Technical Report on ESPAM2.0 Modeling Issues

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October 1, 2012

INTRODUCTION

Topics

This report addresses eight technical issues that relate to the use of Eastern Snake Plain Aquifer Model version 2.0 (ESPAM2.0) for water-right administrative decisions. These are general issues with broad applicability, presented in the context of the Rangen delivery call. The issues addressed are:

1. Technical considerations of Deminimus effects and Trim Line;
2. Technical considerations of Futile Call;
3. Reach discretization for model use;
4. Temporal discretization for model use;
5. Temporal uncertainty of model representation of propagation of pumping effects;
6. Spatial uncertainty of model representation of propagation of pumping effects;
7. General sources of model uncertainty, with qualitative and quantitative discussion of uncertainty;
8. Temporal delay in propagation of effects of curtailment.

Definitions

The following terms will be italicized or capitalized when used in this report, with definitions specific to this report as follows:

a	Horizontal distance from a well or recharge site to a hydraulically-connected surface water body.
Administrative Reach	A group of Model Cells which would be grouped

	together for summarizing ESPAM2.0 model results for administrative purposes.
Calibration	The process of adjusting the mathematical representation of the model, and sometimes its input data. Typically Calibration is performed by comparing model results for key output values with measured or estimated Targets.
Calibration Reach	A group of Model Cells in ESPAM2.0 which are grouped together for calculating flows to or from the Snake River and tributary springs, for model Calibration.
Calibration Period	A period of time for which input data and Targets have been gathered and prepared for model use.
Capture Fraction	The portion of pumping at a well which propagates to a given surface water body or surface water reach. It is expressed as a ratio or a percentage. A Capture Fraction of 0.25 would be equivalent to a Capture Percentage of 25%. If a well pumped 100 acre feet with a Capture Fraction of 0.25 to a specific surface-water body, eventually the supply available from that surface water body would be reduced by 25 acre feet. Capture can also apply to recharge or other positive aquifer impacts, in which case it represents the increase in supply made available at the surface-water body.
Deminimus	A level of relief administratively deemed to be small enough that regulatory action or mitigation requirements are not warranted.
ESHMC	Eastern Snake Hydrologic Modeling Committee
ESPAM1.1	Eastern Snake Plain Aquifer Model Version 1.1
ESPAM2.0	Eastern Snake Plain Aquifer Model Version 2.0
Futile Call	An administrative determination that curtailment of a given junior will not provide enough relief to the calling senior to justify the administrative action.
GIS	Global Information Systems software and procedures for mapping and performing spatial analysis.

IDWR Idaho Department of Water Resources

IWRRI Idaho Water Resources Research Institute

Model Cell The smallest spatial volume in MODFLOW for which calculations are performed and from which results may be extracted. All inflows and outflows for a particular Model Cell are represented as if they occurred exactly at the center of the cell. In ESPAM2.0, Model Cells are one mile by one mile square at land surface and extend to the depth of the aquifer.

Model Water Budget In general a water budget refers to the accounting of all inflows and outflows of water to a hydrologic system. In this report Model Water Budget or Water Budget refers to all the data describing flows into and out of the aquifer during the Calibration Period, except for flows represented as Targets.

MODFLOW The USGS groundwater flow modeling software with which SRPAM, ESPAM1.1 and ESPAM2.0 are represented.

Pilot Point A location in ESPAM1.1 and ESPAM2.0 modeling where an aquifer property is estimated. This technique is used because current computing power does not allow unique estimation at every Model Cell. Pilot Point estimates are interpolated to individual Model Cells.

Predictive Uncertainty This term is used in this report both to describe the general concept of assessing the expected uncertainty associated with individual model predictions, and in reference to a specific IDWR modeling activity given the name "Predictive Uncertainty Analysis."

Range An expression of the expected values that a value might take on. In this report it is defined to include virtually all expected values and so statistically corresponds to four standard deviations (two above the mean, two below). It can be expressed in terms of percentages or values; a Range of "500 plus or minus ten percent" is an equivalent Range to "450 to 550."

S Storage Coefficient. Unitless.

SRPAM — Snake River Plain Aquifer Model. The IDWR/University of Idaho model which preceded ESPAM1.1.

Steady State — A model run that does not consider the timing of propagation of effects. It requires input data of only the magnitude and location of aquifer stress, and produces estimates of the spatial propagation of effects.

Storage Coefficient, Storage — The ratio between the change in volume of water in aquifer storage and the change in aquifer head. In this report, it is applied both to unconfined effects resulting from filling or draining of pore space, and to confined effects resulting from elastic properties of water and the aquifer matrix.

Stress Period — A period of time during which flows in the model input are held at a constant, average level. Stress Period length can be equal to Time Steps, or can be equal to the sum of a whole number of Time Steps.

Targets — Measured or estimated values for various quantities that the model is used to predict. Target values are provided for the period of time for which the Model Water Budget is prepared and are used to test the ability of the model to reproduce known results.

T — Transmissivity. Ft^2 per day

Time to Half — The number of months required for arrival of half of the volume effect that will eventually reach a particular surface water body.

Time Step — The time frequency at which MODFLOW performs calculations and produces output values.

Transient — A model run that includes a timing component. It requires information on the timing of aquifer stress and produces estimates of both the timing and location of the propagation of stress.

Transmissivity — The ability of aquifer materials to convey or transport water, per unit width of flow path.

Trim Line	A geographic representation of Deminimus concepts. Points of diversion within a Trim Line are subject to administration and points without are not. Each different administrative action can conceptually have a unique Trim Line.

DEMINIMUS EFFECTS AND TRIM LINE

The determination and application of a Deminimus effect is a policy question that will not be addressed in this report. The concept of uncertainty may be considered in making this policy determination, and uncertainty will be addressed.

A Deminimus policy could be defined in terms of Capture Fraction, specifying a threshold fraction below which propagating effects are considered Deminimus. This is essentially the definition of a Trim Line which has been applied in administration of water calls using ESPAM1.1. The policy could also specify a threshold total volume or volume per time, below which effects are considered Deminimus. This is the concept that has been applied in use of ESPAM1.1 for water-right transfers.

ESPAM2.0 can be operated to calculate either of these potential Deminimus thresholds. The results will be subject to the inherent limitations of the model.

FUTILE CALL

The Futile Call is closely related to the concept of Deminimus effects, and shares the technical aspects of Capture Fraction and total magnitude of benefit received. It could also have a temporal component; if relief is not expected to arrive within some specified time frame, the action could be considered futile. The timing of relief can be considered in the context of the needs of "crops… in progress, being green" (Fifth District Court for Idaho, case CV-2005-0000600, p. 93).

ESPAM2.0 can be used to estimate timing, Capture Fraction and total magnitude of benefit. For illustration, it has been applied to a hypothetical curtailment of groundwater rights in the Egin Bench area of Fremont Madison Irrigation District, shown in Figure 1. Appendix A provides details of the modeling exercise.

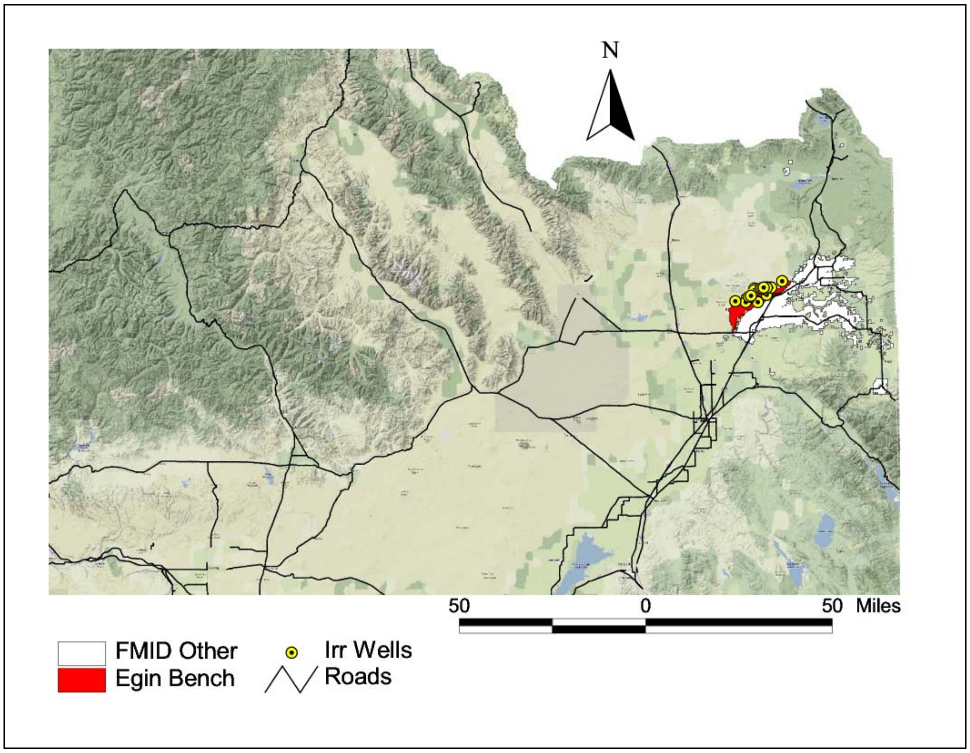

Figure 1. Location of Egin Bench

Many of these wells have priority dates junior to July 13, 1962. Curtailing these junior wells would reduce pumping by an estimated 4,730 acre feet per year. Table 1 shows the benefits that a one-year curtailment would produce for the reach that contains the Rangen diversion, as modeled by ESPAM2.0. It is acknowledged that there are other users in that reach, and there may be discharges that do not sustain any water rights. However, no attempt has been made to apportion these benefits to individual diversions. Because of the coarseness of the curtailed-volume estimates, Table 2 is most reliably interpreted in terms of benefit relative to curtailment.

Table 2
ESPAM2.0 Indication of Benefits to the Rangen Reach
from One-year Curtailment of Egin Bench GW Irrigation
Junior to July 13, 1962

Time Period	Cumulative Benefit to Reach	Benefit Relative to Curtailed Volume
First Year	24 gallons	1.5×10^{-6} %
First Five Years	0.11 acre feet	0.002%
150 Years	1.90 acre feet	0.04%

REACH DISCRETIZATION

General Technical Principles

The modeling software MODFLOW can be configured to produce flux results for any combination of Model Cells that the user desires. In this report, these will be called "Administrative Reaches." The Calibration of the model was constrained by Target measurements and/or estimates of flux to aggregated reaches which in some cases are much larger than individual Model Cells. In this report these will be called "Calibration Reaches." It is technically valid to construct Administrative Reaches that are combinations of whole Calibration Reaches. In Figure 2, Administrative Reach A1 would be a valid combination of Calibration Reaches C1 and C2. It is not technically valid to construct Administrative Reaches that are subsets of Calibration Reaches, or that combine subsets of reaches. Reaches A2 through A4 in Figure 2 are all technically invalid.

The reason that subdividing a Calibration Reach is not technically warranted is that the Calibration process can be successful no matter where in a reach the model indicates flows occur, without any constraint to produce the correct within-reach spatial distribution. For instance, in Figure 2 it may be that Calibration Reach C4 is a uniform gaining reach. However, the model Calibration could have been successful if it had represented all the gains as accruing in the portion of the reach that lies within Administrative Reach A2. Even though the model was well-Calibrated and produced correct results for Reach C4 as a whole, using the model with the illustrated Administrative Reaches would result in overestimation of C4's effects on Reach A2 and underestimation of its effects on Reach A3.

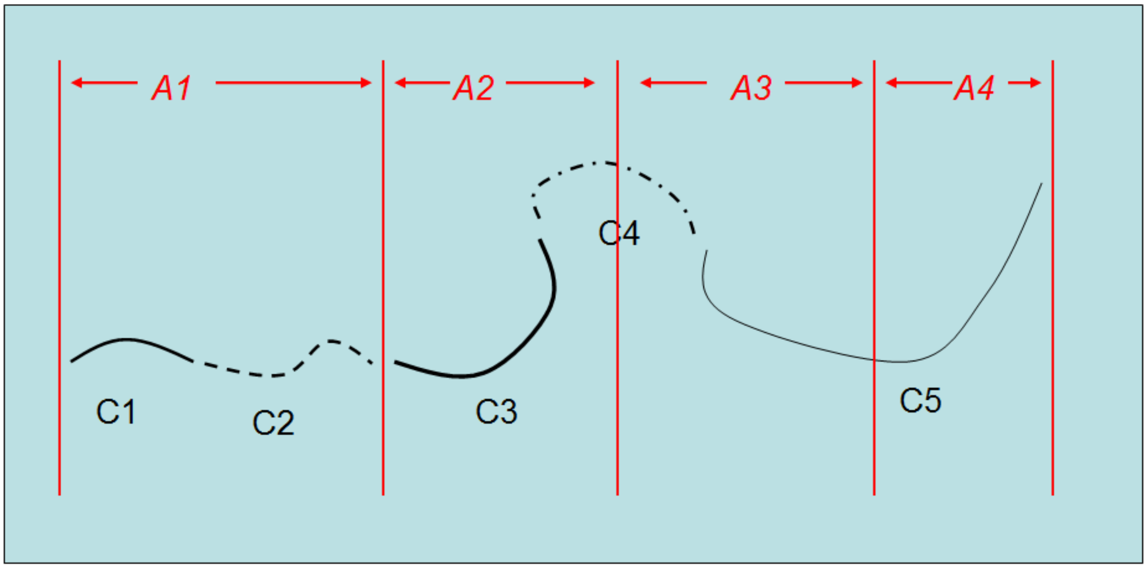

Figure 2. Illustration of hypothetical partition of Calibration Reaches.

Integration with Surface Water Administration

Surface-water priority and delivery above Milner are defined by the reaches in the Water District 01 accounting program. Defining model Administrative Reaches with reference to Water District 01 accounting reaches creates the technical ability for administrative actions to be assessed with reference to their effect on surface-water delivery.

Recommendation

It is recommended that Administrative Reaches be comprised of combinations of entire Calibration Reaches. As described below, uncertainty will be greatly reduced if Administrative Reaches are no smaller than the distance between nearby Transmissivity Pilot Points. Above Milner, Administrative Reaches should correspond to Water District 01 accounting reaches to the extent possible, given the configuration of Calibration Reaches.

TEMPORAL DISCRETIZATION

Concepts

There are two important concepts for time discretization of MODFLOW aquifer models. The first is the Stress Period, which is the period of time during which all inputs to the model are held at a constant rate. The second is the Time Step, which is the frequency of modeling calculations and model output. It is generally desirable to have Stress Periods short enough to capture any important temporal character of the input data for question being asked. For instance, if a question relates to pumping that occurs at a steady rate for a number of months, that typical pumping period could be an appropriate Stress Period. Time steps can be made shorter than Stress Periods to allow more temporally refined output. Technical considerations include the following:

1. Greatest confidence is obtained when Stress Periods for model use are about the same length or longer than for Calibration. ESPAM1.1 was Calibrated with six-month Stress Periods. It has been deployed by IDWR using six-month and four-month Stress Periods, and by University of Idaho using one-month periods. ESPAM2.0 was Calibrated using calendar-month Stress Periods varying in length from 28 to 31 days.
2. The native temporal resolution of the underlying data should also inform Stress Period length. Most data for both ESPAM1.1 and ESPAM2.0 had a native temporal resolution of one month. However, in both cases, tributary underflow was estimated on a long-term average basis and artificially partitioned to Calibration-period Stress Period lengths.

3. The ability of the model to reproduce temporal signals in the Calibration data set is affected by Time Step length. If the Stress Periods are defined so that they correspond approximately to the seasonal variation in aquifer inflows and outflows, the use of time steps shorter than Stress Periods can allow a model to predict flows at a finer temporal resolution than the model Stress Period. ESPAM2.0 was Calibrated using two time steps per Stress Period, giving output every 14 to 15.5 days.
4. While Time Step length can be selected to produce useful results, the confidence in short-term differences in output should be constrained by the ability of the model to match short-term changes in Target data during model Calibration. Both ESPAM1.1 and ESPAM2.0 were able to do a reasonable job of representing short-term changes in some springs and river reaches, but not in others.
5. Uncertainty in temporal representations of model output should temper the reliance on short-term model results. Temporal uncertainty is discussed later in this report.

Recommendation

It is recommended that ESPAM2.0 generally be configured with one-month Stress Periods, either actual calendar days per month or (365.25/12) days per month. If appropriate to the time frame of the question at hand, it is acceptable to have Stress Periods longer than one month. The selection of Time Steps may be left to the user, with the understanding that the fine output discretization resulting from short Time Steps does not imply precision of knowledge of the timing of output.

In any case, from a technical standpoint it is vital for administrative decision that hinges on the timing of arrival of effects to be strongly informed by both the short-term temporal performance of the model in Calibration and the temporal aspects of uncertainty that are discussed below. As a general rule of thumb it is recommended that great caution be exercised whenever the administrative outcome is sensitive to timing differences shorter than approximately four months.

TEMPORAL UNCERTAINTY

The propagation of temporal signals to a stream segment can be expressed by the ratio $(a^2\ S/T)$[1], where a is geometric distance, S is aquifer storage, and T is aquifer Transmissivity. The output of the equation is in the time units of the Transmissivity value, and is the amount of time for half of the rate of pumping or recharge to be

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[1] C.T. Jenkins, 1968. *Computation of Rate and Volume of Stream Depletion By Wells,* Techniques of Water Resources Investigation of the United States Geological Survey, Book 4 Chapter D1

expressed at the Target river reach.[2] The uncertainty of *a, S* and *T* can be estimated from the Ranges of each, and various statistical equations employed to approximate the uncertainty of the product $(a^2\ S/T)$.

In this report, the Range has been defined to include virtually all expected values, equivalent to four standard deviations. Table 2 provides values generally compatible with typical Snake Plain values, for an illustrative calculation. The Range for parameter *a* is estimated based on the fact that in MODFLOW, all wells are represented at the center of the Model Cell. Since the distance from the center of the cell to the diagonal corner is 3,733 feet, it is expected that all wells will be represented within that distance of their actual locations. Estimation of the Range for *T* is described below in the uncertainty section of this report. Uncertainty for *S* is assumed to be similar to *T*.

Table 2
Estimated Uncertainty of Input Data
for Temporal Calculations

Component	Value	+/- Range (value)	+/- Range (%)
a (distance)	528,000 ft (100 miles)	3,733 feet	0.71%
S (storage)	0.05 (unitless)	0.0075	15%
T (Transmissivity)	250,000 ft^2/day	37,500 ft^2/day	15%

Using these input data and the assumptions and procedures described in Appendix B, the estimated value of $(a^2\ S/T)$ is 153 years +/- 23 years, or +/- 15%. Repeating the exercise with a distance of 52,800 feet (ten miles) produces somewhat larger uncertainty on a percentage basis.

SPATIAL UNCERTAINTY

The spatial distribution of pumping effects is best represented by Steady State model results. These are controlled by geometric distance and aquifer Transmissivity, but not by aquifer Storage Coefficient. There are two major components of spatial uncertainty. The first is the uncertainty arising from the ability to measure and estimate distances and Transmissivity. The second arises from the fact that the aquifer is more heterogeneous than can be represented in the modeling software.

[2] This is different from the Time to Half defined in this report; Time to Half is the time for half the *volume effect* to arrive from a one-time event, while $(a^2\ S/T)$ is time for half the *rate effect* to arrive from a continuous process.

Estimation of Distance and Transmissivity Effects

Using ESPAM1.1, IWRRI estimated the Water Budget uncertainty of ESPAM1.1 at approximately +/- 17% (Snake River Plain Aquifer Model Scenario Update: Hydrologic Effects of Continued 1980-2002 Water Supply and Use Conditions Using Snake Plain Aquifer Model Version 1.1 "Base Case Scenario" http://www.if.uidaho.edu/~johnson/ifiwrri/projects.htm#model). Given that the ESPAM2.0 Water Budget was based on similar conceptual models and underlying data, it is reasonably expected that its uncertainty is also in this range.

To propagate the water-budget uncertainty into an indication of the uncertainty of Transmissivity, Darcy's law is applied. It relates the quantity of groundwater flow (in our case, the Water Budget) and the aquifer Transmissivity as follows:

$$Q = T w \, dh/dl$$

where	Q =	rate of flow through the aquifer
	T =	aquifer Transmissivity
	w =	width of flow tube considered
	dh/dl =	gradient along the length of flow

This can be rearranged to express *T* as a function of the Water Budget (represented by Q):

$$T = Q * (1/w \, dh/dl)$$

The variance of a product[3] can be calculated from the variances of the factors and the covariance between them. Relative to the Water Budget (Q), the width and gradient are very well known. If we assume they are perfectly known and their measurement methods are independent of the measurements of the Water Budget, then the variance of Transmissivity is driven entirely by the variance of the Water Budget. Hence, its uncertainty will also be on the order of 17%.

Effect of Heterogeneity

The second component of spatial uncertainty is based on the fact that the aquifer is actually a highly heterogenous combination of fractured basalts, dense basalts, and sediments of varying permeability and Transmissivity. Even if data were available to allow each of the 11,000 active Model Cells to be represented by a uniquely-estimated Transmissivity value, each would be a gross simplification of the heterogeneity with the

[3] A.J. Clemens and C.J. Burt, 1997. *Accuracy of Irrigation Efficiency Estimates,* Journal of Irrigation and Drainage Engineering.

Model Cell. However, the model representation of Transmissivity is actually based on unique estimates at fewer than 300 locations known as Pilot Points, with the value at each Model Cell based on interpolation between Pilot Points. Hence, it is not only impossible for the model to capture heterogeneity that exists within a single Model Cell, it is impossible to fully capture heterogeneity at a scale smaller than the distance between Pilot Points.

Appendix C contains a description of Monte-Carlo steady-state modeling representing a small hypothetical aquifer. The Monte-Carlo variable was spatial distribution of Transmissivity values within aquifer zones, honoring the +/- 15% uncertainty in Transmissivity estimated above. The specific results apply to that simulation, but the general principle demonstrated is that the finer the Reach discretization, the more variability in results. When the Reach length was 1/5 the equivalent distance between Pilot Points, the largest predicted result exceeded the smallest by two to seven times (i.e. was 200% to 700% of the smaller value). When Reach length was approximately equal to the inter-Pilot-Point distance, the larger values were approximately 110% to 250% of the smaller. This underestimates the potential effect of heterogeneity, because only a single geometric representation was used and because temporal and Storage Coefficient effects were ignored.

GENERAL DISCUSSION OF UNCERTAINTY

Effect of Uncertainty

The modeled magnitude of relief addresses the policy question of how much benefit will derive from a contemplated action, and the modeled timing of relief addresses the question of whether it occurs soon enough to be meaningful. From a technical standpoint, the general concept of uncertainty is an attempt to address the policy question, “How confident are we that the administrative action *will* provide the relief indicated?”

Potential Sources of Uncertainty

<u>Context of Sources of Uncertainty</u>

A groundwater flow model is a simplification of a complex physical system which cannot be described fully, due to limitations in knowledge of subterranean structures, lack of data, and limitations in computing power. The blue background in Figure 3 represents the infinite number of simplifications that could be made. Selection of an overall conceptual model puts some bounds on the possibilities, illustrated by the yellow irregular shape. Three existing eastern Snake Plain models (SRPAM, ESPAM1.1 and ESPAM2.0) are simplifications that share the conceptual model of single-layer representation with time-constant Transmissivity, without faults or other discontinuities. The heavy black line represents models that honor the Water Budget data, and the dotted line represents a subset which includes only models that are deemed to be Calibrated. Calibrated means that given the input data representing the Water Budget during a Calibration Period, the model does an acceptable job of reproducing observed measurements called Target values, from the same period. The three different X marks in the figure represent three different models that meet all criteria; they are consistent with the chosen conceptual model, they honor the Water Budget, and they are Calibrated in that they reasonably reproduce the Target data. Conceptually, the X marks could represent the three existing models mentioned.

Some sources of uncertainty relate to the various regions within Figure 3. For instance, conceptual model uncertainty refers to the fact that different conceptual assumptions could reasonably have been made for the eastern Snake plain, which would have changed the shape of the mapped "conceptual model" area in Figure 3. This would have changed the nature of model output for at least some specific questions. Other sources of uncertainty refer to different possibilities within the various regions. All three points marked "X" are within the same conceptual model and Water Budget, and all three are Calibrated. Differences between them can represent the concepts of internal Calibration uncertainty, mathematical uncertainty, parameter uncertainty and Predictive Uncertainty listed below.

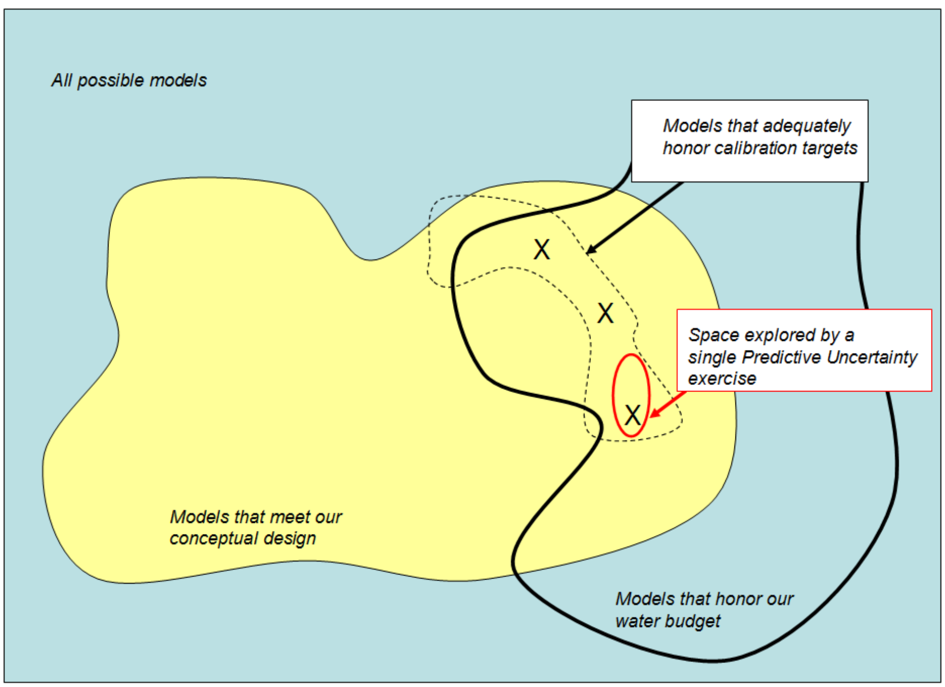

Figure 3. Cartoon of the range of possible models that could be considered.

Listing of Potential Sources of Uncertainty

Dr. Charles E. Brockway et al[4] offer a good listing of the potential sources of model uncertainty. These include:

- Conceptual Uncertainty
- Mathematical Uncertainty
- Parameter Uncertainty
- Internal Calibration Uncertainty
- Calibration Target Uncertainty
- Predictive Uncertainty

This report treats these sources qualitatively, with quantitative estimates made for some components of uncertainty.

Conceptual Uncertainty

Model Layers. Figure 4 shows a hypothetical aquifer that is somewhat analogous to the eastern Snake Plain aquifer. Geologic and well data provide strong indications of locations where there are indeed impermeable layers that separate the aquifer into distinct vertical zones, as shown in Panel A. There are two schools of thought in the proper modeling of such systems. One school of thought is represented by Panel B, that since we are reasonably certain the feature exists, it should be represented. This approach is exemplified by the Spokane Valley Rathdrum Prairie Aquifer model,[5] which represented a multiple layer system in an area where very few data were available to characterize the lower layer. The authors acknowledged the lack of data and provided cautions describing the resulting limitations.

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[4] C.E. Brockway, Jim Brannon, John Koreny, Willem Schreuder, Dave Colvin, Dave Blew and Jon Bowling. February, 2012. Uncertainty Analysis and Utilization of ESPAM2 for Water Rights Administration. http://www.idwr.idaho.gov/Browse/WaterInfo/ESPAM/meetings/2012_ESHMC/02_27_2012/Uncertainty Analysis and Utilization of ESPAM2 for Water.pptx

[5] Paul A. Hsieh, Michael E. Barber, Bryce A. Contor, Md. Akram Hossain, Gary S. Johnson, Joseph L. Jones, and Allan H. Wylie. 2007. Ground-water Flow Model for the Spokane Valley-Rathdrum Prairie Aquifer, Spokane County, Washington, and Bonner and Kootenai Counties, Idaho. Scientific Investigations Report 2007-5044, US Geological Survey.

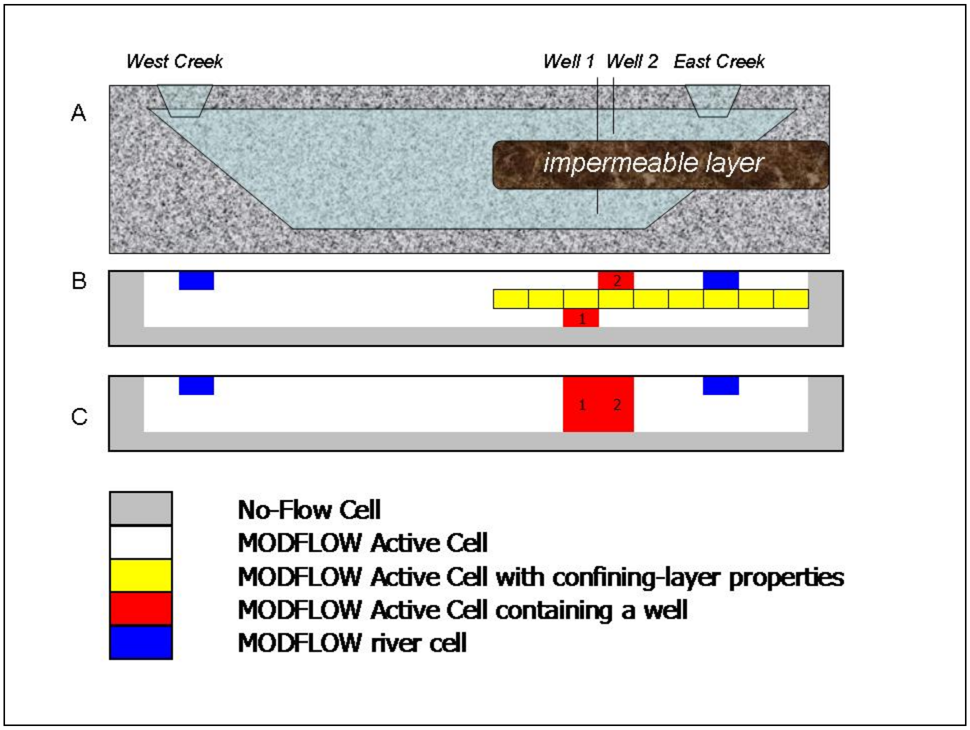

Figure 4. Illustration of differences in conceptualization of model layers.

The other school of thought is represented in the three Snake Plain models, that it is technically irresponsible to represent more detail than can be supported in Calibration by available data. This is illustrated by Panel C. Clearly, the existence of such different conceptual alternatives produces large uncertainty in representation of the effects that pumping Well 1 would have upon East Creek.

Faults. Figure 5 shows a hypothetical aquifer in fairly Transmissive materials, with a fault that is expected to be an impediment to groundwater flow. This is somewhat analogous to the Rexburg Bench area of the eastern Snake plain, which is included in ESPAM1.1 and ESPAM2.0. Figure 6B shows a conceptual representation from the school of thought that the knowledge of the fault's existence and expectations of its effect justifies including it in the model; it is the assertion that representing the fault incorrectly is “less wrong” than omitting it entirely. Figure 6C illustrates the school of thought taken in ESPAM1.1 and ESPAM2.0, that the fault should be omitted since there are limited head data to constrain Calibration of its properties. Both approaches are justifiable, but produce markedly different model representations of propagation of effects from the well to South Creek. This illustrates another large potential uncertainty associated with choice of conceptual model.

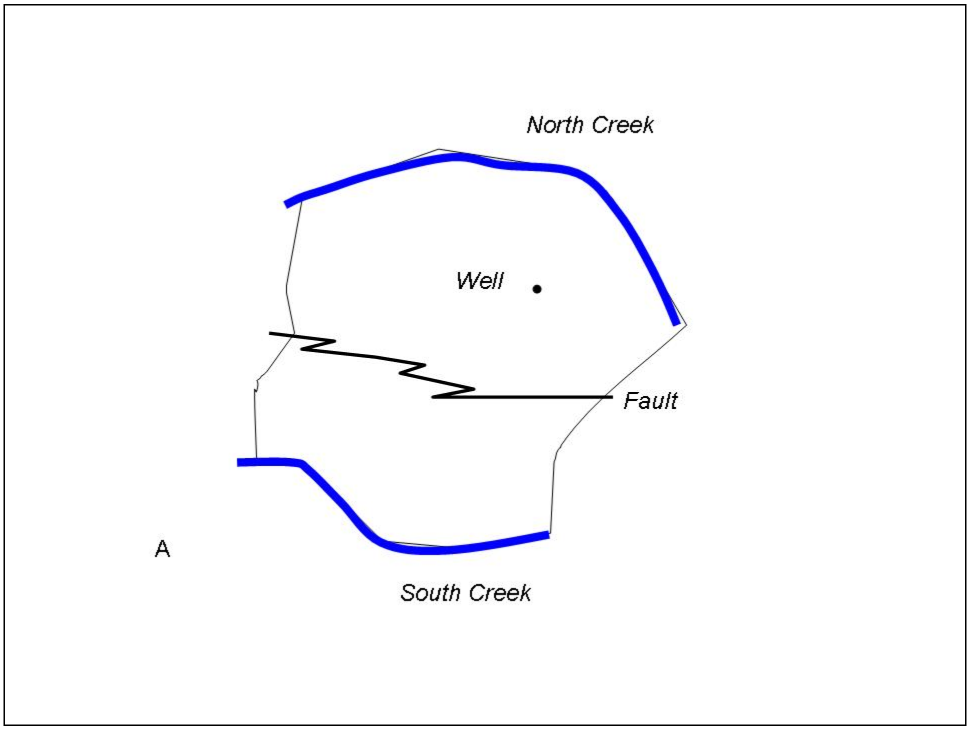

Figure 5. Hypothetical aquifer for discussion of conceptual model of fault representation.

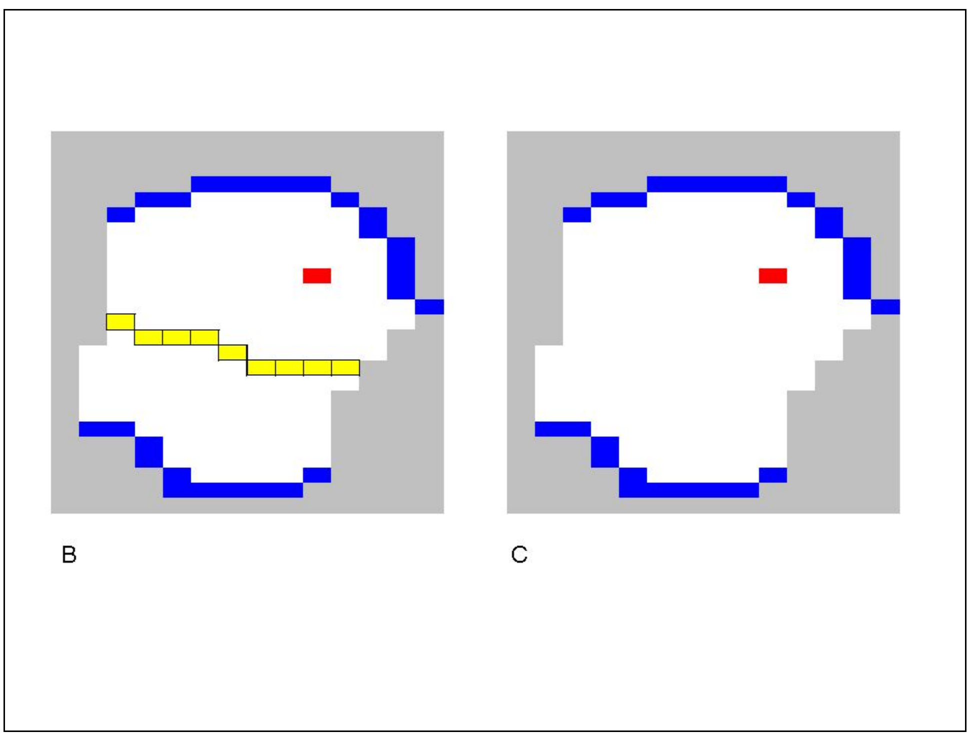

Figure 6. Two conceptual representations of the faulted aquifer shown in Figure 5.

Effect of Conceptual Uncertainty. This report does not quantify the uncertainty implied by these two conceptual model decisions, nor others such as the decision to use a time-constant Transmissivity. Nevertheless, it is important to understand that this is a legitimate part of overall uncertainty, because other conceptual decisions may be as reasonable as the ones taken in ESPAM2.0. The two illustrations provided suggest that this component of uncertainty can be large.

Mathematical Uncertainty

This report does not address mathematical uncertainty.

Parameter Uncertainty

The discussion above of the effect of uncertainty in Transmissivity is a discussion of parameter uncertainty. Later in this report is a discussion of the effect of heterogeneity at a scale finer than the inter-Pilot-Point distance, which is also a parameter uncertainty topic. Uncertainty in the Water Budget, estimated above at approximately 17%, is another example of parameter uncertainty.

Internal Calibration Uncertainty

This is related to the fact that within a given conceptual model, Water Budget and Target data set, there are multiple ways to Calibrate the model. Many of these may give reasonable results relative to the Calibration Targets, but may give different results for a given estimate or prediction made by the model. Further, the questions asked of the model are often different than the ones implicit in the Water Budget data used in Calibration.

A crude example might be a situation where it is known that two integers must add up to 15, but there are few other data to further inform the selection. Many pairs of integers can be identified that satisfy the Target value of 15, but they will give markedly different results for other questions, such as the difference between the two integers. This type of uncertainty is a component of the Predictive Uncertainty discussed below.

The example is not entirely far-fetched. The Calibration Water Budget data represent spatially-distributed recharge to the entire plain, and Targets represent total discharges or changes in discharge at various springs and river reaches. There are no Target data that explicitly relate a change in pumping at a specific well to a change in discharge at a specific spring or river reach. Yet this is the very question that must be asked of the model for evaluating a conjunctive administration water call.

Calibration Target Uncertainty

The model is Calibrated to match the Target data as closely as possible. However, no Target values are known with absolute precision. Some estimates of Target uncertainty are:

- Changes in aquifer head can be measured to approximately 0.01 foot, for changes that range from a few feet to a few tens of feet;
- Calculation of Target river gains and losses relies heavily on measurements of river flow and diversions. These are generally measured to a precision of 5% to 10%. Measured river flows are usually large relative to the gains/losses estimated with this technique, and hence the imprecision can exceed the magnitude of the calculated gains or losses. Gain/loss calculations also rely on estimates of surface return flows from irrigation, which are generally less precisely known than river flows or diversions.
- Some Target spring discharges are measured with standard measuring devices, likely having precision within a Range of plus or minus 3%. Others are measured with non-standard devices or rated sections, with accuracy perhaps of a Range of plus or minus 10% to 20%. Still other spring Targets are based on one-time measurements or estimates, with uncertainty likely greater than 20% to 30%.

Though the relationship is not quantified in this report, conceptually it is clear that the precision of the Target data also limits the ultimate certainty of model results. A model that exactly reproduces incorrect data is not as useful as Calibration statistics would suggest.

Predictive Uncertainty

Predictive Uncertainty is a concept related to parameter uncertainty and internal Calibration uncertainty discussed above. In this report, it is considered by comparing the SRPAM, ESPAM1.1 and ESPAM2.0 models. Predictive Uncertainty is also considered by reporting on IDWR work based upon recalibrating ESPAM2.0 while honoring Calibration constraints, specifically called a "Predictive Uncertainty Analysis" by IDWR and the ESHMC. Both considerations only explore part of the possible range, because in both cases the models compared share many similarities.

<u>Existing Model Comparison.</u> In Figure 3, the dotted line represents models that could be considered to be Calibrated. The X marks represent a sample of three, out of an infinite number of Calibrated models that could be discovered within that space. The three Snake Plain models (SRPAM, ESPAM1.1 and ESPAM1.2) provide one look into the potential magnitude of this type of uncertainty and could be considered to represent three X marks within the domain of Calibrated models.

Figure 7 shows three geographical locations selected to coincide approximately with the centroids of both an SRPAM Model Cell and an ESPAM Model Cell (SRPAM cells are approximately 3 miles square and ESPAM cells are one mile square). Figure 8 shows the estimates made by these three models, in magnitude and timing of effect to the combined Milner to King Hill reach, for the three different locations. The heavy black lines on the Time to Half bars indicate that SRPAM and ESPAM1.1 were set up to produce output every four months, so the represented Time to Half is only known to the level of a four-month trimester. The midpoint of the period is selected for charting in the red bar. The modeling files for this exercise are described in Appendix E and accompany this report.

It is acknowledged that ESPAM1.1 was designed to be an improvement over SRPAM, and ESPAM2.0 similarly is expected to be an improvement over ESPAM1.1. Nevertheless, all three are carefully Calibrated models based on a common conceptual model, and were each in their time the best available science.

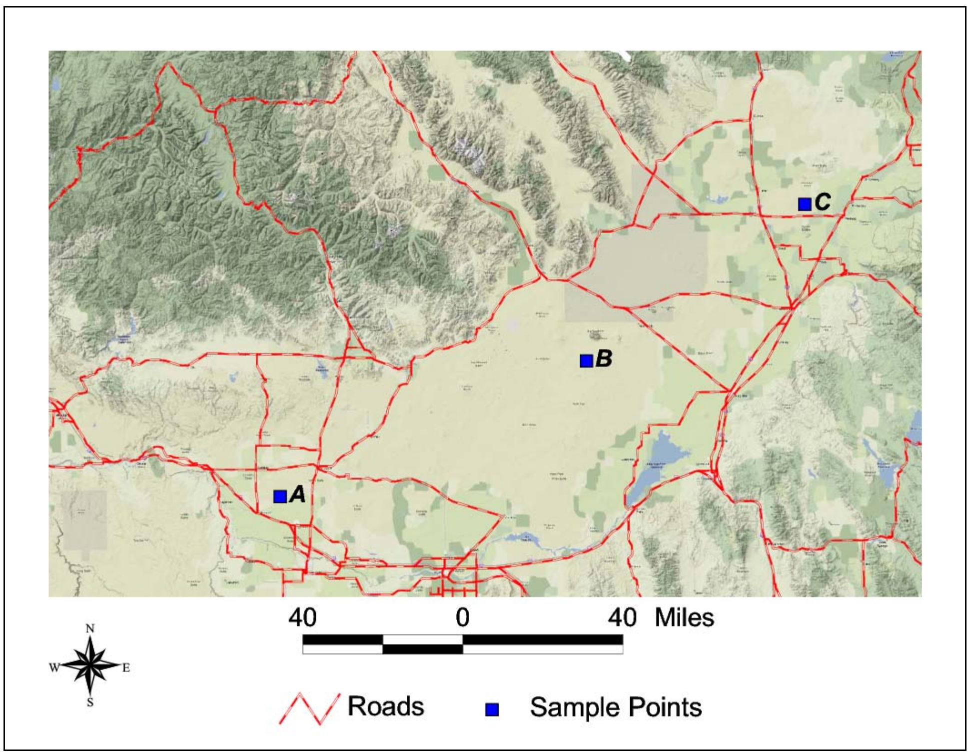

Figure 7. Sample points used to compare SRPAM, ESPAM1.1 and ESPAM2.0.

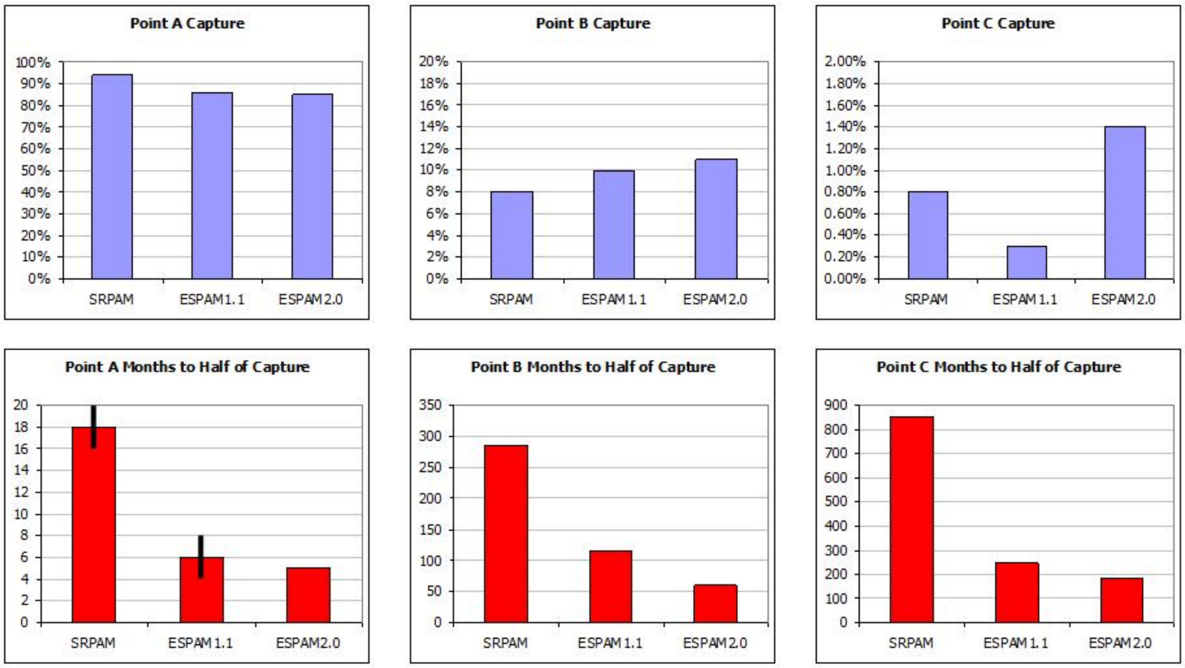

Figure 8. Differences in representation of Capture Fraction and timing of effect, from applying three Calibrated models to the points shown in Figure 7.

At Point A, Capture differences between the three models are within about 10% to 15%. At Point B the largest Capture is approximately 30% greater than the smallest, and at Point C the largest exceeds the smallest by a multiple of about five. Differences in timing are large (on a percentage basis) at all three points.

IDWR Predictive Uncertainty analysis. Another approach to test the range of Predictive Uncertainty is to set the model Calibration procedure to produce a pair of models that are both Calibrated, one maximizing and one minimizing some particular prediction. Conceptually, each such test could be considered an exploration of the red zone within Figure 3. With 11,000 Model Cells and over 60 reaches at which predictions could be assessed, there are a very large number of possible tests that could be run. With input from the ESHMC, IDWR has selected and run 17 Predictive Uncertainty analyses to explore the kinds of differences that might be observed.[6] This is not a statistical sample, but was focused on particular questions of interest. Figure 9 shows the range

[6] E-mail from Dr. Allan Wylie, included as Appendix D.

of results that were obtained, with the reported percentage defined as [(Maximum Effect/Minimum Effect) x 100].

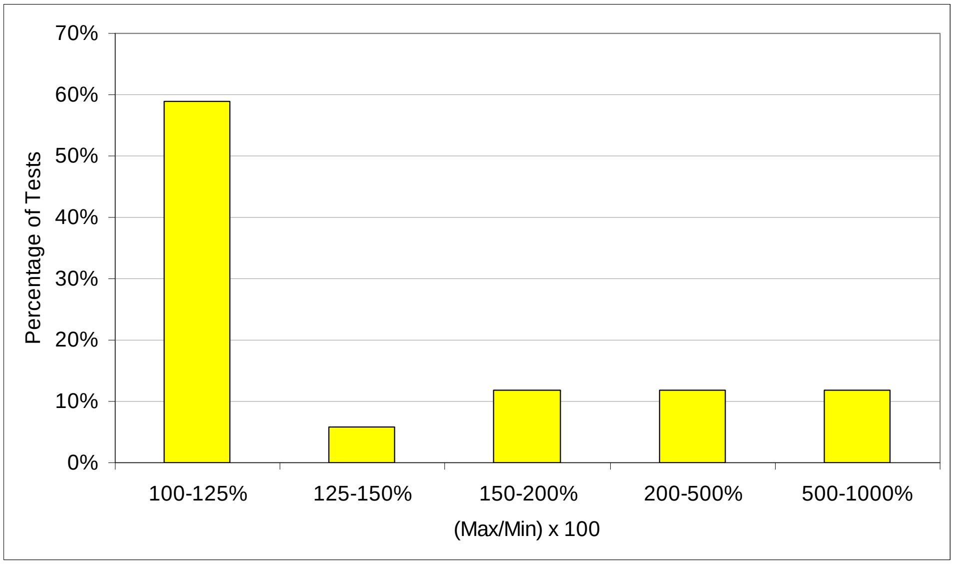

Figure 9. Results of IDWR Predictive Uncertainty tests.

Each test was comprised of a pair of Calibration runs, one configured to maximize and one to minimize the Steady State Capture to a particular reach from a particular location, while maintaining a Calibrated model. Calibration was maintained by requiring that overall match to Targets be within specific criteria, discussed with the ESHMC. The figure indicates that most of the time, the greatest ratio that could be forced while maintaining a pair of Calibrated models was approximately 125% (i.e. the largest estimate is 1.25 times the lowest). However, for more than 10% of the tests, the larger estimate was more than 500% of the lower. Almost a quarter of tests showed ratios of 200% or more. The variability of these results shows that the degree of uncertainty is highly sensitive to the particular question asked.

Each of the IDWR tests explores the potential uncertainty of a single estimate, within the ESPAM2.0 framework of a single conceptual model and a single set of Water Budget and Target data. Expanding the exercise to consider other conceptual models or alternate Water Budget representations would certainly have increased the range of results obtained.

Discretization

Spatial and temporal uncertainties are strongly influenced by the discretization of results required. If the question is "how much of curtailment at point X will benefit the river or springs someday, somewhere?" the answer can be determined with nearly 100% precision and confidence. If the question is "how much benefit will arrive to this particular river reach," uncertainty is introduced. If the question is, "How much will arrive in this reach on the 17th of August, 2018," uncertainty is compounded.

<u>Assessing Overall Uncertainty</u>

The concepts and measures described above are not competing methodologies for addressing the same question. They are descriptions of different parts of the question. The fact that Water Budget analysis indicates 17% uncertainty does not contradict the IDWR finding of much greater uncertainty in some of the Predictive Uncertainty tests; they are approximations of different parts of the larger uncertainty picture.

Because of some overlap or interdependence between various uncertainty estimates, and because extreme differences are generally less likely than small differences, total uncertainty is not simply the sum of estimates of various components. It is, however, certainly greater than indicated by any single estimate of uncertainty.

TEMPORAL DELAY OF EFFECTS

The ESPAM2.0 model run presented in Appendix A indicates that it would take approximately 197 months, or about 16 years, for half of the volume of relief from Egin curtailment to accumulate at the Rangen reach. Table 2 above reports the one-year and five-year arrival of relief. Uncertainty in temporal representations is described earlier in the report.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Trim Line

The technical content of Diminimus considerations is in the determination of whether curtailment of a given point of diversion meets a predetermined threshold. The Trim Line is one approach to establish a Deminimus cutoff. It is a spatial approach which classifies individual model cells as being either Deminimus or non-Deminimus, based on the expected quantity of relief from curtailment within the cell. The quantity threshold could be defined in terms of percentages of total curtailment volume, or of volume of relief per unit time. ESPAM2.0 can perform either calculation, subject to uncertainty. This uncertainty can be substantial. For instance, IDWR's tests indicate that the estimate of total relief to one reach, from curtailment in one particular region, could range anywhere from 3% to 29% of the curtailed consumptive use.[7]

[7] See Appendix D.

Establishing the Trim Line threshold itself is a policy question, which may in part consider uncertainty. The quantity uncertainty arising from the Water Budget and its effect on Transmissivity is likely at a minimum 15% to 20%. Overall uncertainty exceeds this single-component estimate, especially when questions are asked for small reaches and at small time scales.

Futile Call

Futile Call considers quantity effects described above, and also could have a component related to the timing of relief. Aquifer models can only estimate timing; for instance, Figure 8 suggests that for a test point above the springs in Magic Valley, the Time to Half (arrival of half the relief) is somewhere between five and 20 months. For a point in the center of the plain, it is between five and 20 years and for a point in the northeast it is 15 to 70 years.

Reach Discretization

From a technical standpoint, Administrative Reaches should not subdivide Calibration Reaches. Combining Calibration Reaches into larger Administrative Reaches is technically desirable when Calibration Reaches are smaller than the distances between nearby Pilot Points. Above Milner, reach discretization should further be constrained by considerations of the WD01 accounting process.

Temporal Discretization

Modeling using one-month Stress Periods is acceptable, but great caution should be exercised in reliance on administrative decisions that hinge on temporal representations at periods shorter than approximately four months. Great attention should be paid to the ability of the model to match temporal signals in the reach(es) important to the administrative decision, as shown by Calibration results. Temporal reliance on the model should also be tempered by a realization that the model was Calibrated to spatially-distributed Water Budget data, but will be administratively applied assuming that temporal results are valid for a single user at a single point.

Model Uncertainty

The uncertainties expressed here can be considered as expressions of the probability that a given administrative action will produce the benefits to seniors that the model says it will. Combined with the magnitude of benefit to the senior, model uncertainty should be viewed in context of the magnitude and absolute certainty that of the effect that the junior *will* undergo. For any proposed action, a large, rapid and highly probable benefit is more justifiable than a small, delayed and uncertain benefit.

- For any particular question, quantity uncertainty is probably at least in the range of the 17% result obtained from water-budget analysis.
- Additional uncertainty is introduced from conceptual model limitations and from the parameter estimation process. The IDWR Predictive Uncertainty work indicates that the difference between two Calibrated ESPAM2.0-framework models can exceed 500% for some questions, though it is generally much smaller.
- Uncertainty will always decrease as questions are asked on larger spatial scales and longer cumulative time scales.
- Work presented here suggests the lower limit of temporal uncertainty may generally be in the range of 15%.
- Uncertainties from various sources are not strictly additive but they do combine. Overall uncertainty will always be greater than the estimate from any particular source of uncertainty.

Timing of Effects

ESPAM2.0 estimates that half of the volume of benefit eventually arriving at the Rangen reach from Egin curtailment will have accrued during the 16-year period following a one-time curtailment event. Some of this benefit would accrue to Rangen, some to other users within the reach, and perhaps some to springs without water rights.

Overall Recommendation

ESPAM2.0 is a good tool. It is only a tool, and is but one of many. It should be used with careful attention to the limitations described above. Great caution should be used whenever results depend on spatial discretization smaller than the inter-Pilot-Point distance or temporal discretization shorter than approximately four months. In no case should it be relied upon where critical administrative turning points hinge on differences smaller than the Ranges of uncertainty explored in this document and revealed by the IDWR Predictive Uncertainty work.

APPENDICES

Appendix A: Modeling of Egin Bench curtailment.

Appendix B: Calculations of temporal uncertainty estimates.

Appendix C: Monte Carlo exploration of heterogeneity of Transmissivity

Appendix D: IDWR Predictive Uncertainty (e-mail from Dr. Wylie)

Appendix E: List and description of accompanying data files.

APPENDIX A
MODELING OF EGIN BENCH CURTAILMENT

APPROACH

The approach taken to model Egin Bench curtailment was to identify water-right points of diversion with source “ground water” and use “irrigation” within the portion of the Fremont Madison Irrigation District identified as Egin Bench. Points of diversion were selected from IDWR water-right data using GIS processing. All points of diversion with priority date equal or senior to July 13, 1962 were removed from calculations.

The equivalent reduction in consumptives use was calculated from the water-right diversion rate and applied to the appropriate model cells by application of response functions from ESPAM2.0. Results were summarized and data processed in Microsoft Excel.

DETAILS OF GIS PROCESSING

Data set “irrigation_companies.shp”[1] was downloaded from website http://www.idwr.idaho.gov/ftp/gisdata/GISScripts/downloadform.asp?path=Spatial/Irrigation/IrrigationCompanies&package=irrigation_companies.pkg on August 31, 2012. The Fremont Madison Irrigation District was extracted as “fmid_simple.shp,” included within the data folder “Modeling_Egin_Bench_Curtail” provided with this document. The District lands were manually partitioned into Egin Bench lands and other lands as identified in the attribute table and in Figure A1 below.

Groundwater irrigation points of diversion within Egin Bench were extracted from data sets “Wrpod.shp” and “Wrpou.dbf” downloaded from http://www.idwr.idaho.gov/GeographicInfo/GISdata/water_rights.htm on July 16, 2012. The selected lands and junior wells are shown in Figure A1.

[1] In all the appendices, the notation “<xxxx>.shp” will be used as shorthand for the suite of files that comprise an ESRI shapefile.

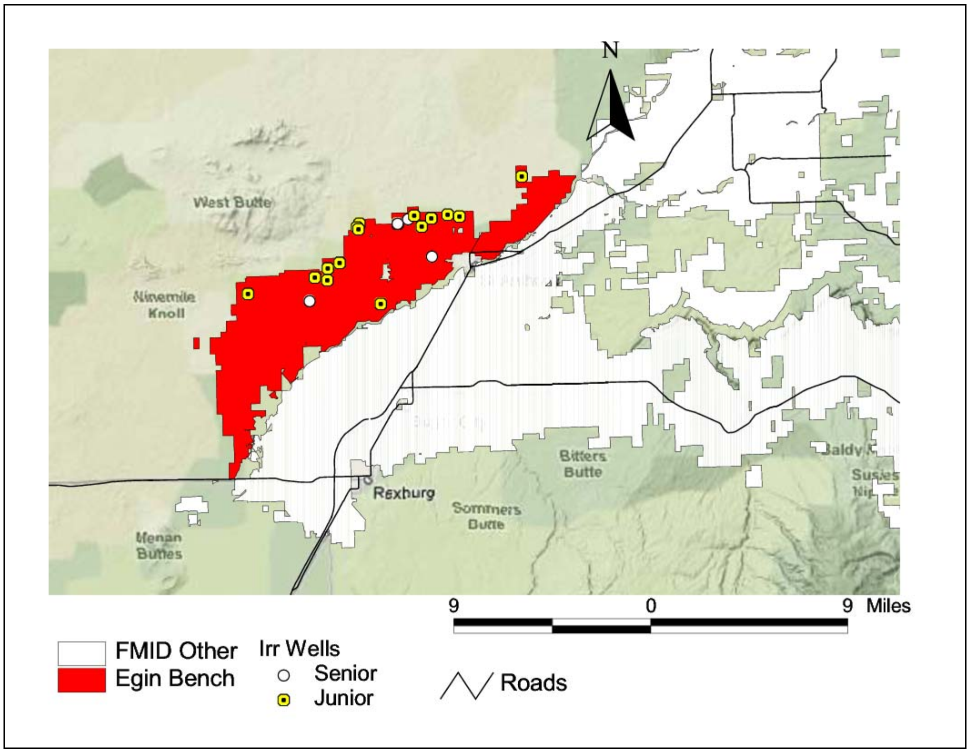

Figure A1. Egin Bench service area and groundwater irrigation points of diversion.

Points of diversion were saved as shapefile "wr_pod_egin_gw_irr_bycell_nodups.shp," included in the data files transmitted with this Appendix. Attribute table fields CALC_PDRATE, CALC_ACRES, CALC_CU and CALC_DIV were manually added and populated. Diversion rate for multiple wells was uniformly apportioned to the wells under the water right. Acres were calculated assuming fifty acres per each cubic foot per second of water right, consumptive use was estimated at two feet per acre, and diversion volume was calculated assuming 80% consumed fraction of field applied groundwater. Model cells were identified using GIS processing with data set "ESPAM2_ModelGrid_06092011.shp," downloaded from http://www.idwr.idaho.gov/Browse/WaterInfo/ESPAM/model_files/Version_2.0_Development/Current_Data/ on August 31, 2012. Because of the coarseness of the assumption used, the modeling results are best interpreted in terms of the ratio or percentage of benefit to curtailed volume.

DETAILS OF AQUIFER MODELING

Aquifer modeling was performed by generating transient aquifer response functions using the transient superposition ESPAM2.0 model provided by IDWR. The extraction of response functions was performed using a batch process. The response functions were further processed by a small utility to produce model output, which was summarized in a Microsoft Excel spreadsheet.

Accompanying folder “Modeling_Egin_Bench_Curtail” contains all the files used. Specific files and folders within this folder are further described here:

Folder “BATCHMAKER” contains the utility and source code used to generate the files for the batch processing. It also contains folder “OUTPUT_OF_BATCHMAKER,” whose contents were used with the MODFLOW files described below. MODFLOW output of the batch process is presented in folder “RESPONSE_FUNCTIONS.”

Accompanying data folder “MODFLOW_AND_ASSOC_FILES” contains the modeling files that were used along with the batch files. The model was set up to run monthly stress periods with one time step per stress period. Months were defined with equal lengths of approximately (365.25/12) days. This folder also includes the MODFLOW executable file and the utility “bud2smp.exe.” Source code was not obtained for these executables and therefore cannot be submitted with this document.

Folder “VB_CONVOLUTOR_II” contains the utility (executable and source code) used to extract modeling results from the response functions. It was applied to input file “jr_summary_bycell.csv” and produced output “jr_summary_bycell_OUT.csv.” In turn, this output was processed in file “jr_summary_bycell_OUT.xls” to calculate the estimates presented in Table 2 in the report.

APPENDIX B
ESTIMATION OF TEMPORAL UNCERTAINTY

APPROACH

Temporal uncertainty was estimated using the *Jenkins Stream Depletion Method,*[1] a standard analytical calculation method for estimating the time for arrival of pumping effects to a hydraulically-connected stream. As stated in the body of the report, "The propagation of temporal signals to a stream segment can be expressed by the ratio $(a^2 S/T)$, where a is geometric distance, S is aquifer storage, and T is aquifer Transmissivity. The output of the equation is in the time units of the Transmissivity value, and is the amount of time for half of the rate of pumping or recharge to be expressed at the target river reach." This ratio has units of time and is one way to represent the temporal propagation of a pumping effect.

The *Jenkins Stream Depletion Method* was populated with values for distance, transmissivity and aquifer storage which are compatible with the eastern Snake River plain. Input Uncertainty was expressed in terms of the expected range that all estimates for a single input value would fall within (approximately equivalent to four standard deviations). That is, a statement that "We can measure X to a precision of plus or minus 5%" we mean that if X were repeatedly measured with the instruments and methods at hand, all the measured values would fall in the range of 0.95 X to 1.05 X.

The approximation that the range is equivalent to four standard deviations allowed the variance to be estimated as the square of the estimated standard devation. Statistical calculation equations were used to propagate the variances of the input values to an expected of the calculated ratio, and using the same assumptions of the range being equal to four standard deviations, the expected range of uncertainty of the time of arrival of effects was derived from the calculated variance.

STATISTICAL EQUATIONS USED

Two basic statistical equations were used; an equation for the variance of a product, and an equation for the variance of a ratio. The product equation was applied to estimate the variance of the product $(a * a)$ or (a^2), then the ratio

[1] C.T. Jenkins, 1968. *Computation of Rate and Volume of Stream Depletion By Wells,* Techniques of Water Resources Investigation of the United States Geological Survey, Book 4 Chapter D1

equation was applied to estimate the variance of the ratio *(S/T).* In turn, these estimated variances were used to approximate the variance of the product [*(a2)* * *(S/T)*].

The equation for the variance of a product was obtained from Clemens & Burt, *Accuracy of Irrigation Efficiency Estimates*, Journal of Irrigation and Drainage Engineering, Nov/Dec 1997 (notation altered):

$$s^2 = m_2^2\ s_1^2 + m_1^2\ s_2^2 + s_1^2\ s_2^2 + 2\ m_1\ m_2\ s_{12} \quad (1)$$

where:

s^2 = estimated variance of product
m_2 = expected value of second factor
s_1^2 = estimated variance of first factor
m_1 = expected value of first factor
s_2^2 = estimated variance of second factor
s_{12} = estimated covariance between the factors

The variance of the ratio *(S/T)* is estimated using an equation from http://stats.stackexchange.com/questions/19576/variance-of-the-reciprocal-ii (notation altered):

$$s_r^2 = (m_1/m_2)^2\ (s_1^2/m_1^2 + s_2^2/m_2^2 - 2\ s_{12}/m_1\ m_2) \quad (2)$$

where:

s_r^2 = estimated variance of the ratio (m_1/m_2)

Both equations require an estimate of the covariance (s_{12}). It is estimated here from the expected correlation coefficient using Equation 3, obtained from Snedecor and Cochrane, Statistical Methods Seventh Edition, Iowa State University Press, 1980, p 180 (notation altered):

$$r = s_{12}\ /\ (s_1\ s_2) \quad (3)$$

where

s_x = estimated standard deviation of variable x = square root of estimated variance of variable x
r = correlation coefficient between the two variables.

This can be rearranged to express covariance in terms of correlation coefficient:

$$s_{12} = r\ s_1\ s_2 \tag{4}$$

Correlation coefficients range between -1 and +1. A correlation coefficient of -1 indicates that the two factors are 100% interdependent and that when one increases the other decreases. Correlation of zero means the factors are fully independent, and correlation of +1 indicates that the factors are fully interdependent and move together when changes occur.

Obviously the correlation of *a* with itself is +1. For this exercise it was assumed that *T* and *S* have positive correlation, since the temporal component of target data constrains the ratio *S/T* and can accommodate an over-estimate in one with a compensating overestimate of the other. However, spatial distribution of gains constrains *T* without the ability for offsetting errors in *S*. Hence, the correlation was estimated at +0.5 for use in Equation (4).

The final calculation also used an equation which adjusts the product for the variances of the terms, also from Clemens and Burt (cited above):

$$m = m_1\ m_2 + s_{12} \tag{5}$$

where

m = expected value of the product

This made only trivial differences in the calculated value of $(a^2\ S/T)$.

CALCULATIONS

Temporal uncertainty calculations are in file “TravelTimeCalcs.xls” in folder “Travel_Time_Uncert_Calcs.” The folder also contains the full Internet page from which Equation (2) was obtained.

The equations were applied to the values in the table in the body of the report, and to a hypothetical location with a shorter distance but the same storage and transmissivity characteristics. The results of the calculations were approximate temporal uncertainties of 15% and 21% for the further and nearer locations, respectively. This includes only temporal uncertainty associated with imprecision in the three input values; it cannot include temporal uncertainty associated with other sources such as the choice between alternate conceptual models.

APPENDIX C
MONTE-CARLO INVESTIGATION OF HETEROGENEITY EFFECTS

APPROACH

To assess the potential effect of heterogeneity at spatial scales smaller than the inter-pilot-point distance, a simple steady-state aquifer model was constructed. It included two Transmissivity zones that were subdivided into smaller subzones. The larger zones were assumed to represent the inter-pilot-point distance, while the subzones were intended to represent heterogeneity at a sub-pilot-point scale. The aquifer interacted with a stream that had been subdivided into two reaches each of length equal to the zone size, analogous to the inter-pilot-point distance. Each reach was further divided into subreaches of length equivalent to one-fifth the inter-pilot-point distance. Two wells were installed, one at just less than the inter-pilot-point distance from the stream and another nearer the stream.

A hypothetical “calibrated” Transmissivity was specified for each zone. Random suites of Transmissivity values were generated for the sub zones, and those which produced reasonable approximations (i.e. within the expected precision of Calibrated Transmissivity estimates) of Transmissivity in both large zones were retained as candidates for evaluation. This approach implicitly includes the combined effects of uncertainty in Transmissivity estimates and of spatial heterogeneity.

The concept of the test is that there is a single underlying spatial distribution of Transmissivity, but that it is unknown and unknowable. Each of the tested parameterizations represents a distribution that is possible given the data at hand, and each could therefore represent the “truth.” The output is a description of how many different underlying “true” configurations could be compatible with a single calibrated result. The calibrated result is represented with a uniform Transmissivity of 20,000 ft^2/day in the west zone and uniform Transmissivity of 100,000 ft^2/day in the east. Because this is a steady-state model, aquifer storage is not estimated nor applied in calculations.

When the suite of parameterizations was assembled, each was evaluated in its steady-state partition of effects to the ten sub-reaches and to the two aggregated reaches, from each of the two wells. The results were presented graphically, to allow some visualization of what the underlying probability distribution may look like. No formal statistical analyses were performed, though basic summary statistics were assembled.

DESCRIPTION OF MODEL

The model is constructed in Microsoft Excel with the option for iterative calculations enabled. The model domain is illustrated in Figure C1. The model has ten vertical columns and four horizontal rows. Wells are represented in Row 1 column 3 and row 3 column 3. Ten river cells border the south side of the model domain.

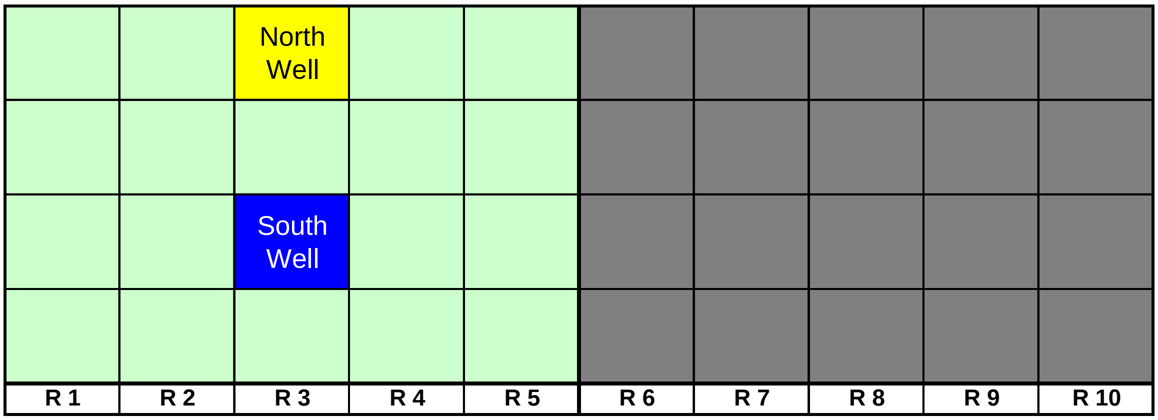

Figure C1. Model domain for a test with two zones representing the inter-pilot-point distance.

1	1	2	3	4	4	6	7	8	8
1	1	2	3	4	4	5	7	8	9
1	2	3	5	5	5	5	7	8	9
1	2	3	3	5	5	6	7	8	10
R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10

Figure C2. Discretization of transmissivity zones and sub reaches.

This representation does not explore the full range of heterogeneity, due both to the large size of the individual transmissivity zones and to the fact that all the simulations assume the same geometric configuration of zones. It also fails to represent any heterogeneity or uncertainty in the nature of the connection between the river cells and the aquifer cells.

Because well-to-river distances are small relative to the inter-pilot-point distance, this test does not explore the effects that heterogeneity at this scale might have upon more distant wells.

Data folder "MONTE_CARLO" accompanies this appendix. In it are subfolders "NORTHSOUTH_R1C3" and "NORTHSOUTH_R3C3," containing the forty individual representations of the model and summary spreadsheets for the respective well locations.

GENERATION OF AQUIFER PROPERTIES

The aquifer properties were generated using a VB6 utility run in developer mode, with no executable ever being produced. The source code is contained in subfolder "VB_TESTMAKER_II." The utility relies upon a pseudo random number generator. Hence, if run again it may not reproduce the twenty realizations used in this simulation. However, it would be expected to produce a suite of twenty realizations which do honor the constraints.

In reality there is a single geometric configuration of the aquifer, which is unknown and unknowable. There is a single assignment of properties to this configuration, also unknown and unknowable. There are a nearly infinite number of simplified representations which could be made. This test assumes a single simplified geometric configuration and explores the implications of 20 different potential underlying suites of Transmissivity values which could actually populate the given simplified representation. The simulation requires conformance with the large-zone Transmissivity values, within an uncertainty range.

Spreadsheet "Aquifer_Property_Summary.xls" in the main folder summarizes the aquifer properties generated. Figure C3 shows that the simulations indeed resulted in the geometric means of the east and west model zones corresponding to approximately +/- 15% of the target values. Though no formal statistical test was performed on the distributions, from the figure it appears that the distributions are more or less centered and are centrally weighted. This corresponds to the assumptions of the techniques used to estimate the uncertainty of Transmissivity estimates.

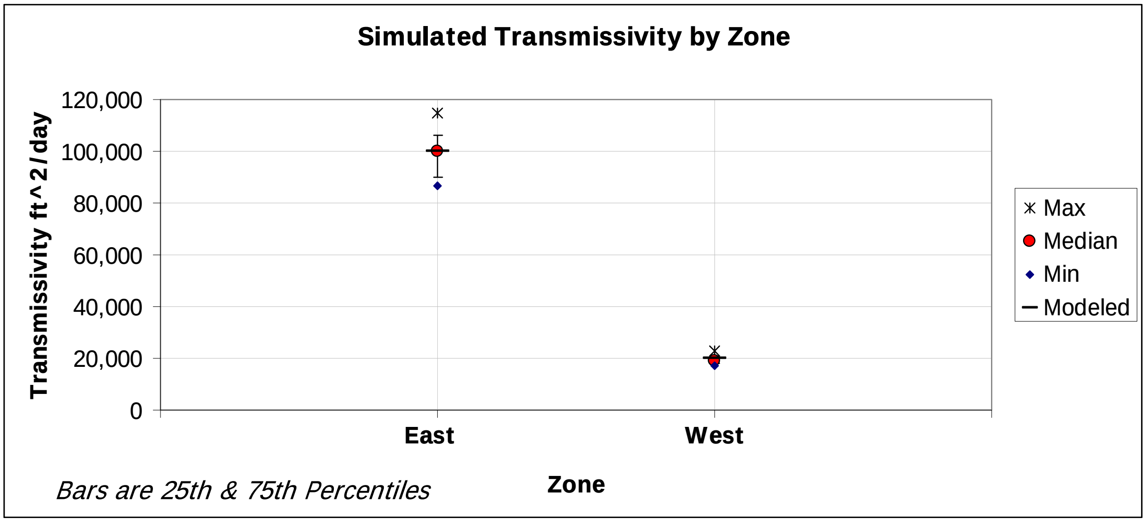

Figure C3. Simulated Transmissivity by zone.

Figure C4 shows the wide range of variability achievable across the ten sub zones while honoring the large-zone constraints. The utility was allowed to vary each zone by five orders of magnitude (less than the range of Transmissivity in the calibrated ESPAM2.0 model). The figure shows that many of the reaches explored this full range. Of course in order to meet the larger zone requirements, when any sub zone was at an extreme value, other sub zone(s) had to be set to offsetting values in the other direction.

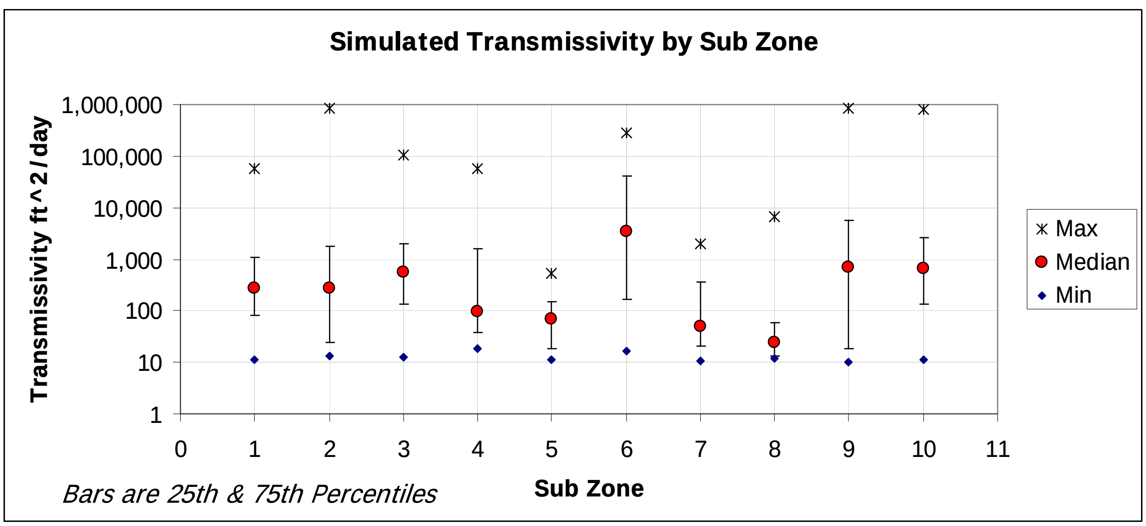

Figure C4. Simulated Transmissivity by sub zone.

RESULTS OF SIMULATIONS

From each simulation, steady-state partition of flux was recorded for each of the ten sub reaches and for the two modeled reaches. Figures C5 illustrates results for the north well (more distant from the stream) and figures C6 shows the south well results.

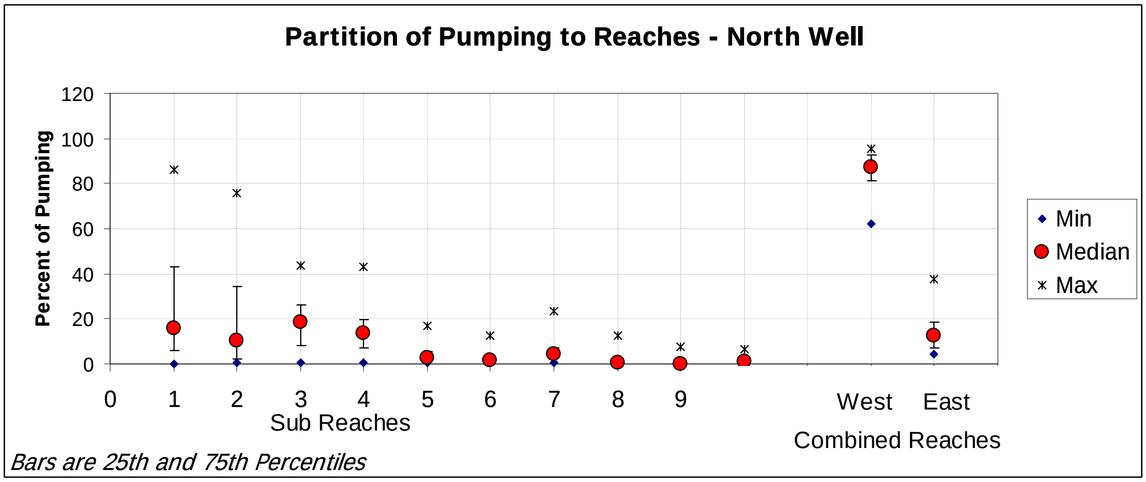

Figure C5. Simulation results for north well.

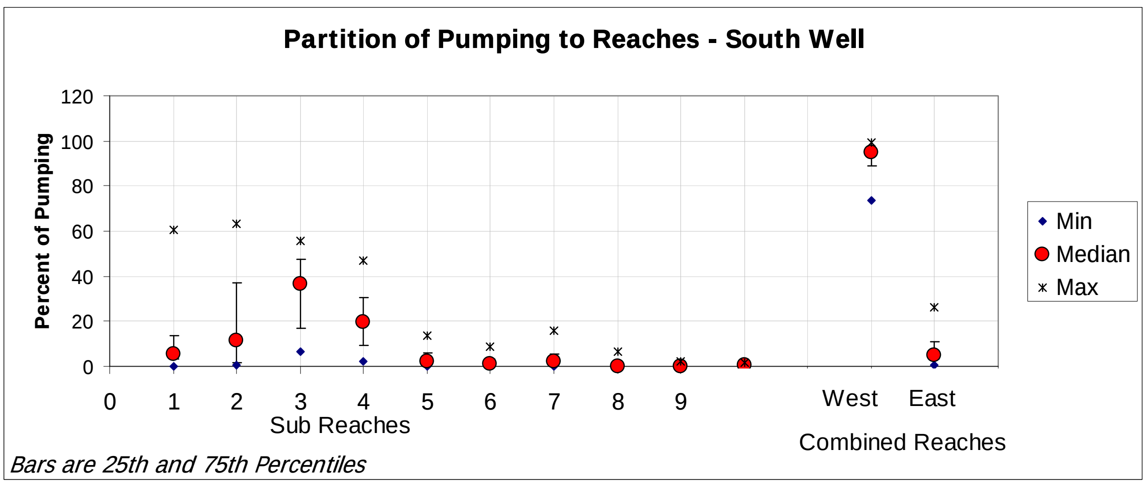

Figure C6. Simulation results for south well.

The meaning of these results is somewhat difficult to articulate. The conceptual model of the test is not an exploration of the range of calibrated results that could be obtained from a single true configuration; it is an exploration of a suite of potential true configurations that are compatible with a single calibrated result. In this light, the subreach-one results from the north well could be described as follows:

> "Given this calibration result, it is possible that the true propagation of north well effects to reach one could be as low as essentially zero, or as much as 85% of pumping."

Two observations arise from Figure C5 and Figure C6:

1. For individual reaches smaller than the inter-pilot-point distance, the range of uncertainty is very large;
2. The uncertainty is much smaller when reach size is approximately equal to the inter-pilot-point distance.

LIMITATIONS OF TEST

The limitations of this test include the following:

1. This test only considers wells whose proximity to the river is within the inter-pilot-point distance;
2. Only one configuration of Transmissivity zones is considered;
3. It is a steady-state test and therefore does not inform temporal considerations of heterogeneity;
4. It actually tests zones as a proxy for pilot points;
5. It does not test heterogeneity or uncertainty in representation of the connection between the aquifer and springs or streams;
6. Only twenty configurations were tested.

The implication of the first limitation is that this analysis is most valid for wells near the river or springs. The implication of the second, third and fifth is that actual uncertainty arising from heterogeneity is expected to be greater than indicated here. The fourth limitation suggests that there is some imprecision in these results. More sophisticated analysis explicitly representing pilot points could show somewhat more or somewhat less uncertainty. This is partially addressed by constraining the test to a narrower range of Transmissivity values than were used in ESPAM2.0 and narrower than expected to actually occur. The sixth limitation applies to the ability to fully describe the probability distributions suggested by the graphical results, or to perform formal statistical tests.

A reader may be tempted to add a seventh criticism, that ESPAM2.0 was calibrated to individual small reaches and therefore some of the more poorly performing simulations should be dropped from this comparison. However, ESPAM2.0 was calibrated to a data set of spatially distributed recharge and discharge across the plain. It can be argued that the calibrated Transmissivity represented by the smoothed surface between pilot points in ESPAM2.0 and the uniform Transmissivity zones represented in this simulation primarily represent calibration response to the large flux entering the zones from the broader plain beyond. Demonstrating the ability to respond to this large, diffuse, distant flux does not at all guarantee that the model can correctly respond to a small, concentrated, nearby stress.

The observed response to the calibration conditions could arguably have been obtained with a number of different localized heterogeneity distributions, since all preferred flow paths essentially will eventually tap the same broad, spatially diffuse pattern of recharge. Even if one assumes that the primary driver is nearby irrigation and canals, their effect is still large and diffuse relative to the effects of a single well at a discrete location, and relative to the inter-pilot-point distance. Further, even a suite of nearby localized stresses that show the same general temporal pattern will not inform the calibration process whether all springs are responding generally to all stresses, or whether specific springs are responding uniquely to individual point stresses.

If the model had been calibrated to known responses at small reaches, from unique, known, nearby point stresses, the seventh criticism would be appropriate. However, that is not the condition the model was calibrated to.

CONCLUSIONS

For wells within the inter-pilot-point distance, this analysis suggests the following:

1. For reaches of length approximately 1/5 the inter-pilot-point distance, actual pumping response can range from essentially zero to more than 80% of pumping, given Transmissivity uncertainty in the range of +/- 15%;
2. The uncertainty is greatly reduced when reach length is at least as great as the inter-pilot-point distance. In this test, half the simulated values for aggregated reaches fell within approximately the same range of uncertainty as was represented for the underlying Transmissivity estimates.

It is recommended that great caution be used whenever administrative decisions hinge on spatial discretization of results at scales finer than the inter-pilot-point distance.

APPENDIX D
IDWR PREDICTIVE UNCERTAINTY ANALYSIS

This appendix provides an e-mail from Dr. Allan Wylie describing the results of the IDWR predictive uncertainty analysis. The penciled notes in the margin are manual calculations of the ratio (Max / Min) x 100.

APPENDIX E
DESCRIPTION OF FILES ACCOMPANYING REPORT

This appendix provides a list and description of the files that accompany the report.

1. Folder “3-Model_Comparison” contains files used for the analysis of uncertainty associated with three different models, applied to three different points on the plain.

   1.1. Subfolder “BatchFile_Input_Files_ResponseFiles” contains files uniquely associated with running ESPAM2.0 for this analysis, using the procedures described in Appendix C and the MODFLOW files described in 2.3 below.

   1.2. Subfolder “BATCHMAKER” contains the source code, executables and output of the batch-file process used to operate MODFLOW to generate response functions.

   1.3. Subfolder “ESPAM_XFR_TOOL” contains the IDWR/University of Idaho groundwater right transfer tool based upon ESPAM1.1, and the three applications of that tool to the points in the comparison. These files were prepared by University of Idaho or generated by the transfer tool, with the exception of the following:
      1.3.1. “Point_A.xls,” “Point_B.xls” and “Point_C.xls” are copies of the transfer spreadsheets as run for the three locations in the analysis.
      1.3.2. “Point_A_Effects_ESPAM1.1.xls,” “Point_B_Effects_ESPAM1.1.xls” and “Point_C_Effects_ESPAM1.1.xls” contain summaries of the results from the three transfer-tool spreadsheets.

   1.4. Subfolder “SRPAM_XFR_TOOL” contains the IDWR/University of Idaho ground water rights transfer tool based upon SRPAM, and the three applications of that tool to the points in the comparison. These files were prepared by University of Idaho or generated by the transfer tool, with the exception of the following:
      1.4.1. “Point_A.xls,” “Point_B.xls” and “Point_C.xls” are copies of the transfer spreadsheets as run for the three locations in the analysis.
      1.4.2. “Point_A_Effects_SRPAM.xls,” “Point_B_Effects_SRPAM.xls” and “Point_C_Effects_SRPAM.xls” contain summaries of the results from the three transfer-tool spreadsheets.

1.5. Eight files “1x1_for_budget_analysis.*” are the ESPAM1.1 model grid GIS shapefile.

1.6. Seven files “espam2_gridcenters_20110609.*” are the centroids of the ESPAM2.0 model grid shapefile.

1.7. Two files “LOCATION_MAP_SAMPLE_POINTS.*” are maps of the three sample points chosen.

1.8. Three files “old_grid_centroids.*” are the centroids of the SRPAM model grid shapefile.

1.9. Seven files “old_mdl_grd.*” are the SRPAM model grid GIS shapefile.

1.10. File “proj1.apr” is an ArcView3.3 project file for the GIS setup used to define the sample points.

1.11. Three files “sample_points.*” are the GIS shapefile for the three selected sample points.

1.12. File “3-Model_Compare.xls” summarizes the results and generates the figure describing this test.

2. Folder “Modeling_Egin_Bench_Curtail” contains the files used for the analysis described in Appendix C.

2.1. Subfolder “BATCHMAKER” contains the source code, executables and output of the batch-file process used to operate MODFLOW to generate response functions.

2.2. Subfolder “Model_Grid_06092011” contains files associated with the ESPAM2.0 model grid GIS shapefile.

2.3. Subfolder “MODFLOW_AND_ASSOC_FILES” contains the MODFLOW setup used to generate response functions.

2.4. Subfolder “RESPONSE_FUNCTIONS” contains the response functions for the locations treated in this analysis.

2.5. Subfolder “VB_CONVOLUTOR_II” contains the source code and executable used to apply the response functions to the modeled stress, along with a sample input file.

2.6. File “Data sources.doc” contains URLs for various data downloads associated with the Appendix C modeling and the report in general.

2.7. Files “EGIN_MAP.*” and “EGIN_MAP_II.*” are illustrations of the Egin Bench service area.

2.8. File “export_podtable.txt” is an intermediate text file.

2.9. Files “fmid.*” and “fmid_simple.*” are files associated with GIS shapefiles of the Fremont Madison Irrigation District service area.

2.10. Files “irrigation_companies.*” are files associated with the IDWR shapefile of canal company and irrigation district service areas.

2.11. File “jr_summary_bycell.csv” is the input file that was used by utility “VB_CONVOLUTOR_II.”

2.12. Files “jr_summary_bycell.txt” and “jr_summary_bycell.xls” are intermediate processing files.

2.13. Files “jr_summary_bycell_OUT.*” are the output of the convolution utility and further processing of that output.

2.14. Files “PODRATE.*” are intermediate processing files.

2.15. File “proj1.apr” is an ArcView3.3 project file.

2.16. File “Screeshots.ppt” is a log of ArcView processing.

2.17. Files “wr_pod_egin_gw_irr_bycell_nodups.*” are files associated with a shapefile of processed Egin Bench groundwater points of diversion.

2.18. Files “wr_pod_gw_irr_egin.*” and “wrpod_egin_irr_gw.*” are intermediate processing files.

2.19. Files “wrpod.*” are files associated with the IDWR water right points of diversion shapefile.

2.20. File “wrpou.dbf” is the attribute table from the IDWR water rights place of use shapefile, used to identify water use for the points of diversion in “wrpod.*”

3. Folder “MONTE_CARLO” contains the files used for the analysis described in Appendix C.

   3.1. Subfolder “NORTHSOUTH_R1C3” contains the twenty model runs and summary worksheet for the north well in the simulation.

   3.2. Subfolder “NORTHSOUTH_R3C3” contains the twenty model runs and summary worksheet for the south well in the simulation.

   3.3. Subfolder “VB_TESTMAKER_II” contains the source code for the utility used to generate transmissivity arrays. No executable was generated for this utility; it was run in developer mode.

   3.4. File “Aquifer_Property_Summary.xls” contains the results of “VB_TESTMAKER_II,” along with summary statistics of transmissivity across the 20 realizations of the model.

4. File “Predictive_Histogram.xls” contains the calculations used to generate Figure 9, using the hand calculations appearing in the margin of Appendix D.