeder Canal basin, the model simulations were in reasonable agreement with observed values.

6.4 Review of Critical Elements

The SFWMM is a regional scale hydrology model and is primarily used as a planning and management tool to assist with environmental management, water supply and flood control. It is not a research model. When judged against this backdrop, the model calibration and verification was done in a satisfactory manner. Having stated that there are certain questions that do not appear to have been answered in the model document. The purpose for raising these questions is to help improve the model in future.

1. *Although individual model component processes seem to have been modeled properly, it is not clear if these processes have been calibrated and verified individually.* Model verification is no guarantee that each process has been modeled in the best possible way in light of the South Florida conditions. This step is important in order to achieve model parsimony and develop a physical basis to model parameters. This will also be helpful to make the model computationally more efficient.

2. *Since the model has a large number of parameters many of which vary in time, it is important to investigate the physical nature of these parameters. It is quite likely that certain parameters do not play a very significant role and can therefore be dropped or taken as constant over time.* Furthermore, it is possible that many of these parameters are interrelated and therefore some of them do not need to be taken as independent parameters.

3. *Model calibration has been done in an iterative manner, which is adequate and acceptable. However, it is not clear if the parameter set is globally optimal. To this end, automatic optimization search techniques may worth considering. This is important for investigating model behavior as related to establishing accurate*

parameter values. The accuracy of model parameters is neither clear nor quantified.

4. *The employment of internal boundary conditions at certain structures during calibration needs further elaboration.* It may be that flows at these structures are being used to check the model simulation to ensure proper model parameters values.

5. *Model simulations results have been given up to 3 decimal places. This level of precision is unnecessary* and it is suggested that model results should be reported up to no more than two decimal places; even one decimal place would be acceptable from a practical point of view.

6. *For model calibration and verification, flow duration curves have been given only for EAA, but not for other regions.* These should be given for other regions as well. Or distributions of model results should be constructed. Along similar lines, the values of RSME should be specified for each model calibration and verification set.

7. *The model documentation contains a discussion of sensitivity and uncertainty analysis. It is not clear how this analysis has been employed to improve model calibration and verification.* Sensitivity analysis should assist with model development and model calibration, and provide a basis for making the model more parsimonious. The purpose of this entire analysis is to improve the model but it is not clear how the model has been improved by undertaking this analysis.

8. Water budgets are frequently mentioned throughout the report, and in this section on Calibration and Verification, but they are rarely shown. *The Panel recommends that water budgets be specifically recognized as key hydrologic performance metrics, and both shown and discussed when included in this chapter.*

9. *Since the model is used for planning and management, what level of model accuracy is truly needed?* This has direct bearing on model calibration and verification. It is probable that model simulations in certain cases may not be hydrologically satisfactory but may be quite so in practical parlance. A discussion of this issue is important for model calibration and verification.

10. *The model verification is based on the model output that is taken as deterministic. The discussion on uncertainty analysis shows that a given model output should be associated with a statement of uncertainty. This will significantly enhance the model value in real life decision-making.*

11. *South Florida is undergoing significant change. Agricultural and municipal water demand and runoff generation change as population, environmental and economic pressures change. Furthermore the South Florida's climate can also be*

assumed to be undergoing change. Many of the calibrated parameters, particularly in the agricultural areas are estimated based on historical practices. Thus it is not clear that these calibrated parameters will actually simulate the system under significantly different conditions. In some cases parameters are varying with each month, but not in all cases. Furthermore, these changes change the hydrology and as a result some processes may not as important as they were before the change.

7.0 Uncertainty and Sensitivity Analysis

The separation of Calibration-Verification and Sensitivity-Uncertainty Analyses into two separate activities as is done in the SFWMM documentation is artificial, and can cause conceptual difficulties. A key input of both sensitivity and uncertainty analyses is a description of the precision with which each parameter has been resolved. When parameters such as impervious area, heights of levees and dimensions of channels, or rainfall depths and potential evapotranspiration rates are specified with external data, then measures of precision should also be generated for those parameter values. But when parameters are the result of a calibration exercise, then that calibration exercise should also provide measures of parameter precision.

In different sections of this report we use the words accuracy and precision, and their meanings are very similar. In general, accuracy is a measure of the extent to which a calculation generates the correct value. We hope that the numerical solution of the equations for overland flow have been solved accurately. Precision, particularly in this chapter, is a form of accuracy perhaps best described by reproducibility. We do not really know what are the best parameters for our conceptual watershed model, so true accuracy may be impossible to evaluate. However, we can evaluate whether different data sets produce similar values of the parameters. By envisioning the errors in the watershed model, and the calibration data, as having particularly probability distributions, one can derive the probability distribution of parameter estimators. Typical measures of precision are the standard error or standard deviation of a parameter, or an interval thought to contain the parameter with some prescribed probability. Both of these measures of precision represent the sampling error in parameter estimates that results from randomness in the data.

A difficulty with the SFWMM documentation is that the precision of parameters estimated in the calibration process has not been specified as an integral part of that exercise. Description of the precision of estimated parameters is a key component of the modeling and calibration process, and it is neglected in the SFWMM documentation. Model selection and calibration, as well as sensitivity and uncertainty analyses, need to be informed by realistic and quantitative descriptions of the precision of estimated parameters.

Traditionally the parameters of most watershed and ecological models have been estimated as part of a calibration process conducted by one individual, or perhaps a small team, over a relatively short period of time. Estimates of precision are seldom explicitly developed, but the modelers involved in the process as a result of their experience with the model usually understand the relative precision with which parameters can be resolved, and how parameters interact.

A current trend in the profession is to make much greater use of automated calibration procedures (Duan et al, 2003). This can eliminate, or at least reduce, tedious trial-and-error exercises that modelers conducted in earlier years. Automated procedures, when applied appropriately by skilled modelers, should yield better fits, and often can provide the range of parameters that describe the data with almost equal precision. However, without the need to conduct such trial-and-error analyses, modelers can lose the previous insight into how well different parameters can be resolved, and how they interact. Uncertainty and sensitivity analyses need to provide such insight for model development and calibration, and well as the appropriate confidence to attach to model predictions. Thus it becomes imperative when using automated calibration procedures to communicate to modelers and model users the relative precision of estimated parameters using objective and quantitative descriptions of precision.

This modeling exercise by the SFWMD offers other challenges. Several modelers conducted the modeling process over more than a decade. In addition there are many stakeholders that are interested in the model, its justification, its performance, and its precision. For this reason, it is not sufficient that a few key individuals have an intuitive understanding of the relative precision of different parameters. The District needs to be much more explicit about the precision of calibrated parameters, and the impact of such uncertainty on the values of simulated metrics of system performance. Chapters 5 and 6 of the SFWMM documentation reflect a tremendous effort on the part of the SFWMD to explore the sensitivity of the model to the values assigned to different parameter.

7.1 Panel Recommendations

The sense of this review panel and the report of the 1998 review panel indicate that it is imperative that the results of the calibration, verification, and the sensitivity and uncertainty analyses be made clearer and more accessible. For example, among other similar comments, the 1998 panel concluded (Loucks et al, 1998, pp. 9-10):

> • "A synthesis is needed of the calibration, verification and uncertainty analysis, which summarizes where the model is more and less accurate."
> • "Criteria by which the calibration and verification were judged to be satisfactory (i.e. bias, mean square error, error percentiles, etc.) should be quantified and presented."
> • "More details on the sensitivity analysis should be given in the documentation. It should be more clearly explained how each parameter was varied …"

The documentation should close with a reflection as to whether the model can meet the objectives. Loucks et al (1998, pp. 10) indicate that:

> "a discussion of the limitations of model output analysis based on the uncertainty analysis results would be useful. Given the District's experience …."

They go on to suggest (Loucks et al, 1998, pp. 10),

> "documentation should anticipate how the model will be, and should be used…. It is better to state clearly just what the model can and can not do well…"

The SFWMM documentation currently lacks a conclusions section that would provide such guidance.

Despite a tremendous effort on the part of the SFWMD, the panel suspects that the sensitivity and uncertainty analyses that have been conducted are inadequate. The Panel found the documentation of the calibration, sensitivity analysis and uncertainty analysis efforts to be unclear: 1) it does not provide a clear description of the precision of different parameters and their cross-correlation, 2) it does not adequately document how the calibration and sensitivity analyses that were conducted, 3) it does not justify the assumptions made, 4) one cannot from the written documentation understand or interpret the sensitivity analyses figures presented, and 5) the sensitivity and uncertainty analyses theory presented does not appear to be correct in some instances. Section 7.2 and the appendices of this report are intended to help resolve some of these concerns.

7.1.1 Specific Panel recommendations Addressing the Approach

Specifically, the Panel has the following general recommendations:

a. That the District adopt as a part of the calibration process procedures that provide quantitative descriptions of the precision of the estimated parameters and their cross-correlations,

b. That the District be much clearer about its objectives for the sensitivity and uncertainty analyses and what it wishes to illustrate,

c. That concepts of precision be integrated from the initial calibration process on through the sensitivity and uncertainty analyses that are conducted on the model parameters and on performance indices,

d. That the District adopt effective and quantitative measures of precision, sensitivity, and uncertainty that are mathematically consistent and generally accepted, and

e. That the report conclude with a discussion of how the sensitivity analysis has answered the initial questions about the precision of model predictions, the stability of parameters estimates, the impact of parameter uncertainty on model precision, and the relative contribution of uncertainty in different parameters to the overall uncertainty in model predictions.

7.1.2 Recommendations Concerning Documentation

The panel has the following recommendations pertaining to the SFWMM documentation:

1. The sensitivity analysis in the documentation is clearly trying to do the right thing, and figures 5.2.4 through 5.2.8 appear to be providing a clever and compact

presentation of the results. But what was done cannot be clearly understood from the documentation.

2. A good example of objectives for the sensitivity analysis can be found on page 61 of the Trimble (1995):

   "Initially, a sensitivity analysis is undertaken to better understand the importance that each of the hydrologic processes has on the water levels and certain flows in the region of concern."

   And on page 63,

   "The initial sensitivity analysis will help determine ranges in which parameters may be varied for different land use types, vegetation classifications, and aquifer characteristics, while maintaining a reasonable calibration of the model."

   The second quote makes clear the close connection between calibration and sensitivity analyses. The District should be clearer about its objectives for the sensitivity and uncertainty analyses and what it wishes to illustrate. Saltelli et al (2000, p. 8-9) provide a general discussion of sensitivity methods and alternative objectives. In short they indicate that one might perform a sensitivity analysis to help with model development, verification, calibration, model identification, and mechanism reduction. Sensitivity analysis can help identify the critical parameters to include in a calibration exercise, and perhaps which parameters are relatively unimportant and which can be omitted or assigned default values.

3. It is very important that the performance indices used in the sensitivity analysis be described clearly, and that they be well chosen. For example, one might look at the impact on the average (over specific years for all months, or the average over specific years during a particular season) of the stage at a key site, or the time series of averages of a set of sites in a key region. Similarly, one might look at the impact on the average (over specific years) of the flow at a key cross-section, or the frequency that a threshold is exceeded, or not exceeded. Any of the critical performance indices that the SFWMD computes so that model users can study the performance of the system would be good candidates for use as the performance indices studied in a sensitivity analysis or an uncertainty analysis.

4. In figures 5.2.4 through 5.2.8, parameters such as runoff coefficients and PET that apply to different land use types, and thus have different values, were all varied together. This is not intuitive and does not seem to make real sense. Parameters that when calibrated separately have different values should be kept separate so that the impact of each distinct parameter that was calibrated can be investigated. On the other hand, runoff coefficients and PET for the Lower East Side should have no effect at all on Everglades's stages and flows. Thus care should be taken to illustrate the effect of parameters on stages and flows where each parameter

logically can have an effect. This decreases the number of interactions that need to be considered.

5. The sensitivity analysis and uncertainty analysis were generally presented in terms of mean values over the 36-year simulation period. In our experience, model results (calibration, validation, SA, UA) are also presented in terms of other flow statistics and flow quantiles, e.g. 10% high flows, 25% low flows, etc., that reflect wet and dry conditions, as opposed to only mean conditions.

6. Limitations of first-order uncertainty analysis based only on physical parameter uncertainty need to be addressed in chapter 6. There are other major sources of uncertainty not captured by this linearized analysis that should be discussed, such as the value of boundary conditions, and the validity of assumptions on how the system will be operated.

7. Proposed use of Singular Value Decomposition (SFWMD, 2005, p. 268) does not appear to be valid (also Trimble, 1995, pp. 58-59, 73-76). See presentation in section 7.2.3 of this report.

8. In the SFWMM documentation (SFWMD, 2005, pp. 279 & 280; also pp. 267 and xiv), the term *confidence limit* or *confidence interval* is used in the context of uncertainty analysis in a way that is inconsistent with frequent usage (Kottegoda and Rosso, 1997). In the statistical literature, the term confidence limit has a very specific meaning (in repeated sampling 95% of all "95% confidence intervals" based upon the sample average with n observations will correctly contain the true mean μ), which is different from the appropriate meaning here.

9. The choice of a half-width as well as the term seemed awkward, pp. 280-290. The term in the table *half-width of 90% uncertainty band* is certainly a mouthful and does not give the sense of what analysis addresses. We suggest when the SFWMD rewrite the text using a different term, such as a probability interval, or uncertainty band, which the documentation also suggests.

10. While use of a regression model may appear appealing for quantifying the precision of a correction made to a simulation model, there seems to be no need for the analysis here. Calibration procedures and associated error analysis should provide the needed measures of precision. Equation 6.1.2.1 is mathematically correct, but requires several important assumptions, including that the errors are normally distributed and independent, and the underlying model is linear. The data presented in figures 6.2.1 and 6.2.2 of the SFWMM documentation, appears to fail to meet these requirements. This is important and should be made clear immediately after the equation, if this analysis is retained for an appropriate purpose.

11. Figures have been drawn with the axes reversed. Data should go on the vertical axis, and model predictions on the horizontal axis. (For example, SFWMD, 2005, pp. 223, 229-230, and pp. 290-291).

12. Please provide a clearer explanation of the difference between Bias, Eff and R^2 than is provided in section 4.2.1.5 (SFWMD, 2005, pp. 235-236), indicating which should be used and why.

13. The observation was made in the discussion of sensitivity analysis procedures that credible regions for the parameters were obtained in different ways, and may have been rather subjective in some instances. Consistency and transparency are desirable, though it is still appropriate to use different regions of the modeled area with appropriate data to estimate different parameters. In one case it was observed that based upon 27 sites, a plausible range for a parameter was obtained by insisting that at least 25% of the sites have negative biases, and at least 25% of the sites have positive biases. If when correctly calibrated, there is a 50:50 probability that a site will have a positive or negative bias, then the probably that seven or fewer sites would have a negative bias is almost 1% (0.0096), and the probably that seven or fewer sites would have a positive bias is also about 1 %. Thus we would anticipate that parameter uncertainty bands created with these criteria employing 27 sites would contain the true parameter values about 98% of the time.

    The following sections and the associated appendices are intended to support the conclusions above, as well as to assist the District's modeling efforts. The panel cannot at this time determine in every instance what methods will be most appropriate for sensitivity and uncertainty analyses; thus some of the text below discusses different options that the District should consider in its efforts to identify the most appropriate methods to adopt given District objectives and resource constraints.

7.2 Sensitivity-Uncertainty Analysis Methods

The District has had three workshops addressing sensitivity and uncertainty analyses, but it is not clear that the needed conceptual framework for the challenge faced by the SFWMD emerged from those efforts. The SFWMM documentation reflected confusion as to the appropriate role of simple and advanced sensitivity and uncertainty analysis methods. Unfortunately, the confusion has deep roots in the literature on this subject.

The discussion here is intended to address these areas of confusion, and thus to support the panel recommendations and future SFWMD activities. Section 7.2.1 and appendix A discuss traditional sensitivity and uncertainty analyses measures and sets the stage for subsequent discussions. In our application, these sensitivity analyses would be useful in identifying the likely importance of different model parameters in the calibration process. Sections 7.2.2-7.2.4 and appendix B discuss nonlinear least squares models and how they can be used to provide an estimate of calibrated parameter precision. This addresses a confusion identified in the SFWMM documentation, and presents procedures that are likely to be attractive to generate measures of calibrated model precision.

Section 7.3 discusses the appropriate definitions of parameter uncertainty when data are used to calibrate several parameters jointly. As a result of the calibration processes, several of the concepts in the first section are shown not to apply, at least in the same way. This explains why many complex Monte Carlo procedures appear in the literature to describe parameter precision and the uncertainty in model performance indices (see Beck, 1987, and for example Gardner, and O'Neill, 1983, and more recently, Kuczera and Parent, 1998, Beven and Freer, 2001; Duan et al, 2003; or Vrugt et al 2003b).

7.2.1 Traditional Measures of Sensitivity

So as to avoid any argument as to the appropriate definition of traditional sensitivity analysis and uncertainty analysis, consider the definitions and motivations for such activities given in the classic text on the subject, *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis* (Morgan and Henrion, 1990, p. 39):

"It is usually not immediately obvious which assumptions and uncertainties may significantly affect the conclusions. The purpose of sensitivity and uncertainty analysis is to find out. *Sensitivity analysis* is the computation of the effect of changes in input values or assumptions (including boundaries and model functional form) on the outputs. *Uncertainty analysis* is the computation of the total uncertainty induced in the output by quantified uncertainty in the inputs and models, and the attributes of the relative importance of the input uncertainty in terms of their contributions. Failure to engage in systematic sensitivity and uncertainty analysis leaves both analysts and users unable to judge the adequacy of the analysis, and the conclusions reached."

"Techniques used in sensitivity and uncertainty analysis may include:

- Deterministic, one-at-a-time analysis of each factor holding all others constant at nominal values.
- Deterministic joint analysis, changing the value of more than one factor at a time.
- Parametric analysis, moving one or a few inputs across reasonably selected ranges such as from low to high values in order to examine the shape of the response.
- Probabilistic analysis, using correlation, rank correlation, regression, or other means to examine how much of the uncertainty in conclusion is attributable to which input."

Morgan and Henrion (1990, pp. 174-176) provide several metrics that may be used to quantitatively describe sensitivity. Other authors provide similar definitions (for example, Loucks and Stedinger, 1994; Saltelli et al, 2000, p. 5; Frey and Patil, 2002; Lall et al, 2002; Loucks et al, 2005; Benaman et al, 2005). These ideas are discussed in the Appendix A.

7.2.2 Parameter Calibration and Nonlinear Least Squares

Calibration is an extremely important step in the development of the SFWMM. The SFWMM documentation in Chapter 6 lists the critical parameters whose values are determined by calibration for each area described in the model, as does the SFWMM documentation in Chapter 4; for example see pages 231-234, 261-263.

The panel recommendations are that as part of the calibration process the SFWMD and the modelers develop quantitative metrics describing the precision of each parameter. Perhaps the most widely used measure of precision of a parameter is its standard error or standard deviation. This section and appendix B describe how such measures of precision are often computed. The nonlinear least squares method is described in the model documentation that the committee received, but it did not seem to be correctly tied to the sensitivity coefficients (See Trimble, 1995; SFWMD, 2005, p. 268). The discussion here should clarify how nonlinear least squares methods can provide estimates of the standard deviations and covariances of calibrated parameters.

If a calibration objective is selected for which the errors in different periods (generally months for the SFWMM; see documentation pp. 217 item 4, 218-219, and 231 bottom) and at different sites are essentially independent over time, then the nonlinear least squares methods are very attractive for automatic calibration and for specification of the precision of the parameters. While daily estimates of stage and flow are likely to have errors that are clearly correlated (Kavetski et al, 2003), the errors for monthly averages are more likely to be fairly independent.

Similarly, if an urban site has stage values that are consistently larger or smaller than the prediction for that cell, then a cell-bias parameter should be added to the model and estimated as part of the calibration procedure. The heterogeneity of the urban environment makes it very reasonable that locations of major streets and roads, canal, wells, recharge basin, and storm water drains may cause a particular recording site to either over or underestimate a cell average. Addition of such cell-bias parameters (where physically appropriate) will appropriately reduce the residual mean square error of the model, thus yielding a more realistic description of the precision of estimated parameters. SFWMM documentation describes this problem on page 235, items 4 and 5.

Appendix B provides a summary of the classic ordinary least squares algorithm, and of nonlinear least squares algorithms. Of critical importance is how measures of precision are generated by those methods.

7.2.3 Singular Value Decomposition and Least Squares

The SFWMM documentation proposes to use Singular Value Decomposition (p. 268) for such least squares computations (also Trimble, 1995, pp. 58-59, 73-76). Singular Value Decomposition (SVD) for use with least squares problems is discussed by Press et al (1992, Section 15.4, pp. 670-673). SVD is particularly useful when the ($S_f^T S_f$) matrix in Appendix B is almost singular due to colinearity among the explanatory variables, which form the columns of the S_f matrix. This happens when different combinations of the parameters can produce almost identical predictions of the y vector used in calibration. By discarding redundancy among the columns of S_f, SVD can be used to produce a stable estimate of the β parameters, which are as good as alternate parameter vectors for prediction.

For the SFWMM, such redundancy would indicate that the model is over parameterized and the available data is unable to resolve the values of certain sets of parameters. SVD essentially provides a mathematically convenient solution to this problem. However, the SFWMD is better served by either bringing additional field data to bear on the problem, fixing some parameters at physically realistic values, or else employing a simpler model altogether. The real danger occurs if calibration data from hydrologically average years is unable to resolve some key parameters, such as the capacity of multiple subsurface layers in many complex watershed models. The danger can occur later if the values of those parameters become very important in future dry years that are of concern in planning studies. Monte Carlo methods discussed in the next section can address this problem.

7.2.4 Use of Automatic Calibration

Automated calibration need not be used for the entire optimization process, or the entire model considered at the same time. Trial-and-error is still appropriate to determine realistic ranges for parameters, perhaps considering areas within the modeled region where model performance is sensitive to specific parameters. However, a few final nonlinear least squares steps as described in Appendix B may then be useful to refine locally the values of the parameters and to estimate their precision. However, if the model has multiple local optima, then this approach may not be sufficient and Monte Carlo procedures discussed in the next section may be the best course of action.

7.3 Rethinking Sensitivity Analysis when Parameters are Calibrated

The traditional measures of sensitivity defined in Section 7.2.1 and Appendix A are based upon a framework wherein parameters are specified externally to a model, so one can independently investigate the impact of uncertainty in those parameters on the output of the model. Figure 7.1 represents a description of a modeling process when this is appropriate.

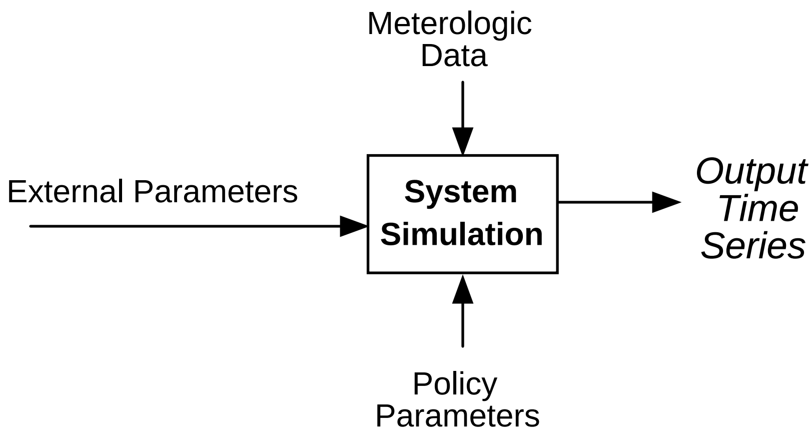

Figure 7.1. Simple conceptualization of modeling process

However, it is important to recognize that the SFWMM has many key parameters that are not determined by external data. Instead they are estimated in an involved calibration process using historical time series, as is done with most conceptual watershed models. That means that these "calibrated parameters" are estimated as best one can to make the model output time series match an observed flow and stage series when the model is run with the corresponding historical meteorological data. This is important for at least three reasons (Madsen, 2000; Kavetski et al 2003):

1. *Any errors in external parameters may have been compensated for by adjustment of calibrated parameters so that the model output matches observed values.* For example, if irrigation water applications are misspecified because of poor records, then irrigation efficiency or the evapotransporation for the crop may compensate in the calibration process so that the resulting model better estimates observed runoff and water levels. Thus calibrated parameters may have errors that are correlated with any errors in external parameters.

2. Because calibrated parameters are estimated jointly, they may be significantly cross-correlated. For example, it may be difficult for the model to exactly estimate a detention depth and a runoff roughness coefficient: over some range almost the same model output can be obtained with a higher detention depth and a higher runoff roughness coefficient, and vice versa. Thus when the calibration procedure attaches to detention depth a standard deviation σ_d (as described by the procedures in Appendix B), that value implicitly assumes that variations in detention depth goes with corresponding and compensating variations in the runoff roughness coefficient. Thus it is no longer appropriate in a sensitivity analysis to independently vary detention depth by $\pm 2\ \sigma_d$ without making the corresponding adjustments in other parameters.

3. Because the mathematical model is not a perfect representation of reality, and the calibration data providing flow and stage data and some groundwater elevations is not without measurement error and does not exactly match the spatial and time averages with which it is compared, the match between the

model predictions and the calibration data is not perfect, making it impossible to precisely resolve the values of the calibrated parameters.

Before serious calibration of a model, traditional sensitivity analysis that varies one parameter at a time can have an important role revealing or documenting when, where, and which parameters have a large impact on model predictions. Shoemaker (2004), Benaman and Shoemaker (2003), and Benaman, Shoemaker, and Haith (2005) discuss procedures for identifying in this framework which parameters of a watershed model that are relatively important to determining how a model will perform. However, after a model is calibrated a different concept of sensitivity analysis is appropriate for parameters that are involved in the calibration exercise reflecting the critical information provided by the calibration data set.

Similarly, the external parameters and the calibration parameters are now linked. It is no longer correct to vary external parameters one-at-a-time without simultaneously considering how the calibration data would cause the calibrated parameters to adjust in response.

On the other hand, policy parameters describing how the system will be operated in the future do not have the problems that we experience with calibration parameters, and the traditional sensitivity criteria can be employed.

7.3.1 Calibration and Parameter Uncertainty

When many of the parameters are calibrated with available data describing watershed behavior, an appropriate concept of the modeling process is shown in Figure 7.2.

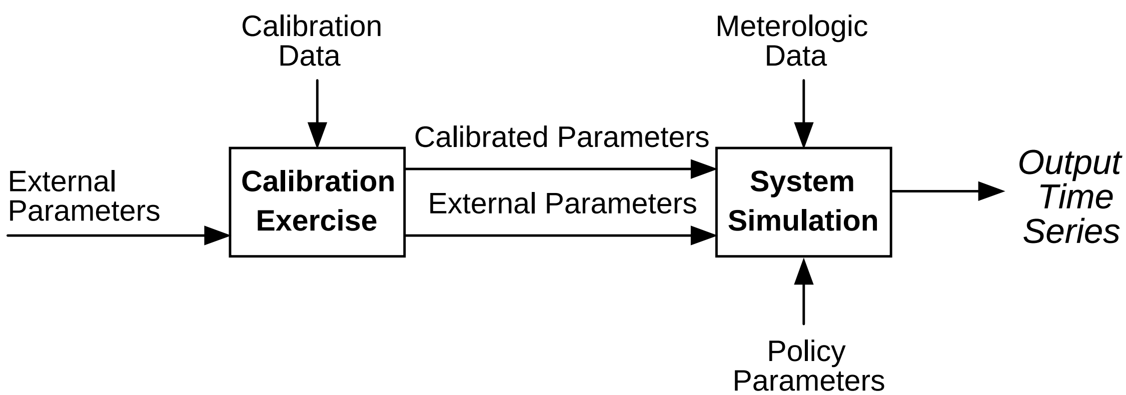

Figure 7.2. Appropriate conceptualization of modeling process when calibration data is employed to estimate some parameters

Given the values of external parameters, calibration data is never sufficient to accurately resolve all of the parameters of complex watershed and environmental models. (See Duan et al, 2003.) Thus in considering the conceptualization of the modeling process above, one recognizes that conditional on the assumed model structure and the external parameter values, there is significant uncertainty in the calibrated parameters. And as mentioned above, the errors in different parameters of complex models are often interrelated. Thus we desire to consider the uncertainty in the calibrated parameters, and the resulting uncertainty in the simulation model output time series and statistics based upon that time series.

Several methods are available to extend classical sensitivity analysis to address the uncertainty in calibrated parameters when there is significant cross-correlation. Conceptually, the simplest is to use the profile likelihood function (Coles, 2003): this corresponds to adjusting all of the parameters except one so as to maximize the goodness-of-fit objective, and then see how the goodness-of-fit objective or a forecast of system performance changes as the value of the one key parameter is varied. Thus we see if uncertainty in that key parameter (given that the other parameters are adjusted so the model still matches the calibration data as best it can) has an impact on the performance index of interest.

Another simple approach is the first-order uncertainty analysis methods described in Appendix A, wherein the cross-correlation among the estimates is included. Thus given the estimated variances and covariances among the parameters, we have for the total prediction error described by the variance in the performance index P reflecting the uncertainty in the parameters β_i:

$$\mathrm{Var}(P) = \Sigma_{i=1}^{n} \; [\partial P/\partial\beta_i]^2 \sigma_i^2 + 2\,\Sigma_{i=1}^{n-1} \Sigma_{j=i+1}^{n} \; [\partial P/\partial\beta_i]\,[\partial P/\partial\beta_j]\,\mathrm{Cov}[\beta_i,\beta_j]$$

The importance of the uncertainty in any parameter β_i can be described by the decrease in Var(P) that would occur were the value of β_i specified, and the model recalibrated. Appendix C describes how that variance can be computed using the equations in Appendix B and the conditional variance of all of the parameters, except the key parameter whose value one imagines has been specified. Again, for policy parameters that were not involved in the calibration process, the simple and traditional sensitivity analysis metrics may still be employed. It does not seem natural to assign uncertainty distributions to policy parameters, so there is no need to attempt to compute the resulting uncertainty in performance indices.

7.3.2 Monte Carlo Simulation and Uncertainty

Beck (1987, p. 1429), Kuczera (1988) and Kuczera and Parent (1998) discuss concerns with the accuracy of such first-order methods. The accuracy of such approximations depends upon the calibration objective having unique and well-defined minimum, which may not be the case, as illustrated by Duan et al (1992). The analysis also assumes that the parameter errors have a covariance matrix that can be computed using the second derivative of the calibration objective. However, Engeland et al (2004) found that descriptions of parameter uncertainty and uncertainty in system performance indices obtained with first-order methods based upon maximum likelihood analysis were almost identical to those obtain by an Markov Chain Monte Carlo (MCMC) analysis on 25 basins in Sweden.

For very complicated watershed models with multiple sub-surface layers or storage volumes, there can be many alternative parameter sets that yield most equal performance. This has long been a concern of those who have attempted to automate the calibration of complex multi-layer conceptual watershed models (Gupta et al, 1998, 2003). Beven and his co-authors have articulated these concerns very well (Beven and Binley, 1992; Beven 1993, 1996, 2002ab; Beven and Freer, 2001). With a given calibration data set exhibiting a limited range of hydrologic conditions, it may not be possible to resolve the parameters used to represent several soil layers, or different surface runoff and other hydrologic processes. This issue is illustrated by Gan and Burges (1991).

Sophisticated Bayesian methods have been developed that can address model prediction uncertainty when parameters cannot be clearly resolved. One basic idea is to generate multiple sets of parameters that are all physically plausible, and then to assign to them weights or probabilities reflecting their relative likelihood (see for example, Kuczera and Parent, 1998). This can be seen as abandoning the vision that there is one best parameter set that one can identify with reasonable precision. In an over-parameterized model (given a particular calibration data set), there will be alternative sets of parameters that for all intents and purposes appear equally valid given the calibration data.

The GLUE method (Generalized Likelihood Uncertainty Estimate; Beven and Binley, 1992; Freer, Beven, and Peters, 2003) has seen many uses for this purpose. Given a prior probability for all of the uncertain parameters (generally uniform over specified ranges), possible sets of parameters are generated randomly. Sets whose performance fails to meet some minimum standard are viewed as not being *behavioral* and are discarded. The remaining sets are assigned probabilities using a goodness-of-fit objective. Unfortunately, the goodness-of-fit objectives that have been used are not always valid likelihood functions, which causes serious problems (Batchelder, 2005; Batchelder et al, 2005). And as Kuczera and Parent (1998, p. 72) explain, use of a simple and uniform prior over a relatively large region can result in an algorithm that after billions of model evaluations may not have generated even one good solution.

More efficient and consistent procedures are based upon use of statistically valid likelihood functions and Bayesian inference procedures. The use of efficient search procedures is illustrated by examples in Duan et al (2003), Vrugt et al (2003), and Tolson and Shoemaker (2005). These procedures sample around parameter sets that have previously been determined to be relatively good, thereby increasing the chances that even better solutions are found.

Good examples of sound statistical analyses for this problem using efficient procedures are provided by Kuczera and Parent (1998), Bates and Campbell (2001), and Marshall et al (2004). All three papers employ Markov Chain Monte Carlo (MCMC) procedures which incorporate a balanced probabilistic sampling methodology what moves from one parameter set to another based upon how well both parameter set performs (Carlin and Louis, 2000, and Gelman et al, 1995): as a result regions of the parameter space that result in good performance are explored extensively, whereas regions with poorly performing parameters are sampled less frequently correctly reflecting their implausibility. Kuczera and Parent also discuss solving the problem of inefficient sampling by using intelligent importance sampling procedures: the likelihood function is used to identify approximately where good solutions will be found. One can then sample from that probability distribution and weight the generated parameter sets to correct for the error in their approximation. This is called importance sampling in the statistical literature (Morgan and Henrion, 1990), and is a well-known method that is effective for many problems. (For a good example see Kuczera, 1999).

Clearly this is an area of very active research and development in the water resources literature. Another issue is that applications of MCMC procedures generally depend upon thousands of model runs, which may not be feasible with the SFWMM. Thus the panel makes no recommendation as to whether the SFWMD should adopt such sophisticated and computationally demanding methods.

7.3.3 Thinking Bayesian

The Bayesian conceptualization of the modeling process is described in Figure 7.3. Here no distinction need be made between external and calibrated parameters. What were before external parameters are now parameters for which external data is thought to provide relatively precise information; as a result their values will not change during the calibration process: the size of canals, the dimension of cells, and the area of land in different crops would be examples. Still the values of these parameters could be adjusted during the calibration process if a much better fit could be obtained, though it is also possible to prohibit such adjustments. The SFWMM documentation (p. 220) notes that externally specified data including rainfall and static data often has errors. Thus very sophisticated calibration exercises can recognize that lack of fit may be a result of a rainfall gauge recording providing a poor description of the actual volume of rain falling on a large cell. Kavetski et al (2003) discuss how such “error-in-variable” problems impact traditional least squares estimation procedures; they recommend a Bayesian Total Error analysis that includes in the likelihood function both the model errors described above, and likely errors in input quantities, such as rainfall depth.

And there are now no internal parameters whose value is only determined by calibration. Such calibrated parameters initially come with some prior distribution representing conceptual reasonableness, physical appropriateness, and experience elsewhere with similar natural systems. Such priors may exclude parameter sets for which a reasonably good fit is possible, but which are conceptually and physically unreasonable. However, if such prior information does not result in a relatively precise resolution of the values of such parameters, then the information about system performance introduced in the calibration process is likely to be the major determinant of the value of such parameters.

As described in Figure 7.3, calibration yields in the posterior distribution for the model parameters. With many numerical procedures, this posterior distribution is described by a large set of possible parameters and associated probabilities. Each of these parameter sets can be fed into the system simulation model along with policy parameters and meteorological data that describe some future scenario of interest. Simulation with these parameter sets results in possible system performance time series for that scenario. These time series represents how the system might operate for that scenario with the ranges of parameters that are reasonable given both prior information and the information added in the calibration process.

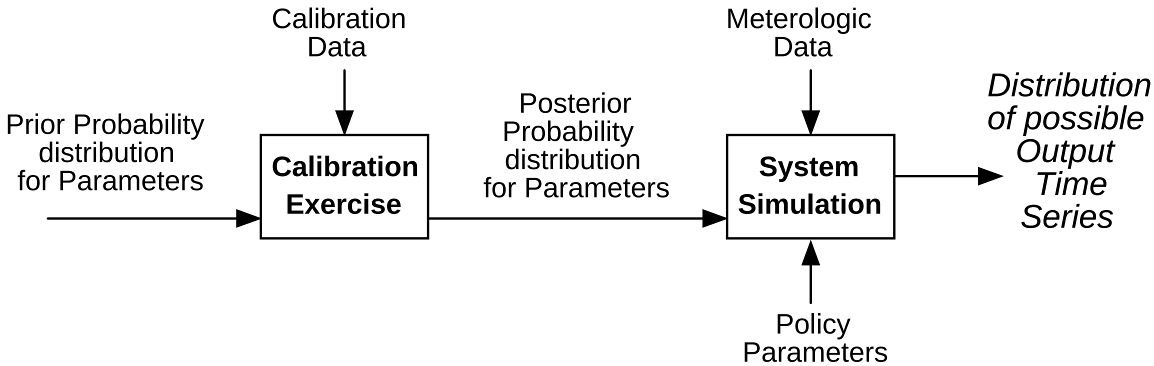

Figure 7.3. Bayesian conceptualization of modeling process when calibration data is employed to improve the ones understanding of the likely values of the parameters

7.4 Sources of Uncertainty and Their Importance

It is wise to recognize that there are many errors inherent in the process of modeling a complex process such as the distribution of rain, evapotranspiration, runoff and subsurface water storage and flow in the South Florida Water Management District. Table 2 lists common sources of error in a planning study employing a conceptual watershed model. In this section the focus will be on causes of lack of fit in the watershed model calibration process, and how such errors may relate to the accuracy with which the model may be able to describe various planning scenarios, corresponding to potential meteorological series (at least rainfall and temperature) along with system capacities and policies.

Table 2. Sources of Uncertainty
(following NRC, 2000)

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1. Variability in natural phenomenon (meteorology) that results in variability in system output and the values of calibrated parameters
2. Errors in model structure
3. Error in model parameters
4. Error in data describing system characteristics during the calibration period, and during a planning period
5. Errors in meteorological, flow and stage data used for calibration
6. Errors in meteorological, flow and stage data used for system simulation over a planning period
7. Errors in externally specified operational decisions that occurred during the calibration period and would occur during a planning period
8. Errors in descriptions of operational procedures used during the calibration period and that are proposed for use during a planning period
9. Errors in numerical solution of model
10. Errors in formulation of indices describing system objectives

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For calibration, let Y be the matrix of stages and flows (at different times and places) that are available for calibration, X the matrix of meteorological series (for each cell at every time step) that is provided including externally specified operational decisions for the calibration period, β a vector of model parameters, and E the vector of prediction errors for the calibration period. Then a watershed model f is a transformation

$$Y = f[\, X, \beta \,] + E$$

The use of a least squares criterion for model calibration would suggest that the only errors that one need consider are the prediction errors $E = Y - f[\, X, \beta \,]$. These are sometimes called the residual errors, or model errors. What is the cause of these errors?

Some model error arises because f[] is really not a perfect presentation of the relationship of X to Y. f[] is not perfect because evapotransportation, infiltration, vadose zone water movement, groundwater flow, and runoff processes are more complicated and spatially variable than the descriptions in our model. Moreover, the water management system including irrigation water applications, reservoir releases, canal flows and other water regulation decisions are not perfectly captured by the model. There may also be numerical solution errors in the evaluation of mathematical equations used to describe the various phenomena, which is another source of model error.

Clearly E also includes randomness in the environmental processes that causes the available inputs to be insufficient for precisely determining the value of Y even if one had the perfect model. What sort of randomness could make it impossible to precisely determine Y given X? Clearly daily average precipitation and daily average temperature are insufficient for determining the runoff from a small 1 square meter plot because they ignore important interactions that occur during a day; in particular they ignore rainfall intensity which is so important for determining runoff from unsaturated soils, as well as flow rates. Similarly, use of daily averages of precipitation and temperature for a cell provide an imperfect description of the values of evapotranspiration and flow across a cell that the SFWMM needs to determine. Moreover, even if the exact spatial description of these values were known, the 2x2 mile description of the modeled area would clearly provide only an approximate response of the watershed to these inputs. Ideally these errors are what is described by the prediction error vector E.

When the model is calibrated, or is run for policy simulation, one does not have the daily averages of temperature and the value of precipitation depth for each cell. Rather, values observed at some (often distant) point within the region are substituted. Thus there is potentially a very large error, which will be denoted as δX, in the specified inputs. In addition, there is some measurement error describing the precision with which observed stages and flows describe the cell-averages predicted by the model; these errors are denoted δY. Thus in the model calibration process, ideally one selects a parameter vector b so as to minimize the magnitude of the errors E' that result when one uses the error corrupted meterological data $X + \delta X$ to attempt to explain the error corrupted stage and flow data $Y + \delta Y$, thus

$$Y + \delta Y = f[\, X + \delta X, b\,] + E'$$

Vrugt et al 2005 and Kavetski et al (2003) provide a discussion of these issues. The errors δY, δX, and the true E all affect the ability of the calibration process to identify the best set of parameters, thus resulting in a parameter estimation error $\delta\beta = \beta - b$.

When we turn to the use of the model for simulation of proposed scenarios for a planning period, the critical errors to consider are:

1. The errors in the meteorological variables that go with the scenarios for the planning period δX_p,
2. The deviations $E_p = Y_p - f[\, X_p, \beta]$ between the actual Y-values Y_p that would occur and what the best model would predict $f[\, X_p, \beta]$ over the planning period, and
3. The errors in the model parameters (parameter uncertainty) that prevent us from producing the best model predictions $\delta\beta$.

This parameter error results in a error in the prediction equal to $f[\, X_p, \beta] - f[\, X_p, b]$. Much of the analysis described in section 7.2 addresses the parameter uncertainty $\delta\beta$ and descriptions of the associated errors $f[\, X_p, \beta] - f[\, X_p, b]$. In terms of model simulation of the planning period, there may no longer be any observations of the true Y values, and thus no Y observation error δY_p.

An important question is: how important are each of the three errors E_p, δX_p, and $\delta\beta$ in terms of our ability to estimate the actual values of Y for a planning scenario, and how important are they for determining the difference in $f[X_p, \beta]$ that result between two different planning scenarios. While this is an excellent question, for realistic watershed models, there are few examples where such an analysis has been done. Moreover, by fitting the model $Y + \delta Y = f[X + \delta X, b] + E'$ as if there are no errors in X or Y, the resultant values of E' reflect three sources of error (those in Y, in X, and the actual predictive error E). It would be useful to try to separate the impact of these three errors on the value of E', as suggested by Kavetski et al. (2003). This is an area in which we anticipate seeing research in the future.

In actual practice, implicitly these errors may have been handled in the following ways. If one defines a scenario as one for which the true cell inputs are those in the specified X matrix, then the X-error is eliminated. This particularly makes sense if one is looking to see how system performance would change with a change in some system characteristic or policy. Thus we ask how the system would operate were the actual input to each cell the tabulated values $X+ \delta X$, rather than were the actual input X which was not observed and can only be estimated.

The remaining two errors, E_p and $\delta\beta$ are not so easily dispatched. However, section 7.2 and the appendices describe how the parameter errors may be addressed using sensitivity anlaysis, uncertainty analysis and Monte Carlo procedures. That leaves the predictive error E_p for the planning period.

The likely magnitude of the predictive error E, frequently described by an error variance or mean squared error of E', is often exaggerated because the calibration process yields errors E' that include the results of X and Y errors. Thus the model may be better than is indicated by the calibration processes at estimating true Ys if given true X values. Still the variance of E' correctly describes the ability of the model to forecast recorded and imperfect $Y+\delta Y$ values given available and imperfect $X+\delta X$ values.

Errors in meteorological inputs can be very important for the SFWMM, as can misrepresentation of controlled releases and irrigation water applications. Still there is surely some prediction error E_p left. One might hope that these errors average out to zero meaning that the model is unbiased in that sense. That would mean that the average value of the real value of $Y_p = f[X_p, \beta] + E_p$ for any specified X_p would on average equal the model estimate $f[X_p, \beta]$. One can view the modeling process as producing an estimate not of the actual flow that would occur $f[X_p, \beta] + E_p$, but rather its mean value $f[X_p, \beta]$. Clearly use of $f[X_p, \beta]$ to describe future environmental stages and flows, should X_p represent the meteorological driving variables, will underestimate the actual variance of future conditions. However, it would provide a reasonable forecast. Efforts then to evaluate the impact of parameter uncertainty are appropriate for evaluating the error we make with such a forecast of the mean equal to $f[X_p, b]$ because of parameter uncertainty in the values of b that are adopted. However, one should not lose sight of the fact that ignoring the real prediction uncertainty E_p associated with each value in the matrix Y_p will result in model simulations that underestimate by some amount the actual variance in future conditions associated with the specified meteorological variables X_p.

Overall, it would appear that the failure of available meteorological data to adequately describe average daily precipitation and temperature across each cell is likely to be a very important component of the observed deviation between the model estimates and observed values of stage and flow during the calibration period. And of course, the model is an incomplete description of the processes in each modeled cell, which operate continuously over each 24-hour period and not in daily time steps. These factors combine to yield the residual errors observed in the calibration process, that provide a description of the ability of the model to reproduce the hydrology of southern Florida. Having determined model parameters that do a good job of reproducing the calibration-period hydrology, one can use those parameters, and proposed planning-period meteorology and management alternatives, to estimate hydrologic stages and flows for the planning period. In this second step, the errors of concern are those in the planning-period meteorology, those in the model parameters, and those that describe the inability of the model to accurately estimate the hydrologic response that results from that meteorology with the planning alternatives. If we assume that the specified planning-period meteorology and planning alternatives define the case of interest, then there would be no errors in those values. Thus the critical errors of the concern are: 1) the accuracy of the true model and 2) the precision of the estimated parameters.

It is generally thought that if one considers the differences between the model output for two similar planning scenarios, then those two sets of errors (model error and parameter error) may in large part cancel out, and this is likely to be true. Many of the flows and stages throughout the south Florida regions would be unaffected by many policy changes, and thus a difference of zero is correct. Similarly, when considering the effectiveness of variations in a Lake Okeechobee flood control policy, both variations of the policy would be simulated with the same natural flows throughout the system, even though the magnitudes of these flows would have errors; thus the relative impact in the change in flood control policy should be clear. Or more specifically, one would see relatively precisely the impact of the policy change were those flows to occur. However, if one focuses on the specific impacts directly associated with a specific physical change in the system, then some errors are unlikely to cancel. For example, a new surface reservoir in the everglades agricultural area (EAA) would provide new opportunities for increased evaporation from open water and subsurface flows from the storage facility; the errors in estimating those fluxes would not cancel because those two fluxes did not exist in a base-case “without_EAA_reservoir” management scenario.

7.5 Concluding Remarks Addressing Uncertainty and Sensitivity Analysis

The SFWMM model has a relatively simple subsurface model, and a great deal of data on groundwater levels, stages and flows relative to the number of subsurface, runoff and potential evaporation parameters that need to be estimated. Such multi-response data can be of great help in resolving model parameters (Kuczera and Mroczkowski, 1998; Madsen, 2000; Vrugt et al, 2003a). Thus the panel suspects that the District may be able to conduct reasonable sensitivity and uncertainty analyses without resorting to more sophisticated and computer intensive Monte Carlo procedures. If that is true, it will make the modeling process simpler conceptually, and less computationally demanding. If the least-squares analysis procedures is unable to provide a good description of the uncertainty in calibrated parameters due to multiple optima, or the failure of the likelihood function to be well approximated by a quadratic function, then the task will require more care and effort. A number of excellent but computationally intense procedures are available to address such difficult situations (Kuczera and Parent, 1998; Bates and Campbell, 2001; Vrugt et al, 2003ab). Again, policy parameters that describe the size of facilities to be constructed, or are guides for future system operation, do not have such problems for they are essentially known a priori.

The development of a comprehensive planning model for South Florida including the Everglades is a daunting task. However the SFWMD has been dedicated to this effort for two decades and with its excellent staff has produced a remarkable digital representation of the system. However, to improve the reliability of the model and its ability to be understood, it is important for the District to be more explicit about precision and uncertainty throughout the model calibration and verification process. This includes recognizing the precision of the data, which are generally point measurements used to represent spatial and time averages. It particularly means that as part of the calibration process quantitative measures of the precision of estimated parameters should be developed. To achieve this goal, sensitivity and uncertainty analyses can be used to quantify the impact of parameter uncertainty on the precision of simulated measures of system performance for the SFWMM.

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Appendix A. Sensitivity Analysis

If P is the SFWMM system performance index of interest (such a total flow during some season into the Everglades, average stage, or frequency a low-flow threshold is crossed), and β_i are parameters, then the almost universal definition of sensitivity is

$$s_i = \partial P/\partial \beta_i$$

which needs to be computed for each variable β_i. (See SFWMM documentation, eqn. 5.1.1, p. 268) These derivatives are commonly evaluated at a nominal or best estimate of the parameters, and can be computed with analytical formulas, or with numerical finite-difference formulas.

These sensitivities s_i have units and thus are difficult to compare directly. Thus one can employ normalized or dimensionless sensitivities, which are called the elasticity in the field of economics

$$e_i = (\beta_i /P)\ \partial P/\partial \beta_i = [\ \partial P / P\ ] / [\ \partial \beta_i / \beta_i]$$

Thus elasticity as a measure of sensitivity describes the relative change $[\ \partial P / P\ ]$ in P that results from a relative change $[\ \partial \beta_i / \beta_i]$ in β_i. While the elasticity is dimensionless and thus compare across variables, they still fail to take an important dimension of the problem into consideration: the relative uncertainty in each parameter. A variable with a small elasticity, but a large uncertainty, may be more important than a variable with a large elasticity that is known very precisely. Thus the first-order or "Gaussian" approximation of the uncertainty, also call the "importance uncertainty", is defined to be

$$u_i = \sigma_i\ \partial P/\partial \beta_i$$

where σ_i is the standard deviation describing the uncertainty in each parameter β_i (Morgan and Henrion (1990, p. 176). Saltelli et al (2000, p. 5) propose as an alternative to u_i that uses the ratio of the standard deviation of P and β_i to obtain dimensionless measure of sensitivity that depends upon the uncertainty associated with both P and β_i:

$$u_i^* = (\sigma_i/\sigma_P)\ \partial P/\partial \beta_i = u_i /\sigma_y\ ,$$

Here the relative magnitude (β_i /P) used to compute e_i above, are replaced by the ratio of the standard deviations (σ_i/σ_P).

Because in the SFWMM documentation, figures such as 5.2.4 compare the sensitivity of stage to changes in different parameters with different units, it is important to select a metric that has no units (such as e_i), or the same units (u_i) for every β_i variable. For the reasons discussed above, u_i is probably the more useful metric.

Uncertainty analysis is very important. It can attempt to answer at least two questions: 1) how uncertain is my prediction of P for some future period and system status, given the precision with which the parameters have been specified, and 2) how much of that uncertainty in P is due to each parameter β_i (and thus which parameter β_i should one strive to estimate more precisely).

A natural definition of importance uncertainty follows from the first-order approximation of the total uncertainty in P that results from uncertainty in each β_i; to first order and assuming the errors in different β_i are uncorrelated:

$$\mathrm{Var}(P) = \Sigma_{i=1}^{n} [\partial P/\partial \beta_i]^2 \sigma_i^2 = \Sigma_{i=1}^{n} u_i^2$$

(See SFWMM documentation, eqn. 6.1.1.1, p. 279.) Thus, using this first-order approximation, the relative importance of variable i is

$$r_i = u_i^2 / \Sigma_{j=1}^{n} u_j^2$$

Other criteria for describing the relative importance of different parameters in complex models are described in Hornberger and Spear (1980) and Shoemaker (2004). However, when parameters are estimated by calibration of the model to data, the resulting parameter estimates are often correlated. As a result, to first-order the variance of P is given by

$$\mathrm{Var}(P) = \Sigma_{i=1}^{n} [\partial P/\partial \beta_i]^2 \sigma_i^2 + 2 \Sigma_{i=1}^{n-1} \Sigma_{j=i+1}^{n} [\partial P/\partial \beta_i] [\partial P/\partial \beta_j] \mathrm{Cov}[\beta_i,\beta_j]$$

(Morgan and Henrion (1990, p. 183; Benjamin and Cornell, 1970; also Trimble, 1995, p. 47).

It can also be useful to report sensitivity analysis results on policy parameters which represent characteristics of the scenarios that the model will be used to study, as opposed to parameters which are critical to describing the physical, chemical and biological characteristics of the natural system. Policy parameters include the dimensions of a canal that will be constructed, the storage volume of a reservoir that might be build, the target release or storage level for a surface or groundwater reservoir in the future, or dissolved oxygen or temperature thresholds selected to control the quality of habitat. Sensitivity analysis should be used to explore how system performance outputs would change if any of these policy parameters were changed. Here the critical idea is that we are exploring how system performance is effected by interventions that have been proposed and which the model is being used to evaluate. This can be very useful for explaining what management actions do, why some actions are effective, and other actions are not.

Appropriate criteria for describing the impact of policy parameters on performance indices are the sensitivity s_i which has units, the elasticity e_i which is dimensionless, and a importance measure m_i which is also dimensionless and similar to the importance uncertainty u_i. The importance measure m_i employs a specified value δ_i to describe a realistic change in policy parameter β_i , or alternative scenarios, so that

$$m_i = \delta_i \, \partial P/\partial \beta_i$$

Thus for a reasonable change in parameter β_i, m_i tells us how large a change can be anticipated in a performance index P. One could also in a table or graph report the value of P obtained with different values of a policy parameter. Measures of uncertainty such as the standard deviation σ_i of β_i do not generally apply here because policy parameters are not measured, but rather are specified.

These are the basic definitions of sensitivity metrics and the commonly given motivation for each.

Appendix B. Least Squares Analysis for Model Calibration

B.1 Linear Ordinary Least Squares

Recall, in ordinary least squares regression, one considers the model

$$Y = X\beta + E,$$

where Y is a vector of values (monthly stages or flows at different sites and different times) that are to be predicted, β is the vector of parameters to be estimated, X is called the design matrix and contains as columns the values of covariates used to explain Y, and E is a vector of residual errors. The optimal estimator of the parameter vector β is

$$b = (X^T X)^{-1} X^T Y.$$

The covariance matrix of the sample estimator b describing the precision with which it can be estimated with the available data (Y, X) is

$$\mathrm{Var}[b] = \Sigma[b] = \sigma^2 (X^T X)^{-1}$$

where σ^2 is the variance of the components of the errors in E. The correlation between two elements i and j of b is

$$\mathrm{Corr}[\, b_i, b_j \,] = \Sigma[b]_{ij} / \mathrm{sqrt}\{ \Sigma[b]_{ii}\, \Sigma[b]_{jj} \}$$

These correlations indicate the extent to which the value of parameter estimator b_i is dependent upon the value of b_j. If the correlation is large (near 1 or -1), than very similar model responses can be obtained by different combinations of the two parameters, so that the model fitting process will have difficulty identifying the best or correct combination. The detention depth and the surface roughness coefficient for a region are two parameters that are likely to interact because runoff can be decreased by increasing detention depth or surface roughness (see discussion SFWMM documentation, pp. 69-71). Similarly the three parameters describing levee seepage surely interact (see SMWMM documentation pp. 73-77). If the correlation is zero, then there is no such interaction, as should occur with parameters that describe hydrologic processes in different regions.

B.2 Nonlinear Least Squares and Estimator Precision

In a nonlinear regression problem where a function $f_i(\beta)$ provides the model estimates of values y_i, one wishes to estimate β by minimizing

$$J = \Sigma_i\, [y_i - f_i(b)]^2$$

Here the set of values $\{y_i\}$ would be groundwater levels, stage and/or flow values at different locations for different months, and b represents the vector of all of the parameters which are to be estimated by calibration.

A common method for searching for the optimal vector b is to linearize the function $f_i(b)$ at the current estimate of b to obtain a sensitivity matrix S_f that is substituted for the X matrix in the equation above. This yields an iterative solution procedure for the optimal estimator of the vector b (Draper and Smith, 1998; Weisstein, 2005). The basic equation

$$y_i = f_i(\beta) + e_i$$

is replaced with

$$y_i \cong f_i(b_t) + S_f\,(b_{t+1} - b_t) + e_i$$

yielding the revised estimate of β:

$$b_{t+1} = b_t + (S_f^{\,T} S_f)^{-1} S_f^{\,T} (Y - \mathbf{f}\,(b_t)).$$

wherein σ^2 is the estimated variance of the independent errors e_i. Dennis and Schabel (Chapter 10, 1983) discuss the relative merits of this approach to solving this nonlinear least squares problem (also called the Gauss-Newton method) versus more sophisticated approaches.

An estimate of the sampling variance of the estimator b is then given by

$$\mathrm{Var}[b] \sim \sigma^2\,(S_f^T S_f)^{-1}$$

This is a reasonable measure of the precision that is required, wherein S_f describes the partial derivates of each of the observed stage or flow at each site at each time point considered (likely a week or month), with respect to each parameter estimated in this step. The whole model need not be run when estimating parameters whose value impacts only a limited geographic area.

Appendix C. Sensitivity and Uncertainty Analysis based upon a Covariance Matrix

This extra and supplemental section describes mathematically how for calibrated parameters, sensitivity analysis and uncertainty analysis indices can be computed based upon a covariance matrix for the parameters.

If an appropriate and statistically valid likelihood function can be developed to describe the linkage between the parameters and observed system states, then sound statistical procedures can be employed. In particular, if the values of the calibrated parameters (or their logarithms) are reasonably resolved and the log-likelihood function is well behaved near the best estimates, then the second-derivative matrix can be used to estimate the covariance matrix of the estimated parameters (Coles, 2003; Benjamin and Cornell, 1970). Use of nonlinear least squares when appropriate also can provide a computationally efficient estimate of the covariance matrix of the parameters (Draper and Smith, 1998).

Let θ represent a critical parameter, and φ a vector containing the other calibrated parameters. (Thus φ is β without θ.) Furthermore, let μ_θ and μ_φ represent the mean for θ and mean vector for φ. Finally let $\Sigma_{\theta\theta}$ represent the variance of θ, $\Sigma_{\varphi\theta}$, the covariance (a column vector) of φ with θ, and $\Sigma_{\varphi\varphi}$ the square covariance matrix of the vector φ with itself. Then using the asymptotic variance approximation provided the covariance matrix of the parameters (perhaps obtained as in Appendix B), one can explore the impact of variations in θ if one simultaneously adjusts φ according to the regression equation

$$\varphi = \mu_\varphi + \Sigma_{\varphi\theta}\,\Sigma_{\theta\theta}^{-1}\,(\theta - \mu_\theta)$$

Thus the sensitivity of the performance index P to changes in θ could be measured by

$$s_i^* = \partial P/\partial\theta + \partial P/\partial\varphi\ \Sigma_{\varphi\theta}\,\Sigma_{\theta\theta}^{-1}$$

wherein $\partial P/\partial\varphi$ is a row vector containing $\partial P/\partial\varphi_i$. The corresponding index that does not include the dimension of θ, but does reflect the uncertainty in θ is

$$u_i^* = \sigma_\theta\, s_i^*$$

where $\Sigma_{\theta\theta} = \sigma_\theta^2$. A measure of the importance of θ can consider the reduction of the uncertainty in φ and in the performance index P if the value of θ were specified (Saltelli et al, 2003, p. 28). The needed conditional covariance matrix for φ given the value of θ is

$$\Sigma_{\varphi\varphi|\theta} = \Sigma_{\varphi\varphi} - \Sigma_{\varphi\theta}\,\Sigma_{\theta\theta}^{-1}\,\Sigma_{\varphi\theta}^{T}$$

One can use $\Sigma_{\varphi\varphi}$ with $\Sigma_{\varphi\theta}$ and $\Sigma_{\theta\theta}$, to estimate the uncertainty in P using the first-order formula for the variance of P at the end of section 7.2.1. And then one can use $\Sigma_{\varphi\varphi|\theta}$ with zero for $\Sigma_{\varphi\theta}$ and $\Sigma_{\theta\theta}$, to estimate the uncertainty in P if θ–uncertainty were eliminated. The difference between the two represents the importance of the uncertainty in θ.

Appendix D. Variability and Uncertainty

When discussing sensitivity analysis, uncertainty analysis and Bayesian statistics, one often asks, what are the sources of uncertainty, and how does uncertainty different from general randomness. Generally speaking, uncertainty can be attributed to two sources: 1) the inherent variability of natural processes ("natural variability"), or 2) incomplete knowledge ("knowledge uncertainty") (NRC, 2000). They arise for different reasons and are usually evaluated in different ways (Morgan and Henrion, 1990). Table 3 below provides a summary of these ideas.

It is not always obvious which uncertainties should be ascribed to natural variability and which should be ascribed to knowledge uncertainty. Although most engineers and planners are familiar with natural variability, they are often less familiar with knowledge uncertainties. Mathematical relationships in this model include parameters that determine how output varies with input-for example, the stability of a levee as water rises behind it. Knowledge uncertainty in its simplest form can be thought of as comprising uncertainty in the appropriate parameter values for the model, combined with uncertainty in the model itself. Parameter uncertainty relates to the accuracy and precision with which parameters can be inferred from field data, judgment, and the technical literature. Model uncertainty relates to the degree to which a chosen model accurately mimics reality.

Table 3. Taxonomy for Describing Uncertainty (NRC, 2000)

Natural Variability
- Replication or individual heterogeneity
- Temporal or spatial variation

Knowledge Uncertainty
- **Parameter:** imprecision in specification of parameters values
- **Model:** lack of knowledge as to best model structure
- **Decision:** uncertainty in objectives and planning parameters

Appendix E: Relevant Parts of the Statement of Work

ATTACHMENT A

STATEMENT OF WORK

PEER REVIEW OF THE FINAL DRAFT DOCUMENTATION FOR THE SOUTH FLORIDA WATER MANAGEMENT MODEL VERSION 5.5

I. Introduction/Background

The South Florida Water Management Model (SFWMM) plays a critical role in South Florida for water resource management and planning purposes. Important regional water management decisions have been aided by simulations of the hydrology and water resource operational rules as provided by the SFWMM. The SFWMM is a computer simulation model capable of simulating surface water and groundwater responses to rainfall, evapotranspiration and well pumpage. Likewise, the model can predict the hydrologic response to proposed modifications to hydraulic infrastructure, changes in land use and alterations to operating rules for water control structures. The SFWMM is the only regional-scale distributed model that performs the combined simulation of hydrologic and water management components of South Florida.

Due to its widespread use in the past, present and anticipated future decision-making processes, it is necessary to document the model algorithms and procedures as well as its usage and applicability. Specifically, the objectives of the model documentation are as follows: 1) identify and layout the scientific basis of the model; 2) enumerate and explain how regional-scale management rules are implemented in the model; and 3) discuss the capabilities and limitations of the model. The document is intended to provide useful model information for interested individuals from within and outside the South Florida Water Management District (District). The District is responsible for maintaining and protecting the water resources in South Florida.

The SFWMM has been a living model – that is, it has been continuously updated, improved, and applied. Updates to the modeling period of record, updates to potential project features for various planning studies, improvements to scientific methodologies, and incorporation of new operational rules and applications are examples of upgrades to the model. Periodically, the SFWMM documentation requires updating to provide information on the numerous updates and improvements to the model. Because the model continues to play an important role in the Comprehensive Everglades Restoration Plan and other planning efforts, there is a need to conduct a peer review of the current model documentation.

Key Terms:

Chair – Panelist who will lead the Panel in the peer review of the SFWMM

District – South Florida Water Management District

Documentation
Final Draft – Documentation of the SFWMM to be peer reviewed
Final – Documentation of the SFWMM after consideration of the Final Peer Review Report

SFWMM – South Florida Water Management Model version 5.5, which is the current version of the model

Panel – The Peer Review Panel, a group of five experts assembled to peer review the documentation of the SFWMM model

Panelist – A member of the Panel

Project Managers – Yanling Zhao (561-682-2043, yzhao@sfwmd.gov) and Jose Otero (561-682-6578, jotero@sfwmd.gov) are the project managers for the District. Jose Otero is the point of contact.

Report
Draft – Peer review document prepared by Panel to be submitted to the District for response and clarification
Final – Peer review document prepared by Panel to be submitted to the District as the final product of the peer review

Web Board – An Internet site implemented by the District and accessible at http://www.sfwmd.gov/misce/1_webboard.html as the primary means of communication among Panelists; and between Panelists, Project Managers, and the public. Under Florida's Sunshine Law, it is mandatory that all communications between two or more Panelists occur in a forum open to the public.

II. Objective

To conduct an independent and objective review of the adequacy of the SFWMM as a regional modeling tool for addressing water resources issues in South Florida. The review shall rely on the latest documentation of the model as the primary source of information about the model.

III. **Skill Requirements**

The Panelist shall possess the following skills:

- Excellent understanding of the principles of hydrology, hydraulics, and water resource management
- Comprehensive experience in model development, implementation, and application of hydrologic and hydraulic models, and integrated modeling systems
- Effective communication skills, particularly good writing skills
- Available to dedicate significant review effort from August through October 2005
- For Chair, excellent communication skills, particularly excellent writing skills. Experience chairing peer review panels and consolidating comments from multiple reviewers.
- Ability to conduct an objective and independent review. Panelist shall be free of any real or perceived conflict of interest, including recent modeling work for the District or for any organization involved in hydrologic or water management modeling in South Florida.

Desired skills:

- Application of regional-scale models for resolving real-world problems in water resource management; including environmental restoration, water supply, flood control, or drought management
- Demonstrated ability to understand the potential impacts to the South Florida region of simulated changes in hydrologic conditions, operational guidelines, and management objectives
- Familiarity with Unix and Fortran 77

IV. **Scope of Work**

Each Panelist shall provide constructive comments and participate in the successful completion of the peer review. The Chair shall lead the activities of the Panel including the development of the Report. The Peer Review shall consist of the following major tasks:

1. District provides Final Draft Documentation.
2. Panel conducts preliminary review of documentation and submits questions prior to the first workshop.
3. First workshop. District presents key aspects of the SFWMM and provides answers to questions by the Panel.
4. Draft Report. Panel submits draft report prior to second workshop.
5. Second workshop. District provides responses or clarifications to Draft Report.
6. Panel submits Final Report.

For each of the tasks above, the Chair shall coordinate the activities and products of the Panel. The Chair shall be the editor of the Report and shall compile and reconcile the contributions from the other Panelists.

The Final Draft Documentation will be delivered to the Panel for review at the start of this contract. The Panel will conduct a review of the Final Draft Documentation and submit Draft and Final Reports. The District will consider and decide how to respond to the recommendations and conclusions of the Final Report. The complete Final Report will be included in the Final Documentation as an appendix.

To comply with the requirements of the Florida Sunshine Law, all communication between two or more Panelists shall be through a Web Board specially set up for this purpose. The Web Board is ideally suited to allow Panelists to submit their comments on the documentation and to distribute documents such as the Draft and Final Report. It also allows the District to disseminate information about this review, and it allows the general public to closely follow the development of the review.

The peer review shall be objective and independent. Each Panelist shall have no substantial personal or professional relationship with the District or any other organization involved in environmental management in South Florida. Each Panelist shall read and review the Documentation independently, then interact with each other out in the open through the Web Board and at the workshops. The Panelists shall collaborate with the Chair to develop the Report to the District.

V. Work Breakdown Structure

Task 1. Receipt of Material

Each Panelist will receive a hard copy of the Final Draft Documentation and a CD containing the electronic version of the documentation. Certain information in the appendices, such as spreadsheets, cannot easily be reproduced in hard copy. Therefore, certain items within the appendices will only be available in electronic format. The CD also contains other related documents which may be informative but not mandatory for the review of the model. The intent is to provide in one single document, the Final Draft Documentation, all the information necessary to conduct a review of the model. The documentation consists of a main body and appendices. The main body describes the model by topic areas. The appendices include backup material or detailed information.

The main body includes the following:

- Chapter 1 - General description
- Chapter 2 - Physical and hydrologic components
- Chapter 3 – System management components
- Chapter 4 - Calibration
- Chapter 5 - Sensitivity analysis
- Chapter 6 - Uncertainty analysis

References
Glossary

The appendices are as follows:

Appendix A – Upgrades from v3.5 to v5.5
Appendix B – Call tree flow chart
Appendix C – Process description
Appendix D – Subroutine description
Appendix E – Main subroutine
Appendix F – Input, output, and post-processing
Appendix G – Man pages (help files)
Appendix H – Topograpy update
Appendix I – Upper Kissimmee model
Appendix J – Tidal data
Appendix K – Public water supply calculations
Appendix L – Calibration and validation for specific regions

CD Only:

Appendix M – Source code
Appendix N – Reference spreadsheet for input files
Appendix O – Program for cell interpolation of rainfall and ET
Appendix P – Lake Okeechobee interactions

Deliverable 1.1. Panelist shall contact the District project manager via email or phone to acknowledge receipt within one day from receipt of materials.

Task 2. Initial Review

The Panel shall conduct an initial review of the Final Draft Documentation and shall prepare a list of specific questions to the District based on the initial review. The purpose of the initial review is two-fold. The initial review is an opportunity for the Panel to identify aspects of the model that may not be clearly or fully covered in the documentation. The initial review will also allow the Panel to begin drafting the Report under Task 4. The Panel shall prepare questions in advance of the first workshop so that the District can provide clarification during the first workshop. The Panelists shall develop specific and general questions regarding items in the Final Draft Documentation, and shall post these questions to the Web Board in advance of the first workshop. The Chair shall assemble and coordinate these questions into a single list to submit to the District via the Web Board two weeks prior to the start of the First Workshop.

Deliverable 2.1. The Chair shall submit to the District a single set of questions from the Panel based on its initial review of the Final Draft Documentation. The questions shall be posted to the Web Board two weeks prior to the start of the first workshop.

Task 3. First Workshop

The first workshop will last two days and will include introductory presentations by the District describing the most important aspects of the model. The workshop will also provide answers to the questions submitted by the Panel and will serve to clarify any issues raised by the Panel based on their initial review of the Final Draft Documentation. The agenda for the workshop will be developed through consultation between the District and the Chair. The District will post a draft agenda on the Web Board one week prior to the start of the workshop. Final comments to the agenda shall be posted to the Web Board by the Chair no later than two days prior to the start of the workshop. The District will provide a final agenda upon the start of the workshop. The agenda will include, at a minimum, the following items:

1. Introductory presentations of the SFWMM.
2. Demonstration of the SFWMM pre- and post-processing tools.
3. Presentation of written responses and discussion to the questions submitted by the Panel under Task 2.
4. Question-and-answer session between the Panel and SFWMM modelers.
5. Discussion of expectations of the District for the Draft and Final Reports.
6. Review of schedule and logistics for the Report.

The District will take minutes of the workshop and will post the minutes to the Web Board within one week after the end of the workshop.

Deliverable 3.1. The Chair shall work with the District to develop the agenda for the first workshop. The District will post the draft agenda one week prior to the start of the workshop. The Chair shall post final comments on the agenda no later than two days prior to the start of the first workshop.

Deliverable 3.2. Panelists shall travel to West Palm Beach and actively participate in the first workshop. “Active participation” is defined as: adhering to ground rules established by the workshop facilitator, attending all presentations, letting presenters know when any part of the presentation is not understood, be familiar with the District expectations for the peer review, and be ready to work within the schedule and through the logistics for the peer review.

Task 4. Draft Report

The Panel shall comment on the Final Draft Documentation, on answers and information provided during the first workshop, and on clarification to the documentation provided by the District. Reference information will be provided to the Panel in a disc, but reviewers are not asked to comment on reference material. The Chair shall be the editor of the Report and shall coordinate all the activities of the Panel to this end. Panelists shall provide their products to the Chair in a timely fashion closely following the review schedule developed during the first workshop. Panelists shall be contributors to the Report.

The Panel shall review the SFWMM documentation and provide comments and recommendations on, but not limited to, the following:

1. Correct application of scientific principles
2. Appropriate representation of the South Florida water management system
3. Adequacy to simulate system-wide hydrologic responses

Comments are also sought regarding the overall structure of the Final Draft Documentation, its readability of both text and illustrations (tables and figures), and its value as a comprehensive documentation of the SFWMM. For areas in which the Panel identifies deficiencies, specific recommendations to resolve the deficiencies are required to facilitate revisions of the document.

It is recognized that each member of the Panel will comment most substantively on areas within their primary expertise, but comments are welcome on any aspect of the SFWMM. The District also acknowledges that a review of the model source code is not feasible within the schedule for this review. Although the source code and related material will be provided as an appendix, it shall be considered auxiliary to the documentation. The Panel is not asked to comment on the source code. The Final Draft Documentation shall be used as the primary basis of information on the structure, functions, processes, features, rules, and capability of the SFWMM.

In addition to comments and recommendations, the Report shall include specific responses to the questions below. The responses by the Panel shall be stated in the most unambiguous manner possible based on the SFWMM documents provided and the explanations presented. The Chair shall pay special attention to ensure that the questions are fully answered.

G. Clarity and appropriateness of the documentation

   Are the objectives of the documentation clear? Are the objectives met? Is it readable? Are the figures clear? Are additional levels of detail required to serve the intended objectives? After reading the documentation, are you able to understand the purpose, scope, strengths, and limitations of the SFWMM? Does the scope or format of the documentation need to be modified or expanded?

H. Model Structure

1. Based on the documentation and presentations provided by the District, are the modeling techniques and methodologies used in the SFWMM appropriate for the temporal and spatial scale of the model?
2. Are the following model structure components appropriate?
   a. Grid resolution and structure
   b. Grid spatial extent
   c. Time step
   d. User-specified input
   e. Logic in representation of the system
   f. Numerical methods
   g. Boundary conditions
   h. Model output
   i. Others

I. Physical and Hydrologic Processes

1. Does the SFWMM include all the important physical and hydrological processes necessary to address regional-scale water resource issues in South Florida?
2. Are the following physical features and hydrologic processes represented adequately?
   a. Rainfall
   b. Evapotranspiration
   c. Land use
   d. Topography
   e. Overland Flow
   f. Groundwater Flow
   g. Channel Flow
   h. Levee seepage
   i. Coupling of Processes
   j. Others

J. Structural Features and Operational Rules

1. Does the SFWMM include all the important structural and operational rules to address regional-scale water resource issues in South Florida?
2. Are the structural features and operational rules addressed adequately?
   a. Water control structures
   b. Canal flow routing
   c. Flow computation
   d. Lake Okeechobee operations
   e. Water Conservation Area operations
   f. Flood control operations
   g. Environmental operations
   h. Consumptive-use water supply and water shortage operations
   i. System storage components (e.g. reservoirs, ASR, etc…)

j. Local management features (e.g. agricultural practices)
k. Others

K. Calibration and Validation

Is the model calibration process adequate for a predictive model in water resources management? Based on available tools, procedures, and data; is the model validation/verification procedure conducted in an appropriate manner?

L. Overall appropriateness of model comparable to others outside South Florida

Is the level of sophistication of the SFWMM comparable to other modeling efforts outside South Florida directed towards addressing similar complex, regional-scale, water-related issues? Given the current state of the model (scale, sophistication of algorithms, and degree of calibration), can it be considered an adequate tool for such an application?

The outline of the Report shall consist, at a minimum, of the following:

1. Introduction
2. Adequacy of Physical and Hydrological Processes
3. Adequacy of Structural Features and Operational Rules
4. Calibration and Validation
5. Sensitivity and Uncertainty
6. Responses to Specific District Questions (stated above)
7. Overall Findings and Recommendations
8. Appendices
    a. Scope of work for Peer Review
    b. Workshop questions and answers
    c. Panelist comments

Panel concurrence on each topic is strongly recommended. In the event that differences of opinion cannot be reconciled by the Chair, then they may be reported as such or as minority opinions.

Deliverable 4.1. Deliver a Draft Report. Provide comments and recommendations based on the review of the SFWMM documentation. The Chair shall coordinate, collect, and consolidate the individual comments, conclusions, and recommendations by the Panel. The Report shall be written in Microsoft Word and posted to the Web Board. The Panel shall answer in the most unambiguous manner the questions posed by the District under Task 4.

Task 5. Second Workshop

The second workshop shall also last two days and is intended to provide responses or clarifications to the Draft Report. The agenda for the workshop will be developed through consultation between the District and the Chair. The District will post a draft agenda on the Web Board one week prior to the start of the workshop. Final comments to the agenda shall be posted to the Web Board by the Chair no later than two days prior to the start of the workshop. The District will provide a final agenda upon the start of the workshop.

The District will prepare written responses or presentations for the workshop, as appropriate. At the workshop, the Panel and the District will discuss any issues related to the Draft Report.

The Panelists shall discuss the use of any new information received during the workshop related to the Final Report. The Chair shall facilitate this meeting. District staff will be available during this period to provide information to the Panel as requested by the Chair.

Deliverable 5.1. The Chair shall work with the District to develop the agenda for the second workshop. The District will post the draft agenda one week prior to the start of the workshop. The Chair shall post final comments on the agenda no later than two days prior to the start of the second workshop.

Deliverable 5.2. Panelists shall travel to West Palm Beach and actively participate in the first workshop. “Active participation” is defined as in the first workshop.

Task 6. Final Report

The Final Report is the primary product of this contract. The Panel shall work collaboratively to produce the Final Report based on the Draft Report, any new information received during the second workshop, and any other information received from the District. The Chair shall seek consensus among the Panelists. Each Panelist is responsible for cooperating with the Chair in the development of the Final Report. The Chair is responsible for coordinating and delivering the Final Report. All Panel interaction for the development of the Final Report shall continue to be conducted through the Web Board. The Final Report shall be posted to the Web Board.

Deliverable 6.1. Deliver a Final Report

Appendix F: Panel's Questions and Responses

Panel's Questions

Comments on SFWMM
by V.P. Singh

The SFWMM is, on the whole, a good management model. It does seem to simulate discharges and stages reasonably well, although in some cases discrepancies between simulated values and observed values are significant. The model is good example of how hydrology can be employed in practical and real life decision making. Below are some comments and it will be helpful if they addressed.

1. Pages 1-3 provide a discussion of the area and the purposes for which the model was developed. Pages 4-5 provide a background of the model history. The model area from can be distinguished from other areas, based on: a) climate, b) soils, c) land use, (d) topography, and (e) crops. The model was developed taking into account these specific features. The influence of some of these features on the model structure is clear but that of others is not.

2. In the final draft report there is little discussion of soils and soil types and how these have been incorporated in the model construction. What types of soils are there in the model domain? It will be helpful to provide a discussion of soils, given their importance in hydrology of infiltration, runoff, evapotranspiration, etc.

3. The model domain is divided into 3 areas and into a number of sub-areas (Figure 1.3.5). It is not clear how different are surface water and groundwater basin boundaries? The differences in surface water and ground water basin boundaries will change the water budget of the basin as a whole. How are interactions between surface water and ground water accounted for?

4. Pages 17-24: The discussion of topographic data is comprehensive and the topographic data are quite detailed.

5. Pages 25-35: The land use data is not as detailed, especially in time. The land use description is good. The land use projection based on the 2000 map for 2050 may too far off from what it actually might be.

6. Page 17: How can land use be constant as has been assumed? The land use in 2000 is quite different from that in 1988.

7. Pages 36-37: Rainfall: A very good network of 964 stations for an area of 17,930 square miles. The District is lucky to have such a dense network.

8. Pages 38-43: Rainfall data analysis seems fine. What happens if climate change is occurs. On Page 38 the sentence containing “less than 16 “ or higher than 5” seems to be in error. The basis for dropping abnormal rainfall values may be less than sound in some cases. Abnormality by itself is not a sufficient justification.

9. Pages 44-50: Evapotranspiration modeling for marshes looks good. It is not clear though what the basis of the model is. Why not use a more standard method, such as Penman-Monteith? How was K_r selected?

10. Pages 51-52: The method for calculation of ET for Lake Okeechobee based on water balance may not be the best way-it may too sensitive to errors. Lake stages are too sensitive.

11. Pages: 57-56: ET for Everglades agricultural areas may be okay. However it will be useful to compare this method with other standard methods.

12. Pages 57-58: It is not clear how ET for Irrigated areas is being modulated for moisture deficiency.

13. Pages 58-59: ET-Recharge relation. How was the effect of lack of recharge considered in ET? In other words soil moisture is less than field capacity.

14. Pages 60-63: Irrigation demand computation seems okay. However, irrigation practices are changing and crop water requirements are also changing, as new seed varieties are being developed.

15. Pages 64-71: Overland flow: This is well done. However, on page 69 the basis of equation (2.2.2.8) is not clear. This equation does not seem to be a good equation.

16. Pages 71-72: Infiltration is weakly modeled and may need improvement. It is difficult to justify assuming infiltration as a constant value.

17. Pages 72-73: Canal-ground water seepage may be okay.

18. Page 73-77: Levee seepage is computed all right.

19. Pages 77-83: Groundwater flow is modeled satisfactorily.

20. Pages 83-86: Coupling of surface water and ground water without accounting for unsaturated flow seems unsound and may need improvement. On page 85, eq. (2.5.5.18) does not have right symbols.

21. Pages 87-92: Canal routing seems okay. However, in canal routing one day seems too long a time. Water may flow out a 2-mile long cell in less than a day.

22. Pages 93-107: Initial and boundary conditions are described well. However, figures 2.7.2.3-2.7.2.5 do not look great and may need improvement. How accurate is eq. (2.7.2.1)? It would be better if equations and boundary conditions are specified separately for simulation of each lake/area by SFWMM?

23. Pages 108-122: Policy making and system management of Lake Okechobee are described reasonably well.

24. Pages 123-145: Policy making and system management of Everglades agricultural area are done well.

25. Pages 146-154: Policy making and system management of Lake Okeechobee service area are fine.

26. Pages 155-184: Policy making and system management of Everglades protection area is discussed well.

27. Pages 185-201: Simulation of the lower east coast of South Florida seems good.

28. Pages 202-215: Storage and additional management options are described well.

29. Pages 216-249: Calibration and verification of three different regions are discussed at length. For the EAA basin, Figures 4.1.2.5-4.2.18 exhibit wide spreads. What do they say about the model? On page 217, monthly comparisons are made. Why not daily? On page 220, what is being done to minimize errors?

30. Pages 231-249: In the calibration and verification of the Everglades and the LEC, R squared values on page 238 seem quite low. Why?

31. Pages 250-266: In calibration and verification of lumped LOSA basins, discrepancies seem quite significant. Why?

32. Pages 267-299: The results of sensitivity analysis seem consistent.

33. In model component descriptions, no discussion is provided on the comparison of component-simulated values and observed values. Therefore it is difficult to judge the accuracy of the component model.

34. Where do we go from here? What have we learnt and how can the knowledge gained be incorporated in future model improvement?

35. It is not clear what the model limitations are and what model improvements can be made to make the model more accurate. What kinds of errors can be expected in model results?

36. What are the main factors that should be kept in mind when applying the model t another location?

August 25, 2005

Questions (V2.0) about the SFWMM documentation, version 5.5, August 2005
R. Bras

General

This is overall a very complete and readable document. The introduction and initial description of the system is a good one. There is still some lack of uniformity apparent in presentation. The following will point out areas where style uniformity could be improved. One general criticism is the failure to define terms on first usage; this is true relative to abbreviations. A list of abbreviations alone does not substitute for good definitions at the appropriate time. Some repetition, spelling out of abbreviations, will help readability. The most common stylistic flaw is the slippage, at places, into a "user's manual' approach rather than a general documentation and description. Having said this, it is clear that with the appendices, this document CAN be used as a users manual. All the information is indeed available, reflecting that a very large amount of work and thought went into the preparation of the document.

It would be useful to hear the staff's opinion about:

1. What do you think are the basic weaknesses of the model?
2. Do you feel that the balance of detail in the different sections is appropriate?
3. Are you happy with the calibrations?
4. Clearly the codification of operations and management requires some simplifications, are you satisfied that all relevant management rules have been captured in sufficient detail?

Specifics

Chapter 2

1. How are the different accuracies of topographic data sets reconciled? What effect may the accuracy of the topographic input have on model operation? How was the topographic information verified?
2. How was the subsidence estimates for EAA verified? 1-2 inches a year sounds very high, a big change from the previously used o.1 inches and very different from the 0.57 used. Why should any area be excluded?
3. Are land use projections for 1050 verifiable, how past projections held up, 1988-2000?
4. Is the assignment of a land use to a grid by a simple majority of coverage good enough? Should grids permit mix usage?

5. Why not use precipitation radar of the last few years to corroborate rainfall patterns?

6. Is there a meteorological, atmospheric, explanation to the corridor of high rainfall from LEC area 3, through Everglades, through Big Cypress?
7. Can you provide a sense of how much of the rainfall data was affected by the screening procedures?

8. The Simple Method to compute Evaporation is very much like well-known techniques like the Priestley – Taylor Equation, without the justification. Why difference?
9. Can you explain the limits of Rs between 0.1-0.75 it seems that you are equating it to transmissivity, page 41.
10. Are the Kr values not part of the general calibration of the model?
11. What is the physical reasoning behind the banded NE-SW ETP pattern?
12. Shouldn't the Kr values near Okeechobee be high? See page 47, 48. There is relatively little precipitation over the lake and hence little cloudiness. Why is the PE so different from the annual P, patterns?
13. What is the difference between wet marsh potential evaporation and wet marsh reference crop evapotranspiration?
14. It seems that there are several symbols used for the same thing, for example, ETR (2.3.1.1) and ETP (2.3.4.1)
15. The ET-Recharge model and the AFSIRS model are used to compute, offline, irrigation supply and unsaturated zone evapotranspiration from the LEC. This is appropriate if the relationship is only one way, the SFWMM states cannot impact the offline model results. Is this always true? Are there conditions where this is a serious approximation?

16. It is said that the Curve Number (CN) technique is used to obtain surface runoff by the ET-Recharge model. Is there really any surface runoff?
17. It is said that the fraction of irrigation water from external water supply is not part of the general water balance. Is this true?
18. Is N the same as n (Manning)?
19. How can you physically reconcile the idea that the detention depth of urban areas is larger than that of wetlands or agriculture?

20. Are infiltration rates of 9-100 ft per day real? That is VERY large.
21. Is the assumption of no capillary fringe reasonable in an agricultural area where the groundwater is near the surface?
22. The canal conductivity is given as 0.01 to 9.00 ft per day, very different to infiltration rate. Why?
23. Please explain the concept of fraction of levee seepage rate to be applied and the maximum level of seepage rate. Why such concepts?

24. Is the groundwater section too detailed relative to other ones? Should the numerics be in an appendix?
25. Are transmissivities fixed or recalculated with aquifer thickness. I gather they are not although mention is made of that dependence.
26. In Figure 2.5.4.1 are changes due to saturated thickness or assumptions in hydraulic conductivities?
27. Why is the saturated zone water not available for plants? Rots are generally deep enough, and certainly capillary rise helps.
28. In p84, the variables definition seems out of place
29. The coupling of surface and groundwater in page 83 was confusing. Please explain.

30. Ponding depth, why higher in urban areas?
31. Is a time step of 1 day good enough for a 2-mile discretization? Water will transverse a grid in a channel in less than one day.
32. Please explain rainfall thresholds in page 91.

33. In page 93, please explain sentence: The stage …..cell diagonal.
34. In p 95, please explain the basis for the Lower Kissimmee runoff computation.
35. The regressions for inputs to LOK do not seem that good, how sensitive is the system to this?
36. How sensitive is the system to boundary conditions, it seems there is a lot of uncertainty around them.
37. Please explain the Lake Okeechobee Modified delta Storage Concept. Is this a way to adjust for known errors?
38. The section on the Western Boundary Flows at L-1 and L-3 canals seems telegraphic, unclear and disconnected from the rest.
39. As above for S190.
40. Explain meaning and use of the constants appearing in T2.7.3.1

Chapter 3

1. What are the forecasts of lake inflows, what are the seasonal predictions?
2. What is meant by "solar indicators" (in reference to meteorological forecasts)? Where are those forecasts described?
3. Please expand on the statement: limited or sparse stage data exists for the interior part of the EAA such that calibration by matching historical stages is not possible.
4. Explain statement on p 124, point 4 where hydrodynamically based routing is said to be used for EAA canals but not otherwise. How does this map into the discussion in section 2.6?
5. The use of KCALIB as an adjustment of KVEG seems somewhat redundant and self-defeating. Please explain.

6. Section 3.2.2 reads more like a users manual – a schematic the procedure would be helpful. So would an explanation of goals of the system, and use of simple language, not variables.
7. Why define conveyance as a function of historical operations in section 3.3.2? This means that history, right or wrong, defines operations?
8. How are priorities of EAA canal conveyance use established? P136.
9. Reference, in page 137, to HEC-2 based "look up" tables has no precedent or explanation.
10. Explain figure 3.2.3.1, please.
11. In page 148, lateral flows are assumed zero because saturated zone flows are highly variable. How does this follow?
12. The style of section 3.3 is very different.
13. What does rescaling in page 153 referring to the Seminole Brighton Reservation mean?
14. Please explain T3.3.7.2 – how are tribal rights preserved?
15. Explain phrase "as a consequence of reduction of seepage losses out of the entire area", relative to WC2, p158.
16. Why the large differences in seepage rates among WCAs?
17. Why the large area difference, as modeled, for WCA3-B, T3.4.2.1?
18. Use the same nomenclature in Figures 3.4.2.2 and 3.4.2.3. There are references to regulation and drawdown schedules.
19. The use of pseudo code in pages 174-175 is inconsistent in style.
20. I Equation 3.4.2.3, p177, it is unusual to have the same coefficient for multiple lags. That can lead to non-stationarities.
21. The reference to row-column values in page 178 is irrelevant and out of place.
22. Use rainfall driven or rain driven but not both, it is confusing.
23. The section on rain-driven operations needs clarification.
24. Section 3.5.2 is a different style, algorithmic, and difficult to follow.
25. In page 193 is said that the inefficient component of irrigation that evaporates does not significantly alter the water budget of the saturated zone. Sure?

Chapter 4

1. On page 216 it is said, "calibration and verification is conducted on a limited data set of one to three years" I am confused since that is not the case in what follows. If it were, wouldn't it be too little data for that purpose, particularly calibration? What did I miss?
2. On page 217 it is said that calibration is hampered by changes in operation. But if those changes are known, why can the calibration be done? The model, after all, has a management and operations element.
3. The definition of runoff and supplemental irrigation on page 218 appear as the negative of each other. Clearly the definition must be structure specific. As it stands it is hard to understand.
4. On Table 4.1.1.2, parameter KCLIB differs significantly from the ideal value of 1 and it has a strong seasonal trend. What does that mean?

5. On Figure 4.1.1, is the may change in maximum storage of the Miami River Basin reasonable? It is a very big change-why?
6. The scale of Figures 4.1.2.3 and 4.1.2.4 makes it impossible to evaluate them properly.
7. The verification period of 1979-83 and 1996 – 2000, used in figures, differs from that sated on p217.
8. Errors of calibration and verification shown on figures 4.1.2.5 – 4.1.2.8 do seem big, ranging over 20,000acre-ft, even when the historical value is very small which is most of the time.
9. The flow duration curves sometime indicate what seems like a mass balance problem – the area below the curves is not equal for daily values.
10. Monthly results look better but errors can still be large for small values.

11. The introduction to section 2.3.1, about the Everglades and LEC, is rough and does not flow well.
12. The arguments given against comparisons to daily values would also be valid for other regions – why make them here?
13. What is the difference between and end of the week vs. a daily comparison? The end of the week is still a very variable day. The use of a weekly average to avoid the noisy behavior of daily values would make sense.
14. The arguments in p 231 apply to well data only or also to stages in canals and other places?
15. On page 234 it is stated that historical flows are input as internal boundary conditions so as to isolate physical behavior from the impact of (unknown, uncertain?) operations. Could this over –constrain the system leading to over optimistic calibration and verification results?
16. Appendix C, all 300 pages, is a LOT of information. It is understandable why the use of an appendix. Nevertheless, it would help to illustrate behavior in the main text with a few selected figures from the appendix. Table 4.2.2.1 is difficult to follow alone.
17. Some of the results, Appendix C and Table, are not so good. For example the verification of canal L-38, or L28-2 or BCNPA 8. Some annual and seasonal values like S37B are also off by significant amounts. The table reflects these with low R2, large biases or even negative coefficients of efficiency. Given that this seems to be a very local calibration (internal BCs) is that the best that can be done? It should be acknowledged, though, that overall it is amazing how the model performs reasonably well over so many locations.

18. Why only calibrate the Caloosahatchee? Only calibration, no verification?
19. The parameter EFFI (efficiency) seems like a fudge factor for lost water. Is the 87% reasonable for the Caloosahatchee? Interpreted physically this may actually be too high an efficiency. It is interesting that efficiency is calibrated as lower in other places.
20. Demand errors in Figure 4.3.1.1 can be very high.

21. Are root zone depths verifiable? Root zone of 5.5 inches in wetlands, is that physically reasonable?
22. Only calibration foe Brighton Seminole?
23. The efficiency of Brighton Seminole is calibrated at 60%, why so different to Caloosahatchee's 87%? It is interesting that it is stated that prior calibrations of the Caloosahatchee led to 58%. Why should efficiencies be so different?
24. Why is the storage coefficient twice of the Caloosahatchee? Is there are physical argument?
25. There is a big difference in May demand, Figure 4.3.2.2 as you also noticed.
26. Again, why the parameters are so different for Big Cypress?
27. Why should root zone depths of feeder canal be so different than Calolosahatchee? Is this result verifiable?

Chapter 5

1. How were the parameters for the sensitivity analysis chosen?
2. It is stated that the parameter range was that "for which model calibration remains valid". What is valid? What does that mean? Is this self defeating in that it may restrict the range too much?
3. Please explain the x- axis in Figure 5.2.1 and 5.2.2. Percentile is never defined.
4. Many parameters seem to have very little effect on behavior, at least at the scale of the figures. Does that mean they are unimportant and could be fixed or is it that their range was over constrained.

Chapter 6

1. Please explain how the confidence limits on parameters are set. Is this around the calibrated parameter assuming it is reality? Why a normal assumption when many of these parameters may be physically limited to certain ranges?

Questions on Documentation of the South Florida Water Management Model Version 5.5
W. Graham

Chapter 1: General Introduction

Chapter 1 provides a well-written overview of the history, purpose and capabilities of the SFWMM. SFWMM is a comprehensive, complex model that simulates both the natural hydrologic processes and the engineered hydraulic structures and operating rules that affect the movement of water in South Florida. It includes algorithms to simulate all the significant processes that occur in the area. However the sophistication of the treatment of the processes varies widely from quite empirical (i.e. the way unsaturated flow is simulated) to more physically-based (i.e. the way groundwater flow is simulated). The level of empiricism in simulating many of the processes requires a large number of calibration coefficients.

It would be useful if at the September workshop the SFWMD modeling staff would discuss how the level of complexity chosen for each process; how the differing levels of complexity and accuracy affect the overall model accuracy and stability; how errors in different components of the hydrologic cycle may compound, or offset each other; what methodologies were used to estimate the many empirical coefficients required in some of the less physically based algorithms; and the issues associated with using these coefficients to simulate scenarios that may outside of the hydrologic conditions the model was calibrated for. A discussion of these issues should probably also be included in this documentation, perhaps in a concluding chapter.

Chapter 2: Physical and Hydrologic Components

2.1 Topography and Land Use

The topography data incorporated into the SFWMM comes from a variety of sources, using different measurement and post-processing techniques and is of varying quality. Stated accuracies range from 0.2ft to 0.5 ft. It seems that this level of accuracy is marginal considering the very low relief in the South Florida system. What is the consequence of using topography data with varying degrees of accuracy throughout the modeled domain?

Representing the topography as constant over a 2 mile by 2-mile grid ignores the effects of natural and constructed microtopography and presumably requires larger than realistic Manning's roughness coefficients to properly simulated rates of overland flow. How were Manning's roughness coefficients estimated for each land use type? Could the measured elevation variance within each 2 by 2 cell be retained as an indicator of roughness?

Land Use and Land cover Descriptions on p. 30-35 should also include characteristics of agricultural land uses (i.e. row crops, citrus, sugar cane, pasture etc.). Other land uses are well described. As with the topography, the 2 by 2 resolution requires one land use classification per grid cell, which requires empirical roughness and ET parameters, be estimated for each approximate or aggregated land use category. How accurate are these estimates, and what is the consequence of the resolution on model accuracy? (Note typo p. 35…Second Mangrove Forests heading should be Melaleuca Forests?)

2.2 Rainfall

A fairly dense network of rain gages exists over the modeled region. These data have been screened for outliers, and a triangulation method is used to create areally averaged daily rainfall estimates for each grid cell. It may be useful to try to use NEXRAD or other radar measurements to spatially interpolate the network of point measurements. Is it possible that the spatial interpolation mechanism might vary seasonally depending on the type of rainfall (i.e. frontal, convective, hurricanes, etc)?

In Figure 2.2.2.2 there is a region of low annual average rainfall in the center of Lake Okeechobee, a region in which there are few measurement stations. Is this a real effect? Is there a physical reason for this low? Similarly there is a ridge of somewhat higher rainfall along the coastal area. Is there a physical explanation for this? Topography? Heat island effect?

2.3 Evapotranspiration/Unsaturated zone modeling

There is a somewhat bewildering variety of methods used to estimate ET and unsaturated zone flow processes in the various land uses and management areas in the modeled area, e.g. different methods are used for Lake Okeechobee, the Everglades Agricultural Area, Lake Okeechobee Service Areas, the lower east coast service areas, and non-irrigated areas. Why are so many different methods necessary? Does using this array of methods increase the reliability of the model predictions? This seems difficult to prove since the model is primarily calibrated against aggregated flows and areally averaged stages/heads in the system. The utilization of all the different variants of ET/vadose zone flow estimation should be discussed and justified.

As a result of all the different ET methods there are a large number of empirical coefficients to estimate and the notation is difficult to follow. This is exacerbated by the fact that often in the documentation abbreviations are used but not defined until several paragraphs later. For example it seems that ETp , ETR, ETref It are all used to denote potential ET? Coefficients K1,Kr, Kfact are all multiplicative (at least for some of the methodologies), are they all necessary?

On. P. 44 a radiation-based method is used to estimate wet marsh ET potential. The 0.53 coefficient for mixed marsh, open water and shallow lakes is quite low compared to other similar radiation based methods (i.e. Priestly-Taylor). Was this coefficient developed from data in South Florida? Is there a physical reason for its relatively low value?

A “self calibrating Kr method” is used to estimate solar radiation at the land surface that depends on extra terrestrial solar radiation (calculated from latitude and time of year), temperature and another empirical coefficient. It has been previously shown that temperature based ET estimation methods do not work well in Florida because they don't account for the effect of cloud cover in reducing extraterrestrial radiation. Does using the difference between max and min temperatures take care of this problem? How was this method developed and verified? How accurately does it estimate solar radiation at the land surface under S. Florida conditions? How do the data presented in Table 2.3.1.1 compare to measured data?

Is there a mechanism to estimate evaporation from bare soil? What about evaporation from urban areas? It wasn't clear from the documentation that methods exist for these land uses.

At different points in the documentation various relationships are assumed with the water table… i.e. no ET from the water table, water table assumed constant at 1.5 ft depth, etc. Are these assumptions always consistent with the groundwater flow module in SFWMM? Is there a feedback mechanism between the various ET estimation algorithms and the heads/stages/flows predicted by SFWMM?

2.4 Overland Flow

The documentation states that the diffusion flow model is used to simulate overland flow, however the numerical implementation of this equation it is not clear. For example it is difficult to follow how the non-linear system of coupled equations given by 2.4.1.1, 2.4.1.10 and 2.4.1.11 is simplified and approximated, and how the resulting solution is assured to be accurate, convergent and stable, even after dividing the daily time step into 4-6 hour time steps. More details are in order. Perhaps they can be provided in an appendix.

Is there a discernable physical basis for the variation of overland flow coefficients (e.g. see Table 2.2.1)

There is a font problem with equation 2.4.1.4

2.5 Subsurface flow

On p. 72 it is stated that infiltration rates vary from 9 to 100 ft /day. How were these values estimated? They seem quite large, especially for urban areas. If these values are accurate I assume that infiltration rate is never a limiting factor that causes surface pending? (mechanism 2 on p. 72)

A large number of empirical parameters are needed to describe canal-groundwater seepage, levee seepage, etc., how are these parameters estimated and validated? Is there a discernable physical basis for their variation (e.g. see Table 2.5.3.1)

The two-dimensional unconfined aquifer equation is used to simulate saturated groundwater flow. The formulation of equation 2.5.4.1 assumes the model grid is aligned with the principal axes for transmissivity. Is there a basis for this? Also the definition of Txx and Tyy as transmissivity tensors is not accurate. These are components of the transmissivity tensor, not tensors themselves. Is the final estimation of transmissivity anisotropic? It does not appear so from the information given in figure 2.5.4.1

I do not agree with the explanation in the last sentence of the second to last paragraph on p. 78 regarding why equation 2.5.4.1 is called a diffusion equation.

The model implementation section is quite detailed. These details are what are missing from the overland flow section.

2.6 Canal Routing

Canal routing procedures are adequately described, however it is not clear what the criteria are for determining which canals can be modeled using a constant slope solution and which should be modeled using a dynamic slope solution. What is gained (in terms of model prediction accuracy) by going to a dynamic slope solution? What is lost in terms of stability, computation time, etc?

Variables CHDEP0, CHEDEP0, QSTRin and QSTRout need to be defined the first time they are used (p. 91). This problem occurs throughout the documentation.

2.7 Initial and Boundary Conditions

What does "slightly violated" mean (point 1. p. 94)

What is the implication of the inaccuracies of the regression analyses that are used to define boundary conditions for inflow from the Upper Istokpoga Basin and Taylor Creek/Nubbin Slough?

What is the sensitivity of the model prediction to the assumed boundary conditions?

Chapter 3 Policy and System Management Components

The SFWMM simulates a complex system of policy and management rules, which are described in detail in Chapter 3. Some of the descriptions of the rules are difficult for someone from the outside to follow (e.g. the Caloossahatchee Basin module summarized in Figure 3.1.4.1, and the St. Lucie River module which I assume is summarized in Figure 3.1.4.2, and may be mislabeled) but I assume they are accurate.

A detailed discussion of the multiple methods to estimate ET and simulate the unsaturated zone mentioned earlier is presented in Section 3.2-5.5. Again I wonder if it necessary to use this variety of different approaches (EAA method, AFSIRS method, ET-Recharge model, etc.) Each has a different set of parameters that must be estimated or calibrated. Has it been demonstrated that using these different methodologies in different regions is more accurate than using the same methodology throughout the modeled domain? Has it been demonstrated that some of the non-physical calibration parameters are valid for the "what-if" modeling scenarios that the model will ultimately be used for.

The description of the EAA simulation module introduces new variables that are somewhat confusing. What is ETo as compared to ETMX? I do not understand the sentence that tries to explain this just above table 3.2.2.1. It seems like equations 3.2.2.1, 3.2.2.2 would be more concisely incorporated in a revised Table 3.2.2.1 rather than creating new named variables along the way.

The sequence of stores from which ET is taken (discussed on p. 130) will result in the correct volumes of water in the right stores at the end of the day. However, if the model is ever to be used for water quality modeling purposes… particularly for simulating nutrients or pesticides that originate in the soil surface and move through the vadose zone to the groundwater… I do not believe the defined sequence will end up with the nutrients in the right store at the end of the day.

There is confusing set of rules presented on p. 133 to calculate irrigation requirement. Perhaps a flowchart would be easier to understand.

Discussion on p. 137 is repetitive and could be consolidated and made more concise.

p. 142 point 1. What processes are included in the mass balance? What minimal input data is used?

p. 142 point 2 EAA BMPs have not been described yet, so it is unclear why they are simulated by increasing the upper limit of soil moisture storage in the unsaturated zone.

p. 145 bottom. Why if both STA and non-STA reservoir both exist does the model release water to the non-STA reservoir first?

p. 146 why is the AFSIRS/WATBAL model used for the LOSA? The use of the term Drainage in this section is confusion. I generally think of drainage as vertical gravity drainage through the soil that becomes recharge to groundwater. This section seems to use drainage synonymously with surface runoff. The terms in this section should be defined more clearly. Is there any possibility of recharge to groundwater from AFSIRS/WATBAL?

p. 148 This section states that saturated zone flows are highly variable depending on local conditions, and therefore they are neglected. This doesn't seem like a very good reason to neglect these flows. If they are highly variable they could be highly important.

p. 148 What is CWMP. I don't think this acronym is ever defined.

p. 152 define the meaning of 2/10 monthly demand the first time it is used here.

Section 3.4.2.2 Environmental Deliveries

Three adjustments to trigger levels are described: translation, truncation, and offset. The offset adjustment needs more explanation. I can't understand from the text or figures 3.4.2.8 and 3.4.2.9 how thus adjustment is applied or what it achieves.

Section 3.5

A third different unsaturated zone model is introduced for the Lower East Coast of S. Florida. As requested earlier please explain why this is necessary and what this achieves.

Section 3.3.5.5 Please define "permit" as used in this section. Does a permit imply an actual pumping volume is reported, or is it a maximum volume allowed? Are these permits for municipal withdrawals? Agricultural withdrawals? Private domestic well withdrawals?

Discussion of aquifer storage and recovery (p. 206ff). Somewhere it should be stated that the simulation of these and other potential storage and transmission alternatives makes implicit assumptions about the efficiency of the alternatives that may be a best guess at this point.

p. 212 ff Operational Planning. The discussion of the Position analysis talks about a 36-year simulation that is re-initialized every year. Aren't this really 36 one-year simulations using 36 different historic weather patterns? The difference between conditional and unconditional Position Analyses deserves more discussion. When would each be used? In figure 3.6.2.6 why would the conditional position analysis not begin immediately?

The discussion of initial condition determination says raw data were compared to snapshots of SFWMM to find "similar conditions". How were they compared? What constituted "similar"

Chapter 4 calibration and verification.

Slightly different methodologies and statistics were used to quantify the accuracy of calibrations in the EAA, LEC and LOSA. It would be logical that at least they all used the same statistical comparisons.

The discussion of the EAA calibration should be enhanced to define and discuss the statistics of the calibrated fit and the implications of the graphs presented. The quality of the EAA calibration is currently not discussed at all. Do the calibrated parameters make sense? Does the monthly pattern of soil moisture limits follow a reasonable pattern? Why is the May value for SMAX so much higher than the rest of the values.

A list of significant parameters used to calibrate the LEC model is given on p. 234. Is this list exhaustive? Were aquifer characteristics (such as storativity, transmissivity) calibrated? Are there comprehensive tables of calibrated parameters in the appendices?

In the case of "local parameters" (cell-based data), were different values allowed for each grid cell, or was the calibration done in zones, or was one value calibrated for the entire modeled domain? P. 235 mentions that "regional parameters such as land use type has an influence over a greater area than local parameters" Land use is not on the list of calibrated parameters mentioned above. Was land use calibrated?
Note: This section contains a nice summary of the statistics used to quantify the calibration. This should be common to all sections. Discussion of the calibration and verification accuracy is also much more comprehensive than the other sections.

Chapter 5 Sensitivity Analysis

I do not really agree with the distinction given between sensitivity analysis and uncertainty analysis. I agree that sensitivity analysis defines the change in a particular output variable resulting from the change in a particular input variable, which can be a function of space, time and state of the input and output variables. Uncertainty analysis (at least with respect to input parameters) typically postulates in probability distribution for the input variables of interest and uses this information, together with the sensitivity computations to derive an output variable probability distribution.

It is not clear to me that the space/time dependence of the sensitivity matrix was taken into account in the methodology described in section 5.1. At what time was sensitivity calculated? When the sensitivity of each input variable was calculated was it changed simultaneously and uniformly over the entire domain, or was it done cell by cell? How did sensitivities vary over the spatial domain?

The logic in the second to last paragraph on p. 267 seems circular. Please explain.

In the results section I believe the sensitivity matrix results should be presented before the impact of these sensitivities on the bias and rmse of model predictions. The sensitivity matrix is a function only of the model structure. The bias and rmse of model predictions also incorporate the effects of observation error, model algorithm error, etc., and therefore I question whether they even belong in this section. There are so many things that may contribute to model prediction error outside of parameter error I question whether these results should be used to constrain the allowable variation in parameters. I also question whether these determinations can be carried out independently parameter-by-parameter.

I don't understand what the x-axis of figures 5.2.1 and 5.2.2 is (percentile of what?). I also don't understand figure 5.2.3. How were confidence levels in table 5.2.1 determined?

Why was equation 5.1.1 replaced by equation 5.2.1?

Figures 5.2.4 through 5.2.10 show that Wetland potential evapotranspiration is clearly the most sensitive of the parameters selected for analysis, followed by Coastal PET. However I question the conclusion that wetland potential evapotranspiration should be only varied

+/- 10%. This is a very tight bound. Is it possible to estimate this parameter this closely from independent measurements? Is it possible that something else in the model algorithms may be leading to this conclusion, but that potential ET might really vary over a larger range?

Chapter 6. Uncertainty analysis

Section 6.1.1 The connection should be made between sensitivity coefficients determined here and those calculated in Chapter 5.

Equation 6.1.1.1 is a first order approximation that is typically applied to models that can be formulated with nice compact governing equations and/or solutions. The SFWMM has many non-linear aspects such as decision trees, thresholds etc., that cannot be described in this way. Furthermore it is spatially distributed and discontinuous in many ways. I question whether equation 6.1.1.1 can really capture the uncertainty of this model. For this model Monte Carlo simulation may be the only reliable way to get at model prediction uncertainty.

p. 280 On what basis are the model input parameters considered normally distributed? Most of them are non-negative, meaning that they cannot be normally distributed (because normal distributions indicate a non-zero probably of negative values). Why was the variance of the parameter estimated using the equation on p. 280? It would make more sense to me to postulate a variance based on the physical range of values that can reasonably be taken for each parameters, rather than constrain it based on the range in variation imposed by the model calibration fit. Using analysis of the model calibration behavior to constrain the variance of the parameters seems circular to me. As discussed previously there are many model algorithm errors and observation errors that come into play with the calibration analyses.

Section 6.1.2. Regression analysis

I do not really understand what is being done here. Perhaps some extended discussion at the workshop would help.

Are the uncertainty bands determined in this analysis tight enough to use the model for its intended purpose? Is the analysis comprehensive enough to give confidence in the full space-time predictions of the model that may be produced in future analyses?

INITIAL REVIEW COMMENTS ON THE FINAL DRAFT, Documentation of the South Florida Water Management Model (SFWMM), Version 5.5, August 2005

By

Tony Donigian

August 28, 2005

GENERAL COMMENTS/QUESTIONS:

1. It is clear that an extensive effort has gone into the development, application, and testing of the SFWMM and into the preparation of the documentation. I commend the authors on the overall work and the effort.
2. The South Florida region is an exceedingly complex natural hydrologic system, with extensive superimposed anthropogenic impacts, and as such is a daunting challenge for any modeling system.
3. The 2 mi by 2 mi grid scale is a relatively coarse scale for both surface water groundwater modeling efforts. There are selected discussions of the impacts/restrictions of this scale in various sections of the documentation, but no concise discussion as to how this scale was selected, or a justification that this scale is reasonable for the types of management and policy issues to be addressed. Further elaboration of this would be helpful.
4. It was emphasized that water budgets could be generated for all regions within the SFWMM but I only saw limited water budget information in Section 4.3.3 and only for the Big Cypress and Feeder Canal basins. Were water budgets generated for each of the subregions (i.e. EAA, WCAs, LEC), and if so, where can those be found?
5. Others??

SPECIFIC COMMENTS/QUESTIONS:

<u>Section 2</u>

1. Pg 17: There appeared to be significant processing of topographic data to both update the previous model and refine the landscape representation. Could the updated data support a finer resolution than the 2 mi x 2 mi grid, and what impact does the grid size have on the drainage patterns and surface water processes in this extremely flat topography?
2. Pg 25: What is the projected impact, if any, of using the 1988 land use data for the entire calibration period? Were land use data for any other years available during the calibration and verification periods?

3. Pg 30: Since SFWMM uses a single land use designation for each 2 x 2 cell, how does it accommodate impervious areas that are generally much smaller than this? Also, since most SW models usually use ***effective***, or ***directly connected impervious area,*** does SFWMM make a distinction between effective and total impervious area in each cell? Also I didn't see a clear discussion of how runoff was handled for impervious surfaces – maybe I missed it.

   Also, it is noted on Pg 58, that the BEAs (basic element areas) allow SFWMM to capture land use variability at a smaller scale than the 2 x 2 grid – is this only for the LEC regions, or available throughout the model footprint?

4. Section 2.2: It looks like an extensive effort went into the processing and analysis of the rainfall data to develop the grid-average rainfall for each cell. Were any consistency checks performed with any available isohyetal maps or data as a check on the final generated rainfall distributions across the region?

5. Section 2.3: Since various methods were used for calculating ET, were any checks or comparisons performed among the pan-derived ET (for Lake Okeechobee), AFSIRS and ETo methods of specifying the evapotranspiration time series? It would be interesting to see how they compare for identical conditions.

6. I didn't see any discussion of the impacts of irrigation efficiencies on modeling the irrigation demand. Is this included in the SFWMM and how is it represented?

7. Pg 71. This table shows the highest Detention Depths for urban and agricultural areas, in the range of up to 0.5 to 0.6 feet, or close to 6-7 inches. Since this is applied to the 4 sq mi area of a cell, this corresponds to about 1300 to 1500 ac-ft of storage in that cell. This seems like a relatively large amount of storage before any overland flow can occur – I would welcome some discussion of this and how we can visualize this depth of storage over an entire cell of 4 sq mi.

8. Pg 72: Infiltration rates of 9 to 100 ft/day are noted in the text, and specified for each cell. How were infiltration rates determined – soils data, calibration, or both?

9. I would like to request a presentation/discussion on the SW-GW coupling procedures. I found the discussion in the report difficult to follow, and I was not sure all the assumptions were identified and discussed.

<u>Section 3</u>

10. Section 3: I didn't have time to study this section as much as it deserves, and hope to do that before our workshop. I would like to request a presentation on these critical aspects of the SFWMM and maybe a demonstration/example, if possible.

<u>Section 4</u>

11. Section 4, pg 218. Please explain Equations 4.1.1.1 and 4.1.1.2 – they don't seem clear to me unless I know where the 'structures' are located.

12. Pg 219: Is there a logical explanation for the monthly variation in the calibration parameters shown in these tables? There doesn't appear to be a seasonal pattern

so I question if they are really representing mechanistic processes, or is this merely curve fitting?

13. Pg 219: Are the monthly parameters constant throughout the month, with abrupt changes between months, or is there any interpolation being done for days within a month?
14. The calibration results for EAA look quite good and the R^2 values generally support that. I would recommend showing, or at least examining, the flow duration curves plotted on log-probability scales to emphasize/focus on the extreme high and low flows/ends of the curves.
15. The verification plots and tables show 2 different verification periods, but the text only indicated that 1996-2000 was verification (pg 217).
16. Pg 232-233: The titles indicated V 5.4? Is there much difference between V 5.4 and V5.5?
17. This was clearly a major model calibration and verification effort, and the results generally look good to very good. But I would recommend some additional discussion in Section 4.2.2, and specifically clarifying what is in Table 4.2.2.1. I would like to see some of the flow results like that shown for the EAA, and included in Appendix C. I think that would support the calibration even more.

Section 5

18. How were the specific parameters selected for inclusion in the SA? What criteria were used for selection?
19. It would be helpful to see the actual parameter values used in the SA, not just the % changes.
20. Is the Loucks and Stedinger 1994 report available to the Peer Reviewers? I would like to see a copy, if possible.
21. On pg 268, the report states, "For each parameter, a series of model runs were completed to determine a range of acceptable values such that each parameter value within the range can be used without significantly affecting the calibration." What tolerance or criteria were used to establish whether or not the calibration was ***significantly*** affected?
22. On pg 267 it was noted that the model response would be expressed in terms of simulated nodal stage or canal flow, but all the results in Section 5 are just in terms of stage. Since flow is much more dynamic and variable than stage, would any of the SA results change or be impacted if the results were also shown for flow? I would request that some SA results for flow be shown/presented at the workshop, if they are available.
23. Please confirm that the horizontal scale of Figures 5.2.1 and 5.2.2 refer to the percentiles of comparison points (or calibration points) with the associated bias or rmse values shown on the vertical axis, i.e. are these percentiles derived from values similar to those listed in Table 4.2.2, for the SA runs?

24. The SA appears to have been performed in a systematic and rigorous way, but I would have liked to see more results (e.g. like flow results, noted above), and the specific parameter values used, in order to better assess model performance.

Section 6

25. Sorry, but I didn't fully comprehend the theory and methods used for the UA, so I would request that a presentation on this section be included in the workshop.
26. How valid is the assumption that all the model parameters are normally distributed? That seems to be a major assumption.
27. If the results are valid, what is the impact of having average values of the half-width being in the range of 0.34 to 0.79 ft (so the full range is 0.68 to 1.58 ft)? How significant is this level of uncertainty on the decisions/evaluations to be made with this model?
28. As noted for the SA, all the UA results are presented in terms of **stage**. Were any UA results generated in terms of **flow**, and if so, are they available?

Comments on SFMWM

(version 2; some editing)

by Jery R. Stedinger

27 August 2005

The SFWMD is to be congratulated on developing such a comprehensive and thorough water management model. The management of this system is of incredible importance regionally, as well as of great national interest. I am very pleased to see that such care has gone into the modeling of the system so that the cumulative impact of design and operating decisions can be assessed, and the impact of proposals can be predicted with some assurance. The model is a marvelous accomplishment. The documentation was in general very good. I look forward to reading the comments of other panel members and the discussion at our forth-coming meeting.

I would not be doing my job if I did not develop significant comments on the model, which is really the intellectual activity of interest here. Below are lists of key and significant concerns, and also minor comments. Most of the major concerns are directed at Chapters 5 and 6. Many of the minor comments relate to the clarity of the documentation and thus are not critical. Others minor comments are of greater importance: word choice is often an editorial issue, but in other cases the choice of the words relates to the conceptual representation and explanation of the intellectual character of this activity, and thus is also worthy of careful consideration. Clearly this document is a teaching tool that needs to explain to the general public the intellectual framework and the methods the SFWMD has adopted, as well as their limitations.

Comments of Significant Concern

Model Purposes and Scope

In reading comments by the 1998 review committee (Locks et al, 1998, pp. 5-6), I was struck my their concern that objectives for the model were not spelled with sufficient clarity. In that context the following comment on the stated purposes for the model is a significant concern:

p. 3 – I do not see any difference among items #2, #3, and #4, which may be my lack of understanding of what is meant. I would suggest that the purposes be described more clearly.

I think SFWMD does #1 so as to achieve #2-4, which are basically the same. Therefore #1 is perhaps a means, and #2-4 describes a purpose. But other purposes are not described, or clearly distinguished. For example, there are certainly long-term planning issues, whereas position analysis would appear to reflect within-year operations planning efforts. As the subsequent discussion demonstrates, these activities have different character. The desire to understand the pre-development flow patterns in the region could be considered a third distinct purpose.

It seems very appropriate that a clear statement of the primary purposes and intended uses of the model be made at the beginning of this document, particularly clarifying the spatial and time scales of decisions and processes that the model is intended to address. This is worth a new section between the current 1.1 and 1.2. This suggestion also appears in (Loucks et al, 1998, p. 5 bottom).

Loucks, D.P., W. D. Graham, C.D. Heatwole, J.W. Labadie, R.C. Peralta, A Review of the Documentation for the South Florida Water Management Model, Submitted to SFWMD, March 27, 1998.

p. 4 – **Natural System Model**. It would be appropriate to say:
Because NSM uses the same hydro-meteorological record as the SFWMM, comparison between "natural conditions" and managed systems can be made ***more reliably.***

One can still use the NSM for the purpose of comparing conditions without having matching meteorology. The value of using a common hydro-meteorological record is that the comparison is much more precise. In statistical terms, one generates a paired data set, which allowed a pair statistical test. (See statistical texts cited below.)

p. 24 - Figure 2.1.1.5 – **Depressions in elevations?**
While the observations I am making are sensitive to the thresholds for different elevations in the plot, I am concerned by the depression near the center-northern boundary of the modeled region (just south of Lake Okeechobee). Does this area become a lake?

There are also blue wholes in the southeastern portion of thee modeled areas several rows back from the ocean. Are these numbers correct, and if so, what is the implication?

p. 36 – **Rainfall and Climate Futures**

a. This is a very large area. Its water management could affect rainfall rates through precipitation recycling. Has this been considered? [Page 196 - bottom - discusses how reduced irrigation results in reduced ET, and could this not cause decreases precipitation elsewhere in the basin.]
b. Climate variability is now much better understood than when this project began, and climate change seems to be a certainty over the planning period for this project.

=> How does this project address these issues?

p. 66 - Solution of PDE
I am concerned by the described method of solving the 2nd-order PDEs for flow. I am not an expert on numerical solution of PDEs, though I have some experience. I am use to decreasing the time step to main stability, or reformulating a model or the numerical scheme. Clearly some time-step control is employed here.

What troubles me is the description at the top of the page on how water movement is arbitrarily limited to maintain stability. This may yield stability, but what about accuracy?

While most of the report was very good and demonstrated a very high level of care. I was disappointed by several aspects of Chapters 5 and 6 addressing Sensitivity Analysis and Uncertainty Analysis.

Chapter 5 Sensitivity Analysis
Perhaps we might be better off discussion this analysis rather than my writing a critical review which may be based on a misunderstanding on my part. But as a beginning for a discussion at our meeting, I venture several remarks.

It would be useful to expand the good discussion in the first paragraph of the appropriate role of sensitivity analysis, and provide appropriate citations to support that discussion.

Please state clearly at the beginning of Chapter 5 what issues need to be addressed, and will be addressed, in this application of sensitivity analysis. What are the key questions that we hope to resolve?

p. 267 - paragraph 2 - Sensitivity analysis can be used for, and is often used for, all of the purposes listed. It is not just about parameter uncertainty. One often runs a model with different options, algorithms, data sets, management strategies, and observes the differences. That is sensitivity analysis.

p. 268 – p. 278 - I found the proposed use of *Singular Value Decomposition* on p. 268 to be very interesting, but do not know how it was done. Note that the derivatives frequently have different units making it difficult to perform the analysis that might be suggested. I am concerned as to what was done.

p. 278, what is a *parameter resolution matrix*?

How did SFWMD compute what I would think of as a parameter correlation matrix (the correlation among sample estimators of the parameters) from the matrix of sensitivities?

Recall in ordinary least squares regression, solving

$$Y = X\beta + E,$$

Where Y is to be predicted using independent variables X for estimated parameters β. E is the matrix of errors, which are generally assumed to be zero mean with common variance σ^2. The optimal estimator of the parameter vector β is

$$b = (X^TX)^{-1}X^TY.$$

The covariance matrix of the sample estimator b equals

$$\mathrm{Var}[b] = \Sigma = \sigma^2 (X^TX)^{-1}$$

The correlation between two elements i and j of b is just $\Sigma_{ij} /\mathrm{sqrt}[\Sigma_{ii}\ \Sigma_{jj}]$.

So how did the SVD determine the correlation?

In maximum likelihood estimation the covariances among the parameters are often approximated using the second partial derivatives of the likelihood function, but this discussion did not mention second partial derivatives.

However, sometimes in nonlinear regression, the sensitivity matrix S (equal to $\partial Y/\partial X$ and thus containing the partial derivatives of each y_i with respect to each variable x_j) is substituted for the X matrix in the equation above corresponding to use of a linear approximation of the stage function $f_i(b)$ as a function of the parameters

$$y_i - f_i(b) \approx y_i - f_i(\beta) - S\,(b - \beta)$$

yielding

$$\mathrm{Var}[b] \sim \sigma^2\,(S^T S)^{-1}.$$

Is that what is being done here? One does not need SVD to employ such an approximation. If that is the issue, we might talk about the validity of this approximation of the variance, which requires that the product of the residuals times the second derivatives of f(•) is small. This is a standard method in nonlinear regression analyses. See:

Draper, N. R., and H. Smith**,** *Applied Regression Analysis,* 3rd Edition, ISBN: 0-471-17082-8, J. Wiley and Sons, New York, 1998.

Or, for a discussion of the linearization:

Eric W. Weisstein. "Nonlinear Least Squares Fitting." From *MathWorld*--A Wolfram Web Resource. http://mathworld.wolfram.com/NonlinearLeastSquaresFitting.html

Please provide a standard published reference describing the methods that have been adopted.

p. 268 – Section 5.2 sentence 1 – How was this done? Chapter 4 describes the calibration of the model; that does not seem to be the same as sensitivity analysis. This sentence confuses me.

p. 267 – Section 5.2 sentence 2 – Please expand upon how a reasonable uncertainty range was determined for each parameter. The analysis depends critically upon these decisions and it was not clear what was done, and the extent to which it is consistent across parameters.

>>Later I realized that this is apparently what figures 5.2.1-5.2.2 do. But whole discussion confused me. Please clarify what is being done and why that analysis is justified.

What criterion was employed to identify what is called a 95% confidence value? How was probability or confidence introduced?

p. 267 – Section 5.2 sentence 3 – In particular I did not see how analysis can determine "groups of parameters that are dependent on one another." What does that mean?

The analysis did not vary two parameters at a time and see if the selection value for one parameters can substitute for the value of the other. (In the constraint $x + y = 5$, changes in y can be compensated for by corresponding changes in x.)

p. 267 – Section 5.2 paragraph 2 – Figure 5.2.1 and 5.2.2 – I am sure these graphs are interesting, but I do not understand what they are.

What is WPET? It does not appear on page 314 of the Glossary, or xvi of abbreviations. Okay, list on page 267 tells me where to look. But I could not find the term WPET on pages 44-46 which are section 2.3.1.

Could the list on page 267 be more clear as to what these parameters are, and if there is only one value, or one for each cell, or some other spatial index. Yes, I could try to look each one up and resolve those questions, but I was hoping someone would do it for others and me.

Back to figures Figure 5.2.1 and 5.2.2

I think the caption of figure 5.2.1 might say:
Sensitivity OF the average BIAS during the calibration (verification period?) TO variation of the Wetland Potential Evaporation (WPET) used in all WCAs.

Now those variations are the different lines. But what do percentiles correspond to? Is there not one average bias (at what point(s)?) when the simulation is run over some period?

Or maybe you are computing error for each point, and you call that a bias? So figure 5.2.1 shows me the distribution of all the errors somewhere over some period as a function of different WPET values? But what then is in figure 5.2.2 if it is not the average root mean square error somewhere averaged over some period? I am sorry to be so confused.

The bias is described as being for the gauges in the WCAs. I assume these are stage gauges? What gauges are in the WCAs? Are they uniformly distributed spatially or should we use some weighting? (This is also a concern for calibration and validation when one would also like to combine performance indices for different sites.) Are errors at one site averaged, and then a bias for the site computed so we have a distribution of biases over sites, or are all the sites at one time averaged, so we have a bias for each time point and a distribution of biases over time, or do we have biases (errors) for every time point and gauge yielding a space-time distribution with the distribution shown in figure 5.2.1.

I am referred to chapter 4. Table 4.2.2.1 there reports a bias and root mean square error for calibration and verification periods (which is used in chapter 5?), and for each stage or flow gauge. So it would appear, or I would guess, that we have a bias and root mean square error for each gauge, and the distribution is over different gauges? What was done is not clear to me.

For the sensitivity analysis, why not just sum the mean square errors over all gauges, and have for each region a single mean square error? Why spend any time with bias in the sensitivity analysis section: it is included in the mean square error?

Why are we not exploring the impact of such variations in WPET on stages in ENP?

What is meant by the statement: "To keep both bias and rmse error small, it is preferable to have a small change in WPET." And on page 269, "To keep the modeling output valid, the recommend change of WPET is +/-10%." Why have any change in WPET? When I reached table 5.2.1, I suspected that I have not been reading about a sensitivity analysis, but rather a method for determining uncertainty ranges for the parameters! I did not know that, if it is true. Given the values in table 5.2.1, the analysis is very crude.

p. 272 Does BCNP represents an average stage? At how many gauges?

p. 273 Figure proposes to provide the change in stage (feet) for a 100% change in parameter value? So if WPET has a calibrated value of 10, we are considering zero and 20?

Or did you actually change WPET from its calibrated value to its upper uncertainty value, and its lower uncertainty value? That is what I would have expected. See also equation 5.2.1. But we have equation 5.2.1, which does not seem to correspond to what figure 5.2.4 says is presented. I am really confused.

Figures 5.2.4 through 5.2.8 appear to be providing a clever and compact presentation of the sort of analysis that one would like. What I would like to see is the uncertainty range
$[y(+) – y(-)]$
for each stage averaged over the specified gauges, from a change in each parameter from its lower (-) to its upper (+) uncertainty range. Is that close to what is reported here?

The sensitivity analysis is clearly trying to do the right thing, and figures 5.2.4 through 5.2.8 appear to be providing a clever and compact presentation of the results. But what was done is not clear. Because I can familiar with nonlinear regression methods, I can imagine how the parameter correlations were obtained; but such a vision was not obtained by reading this document.

Chapter 6 Uncertainty Analysis
pp. 279 & 280 (also pp. 267 and xiv)- I think the term *confidence limit or confidence interval* is incorrectly used here in the context of uncertainty analysis. In the statistical literature, the term confidence limit has a very specific meaning (in repeated sampling

95% of 95%-confidence intervals based upon the sample average with n observations will correctly contain the true mean μ), which is different from the appropriate meaning here. Thus I would suggest when the SFWMD rewrite the text using a different term, such as a probability interval, or uncertainty bands, which the text suggests.

p. 279 – the issue is not the *limitations* of model output; rather uncertainty analysis addresses the *precision* and reliability of model predictions. The model may output lots of numbers. The reliability of predictions is the issue of concern.

p. 279 – I do not have Trimble (1995a) and thus am perhaps unable to appreciate the analysis. Do the ideas in Trimble appear in standard texts on this subject to which documentation could refer?

Eqn 6.1.1.1. This is a standard approach that is very appropriate here. For a discussion of this method see:

Morgan, M. G. and M. Henrion, *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*, Cambridge University Press, New York, 1990.

Kottegoda, M. and R. Rosso, *Statistics, Probability, and Reliability for Civil and Environmental Engineers*, McGraw-Hill, New York, 1997.

Benjamin, J. R. and C. A. Cornell, *Probability, Statistics and Decisions for Civil Engineers*, Mc-Graw-Hill, NY, 1970.

However, the analysis assumes that errors in the different parameters are uncorrelated. I have not seen that demonstrated. The top of page 280 indicates that Table 5.2.3 has a correlation matrix which indicates the parameter errors are uncorrelated. Currently I do not understand what was done pertaining to Table 5.2.3. The assertion may be correct.

The choice of the term *half-width* seems unfortunate. The heading in the table *half-width of 90% uncertainty band* is certainly a mouthful and does not give the sense of what analysis is about.

Why not just report the estimated standard deviation?

Or else define your "uncertainty measure" to be 1.645 times the estimated standard deviation? [This is what your half-width of 90% uncertainty band really is.]

Please do not use interchangeably the terms uncertainty band, and certainty band, as text indicate will be done.

p. 281 **Results discussing half-widths.**
The analysis has been done and is of great value. Can we now have some overall conceptual statement about whether these values are too large, quite small, or sufficiently small that the intended analysis with the model will be credible.

Now is the time to reflect on whether the model can meet the objectives. Loucks et al (1998, pp. 10) make a similar request: "a discussion of the limitations of model output analysis based on the uncertainty analysis results would be useful. Given the District's experience …." Those authors go on to suggest (Loucks et al, 1998, pp. 10), "documentation should anticipate how the model will be, and should be used…. It is better to state clearly just what the model can and can not do well…" The documentation lacks a conclusions section that would provide such guidance.

Regression Analysis

To be blunt, it appears to me that this analysis is not needed and its execution is statistically flawed.

First, why do we need to resort to a regression analysis? I believe the standard errors from the validation effort provide a direct description of the predictive precision of the model on a data set not used for calibration. Is that not what we want?

There is another concern here. Both regression and the validation statistics generally describe how well the model predicts the reported or observed values of stage and flow. If those values have errors, then the question remains as to how well the model predicts the real stages and flows. This is a difficult problem to solve. But if we have some idea of the precision of the point measurements as representations of cell averages, the issue can be addressed.

Regression Analysis Critique

Before going further, one should observe that here we are measuring how precisely a linear function of the model predictions estimate the observed stages and flows (if the analysis is done correctly). Thus we are not describing how accurate the model predictions describe the observed stages and flows, which is the issue.

pp. 280-281

This analysis has serious problems. Equation 6.1.2.1 is mathematically correct, but requires several important assumptions, including that the errors are normally distributed and independent, and the underlying model is really linear. This is important and should be made clear immediately after the equation.

The assumption of normality is not addressed, but is probably not critical because we have a large sample. Independence of the residuals is not addressed, and appears to be unlikely is many cases, as is shown by figures in appendix C, such the included here. Clearly there are long series of positive and negative residuals as over a period of many months the model continues to over-predict, and at other times to under-predict, the value of the observed flows. I assume this occurs because the rainfall gauge network has failed to capture the actually volume of rainfall, and it takes awhile for the accumulated difference to work its way out of the system. This kind of correlation in the errors is to be expected.

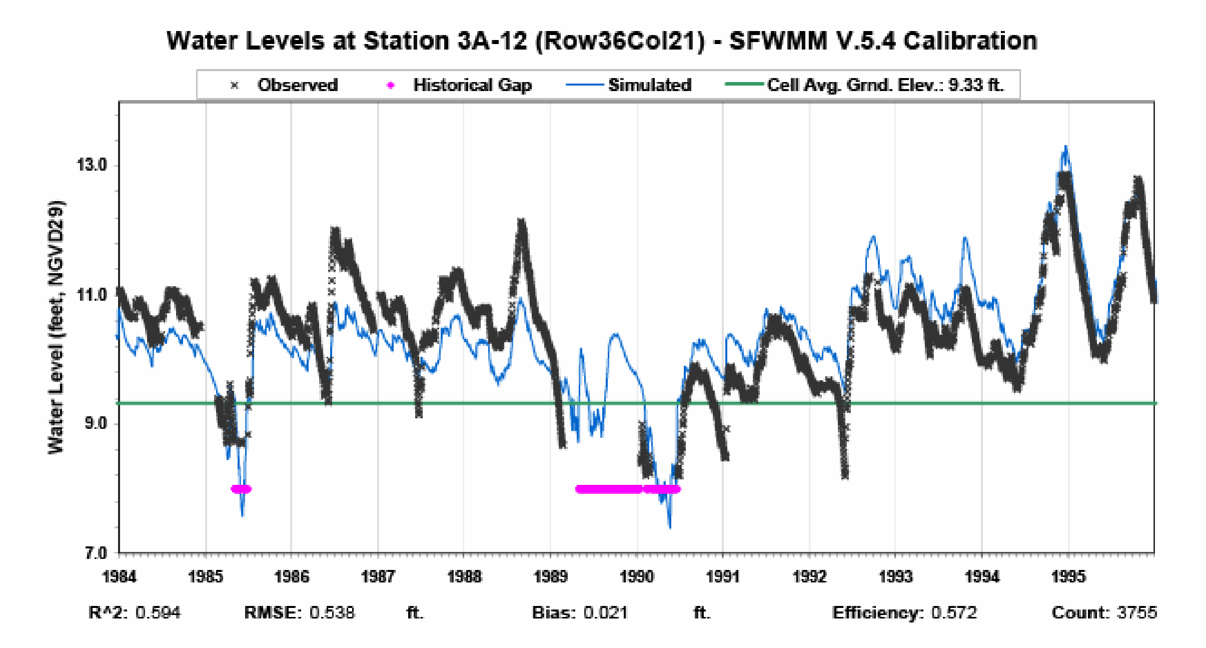

Figure 6.2.1 demonstrates that the linear assumption is invalid. The linear model clearly fails to represent the data at the low end.

Thus while use of a regression model may appear appealing for quantifying the precision with which a *linear function of the simulation model predictions* can predict observed flows (or have the authors done it the other way around; definition of Y is unclear and figures would suggest that the authors are trying to predict the simulation values with the observed values, which would be strange), which requires several assumption that do not seem to have been checked, and probably are invalid. But there seems to be no need for the analysis in the first place because that the calibration analyses provided a good measure of precision.

Minor Comments

p. xiii – what is a "nicely" configured workstation?

p. xiv – Rather than saying the model calibration is used to *reinforce*, would it be more appropriate to say the model is used to *evaluate* …

p. xiv – I think the term *confidence limits* is incorrectly used here in the context of uncertainty analysis. In the statistical literature, the term confidence limit has a very specific meaning, which is different from the appropriate meeting here. Thus I would suggest when the SFWMD can, that the text be rewritten using a different term, such a probability interval.

p. xiv – glossary is WONDERFUL.

p. 1 – last paragraph – text would be clearer if the location of the EAA and five WCAs was described.

p. 4 – line 7 from the bottom – *maintaining* is the wrong word; maybe respecting?

p. 7 – When you say *dominance* of evapotranspiration, overland flow and groundwater movement, this is in contrast to what? That is, what is left that it dominants?

p. 7 – I found the sentence confusing that says: *The model is conceptualized … for three different major geographic areas (1) for … (2)….. and (3). The model is conceptualized … for three different major geographic areas (1) for … (2)….. and (3).* Numbers would make the text clearer.

p. 10 – Rate of evaporation from below the land surface generally depends upon the type of plant and their root system. Some discussion of plants and their root system would be useful? Are their periods when they are dormant?

p. 19-20 Last bullet and first bullet – Why are some cells excluded? Do they not need elevations assigned?

p. 37 – If rainfall is highly variably spatially (thunderstorms in summer months), than applying one station over a large area gives to big a variance to the total rainfall depth is sparsely gauged areas.

p. 38 – **Why were some very large values recorded?** Are these really errors, or isolated and extreme point measurements? If they are real and we exclude them, do we bias our estimate of the mean precipitation?

p. 42 – **constructive suggestion – Figure 2.2.2.3 is very nice.** The mean is easy to understand, but the meaning of +/- one standard deviation is not. I suggest that you pick 10-percentile, mean and 90-percentile or some other percentiles. This is would be more informative that +/- one standard deviation: the date is clearly not normal in Nov-May, and percentiles would help us see what the real distribution looks like.

p. 64 – equation 2.4.1.4 – typo?

p. 64 – it seems to be that rooted vegetation and islands are going to give a Manning's n value different that generally experienced in open-channel flow modeling. If so, such a warning would be appropriate.

p. 70 – figure 2.4.2.2 – Gives n as a function of *ponding depth*, not *depth*.

p. 72 – please define the term *borrow canal.*

p. 96 - Figure 2.7.2.3 – Can you tell us why some points are SO bad? Some of these points are really bad, perhaps invalidating ordinary least squares as an appropriate statistical technique, and I mean that.

p. 97 – figure 2.7.2.4 – Not as bad as figure 2.7.2.4, but still terrible. Same comments apply.

p. 98 – Figure 2.7.2.5 – This may be worse than figure 2.7.2.3; what is going wrong here? How should this process be modeled? Should we maintain the variability that has been lost using Maintenance Of Variance Methods (MOVE)? The straight-line fails to represent the character of the data. Or is this a small and relatively unimportant process.

p. 96-98 – Figures – It would be more standard, and thus much easier for me to understand the figures, if predicted were on the horizontal axes, and observed on the vertical access.

p. 101 – Why no GW flow at Gulf of Mexico at southwestern boundary? Seems unreasonable that there would be no groundwater flow to the Gulf.

p. 105 – with two trial cycles per day, and a 1-day model time step, how are these processes reconciled?

p. 108 – NOT ALL aspects of current and future proposed operations are included. Many are not important. Documentation needs a better perspective.

p. 119 – first paragraph – significance options for the use of the model are hidden here, and should be in a more obvious location.

p. 119-120 – Figures 3.1.4.1 and 3.1.4.2 is unreadable. What do these FORTRAN names mean?

p. 178 – Items 1-2-3 confuses me, even with examples. How is offset different from translation? Because of order?

p. 185 – I found the listing of three consumption categories to be inconsistent and confusing. How is irrigation a source of water? Where does the irrigation water come from?

p. 202 – line 4 – instead of *detailed* say *described.*

p. 208 – paragraph 2 section3.6.2 – what does it mean that water must be replaced?

p. 212-213 - I have heard the term position analysis applied to this sort of analysis before. The method warrants a clearer presentation that found at the bottom of page 213. Pleased provide one or more citations to the literature describing the use of the idea by others. Maybe those below?

Hirsch, R. M., Synthetic Hydrology and Water Supply Reliability, *Water Resources Research*, 15(6), 1603-1615, 1979.

Day, G. N., Extended Streamflow Forecasting Using NWSRFS, *Journal of Water Resource Planning and Management*, vol. 111, no. 2, pp. 157-170, April 1985.

p. 215 - Figure 3.6.2.6 - I got lost and was unable to follow the derivation of this figure. Why do the sequences no longer start at the top of the supply-side management zone?

p. 223 – **Figures in my option have been drawn with the axes reversed. Data should go on the vertical axis, and model predictions on the horizontal axis.**

Simulated values in both figures seem much too large in both figures. Can you explain?

Pp. 223-230 – Please provide calibration and verification goodness-of-fit statistics. These are eventually defined on page 235, but are needed earlier in this section.

p. 267 – Say: *Sensitivity analysis is to be distinguished from uncertainty analysis.*

p. 267 – I do not like the use of *confidence* as a term describing uncertainty as used here.

p. 236 – Can you pleased provided a clearer explanation of the difference between Eff and R^2 than is provided by 4.2.1.5. Please.

Pp. 253 & 255 – figures 4.3.1.2; 4.3.1.5 would be improved by use of quantiles rather and +/-; see earlier comment.

p. 279 - Eqn 6.1.1.1 has a P-subscript in the wrong place.

To: SFWMM staff
From: Jery Stedinger
Subject: Trimble MS Thesis and concerns with SFWMM sensitivity analysis
Date: 5 September 2005

I have been fortunate to find a copy of the Trimble MS thesis cited in the SFWMM documentation. I was particularly interested in learning more about the sensitivity analysis (SA) effort in the SFWMM documentation. SA and uncertainty analysis are special interests of mine.

Please let me share concerns with the analysis so that SFWMM staff can resolve out how I am confused before our meeting this week: we have only 90 minutes Friday to discuss these important issues and have a number of fundamental concerns with the analysis.

p. 60-61 a good statement of objectives for sensitivity analysis

p. 72 Sensitivity Matrix
Starting on page 72 of the thesis, the sensitivity analysis method is described. The sensitivity matrix of partial derivatives of each y_i (the averaged "simulated performance value" <<must be a MSE computed over time>>) with respect to each model parameter x_j form a **matrix A.**

The text implies the "time averaged" values are used for y; what simulated performance value was averaged is not specified, but it sounds like a mean square error; I cannot see anything else that would make sense. Subsequent discussion starting page 80 of the thesis suggests that y is either a bias or a MSE.

p. 73-74 Singular value decomposition
Singular value decomposition indicates for any real-matrix A we can compute:

$$A = U \Lambda V^T$$

where

$\Lambda = \text{diag}(\text{ Singular\_Value}_i)$

U is matrix of eigenvalues for columns of A

V is matrix of eigenvalues of rows of A

T denotes transpose

p. 75 The thesis then defines

Parameter resolution matrix: $R = V V^T$

Information density matrix: $S = U U^T$

In my reading about Singular Value Decomposition

(for example Press et al, *Numerical Recipes…*, Cambridge University Press, 1992; also http://documents.wolfram.com/v4/MainBook/3.7.10.html

http://documents.wolfram.com/mathematica/Built-inFunctions/AdvancedDocumentation/LinearAlgebra/LinearAlgebraInMathematica/MatrixComputations/MatrixDecompositions/AdvancedDocumentationLinearAlgebra3.4.4.html
http://mathworld.wolfram.com/SingularValueDecomposition.html),

the U and V are orthogonal and particularly orthonormal matrices such that $V V^T = I$, and $U U^T = I$. This is a requirement for equations such as (22) in the thesis to be correct in appropriate applications of SVD to least-squares regression with homoscedastic errors, where I write eqn. (22) equation on PAGE 75 of the thesis as:

$$COV = \sigma^2 V \Lambda^{-1} V^T \qquad (22)$$

Page 124 of thesis provides an example of R, and except for round-off error in single precision, indeed it appears that R = I. Thus I found perplexing the discussions in thesis on pages 75 and 123-24 pertaining to why in some applications R is almost the identify matrix, whereas in other applications that would not be so.

Origins of $Cov(x) = \sigma^2 V \Lambda^{-1} V^T$
Use of eqn (22) is very cleaver. I am concern if it is appropriately applied here.
Let me provide an explanation of how eqn (22) often arises; see Press et al (1992).

If we imagine that the parameters are estimated by solution of non-linear least squares, that is or objective was to fit g(x) to observations in a vector y by solving

$$\text{Min } [(y - g(x)] [(y - g(x)]^T$$

where we imagine that

$$y = g(x) + e$$

with e a vector of errors for each observation at each time step, and g(x) describes how the SFWMM transforms the parameters into an ESTIMATE OF THE OBSERVED STAGE OR FLOW at location i and time t; thus we sum the squared errors over all time and locations to obtain the overall mean square error for the model. Here y and e must be a vectors of length N T, where N is the number of sites and T the number of time periods.

Then if A is a sensitivity matrix for the vector of N T observation y as a function of the vector of parameters x, we can use a first order Taylor series to obtain the approximation

$$g(x) \cong g(x_0) + A (x - x_0)$$

which yields the approximation of the best parameters

$$x = x_0 + (A^TA)^{-1} A^T y$$

These estimators have sampling covariance matrix

$$\mathrm{Cov}(x) = \sigma^2 (A^T A)^{-1}$$

ASSUMING that the components of e are ALL independent with COMMON variance σ^2, and we are willing to ignore terms involving the second partial derivatives of g(x). Substitution of the linear approximation $g(x_0) + A\,(x - x_0)$ results in a classic linear least squares regression and the results are found in standard statistical tests.

Substitution of the singular value decomposition of A equal to $U\,\Lambda\,V^T$ wherein U and V are orthonormal matrices yields [corresponding to eqn 22 in the thesis]

$$\mathrm{Cov}(x) = \sigma^2\, V\, \Lambda^{-1}\, V^T$$

This is all in section 15.4 of Press et al describing the application of SVD to nonlinear least squares, as well as in other standard nonlinear least squares citations.

Is $\mathrm{Cov}(x) = \sigma^2\, V\, \Lambda^{-1}\, V^T$ applicable to our situation?

My understanding is that in Trimble the vector y does NOT contain all of the individual observations over time at every site. Rather, I think the components of y are individual MSEs (average of the squared errors over time) for each of the time series of predictions the model would make for each site i. Page 72 calls y the "ith simulated performance value" for i = 1, …, N. So does this equation apply?

We would not be attempting to minimize the square of the mean square errors of each y_i; and in particular, the intent of our model g(x) is not to predict the mean square error values as the equation $y = g(x) + e$ suggests. However, if y were the root mean square error, and if our goal were to minimize the total sum of the errors at all sites and time, then we could say that our objective is to minimize

$$J = y^T y$$

Then if we make the substitution $y = g(x_0) + A\,(x - x_0)$ it starts to look good, but I do not see that we get anywhere because we have lost the sampling error term so that a covariance does not make sense. Moreover, the different components of y would have different variances, or at least different means. I do not see how I can turn the situation wherein y are site (root) mean square errors into a reasonable least squares problem so that $\sigma^2 (A^T A)^{-1}$ is the resulting covariance matrix.

I hope this description of my confusion provides a basis for resolving my concerns. It would help me if each variable were carefully defined including how it is computed and its units. To say y is a simulated performance value is of limited help: what measure exactly, and if it corresponds to an average, over what time period or set of locations is that average computed. For vectors and matrices one should provide their dimensions so others can confirm that equations make sense. I am sorry to have provided these comments so late, but I did not originally have the MS thesis.

Responses

Legend:
J: Jery Stedinger
R: Rafael Bras
S: Vijay Singh
W: Wendy Graham
T: Anthony Donigian

ID # J001
Comment / Question: The SFWMD is to be congratulated on developing such a comprehensive and thorough water management model. The management of this system is of incredible importance regionally, as well as of great national interest. I am very pleased to see that such care has gone into the modeling of the system so that the cumulative impact of design and operating decisions can be assessed, and the impact of proposals can be predicted with some assurance. The model is a marvelous accomplishment. The documentation was in general very good. I look forward to reading the comments of other panel members and the discussion at our forth-coming meeting.
Response: Acknowledged. The good words are appreciated.

ID # J002
Comment / Question: I would not be doing my job if I did not develop significant comments on the model, which is really the intellectual activity of interest here. Below are lists of key and significant concerns, and also minor comments. Most of the major concerns are directed at Chapters 5 and 6. Many of the minor comments relate to the clarity of the documentation and thus are not critical. Other minor comments are of greater importance: word choice is often an editorial issue, but in other cases the choice of the words relates to the conceptual representation and explanation of the intellectual character of this activity, and thus is also worthy of careful consideration. Clearly this document is a teaching tool that needs to explain to the general public the intellectual framework and the methods the SFWMD has adopted, as well as their limitations.
Response: Acknowledged. Your concerns and comments are appreciated.

ID # J006
Comment / Question: p. 4 – Natural System Model. It would be appropriate to say: *Because NSM uses the same hydro-meteorological record as the SFWMM, comparison between "natural conditions" and managed systems can be made more reliably.*
Response: This suggestion will be seriously considered for the final documentation.

ID # J007
Comment / Question: One can still use the NSM for the purpose of comparing conditions without having matching meteorology. The value of using a common hydro-meteorological record is that the comparison is much more precise. In statistical terms, one generates a paired data set, which allowed a pair statistical test. (See statistical texts cited in J051.)
Response: This comment will be seriously considered for the final documentation.

ID # J008
Comment / Question: p. 24 - Figure 2.1.1.5 – Depressions in elevations? While the observations I am making are sensitive to the thresholds for different elevations in the plot, I am concerned by the depression near the center-northern boundary of the modeled region (just south of Lake Okeechobee). Does this area become a lake?
Response: The topography just south of Lake Okeechobee is relatively lower than the surrounding area due to subsidence. This area is heavily managed and does not become a lake since it is managed the same as all of the other agriculture cells in the EAA. The water table is kept at 1.5 feet below land surface.

ID #J009
Comment / Question: There are also blue holes in the southeastern portion of the modeled areas several rows back from the ocean. Are these numbers correct, and if so, what is the implication?
Response: The blue holes represent deep excavated lakes. These are areas where rock mining has occurred. These numbers are correct.

ID # J015
Comment / Question: It would be useful to expand the good discussion in the first paragraph of the appropriate role of sensitivity analysis, and provide appropriate citations to support that discussion.
Response: A Sensitivity analysis may include the study of how variation of model algorithms, parameters, temporal and spatial resolution, and the quality and resolution of input data affect the models simulated outputs. For the past twenty-five years the SFWMM has been the principal tool for integrated regional hydrologic applications within south Florida. The purpose of current sensitivity analysis is to update the previous analysis to include the most recently collected data and to evaluate the effects that infrastructure changes may have affected the parameter selection. At this time, changes to the model algorithms, temporal and spatial resolution of the model, or quality and resolution of spatial and temporal input data are not being considered. The purpose of this analysis is to reaffirm and update the sensitivity analysis of model output to ranges of parameter variations. This sensitivity analysis is undertaken in such a manner that it can be applicable in making a first order estimation of the model parameter uncertainty. This sensitivity analysis is also expected to give additional insight in establishing priorities related to future data collection efforts.

ID # J016
Comment / Question: Please state clearly at the beginning of Chapter 5 what issues need to be addressed, and will be addressed, in this application of sensitivity analysis. What are the key questions that we hope to resolve?
Response: See # J015

ID # J017
Comment / Question: p. 267 - paragraph 2 - Sensitivity analysis can be used for, and is often used for, all of the purposes listed. It is not just about parameter uncertainty. One often runs a model with different options, algorithms, data sets, management strategies, and observes the differences. That is sensitivity analysis.
Response: See #J015

ID # J026
Comment / Question: p. 268 – Section 5.2 sentence 1 – How was this done? Chapter 4 describes the calibration of the model; that does not seem to be the same as sensitivity analysis. This sentence confuses me.
Response: Normally, this would be the case. However, in this case, the sensitivity analysis was preliminary step towards completing the uncertainty analysis (Trimble, 1995) of the model.

ID # J027
Comment / Question: p. 267 – Section 5.2 sentence 2 – Please expand upon how a reasonable uncertainty range was determined for each parameter. The analysis depends critically upon these decisions and it was not clear what was done, and the extent to which it is consistent across parameters.
Response: The compartmentalization of south Florida's surface water systems presents a unique opportunity in which the sub-regions were analyzed separately while the parameters are varied system-wide. This was completed for period 1979 through 1990 with historical flows assigned to major structures where reliable data exist. Probably the most significant results of the compartmentalization is that the PET cannot be varied by more than five or six percent in the WCAs or the EAA without significantly degrading the calibrations of other regions.

In addition, the regions where the groundwater hydraulic conductivity was relatively low; the sensitivity of one region could be analyzed almost independent from the remaining portions of the model. In regions that the groundwater hydraulic conductivity was larger, varying parameters system-wide may limit the parameter variation in one region do to a model response in a neighboring region.

ID # J028
Comment / Question: Later I realized that this is apparently what figures 5.2.1-5.2.2 do. But whole discussion confused me. Please clarify what is being done and why that analysis is justified. (Refer to J027).
Response: The wetland potential evapotranspiration is being varied system wide (% of calibration). Figure 5.2.1 illustrates the distribution of bias at individual cells that have stage recorders available. [It should be noted that an individual cell represents 4 square miles while the recorder represents a point measurement]. Figure 5.2.2 illustrates a similar comparison except that the bias is being replaced with the root mean square (rms) error at the individual cells that HAVE STAGE RECORDERS. Each line on a graph represents the percentile ranking of the bias and rms errors at cells that have recorders within the WCAs as WPET is adjusted incrementally system wide

ID # J029
Comment / Question: What criterion was employed to identify what is called a 95% confidence value? How was probability or confidence introduced?
Response: The 95% confidence value is estimated as the largest system wide incremental change in the value of a parameter beyond which the water budgets of one or more of the sub areas could not be corrected by the adjustment of other parameters.

ID # J030
Comment / Question: p. 267 – Section 5.2 sentence 3 – In particular I did not see how analysis could determine "groups of parameters that are dependent on one another." What does that mean?
Response: (Trimble, 1995) Once the sensitivity matrix is formed, additional information can be determined about the relationship between computed output variables and parameters by use of the method of matrix factorization known as singular value decomposition. The use of this method and related theorems are described in the literature (Noble and Daniel, 1975; Forsythe et al, 1977; and Menke, 1984). Singular value decomposition (SVD) is more suitable for dealing with errors in data, roundoff errors and linear dependents than other more efficient mathematical schemes. It allows for the matrix inversion even if the matrix is rank deficient or ill conditioned. The sensitivity matrix would become rank deficient if there is at least one parameter that has no significant influence on any of the selected observations, or if there is at least one observation that is not sufficiently influenced by any parameters (Lal, 1995). This method allows for determination of model characteristics such as parameter space resolution matrix, the parameter covariance matrix, and parameter correlation matrix. The covariance matrix is also known as the uncertainty matrix. SVD is based on the fundamental theorem that matrix A can be decomposed into three matrices such that:

$$A_{mxn} = U_{mxk}\Lambda_{kxk}V^{T}_{kxn} \tag{18}$$

where U contains k eigenvectors of length m which are associated with the columns (simulated values) of A, V contains k eigenvectors of length n associated with the rows (parameters) of A, and Λ is a diagonal matrix of k non-negative eigenvalues called the singular values of A. k is the number independent equations among the simultaneous equations. The singular values are usually arranged in order of decreasing size. Some of the singular values may approach or equal zero. In this case Λ is partitioned into a sub-matrix Λ_p of p non-zero singular values and several zero matrices. The decomposition then becomes:

$$A = U_p\Lambda_pV_p^{T} \tag{19}$$

where U_p and V_p consist of P columns of U and V, respectively. The other portions of the eigenvector matrices are canceled by the zeros in Λ. The remaining diagonal elements give the sensitivity of the linearly combined model outputs to the linearly combined parameters. The U and V matrices can give additional information about the parameter behavior. The parameter resolution matrix R and the information density matrix S are defined by the U and V matrices as follows:

$$R_{mxm} = VV^{T} \tag{20}$$

and

$$S_{nxm} = UU^T \tag{21}$$

where R is a measure of the independence of parameters. When R equals or nearly resembles the identity matrix, then the model parameters are more easily resolvable. At times, parameters may not be individually resolvable, but may be resolvable as groups of parameters. This type of resolution is characterized by groups of dominant elements in the matrix. The S matrix is the information density matrix and is a measure of the independence of the data. An analysis of columns of A will indicate data distribution among the model outputs. It is possible from such an analysis to determine which data provides the same information as other data.

The covariance of the estimated parameters may be defined for both singular and non-singular sensitivity matrices using the SVD methodology as follows:

$$Cov = V(\sigma^2/\Lambda^2)V^T \tag{22}$$

where

Cov	is the parameter covariance matrix,
σ^2	is the error variance at an observation site.

A value of one is used for σ^2 to obtain the relative values of the matrix elements (Lal, 1995). The very small or zero diagonal terms again must be dropped in this application of SVD.

The covariance matrix can be used to obtain the correlation matrix as follows (Uhrhammer**,** 1980):

$$\rho^2_{i,j} = Cov_{i,j}^2 / (Cov_{i,i}\ Cov_{j,j}) \tag{23}$$

where

ρ	is the parameter correlation matrix

Independent parameters are most desirable when examining uncertainties of model outputs due to the parameter uncertainties. The analysis of a large number of parameters may be simplified by grouping sets of parameters that are dependent on one another but independent of other parameters or group of parameters. These groups of parameters are then treated as a single parameter. The method of SVD is used to understand the relationships between parameters and to isolate groups of parameters that are dependent on one another.

ID # J031
Comment / Question: The analysis did not vary two parameters at a time and see if the selection value for one parameter can substitute for the value of the other. (In the constraint x + y = 5, changes in y can be compensated for by corresponding changes in x.)
Response: The SVD of the sensitivity matrix indicated that the parameters are predominantly independent.

ID # J032
Comment / Question: p. 267 – Section 5.2 paragraph 2 – Figure 5.2.1 and 5.2.2 – I am sure these graphs are interesting, but I do not understand what they are.

Response: Please refer to response to # J035.

ID # J033
Comment / Question: What is WPET? It does not appear on page 314 of the Glossary, or xvi of abbreviations. Okay, list on page 267 tells me where to look. But I could not find the term WPET on pages 44-46 which are section 2.3.1.
Response: Potential ET for wetland, as stated in 5.1 on P267. In section 2.3.1, the calculation of ET of the whole system is explained. The simulation methods of ET in EAA and non-irrigated areas are different from ET in irrigated areas along the coast. Hence, ET is named as WPET (Wetland Potential ET) and CPET (Coastal Potential ET). The influences of WPET and CPET are observed over the entire modeling domain.

ID # J034
Comment / Question: Could the list on page 267 be more clear as to what these parameters are, and if there is only one value, or one for each cell, or some other spatial index. Yes, I could try to look each one up and resolve those questions, but I was hoping someone would do it for others and me.
Response: The referring section explained these parameters in more detail. According to the physical nature of these parameters, they might have different values for different land use types, crop types, ponding depth, etc. It would be helpful to know the parameter in its context to understand it better.

ID # J035
Comment / Question: Back to figures Figure 5.2.1 and 5.2.2. I think the caption of figure 5.2.1 might say: *Sensitivity OF the average BIAS during the calibration (verification period?) TO variation of the Wetland Potential Evaporation (WPET) used in all WCAs*.
Response: The Sensitivity and Uncertainty Analysis are made over the calibration period (1984 – 1995).

The percentile on the x-axis shows the distribution of bias of the gages in the region. The biases of all the gages in the region are sorted from lowest value to highest value, and then plotted against its percentile in the total gages of the region. The number on the x-axis represents the percentage of gages, which have a bias less than the corresponding value. The purpose of this plot is to give an idea of the distribution of the bias of all the gages in the region.

ID # J036
Comment / Question: Now those variations are the different lines. But what do percentiles correspond to? Is there not one average bias (at what point(s)?) when the simulation is run over some period?
Response: Refer to response to # J035.

ID # J038
Comment / Question: The bias is described as being for the gauges in the WCAs. I assume these are stage gauges? What gauges are in the WCAs? Are they uniformly

distributed spatially or should we use some weighting? (This is also a concern for calibration and validation when one would also like to combine performance indices for different sites.) Are errors at one site averaged, and then a bias for the site computed so we have a distribution of biases over sites, or are all the sites at one time averaged, so we have a bias for each time point and a distribution of biases over time, or do we have biases (errors) for every time point and gauge yielding a space-time distribution with the distribution shown in figure 5.2.1.
Response: The Water Conservation Areas are very large regions of the Everglades that have been impounded for coastal water supply and flood protection (See page 156). They are stage gauges and are differences between measured and simulated are summarized by average error bias and rms error as previously discussed. The bias and root mean square error at individual sites are ranked for sub areas (WCAs, LECSAs, EAA). Errors at one site are averaged, and then a bias for the site computed so we have a distribution of biases over sites in figure 5.2.1.

ID # J039
Comment / Question: I am referred to chapter 4. Table 4.2.2.1 there reports a bias and root mean square error for calibration and verification periods (which is used in chapter 5?), and for each stage or flow gauge. So it would appear, or I would guess, that we have a bias and root mean square error for each gauge, and the distribution is over different gauges? What was done is not clear to me.
Response: The Sensitivity and uncertainty analysis was completed independently of the calibration and verification process.

ID # J040
Comment / Question: For the sensitivity analysis, why not just sum the mean square errors over all gauges, and have for each region a single mean square error? Why spend any time with bias in the sensitivity analysis section: it is included in the mean square error?
Response: That is true the bias is included in the Mean Square Error. However, model bias is considered important performance measure in the SFWMD system and it has significant implication on water budget and operational policies (it translates to an overestimation/underestimation of simulated system storage).

ID # J041
Comment / Question: Why are we not exploring the impact of such variations in WPET on stages in ENP?
Response: The WCAs gages were shown as an example. The response of every cell with a gage is considered for each parameter. Therefore the contribution to the Everglades water levels includes the affects of coastal ET. However, it must be kept in mind that Lake Okeechobee and the EAA are considered separately.

ID # J042
Comment / Question: What is meant by the statement: “To keep both bias and rmse error small, it is preferable to have a small change in WPET.” And on page 269, “To keep the modeling output valid, the recommend change of WPET is +/-10%.” Why have

any change in WPET? When I reached table 5.2.1, I suspected that I have not been reading about a sensitivity analysis, but rather a method for determining uncertainty ranges for the parameters! I did not know that, if it is true. Given the values in table 5.2.1, the analysis is very crude.
Response: After completing the sensitivity analysis, the 5% and 95% were selected to be 90% and 110% of the calibrated value.

ID # J043
Comment / Question:
p. 272 Does BCNP represent an average stage? At how many gauges?
Response:

$$\alpha_{ij} = \frac{\partial y_j}{\partial x_i} \approx \frac{O_{95} - O_{calibrated}}{P_{95} - P_{calibrated}}$$

The plot on P273 shows the component of sensitivity matrix: α_{ij} . The output (stage) from the input parameter value at 95% confidence level O_{95} was subtracted by the output from calibrated input parameter value $O_{calibrated}$. Then the resulted (O_{95} - $O_{calibrated}$) was divided by the percentage of the input parameter change to get the normalized value. This is the sensitivity coefficient α_{ij} .

For example, if the input parameter value at 95% confidence level is 150% of the calibrated value, (O_{95} - $O_{calibrated}$) is normalized by being divided by 0.5 (50%).

All the analyzed input parameters are treated this way to get the sensitivity coefficient.

ID # J048
Comment / Question: Chapter 6 Uncertainty Analysis, pp. 279 & 280 (also pp. 267 and xiv)- I think the term *confidence limit* or *confidence interval* is incorrectly used here in the context of uncertainty analysis. In the statistical literature, the term confidence limit has a very specific meaning (in repeated sampling 95% of 95%-confidence intervals based upon the sample average with n observations will correctly contain the true mean μ), which is different from the appropriate meaning here. Thus I would suggest when the SFWMD rewrite the text using a different term, such as a probability interval, or uncertainty bands, which the text suggests.
Response: We agree.

ID # J050
Comment / Question: p. 279 – I do not have Trimble (1995a) and thus am perhaps unable to appreciate the analysis. Do the ideas in Trimble appear in standard texts on this subject to which documentation could refer?
Response: Sure. A copy of Paul's thesis will be provided.

ID # J052
Comment / Question: However, the analysis assumes that errors in the different parameters are uncorrelated. I have not seen that demonstrated. The top of page 280 indicates that Table 5.2.3 has a correlation matrix which indicates the parameter errors are uncorrelated. Currently I do not understand what was done pertaining to Table 5.2.3. The assertion may be correct.
Response: The SVD is a useful tool for better comprehending the relationship between observations and the calibrated parameters. The method indicates which of the observations are the most important within a model for describing each parameter. The sensitivity of the selected parameters of various hydrologic processes is in the form of the singular values of the diagonalized sensitivity matrix. The importance of wetland ET was clearly displayed by this matrix. One of the most important advantages of this method is that it allows for the matrix inversion even if the matrix is rank deficient or ill conditioned. Because of this advantage, SVD is often used for model calibration by iteratively adjusting parameters.

ID # J067
Comment / Question: p. xiii – what is a "nicely" configured workstation?
Response: A workstation having dual processors (operating at about 1.2 to 1.5 GHz) and SCSI hard drives (or better).

ID # J068
Comment / Question: p. xiv – Rather than saying the model calibration is used to *reinforce*, would it be more appropriate to say the model is used to *evaluate* …
Response: This suggestion will be seriously considered for the final documentation.

ID # J070
Comment / Question: p. xiv – glossary is WONDERFUL.
Response: The assessment is appreciated.

ID # J071
Comment / Question: p. 1 – last paragraph – text would be clearer if the location of the EAA and five WCAs was described.
Response: This comment will be seriously considered for the final documentation.

ID # J072
Comment / Question: p. 4 – line 7 from the bottom – *maintaining* is the wrong word; maybe *respecting*?
Response: The suggestion will be seriously considered for the final documentation.

ID # J073
Comment / Question: p. 7 – When you say *dominance* of evapotranspiration, overland flow and groundwater movement, this is in contrast to what? That is, what is left that it dominates?
Response: This statement will be reviewed for improvement, but it was intended to suggest dominance over structure operations.

ID # J074
Comment / Question: p. 7 – I found the sentence confusing that says: *The model is conceptualized … for three different major geographic areas (1) for … (2)….. and (3). The model is conceptualized … for three different major geographic areas (1) for … (2)….. and (3).* Numbers would make the text clearer.
Response: Numbers will be added to the text.

ID # J076
Comment / Question: p. 19-20 Last bullet and first bullet – Why are some cells excluded? Do they not need elevations assigned?
Response: The topography update used best available new data. The areas not updated are located in areas where no topography updates were found. All cells have elevations assigned in the model.

ID # J077
Comment / Question: p. 37 – If rainfall is highly variably spatially (thunderstorms in summer months), then applying one station over a large area gives too big a variance to the total rainfall depth in sparsely gauged areas.
Response: This is exactly why the TIN10 method was employed. The Model grid cell was divided into 100 subcells. Rainfall at each subcell is interpolated using the three rainfall stations forming the triangle surface above that subcell. Rainfall estimates over the 100 subcells are then averaged to estimate rainfall at the model grid cell. Depending on the location of the model grid cell and the network local density, there are **at least 3 stations** contributing to rainfall estimate for that cell.

ID # J078
Comment / Question: p. 38 – Why were some very large values recorded? Are these really errors, or isolated and extreme point measurements? If they are real and we exclude them, do we bias our estimate of the mean precipitation?.
Response: The large values recorded were only flagged as “questionable”. Based on the procedures detailed in the report, we accept and/or reject such a questionable data. All efforts were made to minimize the risk of dropping a data point that is in fact “real”. (The burden of proof is on the rejecter).

ID # J079
Comment / Question: p. 42 – constructive suggestion – Figure 2.2.2.3 is very nice. The mean is easy to understand, but the meaning of +/- one standard deviation is not. I suggest that you plot 10-perecentilie, mean and 90-perecentile, or some other percentiles. This is would be more informative that +/- one standard deviation: the data is clearly not normal in Nov-May, and percentiles would help us see what the real distribution looks like.
Response: A very good idea and it is more informative than the Mean/Standard deviation summary. This will be done for update to documentation.

ID # J080
Comment / Question: p. 64 – equation 2.4.1.4 – typo?

Response: The correct equation is:

$$\vec{\tau}_b = \rho g h \vec{S}_f$$

where $\vec{\tau}_b$ is the resultant bed shear stress in the direction of the maximum energy slope S_f .

ID # J081
Comment / Question: p. 64 – it seems to be that rooted vegetation and islands are going to give a Manning's n value different that generally experienced in open-channel flow modeling. If so, such a warning would be appropriate.
Response: Agree. Later on, in Eq. 2.4.2.8, the use of the "effective roughness parameter" or N is introduced. As suggested in the comment, we will add an appropriate note in p. 64 to state this distinction earlier in the discussion.

ID # J082
Comment / Question: p. 70 – figure 2.4.2.2 – Gives n as a function of *ponding depth*, not *depth*.
Response: Agree.

ID # J083
Comment / Question: p. 72 – please define the term borrow canal.
Response: Typically, the levees and canals are adjacent to each other in South Florida. Where levees are needed, the material often comes from an adjacent canal which is referred to as a borrow canal. The term is analogous to a borrow ditch as used in other parts of the country. Where canals are needed, the material is stacked along the canal as a spoil mound(s).

ID # J084
Comment / Question: p. 96 - Figure 2.7.2.3 – Can you tell us why some points are SO bad? Some of these points are really bad, perhaps invalidating ordinary least squares as an appropriate statistical technique, and I mean that.
Response: Runoff from the Upper Istokpoga Basin flows toward Lake Okeechobee by first discharging through S-70 and S-75, then passing through a sub-basin that may contribute to or utilize part of the water, and finally discharging through S-71 and S-72 directly into Lake Okeechobee.

Flows through S-70 and S-75 depend primarily on: antecedent rainfall, Lake Istokpoga flood control releases, upstream agricultural operations for flood control, and downstream agricultural demands. There is insufficient historical information on Lake Istokpoga flood control releases, and upstream and downstream agricultural operations. Since approximately 27% of the flow record for S-70 and S-75 is missing, it is necessary to estimate these flows with the only available information, which is rainfall. To enhance the regression, and since flood control releases through S-70 and S-75 are normally accompanied by flood control releases through S-71 and S-72, the latter was included in the regression to enhance the estimation.

It is possible that the absence of information for Lake Istokpoga flood control releases, and upstream and downstream agricultural operations is the reason why the regression is not as robust as may be desired. However, since there is a complete record of S-71 and S-72 flows, and 73% of the records for S-70 and S-75 flows are available, it is believed that this regression approach is acceptable to supplement a largely available historical record.

ID # J085
Comment / Question: p. 97 – figure 2.7.2.4 – Not as bad as figure 2.7.2.3, but still terrible. Same comments apply. (Refer to J084).
Response: Structures S-133 and S-191 were built in 1969 and 1972, respectively. Consequently, there is no record between 1965, the start of the simulation period, and the construction of these structures. In order to apply the model to future scenarios, the simulation must assume the existence of these structures for the entire simulation period. Therefore, it becomes necessary to estimate S-133 and S-191 flows for the missing period.

Flows through S-133 and S-191 are dictated by operational criteria that are triggered by upstream water levels reaching a specified elevation. The upstream water levels are dependent on antecedent rainfall over the Taylor Creek/Nubbin Slough and North Lake Shore basins, and on urban and agricultural practices for drainage into secondary canals, and subsequently into the primary canals. It was assumed that, were S-133 and S-191 in existence, these practices would result in flows with similar characteristics to those in the adjacent S65E Basin (Lower Kissimmee River).

The regression to estimate S-133 and S-191 monthly flow volumes and daily variation of flows is based on antecedent rainfall and S-65E flows. It is likely that the absence of information on urban and agricultural drainage practices, and consequently on upstream water levels, limits the ability to estimate flows. However, it should be noted that the historical flow record for S-133 and S-191 constitutes 81% of the record, and the flow estimates from the regressions are only supplemental to a largely available historical record.

ID # J086
Comment / Question: p. 98 – Figure 2.7.2.5 – This may be worse than figure 2.7.2.3; what is going wrong here? How should this process be modeled? Should we maintain the variability that has been lost using Maintenance Of Variance Methods (MOVE)? The straight-line fails to represent the character of the data. Or is this a small and relatively unimportant process.
Response: See response to J085.

ID # J087
Comment / Question: p. 96-98 – Figures – It would be more standard, and thus much easier for me to understand the figures, if predicted were on the horizontal axes, and observed on the vertical axes.

Response: This comment will be seriously considered for the final documentation.

ID # J089
Comment / Question: p. 105 – with two tidal cycles per day, and a 1-day model time step, how are these processes reconciled?
Response: Only daily average tidal values, interpolated from monthly averages, are used for the boundary conditions. Thus, daily average tidal values are used in the daily time step of the model.

ID # J091
Comment / Question: p. 119 – first paragraph – significance options for the use of the model are hidden here, and should be in a more obvious location.
Response: In addition to evaluations of different regulation schedules, the SFWMM has been used as a guide for shorter-term (< 6 months) planning for Lake Okeechobee operations. For short-term planning, operational rules that deviate from normal may be implemented to meet short-term objectives. Flexibility is incorporated into the SFWMM so that changes in operations for Lake Okeechobee for defined periods throughout the calendar year can be simulated, also called deviations. These input options can be used to simulate several types of deviations, including varying the level of pulse releases, modifying breakpoints for classification for climate forecasts or changing regulation schedule lines for a portion or the entire calendar year. Short term operational deviations are often investigated by running the SFWMM in Position Analysis mode (see Section 3.6.2). Deviations for other elements of the systems, such as the WCAs can be investigated in a similar fashion.

We will look for a better location in the document for this paragraph.

ID # J092
Comment / Question: p. 119-120 – Figures 3.1.4.1 and 3.1.4.2 are unreadable. What do these FORTRAN names mean?
Response: A description of each term will be added to the documentation. In the meantime, the description is below.

Figure 3.1.4.1:
LOK2RES = Regulatory flood control release from Lake Okeechobee (LOK) to C-43 Reservoir thru S-77.
LOK2BSN = Water supply deliveries from LOK to the C-43 Basin thru S-77.
LOK2EST = Releases from LOK to Caloosahatchee Estuary thru S-77/S-79. Includes LOK regulatory flood control releases and environmental water supply from LOK to meet estuarine demands.
RF = Rainfall into C-43 Reservoir.
ET = Evapotranspiration from C-43 Reservoir.
SEEPAGE = Seepage from C-43 Reservoir.
SPILLOVER = Spillover from C-43 Reservoir during extreme wet conditions. This excess volume is assumed to be discharged into the Caloosahatchee Estuary thru S-79.

RES2LOK = Backpumping of C-43 Reservoir runoff to Lake Okeechobee. Only allowed if LOK stage is below a certain threshold (typically 13.0 ft). S77 backflow can also occur if Lake Okeechobee is below 11.1 ft.
RES2BSN = Water supply from C-43 Reservoir to C-43 Basin.
BSN2RES = Runoff from C-43 Basin routed to C-43 Reservoir.
RES2EST = Environmental water supply from C-43 Reservoir thru S-79 to meet demand in Caloosahatchee Estuary. This demand is calculated at S-79 based on a prescribed flow distribution that would lead to desirable salinity envelopes within the Estuary.
RES2ASR = Injection from C-43 Reservoir into aquifer storage and recovery facilities (ASR).
ASR2EST = Environmental water supply from C-43 ASR thru S-79 to meet demands in Caloosahatchee Estuary.
INJECTION LOSS = ASR efficiency loss (usually assumed to be 30%).
ASR2BSN = Water supply from C-43 ASR to C-43 Basin.
BSN2EST = Runoff from C-43 Basin routed to the Caloosahatchee Estuary thru S-79 (may meet estuarine demands or may be excess).
S235 = S-4 Basin runoff that is routed to the C-43 Basin thru S-235
S4D2CAL = S-4 Basin runoff from the Diston Water Control District that is routed to the C43 Basin via the 9-mile canal.
CAL2S4D = C-43 Basin runoff routed to the S-4 basin (Diston Water Control District) via the 9-mile canal.

Figure 3.1.4.2:
LOK2RES = Regulatory flood control release from LOK to C-44 Reservoir thru S-308.
LOK2BSN = Water supply deliveries from LOK to the C-44 Basin thru S-308.
LOK2EST = Releases from LOK to St. Lucie Estuary thru S-308/S-80. Includes LOK flood control regulatory releases and environmental water supply from LOK to meet estuarine demands.
RF = Rainfall into C-44 Reservoir.
ET = Evapotranspiration from C-44 Reservoir.
SEEPAGE = Seepage from C-44 Reservoir.
SPILLOVER = Spillover from C-44 Reservoir during extreme wet conditions. This excess volume is assumed to be discharged into the St. Lucie Estuary thru S-80.
RES2LOK = This term is an error in the figure and will be removed. S308 backflow can occur if Lake Okeechobee is below 14.5 ft.
RES2BSN = Water supply from C-44 Reservoir to C-44 Basin.
BSN2RES = Runoff from C-44 Basin routed to C-44 Reservoir.
RES2EST = Environmental water supply from C-44 Reservoir thru S-80 to meet minimum demand in St. Lucie Estuary. This demand is calculated at S-80 based on a prescribed flow distribution that would lead to desirable conditions (identified as salinity envelopes and biological indicators for oysters and sea grasses) within the Estuary.
RES2ASR = Injection from C-44 Reservoir into aquifer storage and recovery facilities (ASR).

ASR2EST = Environmental water supply from C-44 ASR thru S-80 to meet demands in St. Lucie Estuary.
INJECTION LOSS = ASR efficiency loss (usually assumed to be 30%).
ASR2BSN = Water supply from C-44 ASR to C-44 Basin.
BSN2EST = Runoff from C-44 Basin routed to the St. Lucie Estuary thru S-80 (may meet estuarine demands or may be excess).
SLTRIB = Runoff from tributaries of the St. Lucie Estuary including the following basins: C25, C23/C24, Ten Mile Creek, South Fork, Tidal basin. The runoff may meet estuarine demands or may be excess.

ID # J093
Comment / Question: p. 178 – Items 1-2-3 confuses me, even with examples. How is offset different from translation? Because of order?
Response: We realize that the terminology is somewhat confusing. This section will be reorganized to clearly distinguish between the pre-processing of target hydrographs versus their use in the model simulation. The pre-processing of target hydrographs will be discussed first and the text will be changed to:

Adjustments to the input target hydrographs can be made in the *pre-processing phase*. Once an initial hydrograph has been generated (for example, from NSM), three adjustments of the hydrograph can be made to generate the target hydrograph:

1. Translations – Vertical shift or adjustment to target depth; e.g. shift the target depth time series by 0.2 ft (See Figure 3.2.4.6).
2. Truncations – Application of a maximum or minimum threshold depth to the target location; e.g. target depth not to exceed 1.5 ft depth (any depths that are greater are set to 1.5 ft) (See Figure 3.2.4.7).
3. Truncation of the target depth following the application of translation criteria; e.g. shift target depth time series by 0.2 ft, then limit target depth not to exceed 1.5 ft depth.

The term offset is reserved to refer to the adjustment of trigger levels *in the model simulation*. These offsets are inputs to the model and therefore can be easily modified by the user. As described in the documentation, there are two kinds of offsets. An import offset, applied to the import trigger target hydrograph, defines an environmental needs zone below which water supply deliveries from upstream are triggered. Two export offsets, applied to the export trigger target hydrograph, define zones of conditional releases (i.e. depending on whether downstream trigger has needs) and flood control releases (i.e. regardless of whether downstream trigger has needs).

ID # J094
Comment / Question: p. 185 – I found the listing of three consumption categories to be inconsistent and confusing. How is irrigation a source of water? Where does the irrigation water come from?

Response: Sources for water consumption within the LEC can be broken down into the following three categories:

1. Local well field withdrawals from the surficial aquifer to meet water supply needs – Includes well field withdrawals by water utilities for public consumption as well as withdrawals for industrial and residential self-supplied users. Refer to Section 3.5.5 of the documentation for more details.
2. Irrigation used to satisfy supplemental requirements of different LEC urban water use types (landscape, nursery, golf course and 3 agricultural categories). Irrigation needs for the LEC are pre-processed using the ET-Recharge package. In general, the SFWMM assumes that the main source of irrigation in the LEC is the surficial aquifer. This is generally the case for agricultural and golf course irrigation, older urban developments as well as areas to the east of the saltwater interface. However, it is also possible to specify fractions of the urban and golf course irrigation demands within a cell to be met from alternate sources such as wastewater reuse or public water supply well fields. Refer to Sections 2.3.5 and 3.5.3 for more detail.

Regional water deliveries to maintain LEC canals at desired levels – Several canals in the Lower East Coast must be maintained at desired maintenance levels. These levels are necessary for several reasons: 1) primarily, to prevent saltwater intrusion near the coast, 2) to recharge the groundwater near well fields, and 3) to hydrate wetlands. The sources of water for maintaining LEC canals, in order of priority, are: 1) local sources such as excess water in upstream canals, reservoirs and aquifer storage and recovery systems (ASR), 2) the Water Conservation Areas, and 3) Lake Okeechobee.

It is proposed that the paragraph be revised as follows:

An important management option available in the model is its ability to impose short-term water restrictions on the various water users within the Lower East Coast (LEC) of South Florida. Sources of water and water consumption types for the LEC can be broken down into three categories: (1) well field withdrawals made to meet public water supply needs via utility well fields; (2) groundwater withdrawals used to satisfy supplemental irrigation requirements (in addition to rainfall and local storage) of different LEC urban agricultural water use types (landscape, nursery, agriculture, and golf course); and (3) regional deliveries made to maintain LEC canals at desired levels. These desired levels, also referred to as maintenance levels, are necessary to prevent saltwater intrusion from the eastern seaboard, and to some extent, to satisfy agricultural needs within the LEC and help recharge the aquifer. The first two categories use ground water from the surficial aquifer, primarily the Biscayne aquifer, while the third category utilizes surface water available from the Conservation Areas and Lake Okeechobee

ID # J095
Comment / Question: p. 202 – line 4 – instead of *detailed* say *described*.
Response: Agree.

ID # J096
Comment / Question: p. 208 – paragraph 2 section 3.6.2 – what does it mean that water must be replaced?
Response: The Everglades Forever Act (Florida Statutes, Chapter 373.4592, 1994) required that the District develop a model to quantify the amount of water that needs to be replaced as a result of reductions of runoff to the Everglades Protection Area (EPA) from EAA Best Management Practices (BMP) implementation. Water will be delivered from Lake Okeechobee to replace the water that will no longer reach the EPA due to runoff reduction. The timing of the deliveries (fixed percentages defined for October-February) was designed to produce flows that mimic the seasonal distribution of flows from the EAA under more natural conditions.

ID # J097
Comment / Question: p. 212-213 - I have heard the term position analysis applied to this sort of analysis before. The method warrants a clearer presentation that found at the bottom of page 213. Please provide one or more citations to the literature describing the use of the idea by others. Maybe those below?
Hirsch, R. M., Synthetic Hydrology and Water Supply Reliability, Water Resources Research, 15(6), 1603-1615, 1979.
Day, G. N., Extended Streamflow Forecasting Using NWSRFS, Journal of Water Resource Planning and Management, vol. 111, no. 2, pp. 157-170, April 1985.
Response: The Position Analysis section in the SFWMM document will be rewritten using the same format and outline as during the September workshop presentation. The references provide above and articles published by District staff on these topics will be also included.

ID # J098
Comment / Question: p. 215 - Figure 3.6.2.6 - I got lost and was unable to follow the derivation of this figure. Why do the sequences no longer start at the top of the supply-side management zone?
Response: The Position Analysis section in the SFWMM document will be rewritten using the same format and outline as during the September workshop presentation. As a matter of fact, the text does not give a good explanation for this figure. Also, Fig. 3.6.2.6 refers to an application of PA different from the other two previous figures. They correspond to different initialization dates and different initial conditions.

ID # J099
Comment / Question: p. 223 – Figures in my opinion have been drawn with the axes reversed. Data should go on the vertical axis, and model predictions on the horizontal axis.
Response: This suggestion will be seriously considered for the final documentation.

ID # J100
Comment / Question: Pg 223 Simulated values in both figures seem much too large in both figures. Can you explain?

Response: Simulated values in both figures are generally larger than observed values as shown in the figures on page 223 of the documentation. Although one objective in the calibration of the EAA is to have a bias in runoff to be zero, there were other statistics, e.g. R squared, which played a role on how the model simulates the overall EAA.

ID # J101
Comment / Question: pp. 223-230 – Please provide calibration and verification goodness-of-fit statistics. These are eventually defined on page 235, but are needed earlier in this section.
Response: This recommendation will be seriously considered for the final documentation.

ID # J102
Comment / Question: p. 267 – Say: *Sensitivity analysis is to be distinguished from uncertainty analysis.*
Response: This suggestion will be seriously considered for the final documentation.

ID # J103
Comment / Question: p. 267 – I do not like the use of *confidence* as a term describing uncertainty as used here.
Response: Acknowledged, a change will be considered for the final document.

ID # J105
Comment / Question: pp. 253 & 255 – figures 4.3.1.2; 4.3.1.5 would be improved by use of quantiles rather and +/-; see earlier comment.
Response: This suggestion, and the earlier comment, will be seriously considered for the final documentation.

ID # J106
Comment / Question: p. 279 - Eqn 6.1.1.1 has a P-subscript in the wrong place.
Response: Agree. This will be fixed for the final documentation.

ID # R001
Comment / Question: This is overall a very complete and readable document. The introduction and initial description of the system is a good one. There is still some lack of uniformity apparent in presentation. The following will point out areas where style uniformity could be improved. One general criticism is the failure to define terms on first usage; this is true relative to abbreviations. A list of abbreviations alone does not substitute for good definitions at the appropriate time. Some repetition, spelling out of abbreviations, will help readability. The most common stylistic flaw is the slippage, at places, into a "user's manual' approach rather than a general documentation and description. Having said this, it is clear that with the appendices, this document CAN be used as a users manual. All the information is indeed available, reflecting that a very large amount of work and thought went into the preparation of the document.
Response: The comments are appreciated; the criticism to define terms on the first usage will be considered for the final draft.

ID # R003
Comment / Question: Do you feel that the balance of detail in the different sections is appropriate?
Response: We acknowledge that the balance of detail can be improved for the final documentation. For example, a couple of the sections describing the physical and hydrologic components could be trimmed, while Chapters 5 and 6 could be expanded.

ID # R005
Comment / Question: Clearly the codification of operations and management requires some simplifications, are you satisfied that all relevant management rules have been captured in sufficient detail?
Response: The general answer to this question is yes. The development of the SFWMM through the years has been highly dominated by the clients' needs, which are mostly in the form of operational flexibility. The flexibility incorporated in the model has been a compromise between maintaining the regional perspective of the model, but at the same time allowing key elements to provide adequate signals that affect the behavior of the regional system.

ID # R006
Comment / Question: How are the different accuracies of topographic data sets reconciled? What effect may the accuracy of the topographic input have on model operation? How was the topographic information verified?
Response: The different accuracies of data are reconciled by using the best available data at all times in any given area. Outlier tests were undertaken and after thorough QA/QC topographic values were aggregated or interpolated into one value for each 2 mile by 2 mile cell.

Veracity of raw topographic data sets was the responsibility of the agency of origin.

New topographic data incorporated into SFWMM topography layers was checked through both north-south and east-west transect analysis. Trends in the data as well as borders of new data and old data were checked.

Hydrographic break points were used to further verify the average 2x2 mile representation of the topo.

ID # R007
Comment / Question: How was the subsidence estimates for EAA verified? 1-2 inches a year sounds very high, a big change from the previously used 0.1 inches and very different from the 0.57 used. Why should any area be excluded?
Response: Farming practices in the EAA, mainly sugar cane, contribute to subsidence in the organic muck. Typically Sugar Cane is burned before harvesting resulting in burning of the upper parts of the much layer.

Lower water tables also expose the muck to oxygen which allows microbes to deplete the organic material, resulting in subsidence.

1 to 1.2 inches/yr of subsidence were assumed from 1960-1988 (a total of approximately 2.8 ft) based on the literature of Ingebritsen et al (1999), Stephens and Johnson (1951), Shih et. al. (1979) and Stephens et al (1984). In the latest topography update, more recent data from 4 transects to measure subsidence in the EAA (Shih et al, 1997) was used. Subsidence rates were less than previously quoted possibly due to compaction with time and also improved farming practices. The average value from the transects of 57 inches/year was applied to all the ag cells in the EAA for the 1990 to 2000 period (a total of approximately 0.5 ft).

Holey Land WMA and Rotenberger WMA were excluded due to the lack of agriculture and higher water tables which allow the muck (if present) to remain saturated. Each of these areas seek to maintain higher water levels than the rest of the EAA. Values from a recent survey 919990 were used in the Rotenberger WMA.

ID # R009
Comment / Question: Is the assignment of a land use to a grid by a simple majority of coverage good enough? Should grids permit mix usage?
Response: In the majority of the model domain, land use / land cover is uniform for large areas. In the Everglades Protection Area and the Everglades Agricultural Area, an assumption of homogeneous land use is appropriate since the dominant land use represents that vast majority of the spatial extent of an assigned cell. In the Lower East Coast, heterogeneity within a four square mile area needs to be considered in the model solution. In order to provide a mechanism to accomplish this, the ET-Recharge model is employed to allow for consideration of land use at a much finer scale.

ID # R013
Comment / Question: The Simple Method to compute Evaporation is very much like well-known techniques like the Priestley – Taylor Equation, without the justification. Why difference?
Response: In earlier versions of the SFWMM the Penman-Monteith method was used to estimate reference crop evapotranspiration. Review of this method indicated that the comprehensive meteorological data needed to provide meaningful Penman-Monteith evpotranspiration estimates was not available spatially or historically in south Florida so a simpler method was needed. Several methods have been investigated for ET estimation in south Florida (e.g. Jacobs and Satti, 2001; Jones et al, undated; and others) and these methods, including the Priestly-Taylor method have not been shown to be significantly better than the simple Abtew method used (Odin et al, 2005). The Abtew method has been calibrated to lysimeter data for south Florida so is preferred.

Jacobs, J.M. and Satti, S.R. 2001. Evaluation of reference evapotranspiration methodologies and AFSIRS crop water use simulation model. Draft technical Report to J.M. Fitzgerald, St. Johns Water Management District. January 2001.

Jones, J.W., Allen, L.H., Smith, S.F., Rogers, J.S., Hammond, L.C., Smijstrala and Mertsol, J.D. Undated. Estimated and measured evapotranspiration for Florida climate, crops and soils. University of Florida Bulletin.

Odin, L, Herviea, F., Michel, C., Perrin, C, Andreassian, V., Anctil, F. and Loumagne, C. 2005. Which potential evapotranspiration input for a lumped rainfall-runoff model? Part 2 – towards a simple and efficient potential evapotranspiration model fro rainfall-runoff modeling. J. Hydr. 303 (2005)290-306.

ID # R014
Comment / Question: Can you explain the limits of Rs between 0.1-0.75 it seems that you are equating it to transmissivity, page 41.
Response: There is a typo at the top of page 46. The first sentence will be modified as follows (delete text in parentheses):

> *In order to guarantee reasonable estimates the following two constraints were incorporated into the Rs estimation ~~(from 0.1 to 0.75):~~*
> - *A constant upper bound for the transmissivity is set to 0.75 across South Florida (i.e. clear-sky transmissivity defined as 75% of the extraterrestrial solar radiation; Smith 1991).*
> - *A lower bound for the transmissivity is set at 10% of the clear-sky transmissivity.*

Doorenbos and Pruitt (1977) recommend using 0.75 for clear sky transmissivity so the upper bound was set to 0.75 of clear-sky transmissivity. Following the method of Thornton and Running (1999) a lower bound for the transmissivity is set at 10% of the clear-sky transmissivity.

The Kr coefficient in eq 2.3.1.2 (p45) below

$$R_s = \tau R_a = K_r (T_{\max} - T_{\min})^{0.5} R_a$$

was first determined visually by trying to fit most of the Rs estimates under the clear-sky solar radiation envelope. (See Fig 1 as an example for Miami International Airport) Given that a constant clear-sky transmissivity of 0.75 has been assumed throughout the year, some values exceed the assumed clear-sky envelope.

For each of the 17 NOAA stations (Fig 2.3.1.1, p47), the Kr was adjusted so that the long-term average annual wet marsh potential ET estimated by the Simple method matched an expected north to south gradient (Visher and Hughes, 1969, Fig 2 below).

The Kr values are not part of the general calibration of the model but rather part of the calibration of pre-processed potential evapotranspiration values to long term historic potential evapotranspiration patterns.

The physical reason for the banded NE-SW ETp is to match long term historic ETp.

ETp patterns don't necessarily match the precipitation patterns because due to significant rainfall can occur without necessarily a significant change in cloud cover due to the orographic nature of the rainfall.

The temperature based method for estimating solar radiation works fairly well except for the late summer months (Fig 1.) During this time the variability in estimated Rs is not as great as the variability in observed Rs due to the fact that in south Florida similar temperature differences can occur with different cloud cover and hence different observed Rs values.

Long term average values in Table 2.3.2.2 were "pegged" to match long term observed observed data at Miami and the adjusted kr values ensure that the long term average potential evaporation patterns are matched.

Doorenbos, J. and Pruitt, W. O., 1997. "Guidelines for prediction of crop water requirements." FAO Irrigation and Drainage Paper No. 24, 2nd ed. Food and Agriculture Organization of the United Nations. Rome, Italy.

Thornton, P. E. and S. W. Running, 1999. "An improved algorithm for estimating incident daily solar radiation from measurements of temperature, humidity, and precipitation." Ag. For. Meteor., 93:211-228.

Visher, F. N. and G. H. Hughes, 1969. "The difference between rainfall and potential evaporation in Florida." 2nd Ed. Florida Bureau of Geology Map Series 32. Tallahassee, FL.

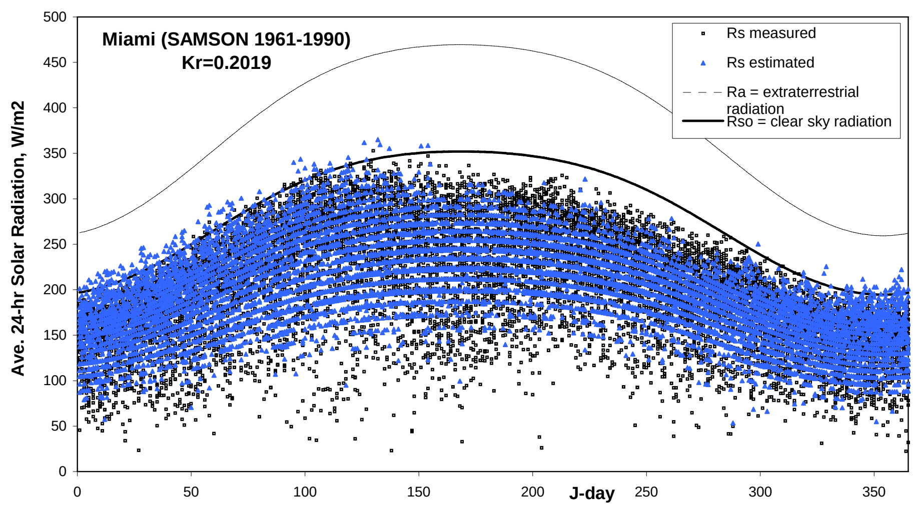

Fig. 1. Measured and estimated solar radiation by the K_r method at Miami International Airport (SAMSON 1961-1990) plotted as a function of Julian Day.

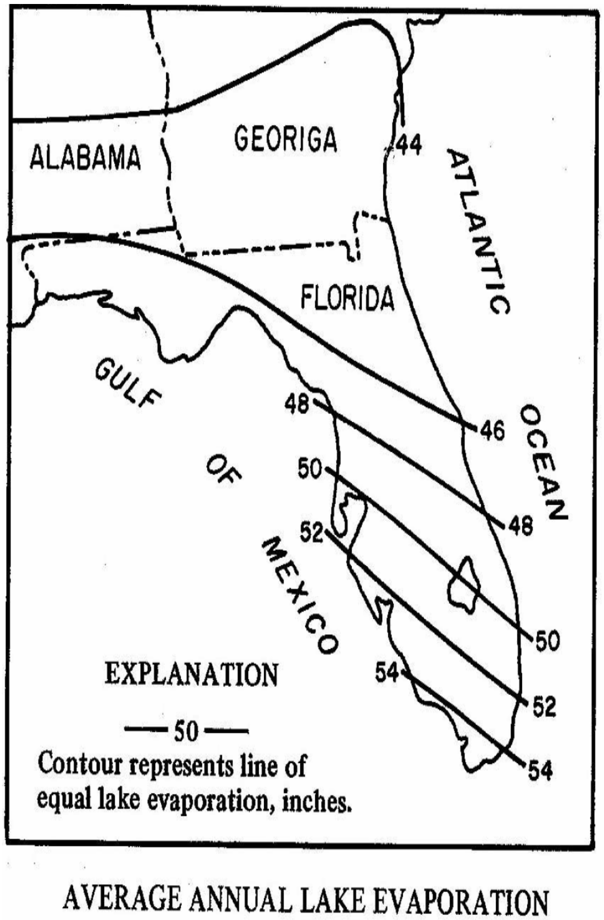

Fig. 2. Average annual lake evaporation in inches (Visher and Hughes, 1969)

ID # R015
Comment / Question: Are the Kr values not part of the general calibration of the model?
Response: Please refer to #R014.

ID # R016
Comment / Question: What is the physical reasoning behind the banded NE-SW ETP pattern?
Response: Please refer to #R014.

ID # R017
Comment / Question: Shouldn't the Kr values near Okeechobee be high? See page 47, 48. There is relatively little precipitation over the lake and hence little cloudiness. Why is the PE so different from the annual P, patterns?

Response: Please refer to #R014.

ID # R020

Comment / Question: The ET-Recharge model and the AFSIRS model are used to compute, offline, irrigation supply and unsaturated zone evapotranspiration from the LEC. This is appropriate if the relationship is only one way, the SFWMM states cannot impact the offline model results. Is this always true? Are there conditions where this is a serious approximation?

Response: It is not always true that the calculated state variables based on a 2-mile-by-2-mile grid cell will not impact (or be impacted) by the results of the ET-Recharge model. AFSIRS, the main computation engine within the ET-Recharge model, assumes a soil moisture accounting procedure where irrigation and ET occurs completely within the crop root zone, i.e. the location of the water table is always assumed below the roots. The one way relationship is perfectly valid when the water table does not encroach upon the root zone. During wet events when the water table rises up into the root zone, a two-way relationship would exist between the saturated and crop root zones. This situation is handled by an appropriate update in the computed water table as the aquifer absorbs additional 'moisture' from the root zone. Likewise, during some dry events, there is a possibility that the pre-calculated AFSIRS-based ET can exceed the available soil moisture, resulting in an ET deficit in the root zone as tracked by the model. This situation, on the other hand, is circumvented by assuming an additional water table ET: effectively lowering the water table by an equivalent depth equal to the ET deficit. Both types of adjustments are done so as to maintain water balance in the water budget calculations.

ID # R023

Comment / Question: Is N the same as n (Manning)?

Response: Manning's roughness coefficient, n, is strictly applicable to fully developed turbulent flow. The use of N or "effective roughness parameter" is to illustrate its application to overland flows that are not fully turbulent flow.

ID # R024

Comment / Question: How can you physically reconcile the idea that the detention depth of urban areas is larger than that of wetlands or agriculture?

Response: Please see response to #T011.

ID # R025

Comment / Question: Are infiltration rates of 9-100 ft per day real? That is VERY large.

Response: Soil Survey data published by the United States Department of Agriculture Soil Conservation Service was used in determining the soil infiltration rates applied in the South Florida Water Management Model. Soil infiltration rates are very high in South Florida and, in general, are not a limiting factor in calculations of infiltration volumes.

ID # R027
Comment / Question: The canal conductivity is given as 0.01 to 9.00 ft per day, very different to infiltration rate. Why?
Response: The canal-aquifer conductivity or connectivity coefficient has the units of ft/day per foot of head difference. The presence of sediments in the bottom of the canals impacts the connectivity between the canal and the aquifer. Canal conductivities were adjusted as part of the calibration process.

ID # R028
Comment / Question: Please explain the concept of fraction of levee seepage rate to be applied and the maximum level of seepage rate. Why such concepts?
Response: The fraction of levee seepage rate is directly applied to the calculated seepage rate that is determined from the levee seepage regression equations. This variable is generally 1.0 but was adjusted for specific levees, if needed, during the calibration process. This variable is also useful in evaluating future scenarios where components are introduced that would decrease levee seepage from current values. The maximum level of seepage rate is applied to ensure that calculated levee seepage rates are within reasonable bounds.

ID # R029
Comment / Question: Is the groundwater section too detailed relative to other ones? Should the numerics be in an appendix?
Response: The level of detail in Section 2.5 could be reduced to provide a better balance. Numerics could be placed in the appendix or referenced in earlier documents. This suggestion will be considered for the final draft.

ID # R030
Comment / Question: Are transmissivities fixed or recalculated with aquifer thickness. I gather they are not although mention is made of that dependence.
Response: The transmissivity map (Figure 2.5.4.1) in the documentation is for a fully saturated aquifer. The transmissivity calculated in the model is the product of the hydraulic conductivity, which is input, and the saturated thickness in the aquifer.

ID # R031
Comment / Question: In Figure 2.5.4.1 are changes due to saturated thickness or assumptions in hydraulic conductivities?
Response: Both the hydraulic conductivity and the aquifer depth vary spatially. The transmissivity map (Figure 2.5.4.1) in the documentation is for a fully saturated aquifer. The transmissivity calculated in the model is the product of the hydraulic conductivity, which is input, and the saturated thickness in the aquifer.

ID # R032
Comment / Question: Why is the saturated zone water not available for plants? Roots are generally deep enough, and certainly capillary rise helps.
Response: Saturated zone water is available for plants.

Two input parameters are used to define the root zone depth: the depth from land surface to the bottom of the shallow root zone and the depth from land surface to the bottom of the deep root zone (see Fig. 2.3.4.1 for reference)

As long as the water table is above the bottom of the deep root zone, saturated zone water is available for plants.

ID # R033
Comment / Question: In p84, the variables definition seems out of place.
Response: This comment will be seriously considered for the final documentation.

ID # R035
Comment / Question: Ponding depth, why higher in urban areas?
Response: Please see response to ID #T011.

ID # R036
Comment / Question: Is a time step of 1 day good enough for a 2-mile discretization? Water will transverse a grid in a channel in less than one day.
Response: The mass balance approach is used in the SFWMM for canal or channel flow routing. Though the entire canal reach can span multiple grid cells, it is treated as a single unit in determining the equilibrium stage at the downstream end and the canal slope. Water can transverse the entire canal length within the daily time step.

ID # R040
Comment / Question: The regressions for inputs to LOK do not seem that good, how sensitive is the system to this?
Response: A sensitivity analysis on the effect of estimated inflows into Lake Okeechobee was not performed. However, the effect should be small considering the following:

1. Only part of the record is estimated. The regressions for inputs to Lake Okeechobee are necessary only to supplement a largely available historical record. For the Upper Istokpoga Basin, 27% of the record is missing for two water control structures, while the record is complete for the remaining two water control structures. For the Taylor Creek/Nubbin Slough and North Lake Shore basins, 19% of the record is missing. (See responses to J084 and J085 for details)
2. The average inflow from the Upper Istokpoga Basin, and Taylor Creek/Nubbin Slough and North Lake Shore Basin is small (6.5% and 6.8%, respectively) compared to the total inflow into Lake Okeechobee.

Any errors in estimating inflows into Lake Okeechobee are accounted for by using the Modified Delta Storage approach.

ID # R041
Comment / Question: How sensitive is the system to boundary conditions, it seems there is a lot of uncertainty around them.
Response: A sensitivity analysis of the boundary conditions was not performed. Because of the use of MDS in the Lake budget, errors from the boundary conditions would be incorporated into the water budget.

ID # R042
Comment / Question: Please explain the Lake Okeechobee Modified delta Storage Concept. Is this a way to adjust for known errors?
Response: The methodology is intended to account for significant unmeasured inflows into Lake Okeechobee. However, it will incorporate errors from other sources such as ET predictions, rainfall distribution, and flow measurement errors.

ID # R043
Comment / Question: The section on the Western Boundary Flows at L-1 and L-3 canals seems telegraphic, unclear and disconnected from the rest.
Response: This comment will be seriously considered for the final documentation.

ID # R044
Comment / Question: As above for S190. (Refer to R043)
Response: Acknowledged.

ID # R045
Comment / Question: Explain meaning and use of the constants appearing in T2.7.3.1.
Response: The time lag or lead, for the various stations, is added to the high and low water times recorded at Virginia Key. To determine the amplitude of the high and low water stages, the constant is multiplied times the amplitude of the Virginia Key values.

ID # R046
Comment / Question: What are the forecasts of lake inflows, what are the seasonal predictions?
Response: The Lake Okeechobee current regulation schedule was adopted in the middle of 2000 and is known as Water Supply and Environment (WSE). An important contribution of WSE is the use of decision trees to recommend flood control releases from the Lake. These decision trees incorporate hydro-climatological information, such as past and forecast flows. The WSE process requires hydrologic outlook of net inflows into the lake (rainfall – evapotranspiration + structural inflows) at two different temporal aggregation windows. Seasonal outlook refers to the six-month window, starting with the current month. Multiseasonal outlook comprises the reminder months of the current season, plus the months in the on-coming season. Two seasons are considered for this purpose: 1) Dry season: November to April, and 2) Wet season: May to October.

This is also described in the following reference, which will be added to the document: U.S. Army Corps of Engineers, Jacksonville District, July 2000, “Central and Southern Florida Project – Water Control Plan for Lake Okeechobee and Everglades Agricultural Area”.
This reference also contains different methods proposed and used to produce the hydrologic or Lake Okeechobee net inflow outlooks.

ID # R047
Comment / Question: What is meant by “solar indicators” (in reference to meteorological forecasts)? Where are those forecasts described?
Response: Solar indicators such as the number of sun spots and geomagnetic activity have been associated in the past with different climatic conditions in south Florida. They have been also associated with methods to produce hydrologic outlooks for Lake Okeechobee (see response_r046.doc). The following references could be included in the document to help the reader with this topic:

Trimble, P.J., E.R. Santee and C.J. Neidrauer, “Including the Effects of Solar Activity for More Efficient Water Management: An Application of neural Networks”, Second International Workshop on Artificial Intelligence Applications in Solar-Terrestrial Physics, Lund, Sweden, July 1997.

Zhang, E. and P. Trimble, “Predicting Effects of Climate Fluctuations for Water management by Applying Neural Network”, World Resources Review, vol. 8, no. 3

Zhang, E. and P. Trimble, “Forecasting Water Availability by Applying neural Networks with Global and Solar Indices”, Proceedings of the Sixteenth Annual American Geophysical Union Hydrology Days, Fort Collins, Colorado, April, 1996.

ID # R048
Comment / Question: Please expand on the statement: limited or sparse stage data exists for the interior part of the EAA such that calibration by matching historical stages is not possible.
Response: The Everglades Agricultural Area (EAA) is a highly managed system where the predominant land use is the cultivation of sugar cane. In general, the water table is maintained a foot and a half below land surface. Individual farmers (sugar cane growers) may deviate from this value but they all operate within a narrow range of fluctuations. What matters more than stage fluctuations (both to the farmers and water managers) is the management of 1) excess water from the EAA to be released downstream (runoff); and 2) lack of irrigation water within the EAA to be supplemented from upstream (supplemental irrigation). In modeling terms, this translates into a volumetric accounting of runoff and supplemental irrigation in the EAA. Calibration in the EAA emphasizes on matching these discharges against historical discharges. EAA calibration to stages may not be possible due to the lack of observed data.

ID # R049
Comment / Question: Explain statement on p 124, point 4 where hydrodynamically based routing is said to be used for EAA canals but not otherwise. How does this map into the discussion in section 2.6?
Response: Canal routing in the model generally uses a water balance approach. Routing of water through the EAA canals is done differently due to the need to quantify pass-through capacity for water supply and regulatory discharges from a major source in the system, Lake Okeechobee, to major basins downstream of the EAA, the natural Everglades and the urbanized Lower East Coast of Florida. Section 2.6 describes routing

in the Lower East Coast while point 4 on page 124 states how routing is performed in the EAA canals. However, a correction needs to be made on page 125 where it was mentioned that for non-EAA canals "a hydraulic grade line with time-invariant slope is assumed." As discussed in section 2.6.2 a dynamic (transient) longitudinal profile is calculated as a function of both inflow and outflow to the canal.

ID # R050
Comment / Question: The use of KCALIB as an adjustment of KVEG seems somewhat redundant and self-defeating. Please explain.
Response: Please refer to response to # R074.

ID # R051
Comment / Question: Section 3.2.2 reads more like a user's manual – a schematic of the procedure would be helpful. So would an explanation of goals of the system, and use of simple language, not variables.
Response: This suggestion will be seriously considered for the final documentation.

ID # R056
Comment / Question: In page 148, lateral flows are assumed zero because saturated zone flows are highly variable. How does this follow?
Response: Please refer to response to # W037.

ID # R060
Comment / Question: Explain phrase "as a consequence of reduction of seepage losses out of the entire area", relative to WCA2, p158.
Response: Agreed. The sentence is confusing. Suggest changing to ", and as consequence, reducing seepage losses out of the entire area. WCA-2B occupies an area of significant recharge to the Biscayne Aquifer. Water supplied to the aquifer by way of WCA-2B is important in maintaining groundwater levels in coastal areas to the east (Cooper and Roy, 1991)"

ID # R061
Comment / Question: Why the large differences in seepage rates among WCAs?
Response: The SFWMM divides seepage into two components: 1) levee seepage, and 2) regional groundwater flow. Levee seepage is a local process wherein surface water moves across a levee embankment and is captured by a borrow canal. This component is especially significant across the eastern protective levee separating the Everglades (WCAs and ENP) from the Lower East Coast urban area. Regional groundwater flow corresponds to the horizontal movement of groundwater from grid cell to grid cell.

These two seepage components are significant and highly spatially variable due to the high transmissivity of the surficial aquifer, which is also highly variable across the model domain. The most transmissive areas are located in Miami Dade County in the southeastern corner of WCA-3B and in the eastern central portion of Everglades National Park, where the seepage losses are most significant.

Several components of the Comprehensive Everglades Restoration Plan (CERP) are aimed at reducing seepage from these highly transmissive areas by constructing buffer areas next to the eastern protective levee. Curtain walls will be installed near the L-31N levee and water levels in the L-30/L-33/L-37 canals will be managed to reduce seepage from the natural areas. The SFWMM is capable of modeling these features.

ID # R062
Comment / Question: Why the large area difference, as modeled, for WCA3B, T3.4.2.1?
Response: We double checked the numbers and it is true that the area of WCA-3B as modeled in the SFWMM is 108 square-miles while the area shown in the SWIM Plan is 128 square-miles. When delineating a basin we try to strike a balance between matching the geographic location of the basin boundary (i.e. location of major features such as levees, canals, etc.) as well as the basin area as close as possible. We agree with your assessment that the areas should have been closer. We will revise the area at a future opportunity when there is a major revision of the model.

ID # R063
Comment / Question: Use the same nomenclature in Figures 3.4.2.2 and 3.4.2.3. There are references to regulation and drawdown schedules.
Response: Closer examination of these figures shows that they require some updating and editing. WCA-1 figure does not show the currently approved schedule and it needs a table specifying the releases in different zones. The regulation schedule for WCA-2A is commonly referred to as the Drawdown Schedule. This not will be added to the figure.

ID # R064
Comment / Question: The use of pseudo code in pages 174-175 is inconsistent in style.
Response: This suggestion will be seriously considered for the final documentation.

ID # R065
Comment / Question: In Equation 3.4.2.3, p177, it is unusual to have the same coefficient for multiple lags. That can lead to non-stationarities.
Response: The documentation needs to clarify that the SFWMM uses a pre processed time series representing Rainfall Plan based deliveries from WCA-3A to the ENP. In any simulation in which the option to use the Rainfall Delivery Plan is active, the model will attempt to meet the specified deliveries. The pre processing phase has borrowed the equations used in the weekly implementation of the Rainfall Delivery Plan (day-to-day operations of the system).

This is a good comment and will be considered in the future if the Rainfall Delivery Plan computation methodology is revised by the SFWMD.

On a separate but related note, Rainfall Delivery Plan is different from Rainfall Driven Operations.

ID # R066
Comment / Question: The reference to row-column values in page 178 is irrelevant and out of place.
Response: The row-column designation does not need to be presented here. This comment will be seriously considered for the final documentation.

ID # R067
Comment / Question: Use rainfall driven or rain driven but not both, it is confusing.
Response: Agree. This will be addressed in the final documentation.

ID # R068
Comment / Question: The section on rain-driven operations needs clarification.
Response: Rain-driven operations will be presented at the SFWMM peer review workshop on September 9, 2005. The documentation will also be revised to clarify any outstanding questions and make this section easier to understand. See response to comment #W040 for some clarification.

ID # R069
Comment / Question: Section 3.5.2 is a different style, algorithmic, and difficult to follow.
Response: This comment will be seriously considered for the final documentation.

ID # R070
Comment / Question: In page 193 it is said that the inefficient component of irrigation that evaporates does not significantly alter the water budget of the saturated zone. Sure?
Response: The ET-Recharge AFSIRS model was run assuming 100% irrigation efficiency. This is consistent with the assumption in the SFWMM that there is no inefficient component of irrigation, i.e. 100% of the irrigation withdrawals from the groundwater are applied to the unsaturated zone. We realize that this simplifying assumption may have implications on the simulated groundwater levels. This enhancement will be considered for a future model release.

ID # R071
Comment / Question:
On page 216 it is said "calibration and verification is conducted on a limited data set of one to three years." I am confused since that is not the case in what follows. If it were, wouldn't it be too little data for that purpose, particularly calibration? What did I miss?
Response: The statement "Generally, calibration and verification is conducted on a limited data set of one to three years." was intended to characterize modeling efforts other than the SFWMM application. The 36-year period of record modeling allows for longer period of records for both calibration and verification than normally available. A re-write of this paragraph will be considered for the final documentation.

ID # R072
Comment / Question: On page 217 it is said that calibration is hampered by changes in operation. But if those changes are known, why can the calibration be done? The model, after all, has a management and operations element.
Response: The model is intended to be used as a regional planning tool which captures the essence of water management. Although it is possible to build a model that mimics all operational deviations due to field-scale and policy-based operational changes, model calibrations do not merely focus on history-matching. The overall objective of model calibration is to historically recreate system response corresponding to a generally accepted norm of management and operational rules during the calibration period. When deviations to the norm occur, an attempt to identify such periods is made and/or the statistics are calculated at a time scale more coarse than the calibration simulated time scale.

ID # R073
Comment / Question: The definition of runoff and supplemental irrigation on page 218 appear as the negative of each other. Clearly the definition must be structure specific. As it stands it is hard to understand.
Response: Runoff and supplemental irrigation are not the negative of each other, but they are mutually exclusive. The two equations on pg 218 are applicable only when the resolved volume of inflow and outflow difference is non-negative. In this way, the volume of water that is captured within the basin (inflows > outflows) is calculated as supplemental irrigation and the volume of excess water removed from the basin (outflows > inflows) is calculated as runoff.

ID # R074
Comment / Question: On Table 4.1.1.2, parameter KCALIB differs significantly from the ideal value of 1 and it has a strong seasonal trend. What does that mean?
Response: For many of the land use / land covers defined in the SFWMM, Kveg is calibrated in one step to account for crop type, scale and heterogeneity. However, in irrigated areas, known theoretical Kveg values (which are solely due to crop type being different from reference grass) are available from scientific studies. The inclusion of the Kcalib term in the EAA is an attempt to document what additional SFWMM calibration adjustment to Kveg is applied due to scale, management, atmospheric efficiency, assumed reference crop and/or land use heterogeneity. The seasonal trend in Kcalib is largely due to a difference in PET reference crop (reference grass for the theoretical values and wet marsh for SFWMM), but is also partially due to the other factors mentioned above. Since Kcalib accounts for many valid considerations in ET accounting (e.g. efficiency loss, regional versus field scale, etc…), it is not appropriate to assume that the ideal value of Kcalib is 1.

ID # R075
Comment / Question: On Figure 4.1.1.1, is the May change in maximum storage of the Miami River Basin reasonable? It is a very big change-why?
Response: Please refer to comment # T016.

ID # R077
Comment / Question: The verification period of 1979 - 83 and 1996 - 2000, used in figures, differs from that stated on p217.
Response: Acknowledged. The statement on p217 is incorrect.

ID # R078
Comment / Question: Errors of calibration and verification shown on figures 4.1.2.5 - 4.1.2.8 do seem big, ranging over 20,000acre-ft, even when the historical value is very small which is most of the time.
Response: It is true that on a daily basis the simulated runoff and demand in the Everglades Agricultural Area (EAA) can be in error by a large amount. However, the model performance in the EAA is usually evaluated at a larger time scale: seasonal and at times, monthly. Since the model is used primarily as a planning and not as an operational tool, large daily variations are not as problematic as it looks. The daily deviation of simulated values to observed values are primarily due to the difference in scale by which management decisions are made: the model follows a day-to-day operating rule while in reality a more frequent decision making process, e.g., up-to-the-minute operations during flood events, is employed in the field.

ID # R081
Comment / Question: The introduction to section 2.3.1, about the Everglades and LEC, is rough and does not flow well.
Response: It seems the comment was directed to page 231, rather than section 2.3.1. Either way, the comment will be seriously considered for the final documentation.

ID # R085
Comment / Question: On page 234 it is stated that historical flows are input as internal boundary conditions so as to isolate physical behavior from the impact of (unknown, uncertain?) operations. Could this over–constrain the system leading to over optimistic calibration and verification results?
Response: By imposing historical flows at internal structures, the overall model calibration becomes more constrained, i.e., less state variables to calibrate. It is true that calibration and verification results based on a smaller set of targets may improve statistics if such an approach is made. The focus, however, is to demonstrate that the model will respond appropriately, in terms of simulated canal and groundwater levels, given different water resources management scenarios. Historical flows encapsulate such management scenarios which are subject to changes over time either by new rules and guidelines, or changes to the plumbing system. It the earlier years of the calibration/validation, field-level decision-making actions may be less centralized and would be difficult to recreate, if at all needed to be recreated.

ID # R088
Comment / Question: Why only calibrate the Caloosahatchee? Only calibration, no verification?
Response: The Caloosahatchee basin is the only LOSA basin to be calibrated for AFSIRS/WATBAL implementation because it is the only lumped LOSA basin that has

flow and land use data that is reliable and of sufficiently long record for a calibration effort on this scale. Other lumped LOSA basins share common characteristics with the Caloosahatchee basin (e.g. climate pattern, soil type, planted crops, management practices) and as such, it is appropriate to apply the calibrated parameters from the Caloosahatchee to these other areas. Since the available data for Caloosahatchee calibration is limited to a shorter period of record (1991-2000) relative to other portions of the SFWMM (1981-2000), it was decide to include all years in the calibration period, rather than splitting the period into calibration and verification ranges.

ID # R089
Comment / Question: The parameter EFFI (efficiency) seems like a fudge factor for lost water. Is the 87% reasonable for the Caloosahatchee? Interpreted physically this may actually be too high an efficiency. It is interesting that efficiency is calibrated as lower in other places.
Response: The EFF1 (efficiency) parameter is a representation of basin scale atmospheric loss. Efficiency losses are commonly used in irrigation modeling to represent both atmospheric and non-atmospheric (over application) losses. In the case of AFSIRS/WATBAL, the field scale AFSIRS model accounts for non-atmospheric losses as part of the root zone accounting while at the basin scale, the EFF1 accounts for atmospheric losses in the form of canal, ditch & catchment storage ET or incidental irrigation.

For highly efficient systems, 85% is a commonly used value for atmospheric loss efficiency. The Caloosahatchee basin, especially since the early 1990s, when microjet-irrigated citrus became the predominant crop type, is a highly efficient system due to the means in which water levels are managed at both the basin and field scales. The efficient management of water is also evident in the relatively low calibrated value of local storage depth (0.1 inches). Lower efficiency terms in other areas and for previous calibration efforts for the Caloosahatchee (which were performed for a period from 1985 to 1995) represent less constrained management approaches to irrigation and the prevalence of inefficient land use types (e.g. irrigated pasture).

ID # R090
Comment / Question: Demand errors in Figure 4.3.1.1 can be very high.
Response: Acknowledged. Please see comment # V032 for additional response.

ID # R091
Comment / Question: Are root zone depths verifiable? Root zone of 5.5 inches in wetlands, is that physically reasonable?
Response: The root zone of 5.5 inches in wetlands in the Caloosahatchee basin implementation of AFSIRS/WATBAL is on the low end, but is still reasonable, given that the model's "wetland" land use classification accounts for many different types of actual landscape type. Please review comment # R097 for additional information.

ID # R092
Comment / Question: Only calibration for Brighton Seminole?

Response: Since the available data for Brighton Seminole / Istokpoga calibration is limited to a shorter period of record (1995-2000) relative to other portions of the SFWMM (1981-2000), it was decided to include all years in the calibration period, rather than splitting the period into calibration and validation ranges.

ID # R093
Comment / Question: The efficiency of Brighton Seminole is calibrated at 60%, why so different to Caloosahatchee's 87%? It is interesting that it is stated that prior calibrations of the Caloosahatchee led to 58%. Why should efficiencies be so different?
Response: Please refer to comment # R089.

ID # R094
Comment / Question: Why is the storage coefficient twice of the Caloosahatchee? Is there a physical argument?
Response: The storage coefficient is the same for both Brighton and Caloosahatchee calibrations (7 days). However, the calibrated term representing depth (volume) of local storage available within the basin is double in the Brighton calibration relative to the Caloosahatchee calibration. The change in the calibrated storage parameter would indicate that the Brighton basin tends to retain water on-farm for longer periods relative to the Caloosahatchee. This could be due to larger storage capacity or different management practices.

ID # R095
Comment / Question: There is a big difference in May demand, Figure 4.3.2.2 as you also noticed.
Response: Yes, there is a big difference in May demand. The documentation (page 260) explains possible reasons for this observation.

ID # R096
Comment / Question: Again, why the parameters are so different for Big Cypress?
Response: Please refer to comments # R089 and R097.

ID # R097
Comment / Question: Why should root zone depths of feeder canal be so different than Caloosahatchee? Is this result verifiable?
Response: The AFSIRS/WATBAL model is only capable of simulating the response of seven land use types: citrus, sugarcane, vegetable, irrigated pasture, rangeland, upland forest and wetland. While these categorizations define the vast majority of the land use in the basins to which the model is applied, the crosswalk from observed (or projected) land use to modeled representation is not a perfect one. As a result, some of the land uses as defined in AFSIRS/WATBAL are forced to represent the aggregated response of many similar land use types. As an example, the "wetland" land use type is actually made up of a mixture of marshes (forested and prairies), sloughs, swamp land and open water. Similarly, the rangeland category includes any urban or fallow lands. Since the distribution of the lands that make up the land use definitions for AFSIRS/WATBAL vary on a basin by basin basis, individual implementations of the model are calibrated to

ensure that the regional runoff response of the defined area is appropriate based on goodness of fit measures from runoff volume and maximum ponding depth.

While the model response was primarily calibrated to ensure that regional runoff was correct, it is desirable that the field scale rooting depths have meaning. The process for determining root zone depths through calibration was to begin with an initial estimate of effective rooting depth based on soil type and characteristics (porosity). Once the initial estimate was made, rooting depths were varied to obtain a better fit to the regional runoff measures. Additional text explaining this concept will be considered in the future re-writes of document.

At this time, inadequate data exists to independently verify the parameters for the AFSIRS/WATBAL model implementations given the areas to which the model is applied (less data availability) and the way in which the model is conceptualized (lumped land use). Investigations of this sort at both the field scale and basin scale would be of great benefit to this effort.

ID # R100
Comment / Question: Please explain the x- axis in Figure 5.2.1 and 5.2.2. Percentile is never defined.
Response: Refer to comment # J035.

ID # R101
Comment / Question: Many parameters seem to have very little effect on behavior, at least at the scale of the figures. Does that mean they are unimportant and could be fixed or is it that their range was over constrained?
Response: It means that during the majority of the time they have only a small effect. However, during certain periods their importance may become very important. For example, during a drought, the groundwater hydraulic conductivity, seepage through the levee system, and channel-groundwater hydraulic conductivity become very important.

ID # R102
Comment / Question: Please explain how the confidence limits on parameters are set. Is this around the calibrated parameter assuming it is reality? Why a normal assumption when many of these parameters may be physically limited to certain ranges?
Response: Yes, when considering time scale of season to annual performance measure that are taken from the model output these assumptions are not usually limited by physically properties. Normally the differences in measured and model output support the concept.

ID # T001
Comment / Question: It is clear that an extensive effort has gone into the development, application, and testing of the SFWMM and into the preparation of the documentation. I commend the authors on the overall work and the effort.
Response: Thank you for the comment.

ID # T002
Comment / Question: The South Florida region is an exceedingly complex natural hydrologic system, with extensive superimposed anthropogenic impacts, and as such is a daunting challenge for any modeling system.
Response: Strongly agree!

ID # T003
Comment / Question: The 2 mi by 2 mi grid scale is a relatively coarse scale for both surface water groundwater modeling efforts. There are selected discussions of the impacts/restrictions of this scale in various sections of the documentation, but no concise discussion as to how this scale was selected, or a justification that this scale is reasonable for the types of management and policy issues to be addressed. Further elaboration of this would be helpful.
Response: In the early 1980s, the SFWMM grid size was selected to be 2mile-by-2mile with consideration for the following items:

- Availability of spatial data, e.g. topography
- Accuracy of modeling the physical and management processes of the South Florida System in the context of the intended level of detail required by the model application (regional planning tool)
- Large spatial extent of domain
- Run time and limited computational power

By the early 1990s as computational speed and capabilities increased, limited SFWMD model development resources were prioritized to focus on the next generation regional modeling tool, the South Florida Regional Simulation Model (SFRSM), and no development of an implementation of the SFWMM at a finer grid scale was completed. Since that time, SFRSM development has continued and the SFWMM has become the preeminent regional application modeling tool for long term and operational planning in South Florida. Over this period, SFWMM development has continued to serve its application needs, with additional detail (ET-Recharge package, levee seepage, small reservoirs, water shortage rule implementation, etc…) being added to the model as required by calibration or application requirements (for further detail on this concept, please see comment ID # W002).

The theoretical basis for using a 2-mile grid as the basis for a large portion of the model is detailed in section ten (page 1245) of the following reference:

> Lal, Wasantha, A. M. (2000). "Numerical errors in groundwater and overland flow models", Water Resources Research, 36(5), pp. 1237-1247.

This paper will be provided to peer review panel.

ID # T004
Comment / Question: It was emphasized that water budgets could be generated for all regions within the SFWMM but I only saw limited water budget information in Section 4.3.3 and only for the Big Cypress and Feeder Canal basins. Were water budgets

generated for each of the subregions (i.e. EAA, WCAs, LEC), and if so, where can those be found?
Response: The regional system demands and runoff from Lake Okeechobee Service Area (LOSA) basins, with the exception of the Everglades Agricultural Area, are pre-processed offline using the AFSIRS-WATBAL model. Section 4.3.3 shows some water budget results for two of these LOSA basins: the Big Cypress Reservation and Feeder Canal Basins. The pre-processed time series are used in the SFWMM as target demands on the regional system and boundary conditions, respectively. It is important to notice that the target demands from these basins may not be fully met in the SFWMM. There is also no feedback between the operational decisions made by the SFWMM and the time series; so for example, deficit irrigation cannot be simulated.

Once a SFWMM simulation is performed, a suite of post-processing utilities is run (refer to Section 1.3, p. 15, 2nd paragraph). This includes a water budget package that is capable of generating monthly, annual, seasonal and water year budgets for each of the major sub regions in the model domain. Water budgets for smaller sub basins can be generated as well as long as canals are fully contained within the sub basin boundary. For some examples, see
http://modeling.cerpzone.org/pmviewer/servlet/PMViewer?req=send_doc&doc_id=52599
and
http://modeling.cerpzone.org/pmviewer/servlet/PMViewer?req=send_doc&doc_id=52614

ID # T005
Comment / Question: Pg 17: There appeared to be significant processing of topographic data to both update the previous model and refine the landscape representation. Could the updated data support a finer resolution than the 2 mi x 2 mi grid, and what impact does the grid size have on the drainage patterns and surface water processes in this extremely flat topography?

Response:
- The available updated data does not cover the entire model domain; therefore, the lack of high accuracy data outside of the updated area limits its use below the 2-mile resolution. This data has been used to provide finer resolution topography to local scale models
- Microtopographic drainage due to features at a scale of less than 2 miles x 2 miles is obviously not captured. This limits the application of the SFWMM to more regional scale comparisons. It is even recommended that users compare average values over several grid cells rather than for cell-by-cell comparisons to increase confidence in the model results.

ID # T006
Comment / Question: Pg 25: What is the projected impact, if any, of using the 1988 land use data for the entire calibration period? Were land use data for any other years available during the calibration and verification periods?

Response: Please refer to comment # V007.

ID # T007
Comment / Question: Pg 30: Since SFWMM uses a single land use designation for each 2 x 2 cell, how does it accommodate impervious areas that are generally much smaller than this? Also, since most SW models usually use effective, or directly connected impervious area, does SFWMM make a distinction between effective and total impervious area in each cell? Also I didn't see a clear discussion of how runoff was handled for impervious surfaces – maybe I missed it.
Also, it is noted on Pg 58, that the BEAs (basic element areas) allow SFWMM to capture land use variability at a smaller scale than the 2 x 2 grid – is this only for the LEC regions, or available throughout the model footprint?
Response: In the SFWMM, some hydrologic components are accounted at a scale smaller than the 2 mile by 2-mile size of the distributed mesh. In the Lower East Coast (LEC) only, the ET-Recharge package simulates evapotranspiration processes based on land use data at a polygon-scale, with minimum mapping units of 2 to 10 acres. Each of the land use types in the urban area is given coefficients that define the percentage of effective impervious land. Low Density Urban has 67% pervious and 33% impervious land, Medium Density Urban has 53% pervious and 47% impervious land and High Density Urban has 45% pervious and 55% impervious land. Other urban land uses have varying percentages depending on the average amount of pervious area. The SFWMM grid is then merged with the land use data to define irrigation requirements and evapotranspiration values for each urban grid cell.

From the perspective of overland flow (runoff) the SFWMM relies on the grid-scale calibrated lumped parameters of detention depth and effective roughness to account for different performance between varied land use types. As can be seen in Table 2.4.2.1, the "A" coefficient and detention depth values for calculation of effective roughness decrease as urban density increases. This is an indirect accounting of response to impervious surfaces – as urban density increases, overland flow is allowed to occur sooner and with less resistance.
SFWMM also captures land use variability in the Lake Okeechobee Service Area using a lumped parameter approach versus distributed parameter modeling in the gridded portion of the model footprint.

ID # T010
Comment / Question: I didn't see any discussion of the impacts of irrigation efficiencies on modeling the irrigation demand. Is this included in the SFWMM and how is it represented?
Response: Efficiency losses are commonly used in irrigation modeling to represent both atmospheric and non-atmospheric (over application) losses. Since the SFWMM conceptualizes irrigated lands in a variety of ways in different areas of the model domain, the means by which irrigation efficiency is accounted is also variable.

In the lumped Lake Okeechobee Service Area basins the AFSIRS/WATBAL is used to handle irrigated lands (Section 3.3). In this tool, the field scale AFSIRS model accounts for non-atmospheric losses as part of the root zone accounting while at the basin scale, the calibrated EFF1 accounts for atmospheric losses in the form of canal, ditch & catchment storage ET or incidental irrigation.

Similarly, in the Lower East Coast, the ET Recharge model (Section 3.5) utilizes the field scale AFSIRS model. Irrigation system efficiency is input driven.

In the Everglades Agricultural Area (Section 3.2), the total efficiency is indirectly accounted for in the calculation of the soil moisture trigger levels that indicate the need for irrigation supplemental to local rainfall and storage; and atmospheric efficiency which is indirectly accounted for in the calibration parameter KCALIB.

ID # T011
Comment / Question: Pg 71. This table shows the highest Detention Depths for urban and agricultural areas, in the range of up to 0.5 to 0.6 feet, or close to 6-7 inches. Since this is applied to the 4 sq mi area of a cell, this corresponds to about 1300 to 1500 ac-ft of storage in that cell. This seems like a relatively large amount of storage before any overland flow can occur – I would welcome some discussion of this and how we can visualize this depth of storage over an entire cell of 4 sq mi.
Response: Land Use classes with higher detention depths reside mainly in the urbanized and agricultural areas of the Lower East Coast. The detail of the urbanized storage and drainage features are not necessary in this Regional Simulation Model. However, at the same time, it is important to capture the relationship between the Rainfall, ET and groundwater stages. In general, only the primary canals and important secondary canals are explicitly modeled in the SFWMM, whereas, in reality, additional storage is present in the remaining secondary and tertiary canal and lake systems. Furthermore, in the urbanized areas, recharge, not overland flow, is the primary mechanism in removing rainfall or ponded water. The range of 0.5 to 0.6 feet adequately addresses the additional storage and allows recharge to occur before overland flow. The detention depths were adjusted during the calibration process to best capture the wet and dry extremes.

ID # T012
Comment / Question: Pg 72: Infiltration rates of 9 to 100 ft/day are noted in the text, and specified for each cell. How were infiltration rates determined – soils data, calibration, or both?
Response: Soil Survey data published by the United States Department of Agriculture Soil Conservation Service was used in determining the soil infiltration rates applied in the South Florida Water Management Model. No adjustments to the soil infiltration rates were done during the model calibration. Soil infiltration rates are very high in South Florida and, in general, are not a limiting factor in calculations of infiltration volumes.

ID # T014
Comment / Question: Section 3: I didn't have time to study this section as much as it deserves, and hope to do that before our workshop. I would like to request a presentation on these critical aspects of the SFWMM and maybe a demonstration/example, if possible.

Response: Some presentations will address the topics covered in Section 3 during the September workshop.

ID # T015
Comment / Question: Section 4, pg 218. Please explain Equations 4.1.1.1 and 4.1.1.2 – they don't seem clear to me unless I know where the 'structures' are located.
Response: This comment will be seriously considered for the final documentation.

Sometimes, listing several structures that are generally unknown to the reader can be confusing as well. The equations were presented as a description of the method only.

ID # T016
Comment / Question: Pg 219: Is there a logical explanation for the monthly variation in the calibration parameters shown in these tables? There doesn't appear to be a seasonal pattern so I question if they are really representing mechanistic processes, or is this merely curve fitting?
Response: Tables 4.1.1.2 and 4.1.1.3 on page 219 illustrate the monthly values used for various Everglades Agricultural Area (EAA) calibration parameters. For a detailed explanation of Table 4.1.1.2, please see comment ID # R074. The ratios for calculation of maximum and minimum unsaturated zone soil moisture triggers shown in Table 4.1.1.3 (and corresponding storage triggers of Figure 4.1.1.1) are calibrated to match historical response of the system and as such can be characterized as primarily a curve-fitting approach.

The reason for variability from month to month is largely due to the management practices of farmers in the EAA, who have the capacity to retain large volumes of water on their farms and who manage the capture and discharge of this water depending on several factors including climate conditions (both current and anticipated seasonal changes), crop growth patterns and regional water available for supplemental irrigation in Lake Okeechobee.

One observation of interest is that the monthly minimum fracdph term is lowest during the months of May and September. These months correspond to the two final months of the Lake Okeechobee Service Area (LOSA) dry season (October – May) and wet season (June – September). Similarly, the highest values of maximum fracdph are observed in May. These values are likely being influenced by changes in management practices in which farmers tend to retain extra water on their land in anticipation of 1) a delay in the onset of the wet season during periods of high ET (for May) and 2) the oncoming dry season when regional water availability may be an issue (in September).

ID # T017
Comment / Question: Pg 219: Are the monthly parameters constant throughout the month, with abrupt changes between months, or is there any interpolation being done for days within a month?
Response: The monthly parameters represent mid-month values. Interpolation is done when in any other day within the month. For example, the value corresponding to the 20th

of a given month is a combination of the parameter values assigned for the same month and the succeeding month, with more weight assigned to the current month.

ID # T018
Comment / Question: The calibration results for EAA look quite good and the R^2 values generally support that. I would recommend showing, or at least examining, the flow duration curves plotted on log-probability scales to emphasize/focus on the extreme high and low flows/ends of the curves.
Response: Yes, it will be considered in the future re-writes of document and during the next release of the model calibration.

ID # T019
Comment / Question: The verification plots and tables show 2 different verification periods, but the text only indicated that 1996-2000 was verification (pg 217).
Response: Agree. The text on pg 217 is incorrect.

ID # T020
Comment / Question: Pg 232-233: The titles indicated V 5.4? Is there much difference between V 5.4 and V5.5?
Response: SFWMM Version 5.4 and Version 5.5 are very similar and no calibrated parameters were changed between the two versions. Source code modifications between Version 5.4 and Version 5.5 were made to 1) allow for some increased system operational flexibility as needed by the model clients, and 2) add additional comments to the code to improve readability and internal documentation.

ID # T021
Comment / Question: This was clearly a major model calibration and verification effort, and the results generally look good to very good. But I would recommend some additional discussion in Section 4.2.2, and specifically clarifying what is in Table 4.2.2.1. I would like to see some of the flow results like that shown for the EAA, and included in Appendix C. I think that would support the calibration even more.
Response: Yes, it will be considered in the future re-writes of document and during the next release of the model calibration.

ID # T023
Comment / Question: It would be helpful to see the actual parameter values used in the SA, not just the % changes.
Response: Point well taken!

ID # V001
Comment / Question: The SFWMM is, on the whole, a good management model. It does seem to simulate discharges and stages reasonably well, although in some cases discrepancies between simulated values and observed values are significant. The model is good example of how hydrology can be employed in practical and real life decision making. Below are some comments and it will be helpful if they addressed.
Response: Thank you for this comment.

ID # V003
Comment / Question: In the final draft report there is little discussion of soils and soil types and how these have been incorporated in the model construction. What types of soils are there in the model domain? It will be helpful to provide a discussion of soils, given their importance in hydrology of infiltration, runoff, evapotranspiration, etc.
Response: Yes, incorporation of a discussion of soil and soil type will be considered in future re-writes of the documentation. Soils play an important role in the hydrology of South Florida systems, affecting infiltration, runoff and evapotranspiration processes. In the distributed grid, soils are not specifically defined, but are represented in several of the model input and calibration parameters, including storage coefficient, infiltration rate, detention depth and effective roughness (in conjunction with land cover); consideration for soil characteristics also plays a role in calibration of empirical coefficients for levee seepage and canal seepage estimations.

In the ET-Recharge and AFSIRS/WATBAL implementations, soil types are model input. The four major soil types considered in these models are: sand, sandy loam, fine sand muck. Additional input parameters associated with each of these soil classifications are depth of soil column and range of available water content (upper and lower bounds).

ID # V004
Comment / Question: The model domain is divided into 3 areas and into a number of sub-areas (Figure 1.3.5). It is not clear how different are surface water and groundwater basin boundaries? The differences in surface water and ground water basin boundaries will change the water budget of the basin as a whole. How are interactions between surface water and ground water accounted for?
Response: Surface water and groundwater processes are modeled in all areas of the distributed domain. The South Florida system is in general compartmentalized and heavily managed with low topographic relief. Watersheds or drainage basins are not typically delineated by natural divides, e.g. ridges, but more commonly with man-made levees. As a result, the impacts of inter-basin surface and groundwater exchanges in the system are normally limited. SFWMM implementation was designed with consideration for predominant surface and groundwater flow patterns within sub-basins as well as for the overall regional pattern. Inter-basin interaction is limited by many features in the SFWMM (e.g. structures, levees, curtain walls) and the model accounts for inter-basin interactions or impediments to flow using several processes and features (e.g. levee seepage, use of basin numbers). In general, groundwater flow is not restricted by basin boundaries except where indicated at the SFWMM model boundary. The two main modeled vertical interactions between surface and groundwater are infiltration and percolation. The model also allows for surface and groundwater interaction through canals and reservoirs.

ID # V005
Comment / Question: The discussion of topographic data is comprehensive and the topographic data are quite detailed.
Response: The comment is acknowledged.

ID # V006
Comment / Question: The land use data is not as detailed, especially in time. The land use description is good. The land use projection based on the 2000 map for 2050 may too far off from what it actually might be.
Response: Land uses, like water supply demands and operational rules, are intended to represent specific years used in the planning process and are not intended to show change throughout the period of record. The best information from several sources are used to develop the 2050 land use. It is acknowledged that the predictions may be far off since many new factors are likely to be encountered over the projection period.

ID # V007
Comment / Question: How can land use be constant as has been assumed? The land use in 2000 is quite different from that in 1988.
Response: One of the limitations of the SFWMM is that it assumes that land use is a static parameter and will not change over the course of simulation (it was not conceptualized as a succession model). This assumption is a good fit for the intended application of the model in planning exercises, but it is not ideal for calibration efforts. Additionally, there exists a data limitation in that the frequency at which the SFWMD collects complete land use information is limited to once every several years. Land use information only exists for the 1988, 1995 and 2000 conditions. In order to help overcome these limitations, the SFWMM calibration/verification effort utilized land use as could best be accommodated considering data availability and model input limitations. This resulted in the land use from 1988 being used in the calibration (1984-1995) and early verification (1981-1983) periods and land use from 2000 being used in the later verification (1996-2000) period.

By using a constant land use for specific periods of time, the calibration team exercised caution in interpreting the calibration statistics. Greater confidence in the calibration results should be made in the middle years of the calibration period while more weight should be put in the latter years of the verification period.

ID # V008
Comment / Question: Rainfall: A very good network of 964 stations for an area of 17,930 square miles. The District is lucky to have such a dense network.
Response: We agree. However, spatial variability of daily rainfall in South Florida is so high that traditional geostatistical techniques (e.g., Kriging) do not capture such variability. A typical variogram in this environment is mainly nugget.

ID # V009
Comment / Question: Rainfall data analysis seems fine. What happens if climate change occurs? On Page 38 the sentence containing "less than 16 " or higher than 5" seems to be in error. The basis for dropping abnormal rainfall values may be less than sound in some cases. Abnormality by itself is not a sufficient justification
Response: There is a typo: it should read "less than 16 but higher than 5"

Second: At the beginning of this paragraph (Page 38), we said "In the first pass, daily rainfall values greater than 16 inches were flagged as questionable." Flagging a data point as questionable does not constitute a basis for elimination. It just establishes a reason for abnormality as you pointed out. This abnormality is further checked using the QA\QC procedures presented. The data point is then accepted and/or rejected. In fact most of the data that exhibited abnormality were kept.

ID #V010
Comment / Question: Evapotranspiration modeling for marshes looks good. It is not clear though what the basis of the model is. Why not use a more standard method, such as Penman-Monteith? How was Kr selected?
Response: Please refer to #R013 and #R014.

ID # V011
Comment / Question: The method for calculation of ET for Lake Okeechobee based on water balance may not be the best way-it may too sensitive to errors. Lake stages are too sensitive.
Response: Lake Okeechobee stages are not very sensitive to changes in water budget over a short period of time. This is due to the large spatial extent of the Lake (~ 728 sq miles or 466,000 acres) and the corresponding volume of water that this represents (millions of ac-ft). As a result, errors in ET estimation are somewhat mitigated. Additionally, referring to figure 3.1.1.1, it can be seen that above approximately 14 ft, changes in marsh or local Lake surface area do not vary significantly so as to affect ET calculations.

ID # V012
Comment / Question: ET for Everglades agricultural areas may be okay. However it will be useful to compare this method with other standard methods.
Response: Comparison of ET calculation in the Everglades agricultural area with other standard methods will be considered in future implementations.

ID # V015
Comment / Question: Irrigation demand computation seems okay. However, irrigation practices are changing and crop water requirements are also changing, as new seed varieties are being developed.
Response: Acknowledged. Crop water requirements are considered static during the period of record runs; however new crop information can be incorporated into future model versions.

ID # V017
Comment / Question: Infiltration is weakly modeled and may need improvement. It is difficult to justify assuming infiltration as a constant value.
Response: The methodology used is simplified but adequate for South Florida where high soil infiltration rates exist along with relatively flat land surface profiles and where the aquifer table is very close to land surface.

We're not sure if the second part of the question is addressing the maximum soil infiltration rate, which is constant and a model input, or the infiltration volumes which are time varying depending on the water table and hydrologic conditions.

ID # V021
Comment / Question: Coupling of surface water and ground water without accounting for unsaturated flow seems unsound and may need improvement. On page 85, eq. (2.5.5.18) does not have right symbols.
Response: SFWMM was initially developed for wetlands of South Florida where the water table was very close to the ground and the thickness of the unsaturated layer is small. There are also many areas where the water level was above ground for prolonged periods of time. Under these conditions, it was possible to neglect the volume of water in the unsaturated layer.

SFWMM was not to be used under upland conditions where the unsaturated layer is important.

In areas where the unsaturated layer is important, primarily in the developed areas, the unsaturated zone is treated as a separate control volume (see Sec. 2.3.5 for reference).

With respect to Eq. 2.5.5.18 (ht = ht + pondt):

- In the code:
  - "h" is defined as the hydraulic head within the soil column (h has a maximum value of land surface elevation).
  - "pond" is defined as the surface ponding
- Recharge is calculated before the groundwater equations are solved. Recharge includes effects of infiltration, ET, well field pumpages, and canal-groundwater interaction.
- If ponding still exists after recharge, then "h" needs to be temporarily adjusted to reflect the total hydraulic head to be used in the groundwater equation.

ht, in Eq. 2.5.5.18, can be thought of as the total hydraulic head for the groundwater equation.

ID # V022
Comment / Question: Canal routing seems okay. However, in canal routing one day seems too long a time. Water may flow out a 2-mile long cell in less than a day.
Response: Please see response to #R036.

ID # V023
Comment / Question: Initial and boundary conditions are described well. However, figures 2.7.2.3-2.7.2.5 do not look great and may need improvement. How accurate is eq. (2.7.2.1)? It would be better if equations and boundary conditions are specified separately for simulation of each lake/area by SFWMM?
Response: The goodness of fit suggestion is acknowledged. Equation (2.7.2.1) is used to characterize inflows to Lake Okeechobee that are not otherwise measured. Based on a lack of specific data, using the MDS approach is believed to be a sufficiently accurate

way to account for the unmeasured flows, as well as other errors such as those associated with ET predictions and rainfall distribution.

ID # V031
Comment / Question: In the calibration and verification of the Everglades and the LEC, R squared values on page 238 seem quite low. Why?
Response: Page 238 summarizes the observations made for the calibration and verification results for the entire Lower East Coast and Everglades Areas. It is true that low values of R squared suggest that the model may not be a good predictor of stages in some parts of the model domain. This occurrence may be due to the following reasons:

1. Observed data from monitoring stations represent the water level at a point in the landscape or along a canal. Simulated data from the model represent an average water level for a four-square-mile area for surface water or groundwater, or an average water level for a two-mile stretch for a canal reach. It may be a scale issue.
2. Water levels measured at groundwater and canal-monitoring points may be influenced by local phenomena such as well fields or multiple control structures. Observed data for these monitoring stations may be highly variable both spatially and temporally and may not be representative of a larger area or a longer duration. The model may need some reconceptualization in such problem areas.

ID # V032
Comment / Question: In calibration and verification of lumped LOSA basins, discrepancies seem quite significant. Why?
Response: The calibration of the AFSIRS/WATBAL model to the three implementations within the Lake Okeechobee Service Area (LOSA) is not an unproblematic task. The primary reason that a simplified water budget approach is used for these basins is the lack of reliable data for these areas. When calibrating with uncertain model inputs to uncertain historical responses, discrepancies or differences in modeled versus measured supplemental demand and basin runoff are to be expected. Despite this obstacle, the model still does reasonably well, obtaining correlations of greater than 0.8 in the Caloosahatchee and near 0.7 in the tribal lands with virtually no modeled bias.

ID # V037
Comment / Question: What are the main factors that should be kept in mind when applying the model to another location?
Response: The model was not intended to be used in other locations. While the basic hydrologic components of the model could be applied elsewhere, the specifics of structure operations, basin interactions, and operation of storage components may be inappropriate.
The model was designed to deal with high rainfall and ET, as well as significant overland “sheetflow” component not normally found elsewhere.

ID # W001
Comment / Question: Chapter 1 provides a well-written overview of the history, purpose and capabilities of the SFWMM. SFWMM is a comprehensive, complex model

that simulates both the natural hydrologic processes and the engineered hydraulic structures and operating rules that affect the movement of water in South Florida. It includes algorithms to simulate all the significant processes that occur in the area. However the sophistication of the treatment of the processes varies widely from quite empirical (i.e. the way unsaturated flow is simulated) to more physically-based (i.e. the way groundwater flow is simulated). The level of empiricism in simulating many of the processes requires a large number of calibration coefficients.
Response: Acknowledged. In an effort to incorporate the best available information, an empirical approach was often used.

ID # W002
Comment / Question: It would be useful if at the September workshop the SFWMD modeling staff would discuss how the level of complexity chosen for each process; how the differing levels of complexity and accuracy affect the overall model accuracy and stability; how errors in different components of the hydrologic cycle may compound, or offset each other; what methodologies were used to estimate the many empirical coefficients required in some of the less physically based algorithms; and the issues associated with using these coefficients to simulate scenarios that may outside of the hydrologic conditions the model was calibrated for. A discussion of these issues should probably also be included in this documentation, perhaps in a concluding chapter.
Response: The development of the South Florida Water Management Model (SFWMM) up to Version 5.5 has followed a pyramid formulation. The basic framework of the model is a regional distributed 2-mile by 2 mile mesh with a known and true (see references) surface and groundwater formulation applied to the majority of the SFWMD south of Lake Okeechobee.

1. Lal, Wasantha, A. M. (1998) "Performance comparison of overland flow algorithms", ASCE Journal of Hydraulic Engg., 124(4), April 1998, pp. 342-349.
2. Lal, Wasantha, A. M. (2000). "Numerical errors in groundwater and overland flow models", Water Resources Research, 36(5), pp. 1237-1247.

To this basic formulation, complexity has been added over time as a function of need (defined primarily as to improve calibration or to address the requirements of model application clients) and available SFWMD staffing resources. Complexity as added to the SFWMM is limited to regional scale and time-step considerations as well as the constraints of acceptable scientific practices, data availability and run-time. The level of complexity and accuracy of model formulations in the SFWMM V5.5 is somewhat variable as a result of its historical development, but the overall methodology has been one of continual improvement to the tool (given the limitations listed above) with consideration for technical review from the engineering and scientific communities in the form of publications and peer reviews.

It is true that errors may compound or offset; by nature the South Florida system is not a monolithic entity. However, the overall problem of propagated error should not lead to instability in model results or inability to calibrate to historic conditions. This is aided by the fact that the geographic sub-areas are relatively independent from a parameter and system management perspective and that many of the independent parameter interactions have been examined and are well defined (for example, the relationship between ET and storage illustrated in Table 4.1.1.1). In general, the process for modification of empirical coefficients within the SFWMM can be defined as follows: Start from estimated parameters from a technical and literature review of scientific research, data collection, other modeling efforts, etc., then apply a calibration methodology to adjust parameter values to obtain a desired response from the system with a final reasonability check of the parameters to ensure that modeling assumptions are not violated. The SFWMM model calibration represents a large range of climatological and hydrologic conditions and should be sufficient in most cases to assure reasonability in model output. Modeler judgment during application of the tool is still needed to ensure that model output does not move outside of acceptable range.

This comment will be presented in more detail as part of the Peer Review workshop agenda. Consideration will also be made for adding text to future rewrites of the documentation.

ID # W003
Comment / Question: The topography data incorporated into the SFWMM comes from a variety of sources, using different measurement and post-processing techniques and is of varying quality. Stated accuracies range from 0.2ft to 0.5 ft. It seems that this level of accuracy is marginal considering the very low relief in the South Florida system. What is the consequence of using topography data with varying degrees of accuracy throughout the modeled domain?
Response: This is a very good point. Users need to be reminded of uncertainties in model input data including topographic data in their interpretation of model output. Typically the SFWMM is used for relative comparisons, so once calibrated, the absolute accuracy of the topographic data becomes less important since water management scenarios are compared using the same model version with a consistent topo.

ID # W004
Comment / Question: Representing the topography as constant over a 2 mile by 2 mile grid ignores the effects of natural and constructed microtopography and presumably requires larger than realistic Manning's roughness coefficients to properly simulated rates of overland flow. How were Manning's roughness coefficients estimated for each land use type? Could the measured elevation variance within each 2 by 2 cell be retained as an indicator of roughness?
Response: Manning's roughness coefficients are a calibration parameter. Detention depth is used to account for local depressions within a land use. Roughness is a function of depth and decreases as you increase ponding depth. The roughness will decrease to a minimum of 0.5.

ID # W006
Comment / Question: A fairly dense network of rain gages exists over the modeled region. These data have been screened for outliers, and a triangulation method is used to create areally averaged daily rainfall estimates for each grid cell. It may be useful to try to use NEXRAD or other radar measurements to spatially interpolate the network of

point measurements. Is it possible that the spatial interpolation mechanism might vary seasonally depending on the type of rainfall (i.e. frontal, convective, hurricanes, etc)?
Response: We agree RADAR based rainfall data will provide a more effective estimation of areal rainfall average as an input to hydrologic models, e.g., SFWMD. Radar data at SFWMD is only available post 1996 only. A formal procedure to reproduce RADAR "like" data prior 1996 has not been adopted to cover the entire SFWMM spatial extent.

Earlier geostatistical work (Ali, et. al. 1999) shows that spatial interpolation mechanism might vary seasonally. Due to the large amount of rainfall data to be processed and spatial variability in data availability from day to day, make the use of complex geostatistical schemes such as Kriging, local polynomial, MARS, LOWES, etc. impractical.

Ali, A., W. Abtew, S. Van Horn, and N. Khanal. 1999b. Frequency and Spatial Analyses for Monthly Rainfall in Central and South Florida, Technical Publication WRE 371, South Florida Water Management District. West Palm Beach, Florida.

ID # W008
Comment / Question: There is a somewhat bewildering variety of methods used to estimate ET and unsaturated zone flow processes in the various land uses and management areas in the modeled area, e.g. different methods are used for Lake Okeechobee, the Everglades Agricultural Area, Lake Okeechobee Service Areas, the lower east coast service areas, and non-irrigated areas. Why are so many different methods necessary? Does using this array of methods increase the reliability of the model predictions? This seems difficult to prove since the model is primarily calibrated against aggregated flows and areally averaged stages/heads in the system. The utilization of all the different variants of ET/vadose zone flow estimation should be discussed and justified.
Response: The simple answer to this question is that the SFWMM was developed over time, with complexity being added as needed to aid in calibration or application of the model. This "add on" approach to model development and implementation has led to the utilization of many differing methods for ET and unsaturated zone accounting depending upon many factors including scientific accepted wisdom, data availability, model development staffing resources and the applicability of other models to supplement SFWMM capabilities (e.g. AFSIRS, ET-Recharge, etc…). Additional detail on this subject is addressed in comment # W002.

ID # W010
Comment / Question: On. P. 44 a radiation-based method is used to estimate wet marsh ET potential. The 0.53 coefficient for mixed marsh, open water and shallow lakes is quite low compared to other similar radiation based methods (i.e. Priestly-Taylor). Was this coefficient developed from data in South Florida? Is there a physical reason for its relatively low value?
Response: In the Simple Method, the 0.53 is multiplied by the solar radiation received at the land surface (Rs). In the Priestley-Taylor method, the alpha value (typically 1.26) is multiplied by the net radiation. So both coefficients are not directly comparable. Abtew

(1996a, 1996b) explains that the 0.53 has been calibrated for cattails, mixed marsh vegetation and open water as part of lysimeter evaporation studies at the Everglades Nutrient Removal constructed wetland in S. Florida.

Abtew, W. 1996 a. Evapotranspiration measurements and modeling for three wetland systems in south Florida. J. AWRA, 32(3)465-473.

Abtew, W. 1996b. Lysimeter study of evapotranspiration from a wetland. *Evapotranspiration and Irrigation Scheduling*. C.R. Camp, E.J. Sadler and R.E. Yoder (eds.) Proceedings of the international Conference. Nov 3-6, San Antonio, TX pp. 54-60. ASAE.

ID # W011
Comment / Question: A "self calibrating Kr method" is used to estimate solar radiation at the land surface, which depends on extra terrestrial solar radiation (calculated from latitude and time of year), temperature and another empirical coefficient. It has been previously shown that temperature based ET estimation methods do not work well in Florida because they don't account for the effect of cloud cover in reducing extraterrestrial radiation. Does using the difference between max and min temperatures take care of this problem? How was this method developed and verified? How accurately does it estimate solar radiation at the land surface under S. Florida conditions? How do the data presented in Table 2.3.1.1 compare to measured data?
Response: Please refer to #R014.

ID # W013
Comment / Question: At different points in the documentation various relationships are assumed with the water table… i.e. no ET from the water table, water table assumed constant at 1.5 ft depth, etc. Are these assumptions always consistent with the groundwater flow module in SFWMM? Is there a feedback mechanism between the various ET estimation algorithms and the heads/stages/flows predicted by SFWMM?
Response: The relationships between the water table and evapotranspiration (ET) are consistent with the groundwater flow module in SFWMM. Within each time step, all ET calculations are completed and a net recharge term is calculated as input to the groundwater flow module. There is a continuous feedback mechanism between the various ET estimation algorithms and the heads/stages/flows predicted by SFWMM. Simply stated, by employing an explicit solution approach to the overall algorithm, ET affects the predicted heads/stages/flows on the same time step while the latter affects ET for the next time step.

ID # W015
Comment / Question: Is there a discernable physical basis for the variation of overland flow coefficients (e.g. see Table 2.4.2.1)?
Response: The coefficients of overland flow are a function of land use type. Land use is classified for natural areas in the SFWMM according to vegetation type. Various vegetation types have different density and height, which affect resistance to flow. Thus,

in general, the variation of the coefficients of overland flow in natural areas reflects the variation in the physical characteristics of different vegetation types.

In developed areas the density of imperviousness is the main consideration in classifying urban land use types. As a result, the variation in coefficients to overland flow in urban areas is a function of urban density.

ID # W016
Comment / Question: There is a font problem with equation 2.4.1.4.
Response: Agree. The equation should have been:

$$\vec{\tau}_b = \rho g h \vec{S}_f$$

where $\vec{\tau}_b$ is the resultant bed shear stress in the direction of the maximum energy slope S_f.

ID # W017
Comment / Question:
On p. 72 it is stated that infiltration rates vary from 9 to 100 ft /day. How were these values estimated? They seem quite large, especially for urban areas. If these values are accurate I assume that infiltration rate is never a limiting factor that causes surface ponding? (mechanism 2 on p. 72)
Response: Soil Survey data published by the United States Department of Agriculture Soil Conservation Service was used in determining the soil infiltration rates applied in the South Florida Water Management Model. Soil infiltration rates are very high in South Florida and, in general, are not a limiting factor in calculations of infiltration volumes. In urban areas, no adjustments were made to the soil infiltration rates since calibration groundwater stage targets are located in pervious zones.

ID # W018
Comment / Question: A large number of empirical parameters are needed to describe canal-groundwater seepage, levee seepage, etc., how are these parameters estimated and validated? Is there a discernable physical basis for their variation (e.g. see Table 2.5.3.1)?
Response: A range of 0.1 to 10 (ft/day per foot of head difference) is an acceptable range for the canal-groundwater seepage coefficient (variable CHHC as depicted in Eq. 2.5.2.1). This parameter was adjusted, on a canal by canal basis, during the calibration process. In general, higher coefficients are used for canals in areas that have higher aquifer conductivities (for example, in South Miami-Dade County).

As mentioned in section 2.5.3 (Levee Seepage), the SEEP2D model was used to determine the initial estimate of the empirical parameters used in the levee seepage flow regression equations. The parameters were modified, if necessary, during the calibration process.

Differences in the canal-levee configurations in addition to differences in the hydrogeologic properties lead to the variation in the empirical parameters tabulated in Table 2.5.3.1.

ID # W019
Comment / Question: The two-dimensional unconfined aquifer equation is used to simulate saturated groundwater flow. The formulation of equation 2.5.4.1 assumes the model grid is aligned with the principal axes for transmissivity. Is there a basis for this? Also the definition of Txx and Tyy as transmissivity tensors is not accurate. These are components of the transmissivity tensor, not tensors themselves. Is the final estimation of transmissivity anisotropic? It does not appear so from the information given in figure 2.5.4.1.
Response: The comment is true.

The model assumes isotropic transmissivity. Each grid cell has a unique value for transmissivity, independent of direction. Transmissivity does vary spatially, from grid cell to grid cell.

Until recently information on anisotropic transmissivity was not available for South Florida. A limited number of trials were carried out to understand the influence of anisotropy in South Florida.

Some rewrite of this section might be necessary for clarification.

ID # W022
Comment / Question: Canal routing procedures are adequately described, however it is not clear what the criteria are for determining which canals can be modeled using a constant slope solution and which should be modeled using a dynamic slope solution. What is gained (in terms of model prediction accuracy) by going to a dynamic slope solution? What is lost in terms of stability, computation time, etc?
Response: The dynamic slope solution is ideally suited for areas that are highly managed and drained (Lower East Coast Service Areas). Also it is more ideally suited for shorter rather than longer canals. Emphasis on its application has been placed on the major project canals in the Service Areas. Availability of data (stage data and canal geometry data) is another consideration in determining which canals are modeled using the dynamic slope solution.

The dynamic slope solution allows for a better temporal estimate of the canal head slope due to changes in hydrologic conditions. This results in improved calibration results for canal headwater stages and nearby groundwater stages. This improved solution for the canal slopes allows for better representation of existing and proposed structure operations. No loss in stability occurs; however, computational time is increased because more iterations are needed for convergence.

ID # W023
Comment / Question: Variables CHDEP0, CHEDEP0, QSTRin and QSTRout need to be defined the first time they are used (p. 91). This problem occurs throughout the documentation.
Response: Acknowledged. This suggestion will be seriously considered for the final documentation.

ID # W025
Comment / Question: What is the implication of the inaccuracies of the regression analyses that are used to define boundary conditions for inflow from the Upper Istokpoga Basin and Taylor Creek/Nubbin Slough?
Response: A sensitivity analysis on the effect of estimated inflows into Lake Okeechobee was not performed. However, the effect should be small considering the following:

3. Only part of the record is estimated. The regressions for inputs to Lake Okeechobee are necessary only to supplement a largely available historical record. For the Upper Istokpoga Basin, 27% of the record is missing for two water control structures, while the record is complete for the remaining two water control structures. For the Taylor Creek/Nubbin Slough and North Lake Shore basins, 19% of the record is missing. (See responses to J084 and J085 for details)
4. The average inflow from the Upper Istokpoga Basin, and Taylor Creek/Nubbin Slough and North Lake Shore Basin is small (6.5% and 6.8%, respectively) compared to the total inflow into Lake Okeechobee.

Any errors in estimating inflows into Lake Okeechobee are accounted for by using the Modified Delta Storage approach.

ID # W026
Comment / Question: What is the sensitivity of the model prediction to the assumed boundary conditions?
Response: A sensitivity analysis of the boundary conditions was not performed.

ID # W027
Comment / Question: The SFWMM simulates a complex system of policy and management rules, which are described in detail in Chapter 3. Some of the descriptions of the rules are difficult for someone from the outside to follow (e.g. the Caloosahatchee Basin module summarized in Figure 3.1.4.1, and the St. Lucie River module which I assume is summarized in Figure 3.1.4.2, and may be mis-labeled) but I assume they are accurate.
Response: Yes, Figure 3.1.4.2 is mislabeled. It should read "Schematic Diagram of St. Lucie Basin/Estuary Simulation Module." It will be fixed in the documentation. See response to question # J092 for more details.

ID # W030
Comment / Question: The sequence of stores from which ET is taken (discussed on p. 130) will result in the correct volumes of water in the right stores at the end of the day. However, if the model is ever to be used for water quality modeling purposes…

particularly for simulating nutrients or pesticides that originate in the soil surface and move through the vadose zone to the groundwater… I do not believe the defined sequence will end up with the nutrients in the right store at the end of the day.
Response: Acknowledged.

ID # W031
Comment / Question: There is confusing set of rules presented on p. 133 to calculate irrigation requirement. Perhaps a flowchart would be easier to understand.
Response: SFWMD staff recognizes that Section 3.2.2, Simulation of EAA Runoff and Demand, requires further clarification, illustration and re writing. These will be undertaken after the September workshop.

ID # W032
Comment / Question: Discussion on p. 137 is repetitive and could be consolidated and made more concise.
Response: This suggestion will be seriously considered for the final documentation.

ID # W033
Comment / Question: What processes are included in the mass balance? What minimal input data is used?
Response: The answer to the first question is provided in Section 3.6 of the document. Therefore we propose to modify the text for the above comment as follows:

From: A mass balance approach using minimal input data is used in calculating discharge in and out of the STAs. These discharges are subject ……

To: A mass balance approach is used to calculate discharge in and out of the STAs. These discharges are subject …… The reader is referred to Section 3.6 for a more detailed description of the simulation of reservoirs.

ID # W034
Comment / Question: p. 142 point 2 EAA BMPs have not been described yet, so it is unclear why they are simulated by increasing the upper limit of soil moisture storage in the unsaturated zone.
Response: A portion of section 3.6.2 (p. 208) has been extracted below to help answer this question. A reference to section 3.6.2 will be added in p. 142.

As part of the Everglades Forever Act requirements (Florida Statutes, Chapter 373, 4592, 1994), Best Management Practices (BMPs) have been implemented in the Everglades Agricultural Area (EAA). The purpose of the BMP implementation in the EAA is to improve the quality of the water entering the Everglades Protection Area (EPA) by reducing phosphorus loads.

Agricultural BMPs include the retention and recycling of drainage generated by farms through the use of additional storage and conveyance facilities. This runoff retention is simulated in the SFWMM by increasing the desired upper limit of soil moisture storage in the unsaturated zone. As described in section 3.2.2 of the documentation, runoff is produced whenever the soil moisture content in the EAA exceeds this desired upper limit of soil moisture (SOLCRNF), which represents the desired basin storage. Therefore, increasing this value results in reduced runoff production from the EAA.

ID # W035
Comment / Question: Why if both STA and non-STA reservoir both exist does the model release water to the non-STA reservoir first?
Response: The paragraph on bottom of p.145 refers to the case of a reservoir and a STA located in the same EAA basin. The intent of the reservoir is to capture excess water for potential irrigation or environmental future use, so the reservoir has priority in receiving the water. The intent of the STAs in the EAA is to capture runoff and Lake Okeechobee flood control releases, in that order. If the reservoir is full or has no inflow capacity, and flood control operations are still required, water is captured by the STA. If the STA is full or has no inflow capacity, and flood protection operations are still required, water is discharged in the Everglades therefore by-passing the STA. Even though the SFWMM does not simulate water quality, the intent is to maximize the treatment capacity before any releases are made to the Everglades.

ID # W036
Comment / Question: p. 146 why is the AFSIRS/WATBAL model used for the LOSA? The use of the term Drainage in this section is confusion. I generally think of drainage as vertical gravity drainage through the soil that becomes recharge to groundwater. This section seems to use drainage synonymously with surface runoff. The terms in this section should be defined more clearly. Is there any possibility of recharge to groundwater from AFSIRS/WATBAL?
Response: The AFSIRS/WATBAL model is used for LOSA in order to provide a consistent means of estimating supplemental irrigation requirements and excess runoff for the portions of the South Florida System that are 1) not part of the distributed mesh portion of the SFWMM and 2) subject to the Lake Okeechobee Supply Side Management Protocol. The use of AFSIRS/WATBAL in this role is considered to be appropriate for several reasons including:

1. AFSIRS/WATBAL has been successfully applied to basins in the LOSA in previous efforts (e.g. Caloosahatchee Water Management Plan, 2000)
2. The model outputs of daily supplemental demand and runoff are consistent with the required inputs to the SFWMM.
3. Input data for running AFSIRS/WATBAL, including climate data, landuse, soil data, etc. is available or can be readily estimated.
4. Model run-times are short enough to allow for modeling long-term periods of record (36 years).

The drainage term used is Section 3.3, although illustrated in a manner that implies surface runoff in Figure 3.3.2.1, is in fact a quantification of the excess water that leaves the root zone. The physical methods by which this may occur include surface runoff, ditch or local storage capture and groundwater recharge. Recalling that AFSIRS on the field scale is a water budget accounting of the root zone, this drainage term is accounted as excess water and is treated as a loss term, regardless of destination or transmission means. Since this representation is not on its own sufficient for the basin scale AFSIRS/WATBAL model, the AFSIRS Water Budget Model is employed to route drainage to surface runoff, local storage or groundwater recharge, depending on the characteristics and connectivity of the sub-basins being modeled (Figure 3.3.2.3). This will be more clearly defined in the document text and in Figures 3.3.2.1-3.3.3.1.

ID # W037
Comment / Question: p. 148 This section states that saturated zone flows are highly variable depending on local conditions, and therefore they are neglected. This doesn't seem like a very good reason to neglect these flows. If they are highly variable they could be highly important.
Response: The assumption that saturated zone lateral flows be neglected is made by the AFSIRS field scale model (Smajstrla), but it should not adversely affect the performance of the AFSIRS/WATBAL basin scale model. In the AFSIRS field scale model, saturated zone lateral flows are said to be indirectly accounted for in the application efficiency term. While this assumption may not be the best way of accounting for these flows, the impact of this assumption on the basin scale AFSIRS/WATBAL model is negligible. This is due to the fact that the influence of field to field interaction on the regional budget is decreased as spatial extent increases. By modeling at the basin scale, the AFSIRS water budget module (as described in Section 3.3) is able to appropriately route excess water among the individual AFSIRS field scale implementations and the influence of unaccounted saturated zone lateral flows are mitigated by the basin-scale routing.

ID # W038
Comment / Question: p. 148 What is CWMP? I don't think this acronym is ever defined.
Response: CWMP is an acronym for Caloosahatchee Water Management Plan. In addition to the main text, the acronym should have been included in the Glossary.

ID # W040
Comment / Question: Three adjustments to trigger levels are described: translation, truncation, and offset. The offset adjustment needs more explanation. I can't understand from the text or figures 3.4.2.8 and 3.4.2.9 how this adjustment is applied or what it achieves.
Response: We realize that the terminology is somewhat confusing. This section will be reorganized to clearly distinguish between the pre-processing of target hydrographs versus their use in the model simulation. The pre-processing of target hydrographs will be discussed first and the text will be changed to:

Adjustments to the input target hydrographs can be made in the *pre-processing phase*. Once an initial hydrograph has been generated (for example, from NSM), three adjustments of the hydrograph can be made to generate the target hydrograph:

1. Translations – Vertical shift or adjustment to target depth; e.g. shift the target depth timeseries by 0.2 ft (See Figure 3.2.4.6).

2. Truncations – Application of a maximum or minimum threshold depth to the target location; e.g. target depth not to exceed 1.5 ft depth (any depths that are greater are set to 1.5 ft) (See Figure 3.2.4.7).
3. Truncation of the target depth following the application of translation criteria; e.g. shift target depth time series by 0.2 ft, then limit target depth not to exceed 1.5 ft depth.

The term offset is reserved to refer to the adjustment of trigger levels *in the model simulation*. These offsets are inputs to the model and therefore can be easily modified by the user. As described in the documentation, there are two kinds of offsets. An import offset, applied to the import trigger target hydrograph, defines an environmental needs zone below which water supply deliveries from upstream are triggered. Two export offsets, applied to the export trigger target hydrograph, define zones of conditional releases (i.e. depending on whether downstream trigger has needs) and flood control releases (i.e. regardless of whether downstream trigger has needs).

ID # W042
Comment / Question: Section 3.5.5 Please define "permit" as used in this section. Does a permit imply an actual pumping volume is reported, or is it a maximum volume allowed? Are these permits for municipal withdrawals? Agricultural withdrawals? Private domestic well withdrawals?
Response: The first three paragraphs in Section 3.5.5 will be modified as shown below:

The historical well pumpage data file for the SFWMM v5.5 was extended to include the period 1996-2000. Historical pumpage data prior to 1996 was available from earlier model versions (Brion, 1999). The primary source of data was the USGS Water Resource Division, through the publication of historical water use data (1996-2000) for fifteen South Florida counties. The data represents reported monthly pumpages from the different water utilities at different well field locations. Groundwater sources (surficial vs. Floridian aquifers) were also used in the final determination of pumpage input data for the model. Utility-reported pumpage for the last year of simulation, 2000, was obtained from the SFWMD Water Use Regulation Division. Raw total monthly pumpages were used in the final determination of pumpage input data for the model.

A permit is issued by the South Florida Water Management District in order to give water use rights to a public utility or any other entities. Different water use permits are issued to withdraw water from the surface system or from groundwater storage. The permits referred to here apply to ground water withdrawals. A water use permit specifies the location, and the annual and monthly maximum withdrawal. Public water supply utilities and major irrigation applications require water use permits. These include golf course, nursery and other agricultural operations. Single residential houses are exempt from the permit application process.

Historical pumpage for some water allocation permits were excluded during certain years due to several reasons:

1. The permit might have already expired.

2. The permit was considered significantly small relative to the 2mile-by-2mile resolution of the model.
3. The permit referred to surface water withdrawals, which are not explicitly simulated as withdrawal amounts in the SFWMM.
4. Some permits were combined with others as a result of permit re-applications during the 1996-2000 period of record.

A FORTRAN program was used to transform reported pumpages associated with permits to pumpages assigned to SFWMM grid cells. The program has two basic inputs: well field pumpage file which shows monthly pumpages sorted by permit number and well distribution file which specifies the SFWMM grid cell assignment for each well that comprises each public water supply permit.

ID # W043
Comment / Question: Discussion of aquifer storage and recovery (p. 206ff). Somewhere it should be stated that the simulation of these and other potential storage and transmission alternatives makes implicit assumptions about the efficiency of the alternatives, which may be a best, guess at this point.
Response: A paragraph to this effect could be added as the last one in the Section describing Aquifer Storage and Recovery.

ID # W044
Comment / Question: p. 212 ff Operational Planning. The discussion of the Position analysis talks about a 36-year simulation that is re-initialized every year. Aren't this really 36 one-year simulations using 36 different historic weather patterns? The difference between conditional and unconditional Position Analyses deserves more discussion. When would each be used? In figure 3.6.2.6 why would the conditional position analysis not begin immediately?
Response: We find all these comments very appropriate. The Position Analysis section in the SFWMM document will be rewritten using the same format and outline as during the September workshop presentation. The PA simulation can also be viewed as 36 separate one-year simulations. The different types of position analysis will be clarified in the new write up. Conditional Position Analysis should be used whenever climate forecasts or outlooks substantially depart from what is considered "normal" or climatological behavior. Finally, in Figure 3.6.2.6, climate outlook calls for departure from normal by June, 8 months after the initialization in October.

ID # W045
Comment / Question: The discussion of initial condition determination says raw data were compared to snapshots of SFWMM to find "similar conditions". How were they compared? What constituted "similar"?
Response: The Position Analysis section in the SFWMM document will be rewritten using the same format and outline as during the September workshop presentation. Initial conditions for Position Analysis are determined on a basin (or compartment) by basin basis. For the gages for which current data is available, the recorded stage is compared to the simulated stage (extracted from the SFWMM snapshot) and the

difference computed. The initial condition is given by the snapshot for which all the differences are below a pre defined threshold value. The process starts with a small threshold and increases until the snapshot is found. Stages for the selected initial condition snapshot are derived by doing spatial interpolation of the initially computed differences on a cell-by-cell basis and applying those values to the selected snapshot.

ID # W046

Comment / Question: Slightly different methodologies and statistics were used to quantify the accuracy of calibrations in the EAA, LEC and LOSA. It would be logical that at least they all used the same statistical comparisons.

Response: The statistics used for the EAA (figs. 4.1.2.5- 4.1.2.8; 4.1.2.17 – 4.1.2.20) and LEC (table 4.2.2.1) calibrations are very similar: bias, RMSE, R squared & Efficiency. The statistics for LOSA calibration did not include Efficiency but added the following: model-measured error, error as a function of modeled value, slope of modeled-measured line and the Pearson correlation coefficient. Agree: It would be logical that all areas use the same statistical comparison.

ID # W048

Comment / Question: A list of significant parameters used to calibrate the LEC model is given on p. 234. Is this list exhaustive? Were aquifer characteristics (such as storativity, transmissivity) calibrated? Are there comprehensive tables of calibrated parameters in the appendices?

Response: The list of calibration parameters on page 234 is not exhaustive. The storage coefficient is adjusted during calibration on a sub-regional basis for Everglades cells. Also, individual cell topography values were adjusted in the Big Cypress National Preserve, where data sources are sparse and outdated. Transmissivity, land use and rainfall data were not adjusted during calibration. A comprehensive list of parameters could be added to this section or to an appendix.

ID # W050

Comment / Question: I do not really agree with the distinction given between sensitivity analysis and uncertainty analysis. I agree that sensitivity analysis defines the change in a particular output variable resulting from the change in a particular input variable, which can be a function of space, time and state of the input and output variables. Uncertainty analysis (at least with respect to input parameters) typically postulates in probability distribution for the input variables of interest and uses this information, together with the sensitivity computations to derive an output variable probability distribution.

Response: Here is how we plan to rephrase the distinction:

- Sensitivity Analysis is a procedure to determine the sensitivity of model outcomes to changes in its parameters.
- Uncertainty Analysis determines the probability distribution of entire set of possible outcomes by considering the uncertainties in model parameters and algorithm.
- As it pertains to SFWMM, UA is a procedure of mapping uncertainty bands of model outcomes from those of its parameters.

ID # W054
Comment / Question: I don’t understand what the x-axis of figures 5.2.1 and 5.2.2 is (percentile of what?). I also don’t understand figure 5.2.3. How were confidence levels in table 5.2.1 determined?
Response: Please refer to # J035 for the x-axis. The confidence levels in Table 5.2.1 were determined by checking the model output stage.

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