# MEMO

**State of Idaho**
**Department of Water Resources**
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| **Date:** | 25 November 2011 |
| **To:** | ESPAM2 Predictive Uncertainty Files |
| **From:** | Allan Wylie |
| **cc:** | Rick Raymondi, Sean Vincent |
| **Subject:** | ESPAM2 Predictive Uncertainty |

**Reasons to Conduct a Predictive Uncertainty Analysis**

This memo was requested by the Eastern Snake Hydrologic Modeling Committee (ESHMC) during the 27 October 2011 meeting to explain why we are conducting the predictive uncertainty analysis, and how the analysis is conducted. One reason we are conducting an uncertainty analysis is that the Director requested one in his 9 June 2011 letter to the ESHMC (http://www.idwr.idaho.gov/Browse/WaterInfo/ESPAM/meetings/2011_ESHMC/June_30_2011/).

I think the ESHMC should conduct a predictive uncertainty analysis without prompting from the Director. The ESHMC should be aware that any prediction using a ground water flow model has the potential for error or inaccuracy, and this potential must be acknowledged. The ESHMC should also be aware that a predictive uncertainty analysis can be used to locate the origins of that uncertainty by identifying the parameters PEST adjusted to maximize or minimize the prediction. Once the sources of uncertainty are identified, observations or additional data can be collected to reduce or constrain the uncertainty.

**Method**

During the June 2011 meeting, the ESHMC chose to conduct a predictive uncertainty analysis by applying stress at a three cell by three cell centroid within the irrigated lands of each Water District on the Eastern Snake Plain. The following is the procedure used to prepare a PEST predictive uncertainty run to identify the maximum or minimum impact on a spring cell or river reach.

1) The centroid must be identified (this can be done in GIS) .
2) Model files must be prepared to run the prediction, including a well file constructed using the 3x3 cell centriod identified in step one (1).
3) Make a copy of the PEST control file. The PEST control file contains all of the adjustable parameters and their bounds, and all the field observations. Since we are copying the control file, every parameter adjustable in our calibration run will also be adjustable in our predictive uncertainty analysis, and every field observation used as a calibration target will also be used as a target in our

predictive uncertainty analysis. The following adjustments (items 4 – 12) need to be made to the PEST control file.

4) Replace the word 'regularization' with the word 'prediction' on the third line.
5) The number of observations must be increased by one (1) because the prediction will be a new observation.
6) Increase the number of observation groups by one (1) because there will now be an observation group 'predict'.
7) Increase the number of instruction files by one (1) because PEST will now be required to monitor the prediction.
8) Add 'predict' to the list of observation groups.
9) Add an additional observation to the observation section. At this time I expect these will be called 'Predict_CRL' for the Clear Lakes impact, 'Predict_BLK' for the Blue Lakes impact, and 'Predict_nBMin' for impact to the nr Blackfoot-Minidoka reach. Any weight and target observation value can be provided because PEST ignores the weight and target observation value for any observation in the 'predict' group when it is run in predictive analysis mode.
10) Change the model command line to reflect the name of the batch file used to run the model and the prediction.
11) Add the name of the new instruction file and the output file it will read to the list of files used to read model output. I expect the instruction file will be called 'Predict.ins' and the file it will read will be called 'Predict.smp'
12) Add a 'predictive analysis' section to the control file. This will include NPREDMAXMIN, PD0, PD1, and PD2. NPREDMAXMIN tells PEST whether to maximize (+1) or minimize (-1) the prediction of interest. PD0 is a value of the objective function (phi) which is considered calibrated. Naturally, PD0 must be greater than phi for the calibrated model, but only a little greater. Because the shape of the PD0 envelope can be complex, it is extremely hard for PEST to find a parameter set which lies exactly on the boundary. The value supplied for PD1 (which must be slightly higher than PD0) is a value PEST will consider "close enough". If the sum of the squared residuals is above PD2, PEST tries to minimize the objective function until the objective function is below PD2, at which point PEST begins searching for either the maximum or minimum value for the prediction at PD0.

Thus, during a predictive uncertainty analysis run PEST will: 1) run MKMOD, 2) run MODFLOW, 3) compare model output with field observations exactly like in a calibration run, 4) compare the sum of the squared residuals (phi) from this run with PD0, 5) make a model run in super position mode containing only the 3x3 well file constructed during steps 1 and 2, 6) collect the predicted impact at the target spring or river reach, and 7) compare this prediction with the previous maximum (or minimum) prediction and save the value if it is a new maximum (or minimum) and phi for this run is less than PD1.

The PEST manual recommends that phi from calibrated model <PD0 < PD1 < PD2 and further states that PD0 should only be slightly larger than phi for the calibrated model (1or 2% larger), and PD1 should only be slightly larger than PD0 (1 or 2% larger), and PD2 is generally 1.5 to 2 times PD0.

## Comments from John Koreny ESHMC member

My responses to John Koreny's comments on the Predictive Uncertainty Memo are included below. John's comments are in blue and my responses are indented, numbered, and in black.
Allan Wylie

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**Sent:** Monday, November 07, 2011 3:31 PM
**To:** Raymondi, Rick; Wylie, Allan
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**Subject:** RE: Predictive Uncertainty Memo

P.S. I also am opposed to the "model validation" exercise that is planned for version 2. I do not understand the reason for running the model through poorly-constrained old historic data (that was already determined to be insufficient for calibration) and I don't understand what we would do if the result would make us question the model calibration or results. I would like to have a formal vote on this so everyone's position is recorded and understood.

1. The ESHMC was presented two approaches to model validation and chose to conduct both on June 30, 2011.

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McVay, Michael; Mike Beus; Rick Allen; Roger Warner; Sharon Parkinson; Stacey L Taylor; Sukow, Jennifer; Swank, Lyle; Thomas R Wood; Vincent, Sean; Willem Schreuder; Young Harvey Walker
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Rick and Allan-

Thank you for the information.

This memo indicates that the ESHMC decided to proceed with the uncertainty analysis.

I am a member of the committee that does not agree with this uncertainty analysis approach. My input is that I think that an uncertainty analysis is properly used to identify weakness in data or approaches for model calibration. Once calibration is done the model is ready for use and the values that come out of an uncertainty analysis should not be used to constrain the predictive analysis of the model by applying some kind of "uncertainty factor". The reason is- an uncertainty analysis provides information on relative uncertainty in calibration data and approach. It does not provide an absolute value or a factor that can be used to numerically constrain predictions. There simply are too many degrees of freedom and any outcome that you get from an uncertainty analysis is dependent on how you constrain PEST to provide a solution.

1. I agree that an important use of an uncertainty analysis is to identify weaknesses in data or approaches in model calibration and that is an important part of why I agree with the ESHMC's decision to proceed with the uncertainty analysis.
2. I do not agree that once calibration is done the model is ready for use, I believe much time and effort should be expended examining the model checking potential predictions, conducting potential analysis, conducting key uncertainty analysis, and conducting validation runs to determine whether the model is actually ready for use.
3. I have no control over how other ESHMC members, lawyers, or elected officials will try to use the results of our uncertainty analysis. In my opinion, the fact that this important analysis might be misused is not sufficient reason to abort the analysis.

If this document is going to say, "The ESHMC decided that . . .. " with respect to an uncertainty analysis than I request a formal vote on the matter and each committee members' position on this recorded.

1. I disagree, the ESHMC seems to be functioning reasonably well as a relatively informal body, and I do not think that imposing a strict voting protocol would be conducive to the free exchange of ideas that makes the committee valuable. Any committee member that disagrees with any decision has ample means to make their disagreement part of the committee record by either submitting comments to memos like you are doing here, or making sure that their name is included in those dissenting on committee decisions in the meeting notes.

If the committee decides to go ahead with this- than I think the uncertainty analysis documentation should specifically say that the results should NOT be used as a factor to numerically constrain model prediction.

1. I will try to remember that you want a statement like this in the predictive uncertainty report.

Respectfully,

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**Subject:** Predictive Uncertainty Memo

Hi
During our October 27 ESHMC meeting Greg Sullivan requested a memo discussing both why the ESHMC should conduct a predictive uncertainty analysis and how the analysis would be conducted. The attached memo represents my attempt to answer both questions. I am assuming that previous presentations and committee discussions adequate cover the strengths and weaknesses of our chosen approach. The file is also posted in the 'ESPA Model Uncertainty' section of the ESHMC web page. Your comments are welcome. If I don't receive any comments by 21 November 2011, I will consider the memo final.

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## Comments from Greg Sullivan, ESHM Committee member

Allan,

Thank you for your November 7, 2011 memorandum regarding the ESPAM2 Predictive Uncertainty. While you have discussed some of the issues that I had mentioned during the last ESHMC meeting, I think there are additional issues that should be addressed related to the predictive uncertainty of the model. Because of the importance of this matter, and the potential for misunderstanding or misusing the results of the predictive uncertainty analysis, I suggest that a comprehensive "design document" or similar report be prepared on this subject. I realize that there have been various memoranda, emails, white papers, etc. that have been submitted by certain of the ESHMC members. However, it would be helpful to compile all of this excellent information into a single document to help make it easier to understand what the analysis is, how it was performed, and how it should be used.

1. The comprehensive document you are envisioning is the final report.

In the context of the delivery calls, model uncertainty has been used primarily to establish trim lines across the ESPA, beyond which curtailment orders would not apply. However, this is not the only circumstance in the delivery calls in which model uncertainty may be relevant. In addition, knowledge of model uncertainty may be useful in understanding and interpreting model results for other uses (e.g., in evaluating the benefits of managed recharge).

The following are among the information that should be included in the documentation for the predictive uncertainly analysis:

Why the analysis was performed:

- Requested by the Hearing Officer in rulings for the delivery calls by the Spring Users and the Surface Water Coalition.
- Requested by former IDWR Director, David Tuthill.
- Requested by current IDWR Director, Gary Spackman.

1. Good point, I had forgotten that the hearing officer requested an uncertainty analysis, I don't recall Director Tuthill requesting an uncertainty analysis so I will check.

Factors affecting the uncertainty of the ESPAM (from 2009 Brendecke comments, attached):

- Conceptual uncertainty.
- Parameter uncertainty.
- Calibration uncertainty (internal).
- Calibration uncertainty (external).

1. OK

How the predictive uncertainty analysis was performed and the results of the analysis

- It is important that the procedure used in performing the predictive uncertainty analysis be thoroughly documented so that it transparent and repeatable.

1. OK

Factors considered in the predictive uncertainty analysis

- My understanding is that the proposed predictive uncertainty analysis will only consider the effect of the internal calibration uncertainty on the model results. In other words, the analysis will seek to quantify the potential variability in the model predictions if the model calibration was varied to some degree from the optimal final calibration (i.e., with objective function scores within X % of the optimal value).

1. I don't see it that way, we are determining the uncertainty of selected impacts on certain reaches (river or spring) due to the combined impact of parameter uncertainty, internal calibration uncertainty, and uncertainty of our calibration targets (to the extent that our weighting reflects our uncertainty in the calibration targets).

Factors not considered in the predictive uncertainty analysis

- Conceptual uncertainty.
- Parameter uncertainty.
- External calibration uncertainty.
    - Uncertainty of the calibration targets.
    - Relative weighting of the calibration targets (e.g., weighting given to water levels, reach gains, spring targets, etc.).

1. Our analysis will not address conceptual uncertainty or the impact of our weighting scheme.

Spatial variability in the predictive uncertainty of the model

- The predictive uncertainty of the model appears to be dependent on (a) what the model is being used to predict (e.g., impacts to a certain spring or a certain river reach), and (b) what stress is causing the impact (e.g., pumping in a certain region of the aquifer). This concept needs to be clearly explained.
- Assuming there is a significant variability in the predictive uncertainties for various combinations of stresses (e.g., pumping in a certain area) and impacts (e.g., depletions to certain springs, certain reaches, etc.), it may be useful to develop an uncertainty matrix.

1. I expect to address this in a final report on our predictive uncertainty analysis.

Limitations on the use of the results

- Description of what can be deduced from the results of the predictive uncertainty analysis, and cautions against inappropriate or unreasonable use of the results.

There may be expectations from some outside of the ESHMC that the predictive uncertainty of the ESPAM can be objectively and conclusively determined, and it is just a matter of doing the work to establish these results. However, as alluded above, it is not a simple task to determine the predictive uncertainty of the model, and the results of an uncertainty analysis will be highly dependent on the sources of uncertainty that are considered and the procedures used to perform the analysis. These matters should be made clear in the documentation report to help ensure appropriate use of the results.

It may be beneficial for there to be some more dialog between the Director and the ESHMC regarding the proposed uses of the results of the predictive uncertainty analysis. The Director should be informed as to the scope and limitations of the proposed uncertainty analysis so that he can judge whether the analysis will conform with his expectations and with the way that he may use the results.

1. John Koreny also requested a section on limitations on the use of the results, and I intend to include something in the final report.

I appreciate your consideration of these comments.

Greg

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