DP Loucks,
Consolidated Task 1
August 18, 2003

Modeling and Peer Review Protocols for Use in HSM (OOM) and IMC for CERP and RECOVER

Contents:

1. Background

The Interagency Modeling Center (IMC) has been established to provide modeling service to Project Development Teams (PDTs), the Restoration Coordination and Verification Program (RECOVER), and to senior management of the SFWMD and Corps. The CERP Guidance Memorandum (CGM dated July, 22, 2003) specifies the responsibilities and authority given to the IMC. These responsibilities and authority can be summarized as:

- Prioritize, coordinate, and provide consistency, technical guidance and oversight for all modeling applications,
- Approve model selection and insure that each requested application is carried out using the most appropriate model(s) and input data,
- Provide documentation of the modeling process itself as well as the modeling results, and to
- Insure that the results are expressed and made available in a way such that others in CERP can understand and benefit from that modeling application, as applicable.
- Implement peer reviews of models and their applications as deemed appropriate.

This CGM document suggests some procedures intended to accomplish these goals.

The modeling needed for PDTs and RECOVER has been divided into various groups based on spatial scale and the particular types of issues (disciplines) being addressed. There are three groups based on spatial scales:

- Regional (system-wide, such the South Florida Water Management Model (SFWMM (2x2)), the Regional Simulation Model (RSM), the Everglades Landscape Model (ELM), etc.)
- Sub-regional (covering CERP sub-regions, multiple CERP projects, or entire counties), and
- Project Specific (addressing project-specific questions and issues).

Each of these three spatial scale groups can be divided into different disciplines:

- Hydrologic
- Hydraulic
- Water Quality
- Ecologic
- Hydrodynamic
- Flood Protection

To help meet their responsibilities the IMC will need to implement some standard procedures for working with the PDTs and RECOVER and for insuring the quality of the entire model development and application process. They will need to identify among all the models that might be used, which are the most appropriate to address each of these separate groups of model applications. They must establish a model toolbox, from which clients can choose the model that best meets their needs (or perhaps argue that another model should be added to the toolbox). The IMC will also need to identify what documentation is appropriate to allow for peer reviews of any model and/or its use in a CERP project. These two topics are discussed in more detail later in this document.

2. CMM Level 3 Performance Expectations

The Corps and the District plan to meet the requirements of Capability Maturity Model Level 3 (CMM 1994) in software development and peer review. This level is reached when:

- Integrated modeling and model application processes are used throughout the organization.
- Modeling related problems are anticipated and prevented, or their impacts are minimized.
- Model development and application groups work together, perhaps as an integrated product team.
- Model use training is planned and provided as is needed.
- New modeling methodologies are identified and evaluated for possible implementation on a qualitative basis.
- Data are collected and used in all defined processes.
- Data are systematically shared across various projects.
- Both the models and their applications are evaluated and judged satisfactory by independent reviewers.

While planning for, conducting, and documenting these activities will require additional time and money, the expectation is that in the long run, such documentation and review will save time and money by redirecting misguided initiatives, identifying alternative approaches, or providing valuable technical support for a potentially controversial decision.

3. IMC Model Toolbox

Everyone will agree that all modeling applications should be performed with the 'best' models available. However, this should not mean that all models used should be the most detailed, complex, realistic and thus usually the most expensive models available. The decision regarding the 'best' or most appropriate model must be based on the particular issues or questions being addressed, on the quantity and quality of the available input data, and on the time, personnel, and money available to perform the modeling application. The central question to be answered before initiating any modeling application is just what model output information (and precision) is needed to meet the needs of the decision making process. Expressed in other words, just how sensitive will the decision be to the type, amount and precision of the model output?

In reality, IMC will need to judge the adequacy of the particular model requested by each client with respect to its data needs, its spatial and temporal resolutions, its documentation and status with respect to peer reviews, its capabilities, its limitations, and the theory upon which it is based. Similar considerations must be given to the proposed input data. To provide these services to each client requesting services from the IMC will require IMC to be staffed with personnel acquainted with models in each of these groupings, as well as be able to perform all the regional hydrologic simulations requested by PDTs and RECOVER. While many of the other subregional and disciplinary models may be contracted out, the technical content of the proposals written for this work, as well as the proposals written by the contractors to perform this work, will need to be reviewed and approved by the IMC. This is going to be a considerable amount of work for the IMC and they should be staffed accordingly.

4. Information Flows and Documentation

The IMC will be devoting a substantial amount of time giving guidance to clients and, when applicable, to the contractors involved in model applications. They will need to be working with the clients who are requesting model applications, and in situations where they are not doing this work, they will need to be reviewing and approving the work of the contractors who are performing the modeling services. Just what documents are to be prepared and approved together with these communication links can be illustrated in a Figure 1 below.

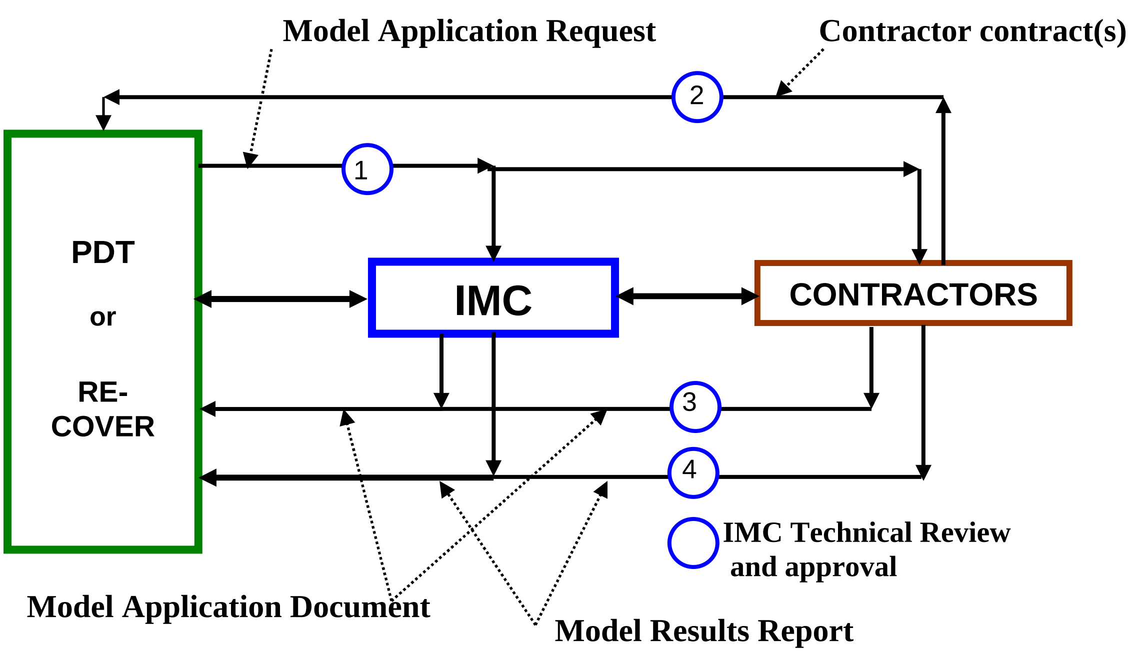

Figure 1. Schematic showing interactions, responsibilities and products involving clients, IMC and contractors.

One can imagine a modeling process that involves the following steps, as shown in the above schematic. The client, say a PDT, needs the results of a simulation or other type of model. The PDT prepares a Model Application Request (MAR) and submits it to the IMC. The IMC reviews that request (Circle 1) based on technical criteria, and perhaps after some negotiation, approves it, either to be done in house, i.e., by the IMC, or by a contractor.

If the modeling application is to be accomplished by IMC, the IMC works with the PDT throughout the process, and prepares two reports. One is the Model Application Document (MAD) that documents the modeling process, the assumptions made, the calibration and verification data and procedure, etc. The other is the Model Results Report.

If the modeling application is to be accomplished by a contractor, one or more contractors are asked to prepare a proposal for the work based on the approved MAR. The IMC reviews the proposals (Circle 2) to see if they meet technical criteria. Those that do are approved. The PDT then prepares the contract(s). The IMC works with the PDT and contractor to insure satisfactory performance, again from a technical point of view. Finally the IMC reviews and approves the Model Application Documentation (Circle 3) and Model Results Report (Circle 4).

Of course the final approval will be the client, in this scenario, the PDT. The client will also be responsible for selecting and making all administrative arrangements with any contractors. IMC serves only as a resource to provide technical assistance as well as oversight and coordination among all CERP modeling activities.

IMC should also be responsible for carrying out peer reviews of any of the steps in the model application process. Such peer reviews of model applications will benefit from having the documents mentioned above. Peer reviews of the models themselves could be the responsibility of the Office of Modeling.

5. Proposed Modeling Application Procedure

5.1 Modeling Application Request (MAR) (Statement of Work)

Each request for model results should be in the form of a proposal. This Modeling Application Request (MAR) should identify the

- Reason for modeling,
- Type of modeling (e.g., event based or continuous),
- Particular model preference if any, and why, and possible alternatives,
- Model output information (data) needed and why and when it is needed,
    - What questions are the model results going to answer?
    - What issues are being studied?
    - What decisions are to be made, or at least to be informed, based on these model results?
    - When are the model results needed?
- Location or site being modeled and the spatial and temporal scales desired,
- Particular boundary conditions and other regional assumptions required,
- Source of input data, and format required or desired for the output data,
- Model calibration and verification needs and preferred procedures if any,

- Money available for modeling,
- Extent (duration) of the simulations to be performed,
- Desired performance measures, other than variables being simulated, if any,
- Alternative scenarios to be modeled (i.e., number of simulation runs needed),
- Other analyses or model applications that may or will need the output from this model application,
- Sensitivity and uncertainty analyses needed, and for which decision variables and why,
- PDT or RECOVER contact person – e.g., the PDT leader,
- Requirements for intermediate reviews of results or needs for periodic review of modeling application process logs and documents, and
- Other particular requirements or needs.

This list of topics can be changed or modified to better meet the needs of IMC and CERP. They are mentioned above just as possible topics that might be considered.

PDTs should first identify the role of proposed modeling and how it contributes to the overall CERP. They should identify what part their project modeling contributes to the quantification of the overall conceptual model for the region or sub-region and what questions are the model results going to answer.

The use of a model nearly always takes place within a broader context. The model itself can also be part of a larger whole, such as a network of models in which many are using the outputs of other models. These conditions may impose constraints on the simulation modeling project. All these considerations need to be specified in the Modeling Application Request.

Along with the proposal, there should also be a simple order-of-magnitude estimate of the expected values of all relevant decision variables based on simple mass-balance analytical solution methods that can be used without requiring a computer. These estimated values should be used to validate (check the reasonableness of) selected portions of the model runs. If there are any serious discrepancies, it may signify a major problem in the model output (suggested by Lal).

Question: Is all this paperwork useful?

Preparing a formal modeling application request requires some serious thought as to just why modeling is necessary and just what information is needed to further the project or analysis by PDT's or RECOVER. It involves defining the problem to be modeled and the objectives that are to be accomplished. Writing this down in some detail helps reduce the differences in perception that can exist between those who need information (e.g. a PDT or RECOVER) and those who are going to provide that information (IMC or a contractor). The problem as stated is often not the problem as understood, by either the client or the model user. In addition, problem perceptions and modeling objectives can change over the duration of a project. One should ask and answer the question of whether or not modeling in general is the right way to obtain the needed information. What are the alternatives to modeling?

5.2 IMC Response to MAR

Once IMC receives a Modeling Application Request the appropriate IMC team leader should prepare a timely response to the PDT or RECOVER who submitted the MAR, taking into account the need for

- model coordination, compatibility, and its importance or benefit for the entire CERP,
- IMC or contractor resources available, and
- model application priorities.

This response might be an acceptance of the conditions specified in the MAR, or it might suggest changes. For example, the decision to use a model, and which model to use, is an important decision in implementing CERP. Even though there are no clear rules on how to select the 'right or best' model for the particular application, IMC might suggest an alternative model based on their assessment of

1. The problem being addressed and what information is needed and what questions are to be answered.
2. The desire to use the simplest method that will provide the required accuracy and address the issues and questions being considered.
3. The availability of another model that better fits the problem and meets the information needs.
4. The value of the accuracy desired compared to the increased effort and increased cost of data collection.
5. Assumptions underlying the proposed model and their influence on the simulation results and their reliability or usefulness.

Once the MAR, perhaps as modified based on the IMC response, is approved by the IMC, the IMC can fit this work into their work schedule and inform the requesting team or group when the work should begin and when it should be completed, assuming no mid-process changes. Alternatively, the PDT can have the application performed by a contractor and reviewed by IMC, as discussed above.

The objective of any modeling project should be clearly understood with respect to the domain and the problem area, the reason for using a particular model, the questions to be answered by the model, the model assumptions and limitations, and the scenarios to be modeled. Throughout the project these objective components should be checked to see if any have changed and if they are being met.

If IMC is to serve as a central point to coordinate CERP and CERP-related modeling activities, and to provide modeling services, it needs to have the authority to do so. This authority extends to giving advice to the PDTs and RECOVER related to their particular modeling application requests (MARs). This includes issues related to model and input data selection, and for reviewing, approving and prioritizing MARs. Should contractors be involved in particular model applications, IMC must be authorized to specify the technical terms to be met and oversee the work done by the contractor. Finally IMC will need the financial and human resources needed to do this in a timely manner.

5.3 Modeling Application Documentation

One common problem of model studies once they are underway occurs when one wishes to go back over a series of simulation results to see what was changed or why a particular simulation was made or what was learned. It is also commonly difficult if not impossible for third parties to continue from the point at which any previous modeling project was terminated, especially if some time has passed. These problems are caused by a lack of information on how the study was carried out. What was the pattern of thought that took place? Which actions and activities were carried out? Who carried out what work and why? What choices were made? How reliable are the end results? These questions should be answerable if a model journal is kept. Just like computer programming documentation, this modeling project documentation is often neglected under the pressure of time and perhaps because it is not as interesting as running the models themselves.

The paper trail of what has happened, what assumptions have been made, how calibration and verification were carried out, what results were obtained, why changes, if any, were made, what sensitivity analysis procedures were used and their results, and so on, are to be contained in the Modeling Application Documentation (MAD)*. This documentation begins with the sequence of MARs and IMC Responses and the final approved MAR. Once the model application is completed, a copy of the MAD should be given to the PDT or RECOVER, as applicable and a copy should remain in IMC. These reports, or at least a summary of them, should be available for downloading from the web. Should further model applications be requested and approved, the requester as well as the IMC can refer to this previously prepared documentation to better understand what was done previously that pertains to the current request.

**(MAD is easy to remember. Those having to prepare such documentation will probably be mad!)*

5.4 Modeling Application Process

Applying a model to a particular project to predict the project's impacts is called model application. The process of initiating and carrying out a model application includes:

a) Select Model and Input Data
b) Analyze the Model
c) Use the Model
d) Interpret Model Results
e) Report Model Results

Each of these steps is discussed in the following sections.

a) Select the model and input data

The selection of an existing model and its data to be used in any simulation depends in part on the type of model needed (event-based or continuous), on the processes and the range of alternative scenarios or assumptions that are to be simulated, and on the availability of input data required by the model. The available data must include system observations for comparison of the model results. They should also include estimates of the degree of uncertainty associated with each of the model parameters. At a minimum this might be only estimates of the ranges of all uncertain parameter values. At best it could include statistical distributions of them. In this step of the process it is sufficient to know what data are available, their quality and completeness, and what to do about missing or outlier data.

Determining the boundaries of the model is an essential consideration in model selection. This defines what is to be included in a simulation model and what is not. Any model selected will contain a number of assumptions. These assumptions should be identified and justified, and later tested.

Project-based matters such as the computers to be used, the available time and expertise, the modeler's personal preferences, and the client's (PDT or RECOVER) wishes or requirements may also influence model choice. An important practical criterion is whether there is an accessible manual for operating the model program and a help desk for any possible problems.

b) Analyze the model

Once a model has been selected or developed its strengths and limitations should be studied in more detail. For any models that are not known to the IMC, the first step is to set up a plan for testing and evaluating the model. These tests can include mass (and energy) balance checks and parameter sensitivity analyses. The model can be run under simplified as well as extreme input data conditions to see if the results are as expected.

The selected spatial and temporal discretization has to be checked to see if it meets the resolution requirements of those responsible for making project design or operating decisions. (suggestion of Lal)

Once a model is tested satisfactorily, it can be calibrated. Calibration focuses on the comparison between model results and field observations. In general the smaller the deviation between the calculated model results and the field observations, the better the model. This is true to a certain extent, as the deviations in a perfect model are only due to measurement errors. In practice, however, a good fit is by no means a guarantee of a good model.

The deviations between the model results and the field observations can be due to a number of factors. These factors include possible software errors, inappropriate modeling assumptions such as the (conscious) simplification of complex structures, neglecting certain processes, errors in the mathematical description or in the numerical method applied, inappropriate parameter values, errors in input data and boundary conditions, and measurement errors in the field observations.

To determine whether or not a calibrated model is a 'good' predictor, it should be validated or verified. Calibrated models should be able to reproduce field observations not used in calibration. Validation can be carried out for calibrated models as long as an independent data set has been kept aside for this purpose. If all available data are used in the calibration process in order to arrive at the best possible results, validation will not be possible. The decision to leave out validation is often a justifiable one especially when data are limited.

Philosophically it is impossible to know if a simulation model of a complex system is 'correct'. There is no way to prove it. Experimenting with a model, such as by carrying out multiple validation tests, can only increase confidence in that model. After a sufficient number of successful tests, one might be willing to state that the model is 'good enough', based on the modeling project requirements. The model can then be regarded as having been validated, at least for the ranges of input data and field observations used in the validation.

If model predictions are to be made for situations or conditions for which the model has been validated, there may be some confidence in the reliability of those predictions. Yet one cannot be certain. Much less confidence can be placed on model predictions for conditions outside the range for which the model was validated.

While a model should not be used for extrapolations as commonly applied in predictions and in scenario analyses, this is often exactly the reason for the modeling project. What is likely to happen given events we have not yet experienced? A model's answer to this question should also include the uncertainties attached to these predictions. Depending on the type of model selected and used, one might end up predicting an incorrect future with great accuracy, or predicting the correct future with great uncertainty'. We don't yet know how to predict the correct future with great accuracy – so we do 'what ifs'. One can then argue about what scenarios – the ifs – are the most reasonable or probable, or about the impacts from improbable scenarios that you want to avoid should such scenarios occur. Models can not contribute to that debate.

c) Use the model

Once the model has been judged 'good enough,' the model may be used to obtain the information desired. The PDT's or RECOVER's MAR should specify how the model is to be used, identifying the input to be used, the time period(s) to be simulated, and the quality of the results to be expected. Even given a complete specification of these expectations may be in the MAR, close communication between the client and the modeler during the modeling application process is essential to avoid any unnecessary misunderstandings about what information is wanted and the assumptions on which that information is to be based.

Before the end of this model-use step one should determine whether all the necessary simulations have been performed and whether they have been performed well. Questions to ask include

- did the model fulfill its purpose?
- are the results valid?
- are the quality requirements met?
- was the discretization of space and time chosen well?
- was the choice of the model restrictions correct?
- was the correct model and/or model program chosen?
- was the numerical approach appropriate?
- was the implementation performed correctly?
- what are the sensitive parameters (and other factors)?
- was an uncertainty analysis performed?

If any of the answers to these questions is no, then the situation should be corrected. If it cannot, there should be a good reason for why it cannot be corrected and that should be documented in the MAD.

d) Interpret model results

Interpreting the information resulting from models is a crucial step in the modeling application process, especially in situations in which the client may only be interested in those results and not the way they were obtained. The model results can be compared to those of other similar studies. Are the results consistent? IMC must make that judgment. Any unanticipated results should be discussed and explained. The results should be judged with respect to the modeling project objectives.

The results of any modeling project typically include large files of time-series data. Only the most dedicated of clients will want to read those files. Thus these data must be presented in a more concise form. Statistical summaries should explicitly include any restrictions and uncertainties in the results. They should identify any gaps in the domain knowledge, thus generating new research questions or identifying the need for more field observations and measurements.

e) Report model results

Once the modeling application is completed, the organization doing the modeling (IMC, HSM, contractor) will be responsible for preparing a Model Results Report (MRR). The contents of this report should conform to the agreement made between modeling organization and the client prior to the initiation of the modeling application (see above). Although the results of a model are very rarely used as the sole basis for policy decisions, those requesting model applications may have a responsibility to translate their model results into policy recommendations. Policymakers, managers, and indeed the participating stakeholders typically want simple and clear unambiguous answers to complex questions. Much of the scientifically justified discussion, say regarding the uncertainties associated with some of the data, included in the main body of a report are not included in the executive summary of that report. This executive summary is often the only part read by those responsible for making decisions. Therefore, the conclusions of the model study must not only be scientifically correct, but also concisely formulated, without jargon, and fully understandable by managers and policymakers. When preparing of reviewing contractor Model Results Reports, the IMC should consider this need.

This MRR together with the completed MAD should include sufficient detail to allow others to reproduce the model study (including its results) and/or to proceed from the point where this study ended. The report therefore requires a clear indication of the validity, usability and any restrictions of the model results.

6. Data Management

CERP models will require data. They will also produce data. Many of these data will have spatial and temporal dimensions. This information must be documented (meta data), preserved, and made accessible to IMC customers, coordination agencies and others. IMC will rely on the CERP shared information network and CERP data management system being implemented as part of the CERP Data Management Program. IMC will need to participate in data management strategic development, storage, documentation and dissemination. It will need to work with data base managers of various agencies to help them satisfy the IMC's truly massive data management requirements.

7. Peer Review

The predicted impacts and other information derived from models applied to CERP projects can influence major investment decisions. It is thus self evident that those who use the model results have some indication as to their reliability. Are they derived from models whose science has been reviewed and judged correct? Is the model software free from errors? Are the assumptions made when performing the modeling the correct ones? Are the model results accurately and fully reported? In other words, just how much credence should decision makers place in the model output? Users of the Model Results Reports should be assured that the information contained in them is credible and unbiased. One way to help insure this is to have the models, their associated software, and their applications peer reviewed.

IMC is responsible for creating a toolbox of 'acceptable' models for use by the PDTs and RECOVER. These models will be a mix of those developed by the District, and those developed by other individuals or organizations. In both cases, before any model is placed in the toolbox they should be peer reviewed with respect to their applicability and suitability for use in CERP. If the models have been developed outside of the District, and have been in wide use elsewhere in the world, the theory and coding of these models are likely to have been peer reviewed by others. Examples might include the models obtained from the Corps or from EPA, or the Mike models from DHI. In such cases IMC might decide to have models peer reviewed only for their suitability to conditions here in south Florida. Once they are peer reviewed with respect to their suitability, and for their strengths and limitations, they could be placed in the toolbox. The same would apply to District models that have been previously developed and peer reviewed. For new District models, such as RSM or ELM, a more thorough peer review may be justified. This review could be of the theory underlying the model, the model's software, the documentation of that software, the model's functions and capabilities including those pertaining to model data input and output, model calibration and verification, sensitivity analyses, uncertainty analyses, user control (GUIs), spatial and temporal resolutions, limiting assumptions, and on the model (as opposed to code) documentation.

Just having evidence of published articles about a particular model in peer reviewed journals is not a substitute for a peer review of the model software and its applicability or suitability for certain types of analyses for CERP.

Peer reviews of CERP models, their software, and their use should be accomplished by experts both within and outside of the District, the Corps, and other 'inside' agencies. 'Inside' agency (or internal) reviews may uncover some needed changes and identify other issues or problems that external reviewers could be asked to specifically examine and address. Internal reviews can make the external review process more effective, less costly and less time consuming.

Peer reviews are considered a key process area for Level 3 of the Capability Maturity Model guidelines for improving the software process (Carnegie Mellon University, 1994). The purpose of peer review evaluations is to find defects in the model formulation and software and in its use, i.e., model application. Peer reviewers can also identify possible ways of correcting those defects, if any. If there are no defects, or after all known defects have been corrected, both the developers and users of any model and its software can have a stronger basis for believing that their product and its output are reliable.

Peer reviews serve the same function as accountants. Once a firm's financial records have been peer reviewed by accountants (assuming they are qualified, objective and honest) the board of directors as well as the stockholders will have more assurance of the liabilities and net worth of their firm, and just how well it is being managed. In this case it is the assurance of the quality of the models, their software, and on their use in project evaluations, that actual and potential users of the model results depend upon.

Peer review can be an important tool for judging the quality and credibility of the science upon which decisions are made. Modeling can be divided into three stages, each of which can be peer reviewed:

Models are developed to serve various purposes. These include

- To test different hypotheses and thus to increase scientific understanding.
- To be used as project screening tools.
- To be used to help design and operate infrastructure, or to provide detailed and as precise as possible estimates of impacts.

Each model and its associated material that is used in CERP should be, or have been, peer reviewed. Commercial models widely used throughout the world probably have undergone a peer review in general, but may need some additional verification of their applicability to south Florida. Models developed in house clearly should be peer reviewed, and it is only a question of just how detailed the review should be. Each model and its associated software and documentation should meet certain standards with respect to how well they serve their particular purpose, how well they are conceived (mathematical approximation of the physical, chemical or biological, social, or economic system being analyzed), the adequacy and utility of the model interface for model inputs and outputs and user control, the appropriateness of the algorithms used for numerical solutions and the functions that can be performed (such as sensitivity and uncertainty analyses, calibration and verification procedures, etc.) and the issues that can be addressed, all compared to the current state of scientific understanding and the tools of computer science and technology.

The types of problems and issues for which a model, its software, and its documentation are designed to address are called the model's 'application niche'. Peer review of model development should include the evaluation of the intended application niche along with consideration of other aspects of model performance. Users of any model should be aware of the types of analyses for which the model is best suited and those for which the model is not well suited. This, along with the results of a peer review of any model application, should help the potential model user, or the user of the model results, better understand the limitations of the scientific basis of the model and just how much confidence can be placed on the model output.

7.1 Peer review triggers

Clearly judgment will have to be exercised as to just when and in what detail a peer review needs to be implemented. However the triggers on when a decision about a peer review needs to be made can be defined. The diagram shown in Figure 2 identifies those decision events.

As shown in Figure 2. decisions regarding peer review are needed when models are proposed for the tool box and when model applications are completed. Should IMC decide a peer review is warranted when either of those events takes place, they will have to decide on the type of review and its level of detail. They will also need to identify the individuals to be asked to carry out that peer review.

Peer reviews are going to take time and cost money. They will also require IMC time to prepare the documentation needed for the peer reviewers and to read and act on reports prepared by the peer reviewers. This will apply if the peer review is internal or external.

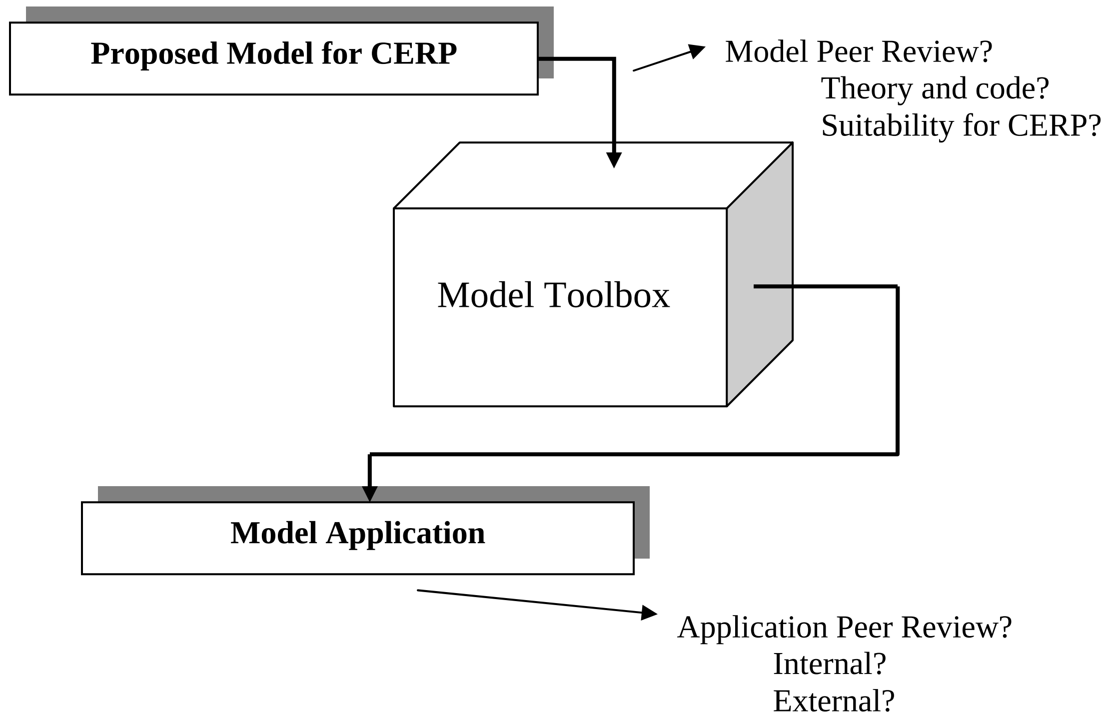

Figure 2. Schematic showing events where a peer review decision can be made.

The particular models and their associated software and documentation to be peer reviewed should be identified by the individuals or departments or agencies (Office of Modeling, IMC, PDTs) that are responsible for determining just which models are to be used by CERP PDTs and RECOVER. This can include model process descriptions, software source code, documents, test results, and other supporting materials, as needed, for an adequate peer review of the entire model and its software. These products to be reviewed should be identified in writing and a written history of the review of different versions of each item should be maintained.

Events that take place in the progression of model development and use and subsequent modifications that warrant a peer review should be identified and specified in a written document. (This fits in to the model development and use documentation that should be maintained for Level 3 CMM) When these events take place a peer review process should be considered, and if warranted, implemented. Depending on the event, the review can be solely internal, or it can involve an independent external review team as well.

Model application reviews should include an evaluation of the intended model application niche, and its applicability to current needs. Peer review may be appropriate for existing models when new information becomes available that could negate some or all of the conclusions of previous reviews or suggest a change in the currently specified application niche. Peer review of a model's applicability to a particular CERP or RECOVER study should be planned well in advance of when model results are needed. The results of application reviews can influence the decisions made based on the model outputs. Once a peer review has been conducted for a particular model and its input data, peer reviews of subsequent applications of a model with similar inputs might be unnecessary. However, any time a PDT or RECOVER feels the model results may be controversial, or end up being litigated, another peer review may be justified.

7.2 Peer Review Process

The extent and process of performing and responding to peer reviews can vary in any organization. The ones discussed in this section attempt to follow the processes recommended by the Capability Maturity Model Level 3 guidelines.

CERP project peer review process should be specified in writing. A first step in this process should be to identify the particular modeling products and processes that will undergo peer review. This includes the models (i.e. the processes being modeled and the assumptions built into the models for describing these processes), their supporting software, the documentation of the model and its software, as well as all the written guidelines on how the models are to be used.

A second step is to perform an internal peer review prior to a model's use for project evaluation. It should be peer reviewed for accuracy, its suitability for use, and for identifying any possible errors in its logic, its coding, or in its documentation. Following an internal review, an external peer review can be performed.

Following the successful conclusion of internal and external peer reviews of a model and its documentation, the model can be applied to evaluate alternative projects. After the model has been applied to a particular project, the modeling process and its results should be peer reviewed to insure that the model has been applied properly, that the input data were appropriate, and that the conclusions drawn were valid.

Peer review teams should be selected, along with a peer review team leader. The particular personnel on the team will depend on the particular model and its software and documentation being reviewed. The District should have a list of qualified peer reviewers representing all applicable disciplines, both internal and external, that it can call upon to perform these reviews. The peer reviews are to be of the models and their use, not of the people who developed or used them. The reviews are to be used to evaluate the quality of modeling products and processes, not of the personnel involved.

Establishing and carrying out ongoing peer review processes costs money. Adequate funding must be made available to

1. identify and recruit a peer review team and team leader
2. prepare and distribute the peer review materials to the peer review team
3. support the time required for the team to review the materials prior to a team meeting
4. support the team meeting and to participate in it as appropriate (e.g., answering questions, conducting model experiments and sensitivity analyses, etc.)
5. reproduce and distribute the team report and to take actions as needed
6. monitor the modifications or changes being made to the model, its software, and its documentation, or redoing the model application, as needed.
7. prepare and distribute to model developers and potential users a report on the results of the peer review and the actions taken.

The particular peer review process may depend on just what is being peer reviewed and the resources and time available to perform the review. In general, however, the steps of a peer review could include the following:

1. The District (Office of Modeling together with IMC) should identify and establish a pool of possible reviewers representing various disciplines, with sufficient redundancy to allow for scheduling conflicts when ever some subset of those reviewers are needed. This includes both internal as well as external reviewers. What ever administrative work is need to establish this pool should be completed prior to when these reviewers will be needed.

2. At particular milestones in any new model development or in model application an internal peer review process could be initiated, to examine the modeling assumptions, the software that implements those assumptions in the case of model development or the data being used for model inputs in the case of model applications, and the documentation being prepared to describe the processes, to document the software code, and to document the tests that were run to test the code, or to document the results of the model application. If deemed appropriate, an external peer review could also be performed. If an external review is to take place, the particular reviewers need to be selected, notified, sent supporting documents, and be scheduled for one or more meetings, as needed. They should be issued contracts specifying the requirements (the checklist of items to be reviewed) and products expected.

3. Recommendations made by the peer review team need to be addressed and the actions taken along with the rationale for those actions should be documented.

4. The peer review team should review the actions taken and the results obtained from these actions. If not judged acceptable new recommendations should be made and submitted. A final report should be prepared by the peer review team when all recommendations have been successfully implemented or addressed, or if no further actions based on review team's recommendations will be taken by the model developers or users.

7.3 Peer Reviewer Selection and Information Needs

Peer review teams should be knowledgeable in their particular disciplines or fields of expertise, and they should be experienced and trained in conducting peer reviews of model products. They should be aware of the scope of the reviews to be performed, and the documentation expected from them. They should know how to plan and organize and carry out a peer review. They should know if and how they will track and confirm any recommended changes in the model, its software, its use, and/or its documentation. They should be aware of the criteria upon which to base the review, and the material that should be provided to carry out the review.

The qualifications for peer reviewers will likely vary for model development as compared to model application. If model software code is to be reviewed, the peer review team should be knowledgeable in code design and documentation standards and test procedures. Emphasis may be given to computer programmers and scientists, systems engineers, and modelers in the particular disciplines being modeled. For model applications, peer reviewers will likely be those familiar with the application site, the input data, the disciplines pertaining to the impacts being predicted, statisticians, systems engineers, and the like.

The time and effort required for various levels of review should also be assessed and provided to the review team so that they can carry out the level of review requested of them. Otherwise the reviews may be superficial and while appearing to be peer reviewed, a model and its associated products may in fact be inadequately reviewed. Peer review teams have the responsibility to specify in writing the scope and limitations of their reviews.

The materials to be sent to the review team to allow them to prepare for their meeting should include the statement of review objectives and the level of detail desired, the applicable requirements and standards upon which to judge the adequacy of the products being reviewed, and of course the material that is to be reviewed. There should be a list of questions for the reviewers to address. Each review team member should be assigned and given responsibility for answering specific questions and for completing specific aspects of the overall review. All team members should be given specific review standards or requirements, including the expected completion dates. Checklists should be provided the review team that are applicable to the specific type of product being reviewed and the level of detail to be examined. These checklists will contain the criteria for judging the product, such as compliance with any standards and procedures, completeness, correctness, rules of construction, and maintainability.

7.4 Peer Review Issues and Questions

Each model development or application review will dictate its own special set of questions to be addressed. Some of these questions could relate to:

- Model Purpose and Objective
    - Use of model related to decisions being considered.
    - Model application niche, and why.
    - Model strengths and weaknesses –is it the best model?
- Model Processes and Limitations
    - Model processes, spatial and temporal scales, grid resolution.
    - Model variables and level of aggregation.
- Model Theoretical Basis
    - Model algorithms, numerical or analytical methods,
    - Model process formulation
    - Modeling approach in comparison with other models
    - Any shortcomings in relation to application niche
- Model Parameter Estimation
    - Methods used
    - Data available for parameter estimation
    - Parameter estimate reliabilities
    - Boundary conditions and appropriateness.
- Model Input Data Quantity/Quality
    - Data used in design of model
    - Data adequacy (quantity, quality, resolution) for model purpose and application
    - Data necessary for application of model
    - Key data gaps in model application
    - Additional data needs and why
- Model Key Assumptions
    - Basis for major assumptions
    - Sensitivity of model outputs to key assumptions
    - Sensitivity of potential decisions to key assumptions
    - Ease in modifying key assumptions
- Model Performance Measures
    - Criteria for assessing model performance
    - Correspondence of model output with measured observed data
    - Any model bias throughout range of model predictions
    - Variability and uncertainty analyses and representations in model results
    - What determines model's variability and uncertainty.
    - Model performance relative to others in application niche
- Model Documentation and User's Guide
    - Clarity of documentation, comprehensiveness of user's guide
    - Model applicability and limitations
    - Input data requirements for calibration, verification, model runs
    - Post modeling analyses, display and interpretation of results
    - Model code documentation
    - Model application documentation examples for prospective users.
- Review Retrospective
    - How well model and its application meet objectives and needs of project

- Possible changes in the model to improve model performance
- Robustness of model solutions to small changes in uncertain parameters, etc.
- Ease of including uncertainty analyses associated with uncertain input data.
- Key research needs for model improvement.

7.5 Peer Review Completion Reports

Procedures need to be established to track and confirm actions based on suggested changes or modifications in the material being reviewed. Once these actions are taken and completed, and documented, the peer review process for that particular product is completed. Peer review completion reports should contain data on what was reviewed and the results of the review. These data should include a description of the products that were reviewed, the level of detail of the review, any review limitations or qualifications, the number and backgrounds of the reviewers, the time spent preparing for and during review team meetings, the defects found and recommendations made, and the actions taken to address these recommendations.

7.6 Overall Peer Review Evaluations

The District (Office of Modeling, IMC) should document the planning for and scheduling of peer reviews. The products to be reviewed and the level of detail to be examined also need to be specified. The procedures to be followed for selecting peer review team members, and the team leader, should also be determined and documented. Procedures for training potential reviewers, if such training is needed, should be identified and implemented, as required.

Periodically the District (Office of Modeling, IMC) should assess just how well the plan described in the preceding paragraph is being carried out, and just how beneficial these peer reviews are to the overall modeling effort. Measures should be identified and used to determine the status of the peer review activities. These measures could include the number of completed peer reviews performed compared to the number expected to be performed, the overall effort expended on peer reviews compared to that expected, and the number and extent of peer review recommendations requiring actions.

At a minimum these periodic reviews should verify that

1. The planned peer reviews and/or audits are conducted.
2. The peer review leaders are adequately trained for their roles.
3. The reviewers are properly trained or experienced in their roles.
4. The processes for preparing for and conducting peer reviews, and for following up on reviewer's recommendations are adequate and are being followed.
5. The reporting of peer review results is complete, accurate, timely and is being made available to model users.

7.7 External Peer Review Committee for Office of Modeling and IMC

The South Florida Water Management District Strategic Modeling Plan prepared by Plato Consulting, Inc., (June, 2003) defines a method to be used for model development, implementation, and application. The method is designed to 'ensure the soundness of the science and processes that are applied to the modeling effort.' The objective of this Modeling Plan is to improve the consistency and quality of the models being developed and used in support of CERP project planning and analyses and RECOVER.

The Plato report cites the need for peer reviews at two stages of a model's life cycle (Figure on page 28, Plato Report): Code Development Algorithm Testing and Documentation, and Model Implementation (data set development, calibration, verification, sensitivity analyses). Peer reviews of model applications are also possible, and potentially helpful. Furthermore, CMM Level 3 requires it.

The CERP Guidance Memorandum (22 July 2003) groups IMC's modeling activities by spatial scale and subject discipline. This document identifies possible peer reviewers for each of these modeling activities. These peer reviewers could be asked to review particular models, their documentation, or their application either individually or as part of a team or panel of reviewers. Reviews of models themselves could be based on the underlying theory and its description in the actual software code; on model testing, calibration, verification, sensitivity and uncertainty analyses procedures and capabilities; and on model documentation. Reviews of model applications could focus on the appropriateness of the model, its input data, its calibration and verification procedure, and on the interpretation and use of model results.

The skills of outside experts need to range from those required for reviewing the theory upon which the model is based, its translation to software, and the software documentation, to those that are able to critically review site-specific applications of the model. The individuals listed below are among those who I believe could provide such reviews. They are well known and respected for their expertise in modeling in these various disciplines. Some have already been consultants to the District or Corps. Most have served on national review panels in their particular subject areas. Specialists in the supporting areas of computer sciences, chemistry, biology, hydrogeology, hydraulics, economics, social sciences, etc. are not included (there are just too many!).

The following list of potential reviewers is divided into various groups somewhat corresponding to the classification of modeling applications used by the IMC. However, many of the individuals in one group could also be candidates for reviewing models or their applications in other groups as well. The Appendix of this report contains brief resumes and contact information obtained from the web.

a) Regional Hydrologic Modeling

Professor Rafael Bras (MIT) hydrologic statistics
Professor Wilfred Brutsaert (Cornell University) ET expert

Professor Steve Burges (University of Washington) hydrologic systems
Dr. Hal Cardwell (Corps of Engineers, IWR) shared vision modeling,
Dr. Norman H. Crawford (Hydrocomp, Inc.) software, hydrology
Dr. David Curtis (Onerain, Inc.) precip forecasting
Dr. Daryl Davis (Corps of Engineers, HEC) model software development
Professor John Dracup (University of California, Berkeley) climate systems
Professor Darrell Fontane (Colorado State Univ.) water quantity-quality modeling
Professor Efi Foufoula-Georgiou (Univ. Minnesota) stochastic modeling using remote sensed data
Professor Aris Georgakakos (Georgia Institute of Technology)
Professor Jim Heaney (University of Florida) urban systems
Professor Keith Hipel (University of Waterloo) systems, statistics, general
Professor Ben Hobbs (Johns Hopkins University) conflict res. multiobjective
Dr. Chuck Howard (Charles Howard Assoc.,Victoria, BC) systems
Professor Wayne Huber (Oregon State University) runoff, hydrologic systems
Dr. Konstantine Georgakakos (Hydrologic Research Ctr. San Diego) hydrometeorology
Professor Witold Krajewski (Univ. of Iowa) radar hydrometeorology, stochastic hyd. water quality modeling, systems planning
Professor John Labadie (Colorado State University) regional sim/op modeling
Professor Upmanu Lall (Columbia University) statistical, climate, modeling
Dr. Dennis Lettenmaier (University of Washington) climate, hydrology
Professor Jay Lund (University of California, Davis) simulation/optimization
Professor David Maidment (University of Texas, Austin) GIS
Professor Rick Palmer (University of Washington) systems modeling
Professor Marc Parlange (Johns Hopkins Univ.) land-atm. interaction, ET
Professor Ken Potter (University of Wisconsin) hydrology
Dr. Pedro Restrepo (NWS-Silver Springs) hydrology and water resource systems
Professor Rene Reitsma (Oregon State University) decision support systems
Professor Larry Roesner (Colorado State University) hydrologic and wq modeling
Dr. Daniel Sheer (Hydrologics, Inc.) optimization/simulation
Professor Jery Stedinger (Cornell University) syn. hydrology, statistics, optim.
Professor Rich Vogel (Tufts University) Statistical hydrology
Dr. Jim Wallis (Yale University), hydrologic modeling

b) Sub-regional and Project Specific Hydrologic and Flood Mgt. Modeling

Dr. David Ford (David Ford Consulting Engrs.) flood plain management and modeling
Dr. Gerry Galloway ( ) flood plain management
Mr. Allen Groover (Dewberry Companies) stormwater management, FEMA
Professor Jennifer Jacobs (University of Florida) vegetation hydrology, remote sensing, ET
Professor David Moreau (University of North Carolina) urban hydrologic systems

c) Ecological Modeling

Professor Jim Anderson (Univ. of Washington) Fish and ecological systems
Professor Mark Bain (Cornell University) Fish and habitat

Professor Roel Boumans (U. Vermont) ecosystem services
Professor Barbara Bedford (Cornell University) Wetlands ecology
Professor Frank Davis (University of California, Santa Barbara) landscape ecol.
Professor Charlie Hall (Syracuse University) landscape ecology, systems
Edwin E. Herricks (Univ. of Illinois) monitoring, organism-habitat, wetlands
Professor Carolyn Hunsaker (Forest Service) spatial ecology, remote sensing, GIS
Professor Robert Gardner (U. Maryland) landscape ecology, dynamics
Professor Peter Goodwin (U. of Idaho) ecohydrology, computational hydr
Professor Carl Jordan (Univ. of Georgia) agroecology
Professor Michael Kemp (Univ. Maryland) estuarine ecosystems
Professor Si Levin (Princeton University) General, math. ecologist
Dr. Gene Likens (Inst. of Ecosystem Studies) ecological systems
Professor William Mitsch (Ohio State University) wetland ecology
Dr. John Nestler (Corps of Engineers, ERDC) fish modeling
Professor Scott Nixon (University of Rhode Island) estuarine wq
Professor Enrique Reyes (Louisiana State U.) coastal ecology
Professor Suresh C. Rao (Purdue University) aquatic and terrestrial ecosystems
Professor Edward J. Rykiel, Jr. (Washington State U) landscape ecology, regional planning
Professor Monica Turner (U. Wisconsin) spatial ecology
Professor Carl Walters (Florida State University) Adaptive management and ecosystem modeling

d) Water Quality Modeling

Professor Lynn Gelhar (MIT) stochastic gw modeling
Professor Bruce Beck (University of Georgia) water quality modeling
Professor Steve Chapra (Tufts University) wq modeling, numerical methods
Professor Dominic M. Di Toro (University of Delaware) rivers and estuaries
Professor Wu-Seng Lung (University of Virginia) hydrodynamic wq modeling
Dr. Gerry Orlob (University of California, Davis (ret.)) hydrodyn. wq modeling
Professor Ken Reckhow (Duke University) TMDL and water quality modeling
Professor Jerald Schnoor (University of Iowa) phytoremediation, wq & gw modeling.

e) Hydrodynamic and Groundwater Modeling

Professor Mary P. Anderson (Univ. Wisconsin) gw modeling – quality
Professor Alan F. Blumberg (Stevens Institute of Technology) marine hydrodynamics
Professor Forrest Holly (University of Iowa) computational hydraulics sed. transpt.
Professor Daene McKinney (University of Texas, Austin) gw modeling, systems
Professor Dennis McLaughlin (MIT) systems and gw modeling
Professor George Pinder (University of Vermont) gw modeling
Professor Jorge Restrepo (Florida Atlantic Univ.) hydrogeology, GIS, wetland
Professor Christine Shoemaker (Cornell University) gw modeling,
Professor John Wilson (New Mexico Tech.), gw modeling
Professor Bill Yeh (University of California, Los Angles) gw and systems
Professor Larry Weber (University of Iowa) computational hydraulics, simulation

8. References

Brandt, L.A. and Ogden, J.C., 2003, Peer Review Guidance for RECOVER, Draft, July

Carnegie Mellon University, 1994, The Capability Maturity Model: Guidelines for Improving the Software Process, Addison Wesley, Boston

CERP Guidance Memorandum, SFWMD and Corps of Engineers, July 22, 2003

EPA, 1994, Guidance for Conducting External Peer Review of Environmental Regulatory Models, Agency Task Force on Environmental Regulatory Modeling, EPA 100-B-94-001, July

Plato Consulting, Inc., 2003, South Florida Water Management District Strategic Modeling Plan, June 6

Appendix

Contributions to CERP jargon:

MAD Modeling Application Document
MAR Modeling Application Request
MRR Model Results Report

Brief Resumes of potential reviewers

(Separate attachment)