COMPARISON OF SUPERPOSITION MODEL
WITH FULLY POPULATED MODEL FOR
EASTERN SNAKE PLAIN AQUIFER MODEL VERSION 2.0

Idaho Department of Water Resources
Jennifer Sukow
June 21, 2012
DRAFT

Table of Contents

INTRODUCTION 1

METHODS 2

  Fully Populated Model 2

  Numerical Superposition Model 3

  Simulation of Curtailment 3

RESULTS AND DISCUSSION 5

SUMMARY AND CONCLUSIONS 7

REFERENCES 8

APPENDICES

Appendix A. Steady State Simulations

Appendix B. Long Term Transient Simulation

COMPARISON OF ESPAM2.0 SUPERPOSITION MODEL WITH FULLY POPULATED MODEL

INTRODUCTION

This report provides a comparison of the superposition version and fully populated versions of the Eastern Snake Plain Aquifer Model Version 2.0 (ESPAM2.0). The model versions were compared by performing the curtailment simulations presented in Sukow (draft) with both versions of the model.

The fully populated version of the model represents all components of aquifer stress, including recharge on irrigated and non-irrigated lands, discharge from groundwater pumping for agricultural and municipal purposes, tributary underflow, perched river seepage, and other components of recharge. The superposition version of the model is a simplified version that can be used to predict the response to a single component of the water budget. This approach simplifies analysis and presentation of results for simulations involving managed recharge, curtailment of groundwater pumping, transfer of water right diversion locations, and mitigation activities.

The numerical superposition version of ESPAM2.0 applies the principle of superposition as described in Reilly et al (1987). The principle of superposition states that the net effect of multiple applied stresses equals the sum of the effects of each individual applied stress. The advantages of superposition are summarized by Reilly et al (1987) as follows.

1. The effects of a specified stress (i.e. groundwater pumping, managed recharge) on the system can be evaluated even if other stresses are unknown.
2. The effects of a change in stress on the system can be evaluated even if the initial conditions are unknown.
3. The effect of one stress on the system can be isolated from the effects of all other stresses on the system.

The principle of superposition is strictly valid only for linear systems. However, Reilly et al (1987) note that because of the power and convenience of the superposition method it is, in practice, commonly applied to mildly nonlinear systems if it can be shown that the resulting error will be acceptably small.

Nonlinearity in ESPAM2.0 may occur if applied stresses cause the aquifer water level in drain or river cells to fall below the drain or river bottom elevation, severing hydraulic connection between the aquifer and the drain or river. The significance of the potential nonlinearity will be dependent on the magnitude and spatial distribution of the applied stress simulated. This report examines the effects of potential sources of nonlinearity on predicted river reach and spring accruals for the curtailment scenarios presented in Sukow (draft).

METHODS

The superposition and fully populated model versions were compared by simulating curtailment of groundwater pumping within the model boundary junior to selected priority dates. Predicted responses to curtailment were calculated using both the fully populated model and the superposition version.

Fully Populated Model

Simulations with the fully populated model were run with the ESPAM2.0 final calibration files (IDWR, draft). In the river file, river stage was modified to a constant value equal to the average river stage during the last ten years of the model calibration period (November 1998 through October 2008). The model was populated with average water budget values from November 1998 through October 2008. MKMOD8.1 was used to average the water budget values from the final calibration water budget files.

Determining the hydrologic effects of curtailment using the fully populated model requires three steps.

1. The fully populated model was run with the 10-year average water budget and river stage to calculate responses to the average water budget without curtailment.
2. Curtailment was simulated by adding recharge to each model cell containing lands irrigated with junior priority groundwater rights. The recharge added was equivalent to the crop irrigation requirement of the junior groundwater irrigated lands and offsets the withdrawal of water for this use in the fully populated model. The fully populated model was run again with the modified stress file to predict responses to the average water budget with curtailment.
3. The results with and without curtailment were differenced to determine the effects of the curtailment.

Numerical Superposition Model

A numerical superposition version of ESPAM2.0 was created by modifying the ESPAM2.0 final calibration files (IDWR, draft) as follows.

1. Drain cells were converted to river cells.
2. River cells were evaluated based on modeled conditions using the average water budget from November 1998 through October 2008 to identify perched river cells. Twenty-two perched river cells were removed from the superposition river file (Figure 1).
3. Starting heads, river stage, and general head boundary stage elevations were set to zero.
4. River bottom elevations were set to -700 feet.

The numerical superposition version requires less input data than the fully populated model. Only the crop irrigation requirement for the junior groundwater irrigated lands needs to be included in the stress file. The numerical superposition version also requires fewer model runs and less post-processing than the fully populated model. The hydrologic effects of curtailment can be simulated with one model run, which directly calculates the effects of the curtailment.

Simulation of Curtailment

Curtailment was simulated by injecting water in each model cell containing lands irrigated with junior priority groundwater rights. The volume of water injected in each model cell was calculated using the Curtailment IAR Tool in ESPAM2 Recharge Tools V1.4. Water right priority dates and point of diversion data used to calculate the fraction of junior priority groundwater irrigated lands were from the 2012 point of diversion (POD) file, which was based on data retrieved from the IDWR water rights database on January 20, 2012.

The most recent irrigated lands data set from year 2008 was used to delineate irrigated areas. Average groundwater fractions were applied to the 2008 irrigated lands data set to delineate areas irrigated by groundwater. The average groundwater fractions were equal to the fractions used for calibration of ESPAM2.0, except where groundwater fractions had been increased to avoid potential calculation of deficit irrigation on mixed source lands (Contor, 2010). Where groundwater fractions were increased for calibration, the groundwater fractions were replaced with average groundwater fractions based on average surface water availability between 1980 and 2008.

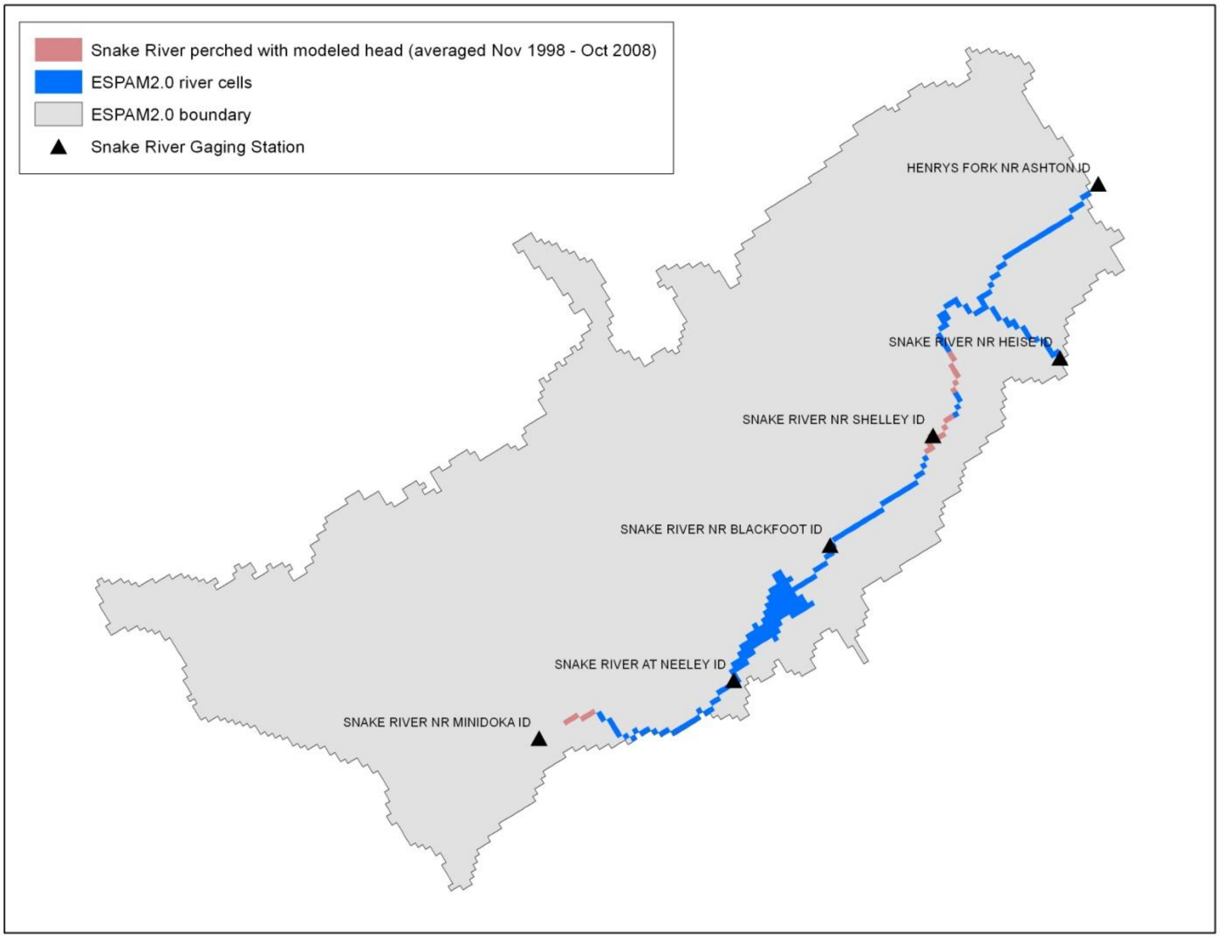

Figure 1. Perched river cells removed from superposition version based on average model head from November 1998 through October 2008.

Average evapotranspiration and precipitation from the last 10 years of the model calibration period (November 1998 through October 2008) were used to calculate the crop irrigation requirement for groundwater irrigated lands. Calibrated evapotranspiration adjustment factors from ESPAM2.0 were applied by groundwater entity.

Curtailment of groundwater irrigation throughout the ESPAM2.0 model domain was simulated for water rights junior or subordinate to five priority dates.

1. January 1, 1870
2. January 1, 1949
3. January 1, 1961
4. January 1, 1973
5. January 1, 1985

Steady state simulations were run for each curtailment date. For the January 1, 1961 date, a transient simulation was also performed. The transient run simulated 150 years of curtailment, assuming continuous stress based on average annual consumptive use.

RESULTS AND DISCUSSION

Results from the steady state fully populated and superposition model simulations are summarized in Table 1. Detailed results are provided in Appendix A. Results from the transient simulation are provided in Appendix B.

The superposition model predictions are less than 1% different from the fully populated model predictions for all of the ESPAM2.0 spring targets and for the Ashton to Rexburg and near Blackfoot to Minidoka river reaches in all five of the curtailment simulations.

The superposition model predictions for the Heise to Shelley reach are 2.1% to 5.9% less than the fully populated model predictions, varying with the curtailment date. The superposition model predictions for the Shelley to near Blackfoot reach are 0.7 to 1.7% greater than the fully populated model predictions, varying with the curtailment date. These differences result from the presence of river cells that are perched during the 10-year average condition, but may become hydraulically connected to the aquifer during the simulation as water levels rise in response to a simulated decrease in groundwater pumping (or other increase in net recharge). The fully populated model is able to respond appropriately to the increase in water levels, but the superposition model cannot because the perched river cells have been converted to normal variable head model cells. As shown in Figure 1, the perched river cells removed from the superposition version of the model occur in the Heise to Shelley, Shelley to near Blackfoot, and Neeley to Minidoka reaches. Model riverbed conductance in the Neeley to Minidoka reach is very low (3,371 ft^2/day), so the effect of these cells on the near Blackfoot to Minidoka reach gain is minimal. The model riverbed conductances in the Heise to Shelley and Shelley to near Blackfoot reaches are 149,793 and 79,510 ft^2/day, respectively, so the effect of the perched river cells is greater in those reaches.

The transient simulation of curtailment junior to January 1, 1961 shows similar results (Appendix B). Results from the superposition and fully populated versions are very similar throughout the 150-year simulation for the Ashton to Rexburg and near Blackfoot to Minidoka river reaches, and for the spring reaches downstream of Milner. For the Heise to Shelley and Shelley to near Blackfoot reaches, the differences between the superposition and fully populated model predictions increase during the 150-year simulation, approaching the -4.7% and 1.7% differences in the steady state results for these reaches, respectively.

Priority date	Total applied stress (cfs)	Difference in predicted response (superposition model prediction less fully populated model prediction)											
		Ashton to Rexburg		Heise to Shelley		Shelley to Nr Blackfoot		Nr Blackfoot to Minidoka		Kimberly to King Hill		Individual spring reaches	
		cfs	% of predicted response	cfs	% of predicted response	cfs	% of predicted response	cfs	% of predicted response	cfs	% of predicted response	cfs	% of predicted response
1/1/1870	3,276	1.6	0.7%	-23.2	-5.9%	4.7	1.1%	12.1	0.9%	4.7	0.6%	0.0 to 0.7	0.2% to 0.7%
1/1/1949	2,868	1.2	0.5%	-18.7	-5.4%	5.4	1.4%	8.6	0.7%	3.5	0.5%	0.0 to 0.5	0.1% to 0.6%
1/1/1961	1,927	0.6	0.4%	-11.5	-4.7%	4.3	1.7%	5.4	0.7%	1.5	0.3%	0.0 to 0.2	0.1% to 0.4%
1/1/1973	1,095	0.2	0.2%	-4.7	-3.4%	1.8	1.3%	2.2	0.5%	0.6	0.2%	0.0 to 0.1	0.0% to 0.3%
1/1/1985	218	0.0	0.2%	-0.5	-2.1%	0.2	0.7%	0.3	0.4%	0.1	0.2%	0.0	0.0% to 0.1%

Table 1. Comparison of steady state responses predicted by fully populated and superposition versions of ESPAM2.0.

SUMMARY AND CONCLUSIONS

Differences in responses predicted by the superposition and fully populated versions of ESPAM2.0 may result from nonlinearity in the model in some circumstances. Potential sources of nonlinearity include aquifer water levels falling below a model drain or river bottom elevation, and aquifer water levels rising above the model river bottom elevation in a river cell that was designated as perched for the superposition version. The removal of perched river cells in the superposition model was based on average conditions between November 1998 and October 2008, with a net recharge of 6,105 cfs (4.4 million AF/year). Scenarios that significantly change the water budget from those conditions, or place a very large stress at a point location near a drain or river reach, are more likely to cause significant nonlinearity in model simulations.

This report presents a comparison of superposition and fully populated model results for five curtailment scenarios. The superposition model predictions are less than 1% different from the fully populated model predictions for all of the ESPAM2.0 spring targets and for the Ashton to Rexburg and near Blackfoot to Minidoka river reaches in all five of the curtailment simulations. The superposition model predictions are less than 2% different for the Shelley to near Blackfoot reach, and range from 2 to 5% different for the Heise to Shelley reach.

These comparisons suggest that the superposition version of the model will be acceptable for simulations that have one of the following characteristics.

1. The applied stress is relatively small compared to the fully populated model water budget. This is typically true for simulations of water right transfers, managed recharge, and mitigation activities. This may also be true for simulations of curtailment, depending on the priority date and areal extent of the curtailment.
2. The applied stress simulates recharge or injection of water, and the magnitude and spatial distribution are comparable to the stress applied in the curtailment simulations presented in this paper. This is expected to be true of most curtailment scenarios.

For simulations that place a very large localized stress near a drain or river reach, or involve very large changes in the model water budget, use of the superposition model may be inappropriate. If predicted response in the Heise to Shelley reach is of interest, the fully populated version of the model may also be more appropriate for simulations involving moderate changes in the model water budget.

The superposition version of the model requires less input data than the fully populated version. For example, for a curtailment simulation, only the crop irrigation requirement for the junior groundwater irrigated lands needs to be included in the stress file. The numerical superposition version also requires fewer model runs and less post-processing than the fully populated model.

The hydrologic effects of the curtailment can be simulated with one model run, which directly calculates the effects of the curtailment.

The superposition version of the model is expected to be acceptable for simulation of curtailment of groundwater pumping, managed recharge, most water right transfers, and mitigation activities including conversions from groundwater to surface water irrigation, the Conservation Reserve Enhancement Program (CREP), and voluntary reductions in irrigation. The fully populated model may need to be used to simulate a water right transfer if it involves withdrawal of water in close proximity to a drain cell. Other types of simulations that may be proposed in the future will need to be evaluated on a case-by-case basis to determine if use of the superposition model is appropriate.

REFERENCES

Contor, B.A., 2010. *Representation of Irrigated Lands and Source of Irrigation Water, Eastern Snake Plain Aquifer Model Version 2*, Idaho Water Resources Research Institute Technical Report 201002, ESPAM2 Design Document DDM V2-04.

IDWR, draft. *Enhanced Snake Plain Aquifer Model Version 2.0 Final Report*, Idaho Department of Water Resources with guidance from the Eastern Snake Plain Hydrologic Modeling Committee.

Reilly, T.E., O.L. Franke, and G.D. Bennett, 1987. *The Principle of Superposition and Its Application in Ground-Water Hydraulics*, U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Chapter B6, 28p., http://pubs.usgs.gov/twri/twri3-b6/pdf/twri_3-B6_a.pdf.

Sukow, draft. *Comparison of Eastern Snake Plain Aquifer Model Version 2.0 with Version 1.1 via the Curtailment Scenario*, Idaho Department of Water Resources.