Uncertainty Analysis and Utilization of ESPAM2 for Water Rights Administration

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1.0 Introduction

Development of ESPAM2 including modifications of data management routines, updating of basic data, improvement of model cell designations, calibration, validation and comparison of ESPAM2 output with ESPAM1.1 output has taken over 3 years of effort and is still not complete. ESPAMversions have been utilized by IDWR in administrative proceedings for water rights, including ESPA transfer analysis, water right call evaluations (curtailment) and planning for ESPA enhancement.

The Director of IDWR has indicated that the ESPAM2 model will not be adopted for use by IDWR until an adequate calibration is performed, a validation has been completed, an uncertainty analysis has been completed and a comparison has been made between ESPAM1.1 output and ESPAM2 output. IDWR (Alan Wylie) is in the process of performing the calibration and uncertainty analysis based on input from the ESHMC committee.

The justification for the performance of an uncertainty analysis is based on the need for users of the model to analyze the potential risk associated with utilization of model output for administrative or financial decision making. A better knowledge of not only the most-likely predicted outcome from a model but the range or probability of occurrence of specific magnitudes of outcomes is helpful to the user. The objective, therefore of an uncertainty analysis is to, hopefully, provide technically sound analyses of the magnitude and/or probability of the range of response of model simulated output to projected changes in stress on the aquifer system. Technically sound and scientifically supported knowledge of model capabilities and limitations is imperative in development of sound administrative policies and decisions. The utilization of the best available scientific information and evaluation tools for administrative water resources and water rights decisions, if not mandated by statute, is certainly required as a standard of practice.

The purpose of this paper is therefore to provide scientifically supportable comments and opinions on the need for and protocol for an uncertainty analysis of the ESPAM2 ground water model and to provide comment and guidelines for the use of the model in aquifer response evaluations for water rights administration. The purpose of this

paper is not to suggest policy for Department administration of water rights in the ESPA but to provide constructive input and suggestions to the Department relative to the use of the ESPAM2 model.
The purpose of this paper is not to propose a different procedure for evaluation of uncertainty in the ESPAM2 model, but to offer input into the need, adequacy and utility of the procedure being followed, to recommend that a more rigorous uncertainty analysis be performed on future versions of ESPAM and offer concerns relative to the use of the model for administrative purposes.

2.0 Review of Uncertainty Analysis Procedure

Referring to ground water flow modeling, the uncertainty may be framed as: a quantification of the range of and/or probability of differences between model simulated response and the natural or "true" response of the complex aquifer system to the processes operating on the aquifer. Various procedures, none of which are short and easy to perform, have been suggested to perform an uncertainty analysis for ground water flow and/or transport models. Procedures vary from simple sensitivity analysis of selected variables with associated error bars on selected output components to elaborate Monte Carlo analysis and automated procedures to develop probability distributions on numerous predicted variables.
IDWR (A. Wylie) proposed a procedure for developing an uncertainty analysis for ESPAM2 that would provide some measure of predictive uncertainty and yet be performable within a reasonable time frame. Completion of ESPAM2 is considerably beyond the estimated completion date and, according to the Director, evaluation of at least one pending water call will not be pursued until ESPAM2 is officially adopted. Petitioners on pending water calls are encouraging the Director to hasten the adoption of the ESPAM2 model.
Completion of the current uncertainty analysis on ESPAM2 should be viewed as a procedure suitable for current and pending water right evaluations but more rigorous uncertainty analysis protocols should be developed and implemented to update ESPAM2 or future versions and provide a better tool.

2.1 Sources of Uncertainty

Ground water model uncertainty arises for several reasons. Since the model is a mathematical representation of a hydrogeologic system, errors in the characterization of the configuration of the modeled system can result in uncertainty in the output. This is termed <u>conceptual uncertainty</u>. Examples of errors in the conceptual model resulting from incomplete physical data or incorrect assumptions include aquifer boundary errors, stratigraphic assumptions, and locations of significant hydrologic features.

<u>Mathematical uncertainty</u> arises because a physical system is being modeled by equations. The mathematical system which simulates the response of the physical system may not be sophisticated enough to adequately respond to the various complex responses of the real system to the input.

<u>Parameter uncertainty</u> refers to uncertainty in input parameters and data which drive the hydraulics of the modeled system. These parameters can never be known with complete accuracy.

Uncertainty can also be manifested by the fact that there is no unique set of input parameters that will yield the "best" calibrated model. Procedures for constraining parameters which are changed in the calibration process may not be specific enough to produce a unique distribution of all parameters or may not touch specific model parameters which are, in fact, significantly correlated with specific output. This effect might be termed internal calibration uncertainty or model overspecification.

Another source of uncertainty related to calibration is the fact that physical observations to which the model output is calibrated are not perfect. Error in these measurements, e.g. spring flow, may be as high as 20%, yet they are treated as if they were perfectly known quantities. This may be called calibration target uncertainty.

All of the above sources conspire to cause overall predictive uncertainty in any variable predicted by the model. This overall uncertainty is perhaps most meaningful to the user of a ground water model. Predictive uncertainty could be defined as the accuracy with which the model can simulate the response of an output parameter, representing the integrated effect of uncertainties due to conceptual, mathematical, parametric, and calibration-related effects.

2.2 Evaluation Methods

Determination or quantification of uncertainty in the output of ground water models due to the uncertainty in model parameters can generally be performed by simultaneously varying multiple parameters and evaluating the results that preserve calibration. This technique can be accomplished on a limited basis, depending on the complexity of the model, by manually varying parameters or utilizing Monte Carlo methods if adequate computational power and time are available. This procedure allows the determination of probability distributions for outputs of interest, and development of confidence intervals for those outputs. Generally, even though the Monte Carlo procedure is preferred, time and computational resources sometimes preclude its use.

2.2.1 Current IDWR Uncertainty Analysis

Use of multi-model-analyses procedures (Poeter & Hill) is useful when multiple models of a single system are deemed necessary to best represent the system. This procedure, used on multiple models calibrated by nonlinear regression, provides ranking of models and calculated posterior model probabilities. Again, this procedure may be overkill for the ESPAM2 model.

The procedure being utilized by IDWR to provide a measure of uncertainty has been outlined by Wylie and Raymondi and consists of a simplified sensitivity analysis. Essentially, the process is to:

1. Identify the model cell at the centroid of groundwater pumping in specific Water Districts and assume a stress at that point equal to the identified ground water pumping in the District.
2. Run the model in a calibration mode and allow PEST to determine the maximum and minimum values of an output (example, Clear Lakes spring cells) within which the model remains calibrated.

This is the procedure which was proposed and reviewed by the ESHMC. It does provide a range for a specific output due to parameter adjustments within which the model will remain calibrated. The criteria for 'remaining in calibration' is the limit placed on the sum of squares of residuals. The procedure being utilized by IDWR for uncertainty analysis of ESPAM2 can be referred to as a duel model approach to an uncertainty analysis. This current dual calibration uncertainty analysis method is being used to determine a range of predictions that the model can produce in one location, while remaining within a modeler defined calibration quality. As presented, the range does not represent a probabilistic confidence limit on the chosen prediction because it is specific to the stress type, magnitude, and location that was used. The spatial limitation of the dual calibration approach also makes it difficult to relate this result to the uncertainty for adjustable input parameters. The input parameters tested are limited to those affected by the stress, and which have an effect on the prediction. As currently used, the dual calibration approach is not an absolute measure of predictive (or calibration) uncertainty or parameter uncertainty. It is also important to note that the dual calibration uncertainty method assumes that both the conceptual model and input data are correct (without error) when determining the range of predictions. A separate analysis would have to be done in order to determine the impact of unadjustable input data or conceptual model uncertainty on model predictions.

The dual calibration method is useful in evaluating the input parameters important to the selected prediction, and could assist in identifying useful locations and data types to collect in future field investigation. Although the dual calibration approach might be expanded to evaluate the probability range of predictions at a given point, more rigorous uncertainty analysis methods are available.

2.2.2 Monte Carlo Uncertainty Analysis

A Monte Carlo uncertainty analysis method allows a more rigorous predictive uncertainty analysis result. Two different types of Monte Carlo uncertainty analysis are:

1. Unconstrained Monte Carlo Analysis - Many model realizations are created using model input parameters that are varied randomly within a range defined by the modeler. One shortcoming of this approach is that the model does not remain calibrated.
2. Constrained Monte Carlo or Null Space Monte Carlo Analysis - With this method, many model realizations are created by using a calibrated model to create random variations on the calibrated parameters (within a range defined by the modeler). Each realization is then recalibrated, generating many calibrated models.

The benefit of Monte Carlo methods is that they provide a probability distribution for any chosen model prediction. In addition, the modeler may define the range of input parameters so that the procedure is indicative of input parameter uncertainty. The downside of Monte Carlo methods is that they are more computationally intensive, especially if the constrained approach is used and the model needs to be recalibrated many times.

2.3 Probability

Decisions for water rights administration, water resource planning and even general populace information needs which are facilitated by use of the ground water model are improved if the user has some idea of the risk involved in implementation of a decision. This implies that, somehow, the user is aware of the probability that the output from the model is significantly different than that of the true aquifer response. To evaluate the risk, there must be a quantifiable range within which the model output is expected to lie. The user may choose to call this range a 'range of uncertainty' in model output. Many times the user is concerned about the difference in output (perhaps spring flow or reach gain) which may occur if a specific input variable is incorrect or varies by a certain percentage or absolute amount (perhaps, tributary underflow).

The procedure now being used by IDWR does not provide a probability distribution or confidence limits on specific input variables and, therefore, cannot assist in quantifying the risk involved in decisions utilizing model output. .

Generally, a rigorous uncertainty analysis, performed during the calibration process, can provide information on sensitive parameters which may be adjusted or re-evaluated to improve calibration of the model. The current analysis was not utilized for improving calibration but is being used to identify the range of specific outputs and shed light on the predictive uncertainty of the nearly completed model.

2.4 Recommendations for Completion of Current Procedures

The model calibration should be completed as soon as possible and minor improvements in input or calibration parameters should be set aside for future model improvement. The uncertainty analysis procedure being followed now by IDWR should be completed and the verification proposed should be completed. More rigorous uncertainty analysis protocol should be planned for future versions of ESPAM. Specific output such as target reach gains and water levels from ESPAM1.1 should be compared with the same output from ESPAM2 to provide a check on differences between the models and guide future evaluations of potential changes and uncertainty analysis requirements. The ESPAM2 model should be officially accepted and adopted by IDWR for use in applicable water rights evaluations recognizing that, as with all models, future improvements are expected. .

3.0 Use of Uncertainty Information

The ESPAM2 ground water flow model, when completed, will be the best available scientific tool for evaluating ESPA hydrologic relationships and providing hydrologic guidelines in administrative decisions. The capabilities of the ESPAM2 model, the technical deficiencies, and the real meaning of the results of any uncertainty analysis must be understood in order to make informed decisions. Policies and decisions in water rights administration will be formulated based on ESPAM2 simulations and these policies and decisions can only be defended if full knowledge of the model capabilities is known and disclosed.

3.1 How Should the Uncertainty Information be used in Model Calibration?

Output from an uncertainty analysis, depending on how it is formulated, can be used to guide model calibration. Sensitivity analyses, whether performed with full Monte Carlo protocol or simpler manual methods, can identify input variables to which the model output is highly sensitive, which may require additional analysis and data or possibly correct errors in the algorithms used to process data for those variables. Multiple model evaluations, if enough resources and time are available, may provide similar guidance. The uncertainty analysis can provide guidance on the assigning of "weights" to the confidence in observations or estimated variables in automated calibration procedures (PEST) or manual methods.

In development of ESPAM2, a structured uncertainty analysis was not used during calibration to guide the procedure. The uncertainty analysis is being performed on the calibrated, or nearly calibrated, model and provides insight into the range of predictive uncertainty for specific model output. As with all models, additional, more rigorous, uncertainty analysis should be considered for future versions of ESPAM but time and resources do not allow this additional analysis on ESPAM 2.

3.2 Model Uncertainty Use for Administration of Water Rights

The methods adopted for use of any type of model uncertainty information in developing policy or decisions for water rights administration are discretionary. Regardless of the purpose for the policy or decision, the application of model output must be scientifically defensible, within the capabilities of the model, and ascribe to the standards of use in the industry (ground water modeling). These criteria are mandatory if the model developer and user are to be able to defend the use of the model and the policies developed and defray potential challenges and/or litigation. Ground water users, spring water users, and surface water irrigators depend on the ESPA outflow and water levels for their livelihood and expect competent and equitable management and administration of the resource. Incorrect use of ground water model simulations which violate the identified capabilities of the model or are contrary to established statistical and/or analytical methods will not go unnoticed. It is therefore imperative that the ESPAM2 model output be interpreted and applied appropriately.

Specifically, application of results from the model should recognize precisely what the output number means. For instance, if the simulation performed with the calibrated model indicates that the steady state spring flow from spring X will be 100 cfs, then the best estimate for the spring X steady state flow is assumed to be 100 cfs and that is the flow that should be used for planning and administration. If a subsequent competent uncertainty analysis indicates that the 95% confidence limits for the model estimate of spring X flow are +-5% then the interpretation must be that there is a 95% probability that the true spring X flow will be between 95 and 105 cfs at steady state. This analysis does not mean that spring X steady state flow is likely to be 95 cfs or 105 cfs, only that there is a 5% chance that it will be outside these limits.

Similarly, a determination that spring X flow simulation is subject to a 95% confidence limit does not mean that the simulated flow is being produced by only a certain portion of the aquifer or that the simulated flow is being produced only by water that can reach the outflow point within a certain time of travel.

These anomalous interpretations of the meaning of uncertainty in the context of ground water model use point out that administrative decisions, such as utilization of a trim line, may have no basis statistically or hydrologically and are likely not based on correct use of uncertainty analyses.

The use of a 'trim line' as defined by former IDWR Director Dreher is one such example of both the incorrect definition of ground water model uncertainty and incorrect use of an assumed uncertainty in the output of ESPAM1.1. No recognized uncertainty analysis was performed for ESPAM1.1. Director Dreher determined that the ESPAM1.1 model 'uncertainty' was +-10% because the US Geological Survey indicated that the Snake River flow measurements utilizing stream flow gages for calculation of most of the river reach-gains were rated as 'good'. The USGS criteria for stream flow gages rated 'good' is +-10%. Based on this one estimate of "uncertainty' of a single parameter used in calibration of ESPAM1.1, it was determined that the 'accuracy' or 'uncertainty' in the ESPAM1.1 model output (reach-gain) was +-10%.

As a 'surrogate for uncertainty' a trim line concept was adopted by the Department to be applied to ESPAM 1.1 for determination of mitigation requirements for spring flow and surface water calls. The trim line was generally used to define the area within the ESPA area of common ground water outside of which pumping from a well would impact spring flow less than 10% of the pumped volume at steady state. The effect of confining impact to springs or river reaches to wells within the area defined by the trim line rather than wells within the entire area of common ground water or the aquifer boundary is essentially to limit the impact on senior water users to about ½ of the true impact from junior pumping. Use of a trim line, as currently defined, is both an inappropriate use of uncertainty criteria and fails to use the best available scientific knowledge. The net effect is to promulgate inequities within the water user community and exclude some users who, based on the best scientific knowledge, are injuring senior water right holders. It also results in incorrect determination of credit for mitigation if there is curtailment, conversions, CREP, recharge or other mitigation procedures occurring outside the trimline. The use of a trimline, even though described as a 'surrogate for model uncertainty' is not related to model uncertainty and should not be advertised as such.
The current IDWR policy attempts to recognize a specific minimum level of impact from junior ground water pumping on senior ground water rights below which no impact will be considered for administration of water calls. This might be defined as a deminimus impact below which no injury is considered. This concept has been defined as analogous to a futile call as defined in surface water rights administration. It is incorrect to make this comparison. In administration of surface water rights, the futile call is made by the Watermaster when he determines that there is no possible way that he can provide water to a senior user by curtailing junior water right holders on the stream, There is no concept of timing or necessarily of diminished discharge possibilities to the senior user or of potential impact on the financial impacts to junior users.
In ground water right administration within the ESPA using a trimline concept, the assumption is that, even though impacts from junior pumping outside the trim line will, in fact, impact senior ground water users at some time, those impacts are deemed deminimus and will not be considered in mitigation or curtailment decisions.

3.3 Minimum Requirements for Future Uncertainty Analyses

Any uncertainty analysis results should include an analysis of the bias in simulated output variables, an analysis of the variability of the output and a sensitivity analysis of specific input parameters. Bias is defined as the average difference in values of the simulated output (most probable) and the measured (assumed 'true') value of the variable. For instance, if the average simulated spring flow for the period of

record is 100 cfs and the measured spring flow for the same period of record (calibration data) is 95 cfs, then the bias in that output is +5 cfs.
An analysis of variance, at a minimum should include an estimate of the probability distribution of the simulated output around the expected value of the output parameter.
Any future analysis should include a sensitivity analysis of specific parameter input to provide guidance to developers for future efforts to improve the model and provide model users with an understanding of the reliability of the inputs.
This will allow administrators to formulate policy for administration and/or planning that factors risk into decisions in a scientifically defensible manner.

4.0 Summary

The ESPAM2 model is the best scientific tool available to IDWR and should be utilized for water rights administration including water rights transfers and water call evaluations. This model needs to be completed soon to include the requested calibration, validation, uncertainty analysis, and comparison with ESPAM1.1 output. The uncertainty analysis being conducted, following the protocol outlined by IDWR, should be completed and a complete evaluation of this analysis relative to the technical limitations of the model developed. Plans should be made to perform a more rigorous uncertainty analysis on the completed model or, subsequently, on future versions of the model with the protocol fully outlined and reviewed by the ESHMC prior to performance. An understanding of the applicability of the ESPAM2 model for water rights administration depends on the technical abilities and constraints to model use. The protocol for utilization of the model for water rights administration involves the discretion of the Director based on full knowledge of the technical applicability of the model and constraints. It is the responsibility of the model developers, IDWR staff, and the ESHMC to assure that the policy formulators are fully informed and knowledgeable of the capabilities and limits of the model and the ramifications of model applications under the developed policies. Generically, the questions such as 'What does this output mean?' need to be answered or answerable.
Any utilization of the ESPAM models should recognize that the most probable value of any simulation is the output of the model and there is some probability distribution of alternate values around the most probable value.
The trim line concept is not defensible as a surrogate for model uncertainty and other protocol should be adopted for application of model output to water rights administration.