# BPA-Solicited Technical Review of "Echo Meadows Project Winter Artificial Recharge: Final Report for 2001 Baseline"

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# Project 2001-015-00

## BPA-Solicited Technical Review of

## "Echo Meadows Project Winter Artificial Recharge: Final Report for 2001 Baseline"

completed February 2004

Provided under
**Contract No. 00015240**
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Review of Interim Progress Report and Associated Data for
**"Echo Meadows Project Winter Artificial Recharge: Final Report for 2001 Baseline"**

**December 2002**

# Preface

The purpose of this report was to provide, at BPA's request, a technical review of interim products received for Project 2001-015-00 under contract 6925. BPA sometimes solicits technical reviews for Fish and Wildlife products or issues where outside expertise is required. External review of complex project deliverables assures BPA as a funding agency that the contractor is continuing with scientifically-credible experimental techniques envisioned in the original proposal. If the project's methodology proves feasible, there could be potential applications beyond the project area to similar situations in the Columbia Basin.

The Experiment involves artificial flooding during high flow periods and a determination of the portion of the return flows that end up in the Umatilla River during low flow months and within acceptable water quality parameters (e.g., low temperature, few contaminants). Flooding could be a critical water source for aquatic organisms at times of the year when flows in the lower reaches of the Umatilla River are low and water is warmer than would be desired.

The experiment was proposed to test whether **"[t]his process, recharges the shallow aquifers of the old flood plain, for natural filtration through the alluvial soils as it returns to the Umatilla River, cleaner and cooler (about 50 degree Fahrenheit) five to six month later (about July and August) substantially cooling the river and [making it] more beneficial to anadromous [fish]".**

A substantial amount of preliminary data had been collected and preliminary results were submitted in an interim report "**Echo Meadows Project Winter Artificial Recharge: Final Report for 2001 Baseline (December 2002).** A substantial amount of addition funding was provided for the last cycle of flooding (Phases II) and final analyses of the full compliment of data collected over the life of the contract (Phase III). Third party scientific review may assist the contractor in producing a higher quality Final Report with completion of the final 2 phases of the project.

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February 24, 2004

Mr. Peter Lofy, KEWL-4
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Dear Mr. Lofy:

As you requested we have performed a technical review of the report "Echo Meadows Project Winter Artificial Recharge: Final Report 2001 Baseline" (December 2002, BPA Project 2001-015-00). The scope of the review includes an assessment of the data collection and analysis presented in the report. As part of the review, we also requested data and supporting documents that were referenced in the subject report. Editorial review of the report was not within the initial scope of the review, however where issues of organization and presentation substantively diminished our ability to provide technical review, we have made suggestions for editorial improvements. A brief summary of major comments is provided below and the full text of our comments is included in the addendum. Comments in the addendum follow the organization of the report. Wherever possible we have attempted to provide suggestions or alternatives for improving the report.

*Summary of Major Comments*
The concept of using aquifers to store available water and utilize that water at a later time for beneficial use is not new. Aquifer storage and recovery (ASR) has become a common means to enhance groundwater supplies and is even being applied in basalt aquifers of the Umatilla Basin by the City of Pendleton. The idea of evaluating the potential to augment baseflow in the Umatilla River using artificial recharge in the Echo Meadows is a good one and worthy of a carefully designed and executed study.

To effectively apply ASR, it is essential to have a thorough quantitative understanding of the hydrogeologic system. This applies whether the aquifer is a deep basalt unit or a shallow alluvial system and whether the recovered groundwater will be extracted by wells or allowed to naturally discharge to a river. In fact, it is more imperative to have a good understanding of the system when the goal is to augment river flow because the natural flow process must be used to extract the water instead of wells whose location and pumping rates can be controlled. The objective of a study to evaluate the feasibility of ASR is not to prove that some fraction of water used to recharge an aquifer can be recovered, that much is given by basic hydrologic principles. The objective is to gain sufficient understanding that the fraction recovered and the timing of recovery can be predicted.

This study has collected many of the types of data that are needed to quantify the hydrologic system and evaluate its capacity to be utilized as an ASR system. Some of these data have been used to develop a numerical simulation model. The model has been used to assess the viability of the recharge project. Unfortunately, not all of the data collected are useful and some of the data needed have not been collected. Some data are not useful because there were insufficient quality assurance procedures used in their collection and documentation. Some of the data has not been fully analyzed to develop the quantitative understanding of the hydrologic system that is needed. Finally, some of the most important data collected by this study, such as water levels, has not been used in the development of the model.
A fully developed conceptual model of the Echo Meadows area requires that the hydrologic processes (recharge and discharge) be identified and quantified to the extent possible. One of the primary weaknesses of this report is that it does not present a conceptual model and does not quantify, or does not accurately quantify, some important hydrologic processes. One of the most important quantities in the conceptual model is the groundwater discharge to the Umatilla River. The project did not establish any monitoring sites on the Umatilla River or revisit any of the sites established by the OWRD for their measurements. The report dismisses the idea that stream flow measurements can be used to detect increases in groundwater discharge to the river yet uses historic data from the OWRD and others to establish that groundwater discharge to the river has decreased.

The model used in the study was initially developed as part of a larger scale study for the U.S. Bureau of Reclamation (USBR). The model may be well suited to the needs of the USBR study; however it has limited application to this study. We found that the model, in its current configuration as presented in the report, would not be useful as a tool to predict the outcome of a full scale implementation of an artificial recharge project in Echo Meadows. A model of the area should have sufficient resolution, horizontally and vertically, to accurately represent the important hydrogeologic features in the system and should be calibrated to the most recent and most detailed data available. This model was calibrated to data from prior to 1992 that was not collected by this study in the Echo Meadows area.

Finally, the report is in very poor editorial condition and should have received some form of in-house peer review before being submitted to BPA. Problems range from basic organization to poorly constructed figures and spelling errors. It is unfortunate because some good work has been accomplished in this study, such as the infrared thermal imaging, which would be of interest to other investigators. We have made some suggestions on how the report could have been organized and how presentation of data could be improved. Perhaps these suggestions can be of use in preparation of future reports from this project.

In summary, the phase I report should have been a thorough hydrogeologic characterization of the Meadows including a quantitative water budget and analysis of relations between groundwater and surface water. Aspects of this characterization were attempted, but they were often incomplete or based on data of questionable quality. As a

result, the basis for the model as presented in the report, was weak. Combined with the model design issues raised in the review, we believe the model has very limited credibility as a tool for validating the claim that an artificial recharge project can be designed and managed to efficiently and effectively increase summer flows in the river. Emphasis in the last sentence is on "efficiently and effectively". As previously stated, there is no question that applying more irrigation water to the Meadows will increase flows in the river. The critical question is: how much of the water will reach the river during the period that it is needed? Some of the water is not going to discharge to the river and some will discharge to the river when it is not needed. The model and report, as reviewed, can not and do not answer those key questions.

We hope you find this review is useful. Please contact me (503-251-3263, dsmorgan@usgs.gov) if you have any questions.

Sincerely,

David S. Morgan
Hydrologist

**Addendum: Comments by Section**

**General Editorial Comments**
The editorial condition of the report is detrimental to its purpose of communicating the results of this work. While we realize that it is unlikely that this report would be modified, we offer the following as suggestions for future reports from this project.

The organization of the report does not allow for a cohesive discussion of the hydrology and each element of the conceptual model of the system. This conceptual understanding is the basis for the simulation model and this makes it critical to have the concepts of how the system works clearly presented. Below we have provided an outline for the report that would present the information in a more cohesive manner.

- Abstract
- Introduction
    - Background
    - Objectives
    - Description of area
    - Methods
    - Previous studies
- Hydrogeology
    - Geologic units: thickness, extent, hydraulic properties
    - Water budget
        - Recharge: precip, irrigation, streams, canals, gw inflow
        - Discharge: wells, ET, drains, streams
        - Changes in storage
    - Groundwater movement
        - Directions and gradients: horizontal, vertical
        - Fluctuations: seasonal, long-term
    - Summary-Conceptual Model
- Simulation Analysis
    - Approach
    - Description of model
        - Discretization
        - Boundary and initial conditions
        - Hydraulic properties
    - Calibration of model
        - Water budget
        - Goodness of fit: heads, flux
    - Simulation of artificial recharge
        - Hypothetical application
        - Trial application
    - Model uncertainty and limitations
- Summary and Conclusions
- References

In our opinion, this outline represents the basic components of a hydrogeologic study involving the use of simulation modeling. Many of the components in this outline are included in the subject report; those that are not will be identified in subsequent sections of this review.

Also, many of the figures in this report are poorly constructed with inconsistently labeled axis, legends that do not match accompanying text, and missing scales. Finally, the report contains many spelling and grammatical errors that detract from its readability and credibility.

**Introduction**

The introduction contains several assertions that would be more appropriate in a results/conclusions section. For example, assertions are made that: 1) surface water is abundant and 2) groundwater is of better quality than surface water. The introduction of a scientific report should provide background on the problem that led to the study, the purpose and scope of the report, the hypotheses, and the approach used to test the hypotheses.

Monitoring locations listed in appendix A are not all shown in figure 1 and several location names on figure 1 are different than what is listed for the same location in Appendix A. Appendix A does not list the type of data collected at each location and there is no consistent naming convention that can be used to infer the type of station.

Figure 1 should label or outline to make distinguishable, all features that are referenced in the text; for example: Umatilla Meadows, Hunt Ditch, and the Umatilla River.

**Data Collection Efforts Completed in the Baseline Phase**

**Objective 1--Determine if groundwater levels increase due to flooding**
The monitoring wells identified as "upgradient" (BAPW-1 and DSW-1) are not located upgradient of the Hunt Ditch according to figure 1.

Although the report states that some pit wells have been monitored since 1998, no data prior to January of 2000 was found in the well data file (pitwell00-01.xls)

Piezometers were not installed on a "grid system" as planned. The rationale that was used to select the monitoring well locations should be clearly described. There is a large area between Hunt Ditch and Umatilla Meadows where there are few monitoring sites. It would be advisable to have additional sites in this area.

The physical parameter data (temperature, pH, and conductivity) that were measured weekly at 24 locations are not discussed or interpreted. It is also not clearly described how these samples were collected. It should be documented in the report or database if the wells were pumped prior to sampling, and if so, how long they were pumped.

**Objective 2—Collect and analyze weather data**
Task 2.2 states that recharge rate will be estimated by "subtracting evapotranspiration rates from soil moisture readings". We are not familiar with any technique by which recharge can be estimated using these two measurements alone; the report should either further explain the method or cite a reference. Recharge is the residual of precipitation plus irrigation minus ET and runoff. Soil moisture is the amount of water in storage in the root zone, which determines when recharge will occur, but available precipitation plus irrigation must be known in order to

compute the residual recharge. On page 10 the report states that estimated recharge will be discussed in the results portion of the report, however, we did not find this discussion in the report.

**Objective 3—Determine amount, timing, and frequency of water application**
Measurement of soil moisture is not the most accurate or efficient means of "measuring the amount and frequency of water application" by the participating farms. A more typical approach would be to directly measure applications by gauging surface-water diversions or placing flow meters on discharge lines from pumps. The stated objective (task 3.5) was to use these data to "do a groundwater balance". We did not find a water balance in the results. The water balance for the Echo Meadows study area is an important part of the conceptual model of the system that is lacking in this work. It is suggested that an effort be made to follow through with the plans to estimate recharge and other components of the water budget in order to complete this important part of the analysis.

**Objective 4—Determine if wetlands are influencing the recharge to groundwater**
Another important question related to the conceptual model of this area is, in fact, what is the function of the wetlands? The report states that, based on anecdote, wetland areas have diminished and this is attributed to reductions in irrigation water application. This suggests that the wetlands are not naturally occurring, but that they are a by-product of a water table that was artificially maintained by irrigation return flow. This further suggests that the wetlands function as groundwater discharge areas. Objective 4 seems oriented toward determining if the wetland areas can be used as locations for artificial recharge. If the wetlands historically function as discharge areas, as indicated, then it is unlikely that application of water in these areas will reverse hydraulic gradients such that they function efficiently as recharge areas. Before any systematic use of wetlands for artificial recharge is implemented, a careful study of individual areas should be done. One component of such studies should be an analysis of the vertical hydraulic gradient underlying wetlands. Multi-level piezometers should be installed to assess the direction, magnitude and seasonal changes in the vertical hydraulic gradient. Areas where there is a persistent upward gradient indicate groundwater discharge is occurring and would not make good sites for artificial recharge.

**Objective 5—To accurately determine the groundwater level in wells**
GPS locations were obtained at all monitoring sites. You should list the accuracy of these locations; GPS locations are generally accurate to +/- 15-20 feet for horizontal coordinates. Elevations were obtained at 12 of 24 groundwater sites (appendix A). This is not "virtually all" as claimed on page 12. Also, the vertical accuracy of the surveyed elevations and how the accuracy was determined should be listed for each site.

A key component of the conceptual model for the groundwater system is an understanding of direction of groundwater flow. This component is missing from the report. The only head map shown is a simulated head map (figure 13) from the model. The new water-level data from the network monitored in this study should be a good basis for construction of a water-table elevation contour map for the alluvial aquifer. These data should be manually contoured, supplemented by river elevations where available from bridge or gauge data. Ideally, maps should be constructed for seasonal high and low conditions to show the magnitude of seasonal fluctuations and changes in flow directions and groundwater storage. These maps can then be compared with simulated water levels for a more complete assessment of the ability of the model to reproduce flow directions and gradients. The comparison of individual points that is made for the four wells discussed on page 47 is insufficient for a rigorous evaluation of model reliability. We also wonder why only four wells were used in the calibration when at least 24 groundwater monitoring sites were established and maintained for the study, twelve of which have been surveyed. See the comments on groundwater modeling in the Results section for more information.

**Objective 6—Determine the hydraulic conductivity and rate of groundwater movement in the basin**

Well-designed, multiple-well pump tests provide valuable information on the hydraulic properties of the aquifer and confining beds. The project should be commended for collecting this type of data which can be time consuming and expensive. Because of the expense, it is not feasible to conduct more than a handful of multi-well pump tests and generally with only a few tests it is difficult to characterize the variability in hydraulic properties in heterogeneous alluvial aquifers. Other sources of information can be very useful and should be fully exploited. These sources include: single-well tests reported by drillers at the time of well construction, pump-test data from previous studies in the region, and literature values for similar lithologies. Single-well, or well-performance, tests can be used where drillers have pumped or bailed the well and reported the drawdown, pumping rate, and duration of the test; these data can be analyzed using the Theis equation to estimate transmissivity for assumed values of storage coefficient. Well reports from the Echo Meadows area should be reviewed to assess how many have sufficient data for transmissvity estimates to be made using this technique. A thorough review of previous reports for the Umatilla basin should be conducted and estimates made by previous workers reviewed and compared with estimates from this study. An example is the report on the hydrogeology of the Lower Umatilla Basin by ODEQ (1995) which includes a discussion of hydraulic properties of the alluvial aquifer and summary (table 2.1). Finally, a complete discussion of the properties should include a comparison of estimated values with literature values for similar geologic materials.

Of interest is the observation (page 45) that "silty-sands" comprise the upper 15 feet of the aquifer and have low hydraulic conductivity ( < 1 ft/d) compared to the value of 44 ft/d for the "coarser" materials below. While it is based on only two points, a conclusion is drawn to explain the differences that there is a significant "fining upward" in the section. If true, this would have a significant impact on groundwater flow and should be represented in the simulation model by including layers with contrasting hydraulic conductivity. This comment will be expanded in the discussion of the Results section.

A summary table of results from the pump tests that have been performed by the authors should be included that lists each test, method of analysis, and the resulting values of hydraulic conductivity and storage.

**Objective 7—To determine timing and amount of groundwater recharging into the Umatilla River**

It would clarify the discussion if consistent terminology were used throughout the report. With reference to the title of this objective, standard usage in groundwater literature is to refer to processes that remove water from the groundwater system as discharge processes; this would include the process of groundwater discharge to the river.

The title of task 7.2 is "refine and calibrate groundwater model by acquiring new groundwater data to match the actual field data". The process of calibration is to use an iterative procedure to modify model parameters until a satisfactory fit between observed (field data) and simulated conditions are obtained. This task title is confusing because it infers that new field data will be acquired to obtain a match with “actual field data”.

Considering the importance of this objective and the complexity of developing and calibrating a numerical model, there should be much more detail given in the discussion of how this model was developed. In the current organizational scheme of the report development of the numerical model warrants an “objective” or first order heading status. In “General Editorial Comments” we have given a topical outline that includes items that should be addressed in this type of report documenting the use of simulation techniques. In that outline, “Simulation Analysis” is a first order heading and shares that status with only one other heading, “Hydrogeology” in which the conceptual model of the system (based on data) is presented.

The emphasis of this section seems to be to impress upon the reader the importance of the model as “proof” that the recharge project will increase return flows to the river. The authors have not presented any evidence that supports this conclusion at this point in the report. The purpose of this part of the report should be to outline the objective of the task, the methods, and the progress. Results are relegated to a later section.

Since this objective is not specifically to develop a model, there should be discussion of other methods for determining the amount of groundwater discharging to the Umatilla River. Methods such as stream discharge measurements, streambed piezometers, seepage meters, and use of heat as a tracer (USGS Circular 1260) should be presented and the strengths and limitations of the methods discussed.

**Objective 8—To detect change in land-use activities in the Echo Meadows area and measure thermal variations within the Umatilla River**

Part of the stated objective was to “detect changes in land-use activities”. The connection of this objective to the overall project goal is unclear from the report. We assumed that the objective was to detect how changes in land-use activities have influenced temperatures in the Umatilla River, however there is no discussion of this topic in either the description of data collection efforts or in the results section. This would also require data from a historical time period for comparison. Another possibility is that the objective was to map existing land cover (“wetlands, ponds, etc”) and document changes due application of artificial recharge. If this is the intended objective, we did not see any documentation of the results in the report; results should be in the form of maps showing specific land-cover types and summary tables listing the areas of these land-cover types under present conditions (pre-artificial recharge). The objectives and methods in this section need to be clarified.

The primary objective of this part of the project was to map the longitudinal temperature profile of the river to: assist in identifying locations of groundwater discharge, and “compare temperatures with fisheries requirements and TMDLs”. Thermal infrared imagery is a very powerful tool for assessing groundwater/surfacewater interactions and the study has employed this method to make some interesting observations on the locations of groundwater discharge. The authors should consider comparing the locations of gaining reaches determined from discharge measurements made by ODEQ and OWRD with the apparent gaining reaches in the infrared imagery to see if there is any agreement between the two independent datasets. For future reference, many of the latest infrared studies are making simultaneous stream discharge measurements at selected points on the stream to provide some additional level of groundtruthing data and to document the range of stream discharge at the time of the survey. In the discussion of the infrared data for this study, the authors should include flow data from the OWRD gauging stations.

**Objective 9—To determine if there will be adverse impact to water quality of the groundwater and the Umatilla River as a result of recharge**

Once again the authors have placed as-yet unsupported conclusions in the introductory part of the report. In this case they state that "….fertilizer migration to the aquifer is not an issue" with little data discussion for support.

This section should describe the type, source, and location of possible contaminants, the potential transport pathways, and how transport of these contaminants might be affected by artificial recharge. Finally, the design of this task seems oriented to establishing what the present water-quality conditions are, as opposed to "determining if there will be an adverse impact" from artificial recharge. To accomplish the stated objective there should have been water-quality monitoring in association with the experimental recharge (trial water application). Nitrogen from fertilizer, stored in the unsaturated zone, is one of the contaminants that might be affected by artificial recharge. Mobilization by excess recharge and transport to the saturated zone and eventually to discharge points at drains or the Umatilla river is a potential pathway. Baseline sampling should inventory nitrogen in the unsaturated (soil) zone beneath prospective recharge areas, During experimental applications, monitoring wells with short screens at the water table should be monitored to determine if a nitrogen or other contaminants are mobilized.

**Objective 10—To determine the quantity of water in the Umatilla River**

This objective seems to duplicate objective 7 (To determine timing and amount of groundwater recharging into the Umatilla River). Since objective seven was focused on development of the simulation model, that objective should be renamed and the surface water analysis described under this objective.

Tasks listed under this objective pertain only to acquiring and analyzing steam gauge data collected by the USBR at two locations. Reference is made to retrieving and analyzing this data, however, apparently these tasks have not been completed in phase I. A thorough analysis of all existing surface water gauging data from these and other sites is a critical element of the hydrologic assessment of Echo Meadows that is not addressed in this report. The suggestion is made in the report (p. 17) that these data are not reliable, but that OWRD "improves" the record quality. The report later states that because the data are so readily available the authors have not made their own measurements. This implies that they will be using the data in spite of its reliability problems. Whatever operational problems have called into question the data reliability should be identified and corrected in cooperation with USBR or OWRD so that future data from these sites will support analysis of trends in streamflow and groundwater discharge to the river. Conversely, if "corrections" can not be made, the effects of the poor quality of the data on the outcome of the conclusions should be acknowledged and thoroughly discussed. Additionally, the authors should suggest locations for additional gauges that could be established to provide better delineation of the timing and location of groundwater discharge to selected reaches of the river and better documentation of long-term trends in discharge.

Discussion of this objective should also include how the various discharge measurements made by OWRD in the 1980s and 1990s were used in this study; the section "historic return flows" in the discussion of results relies heavily on this data, yet there is no mention of these data in the objectives.

**Objective 11—To quantify the inflow into the Umatilla River**
The title of this objective is not consistent with the approach described. Only part of the inflow to the river (from drains) is being quantified as part of this objective. The process of developing a rating curve for each monitoring location is not well described under task 11.3. The authors state that they have not converted the stage values to discharges and analyzed the data. This is another important part of the hydrologic budget that should be analyzed. Even if the magnitude of this component is small with respect to other components, if the effort has been made to collect the stage data and establish the rating curves, there is no reason not to compute discharge values and analyze the data.

**Objective 12—Analyze GIS work**
How does this objective fit into the overall project goals? The tasks listed appear to be primarily related to the infrared imaging (FLIR) work done as part of task 8.

**Objective 13—Report results**
See the general editorial comments listed on page 2.

There is little or no metadata for the project data distributed on the CD-ROM. The user is left to decipher the type of data and units from the terse column headings provided in the excel spreadsheets. Also, common practice is to archive data files in a generic format rather than a software specific format so that the data can be used without having to have a specific program.

**Results**

There are no citations in the report for other studies that directly or indirectly address the topic of artificial recharge as a means of increasing baseflow and enhancing water quality in streams. An important element of any research is a thorough search of the relevant scientific literature. This serves to support the need for the current study by identifying gaps in the existing body of knowledge, provides the reader with additional references for specific methods of data collection and analysis, and lends credibility to conclusions if they are consistent with those of other workers. A very cursory literature search yielded the following examples of journal articles that might have relevance to this study:

Predicting Infiltration and Ground-Water Mounds for Artificial Recharge
Bouwer, H; Back, JT; Oliver, JM
Journal of Hydrologic Engineering [J. Hydrol. Eng.]. no. 4, pp. 350-357. Oct 1999.

Analysis of groundwater migration from artificial recharge in a large urban aquifer: A simulation perspective
Tompson, AFB; Carle, SF; Rosenberg, ND; Maxwell, RM

Water Resources Research [Water Resour. Res.]. Vol. 35, no. 10, pp. 2981-2998. Oct 1999.

Modeling Analysis of Ground Water Recharge Potential on Alluvial Fans Using Limited Data
Munevar, A; Marino, MA
Ground Water [Ground Water]. no. 5, pp. 649-659. Sep-Oct 1999.

Joint Management of Surface and Ground Water Supplies
Basagaoglu, H; Marino, MA
Ground Water [Ground Water]. Vol. 37, no. 2, pp. 214-222. Mar-Apr 1999.

The use of infiltration field tests for groundwater artificial recharge
Abu-Taleb, MF
Environmental Geology [Environ. Geol.]. Vol. 37, no. 1-2, pp. 64-71. 1999.

Evaluation of scraping treatments to restore initial infiltration capacity of three artificial recharge projects in central Iran
Mousavi, S-F; Rezai, V
Hydrogeology Journal [Hydrogeol. J.]. Vol. 7, no. 5, pp. 490-500. 1999.

Effects of artificial recharge on ground water quality and aquifer storage recovery
Ma, Li; Spalding, RF
Journal of the American Water Resources Association [J. Am. Water Resour.Assoc.], vol. 33, no. 3, pp. 561-572,
Jun 1997

Optimal control of ground-water quality management: Nonlinear programming approach
Taghavi, SA; Howitt, RE; Marino, MA
Journal of Water Resources Planning and Management [J. WATER RESOUR. PLANN.MANAGE.],
vol. 126, no. 6, pp. 962-983, 1994

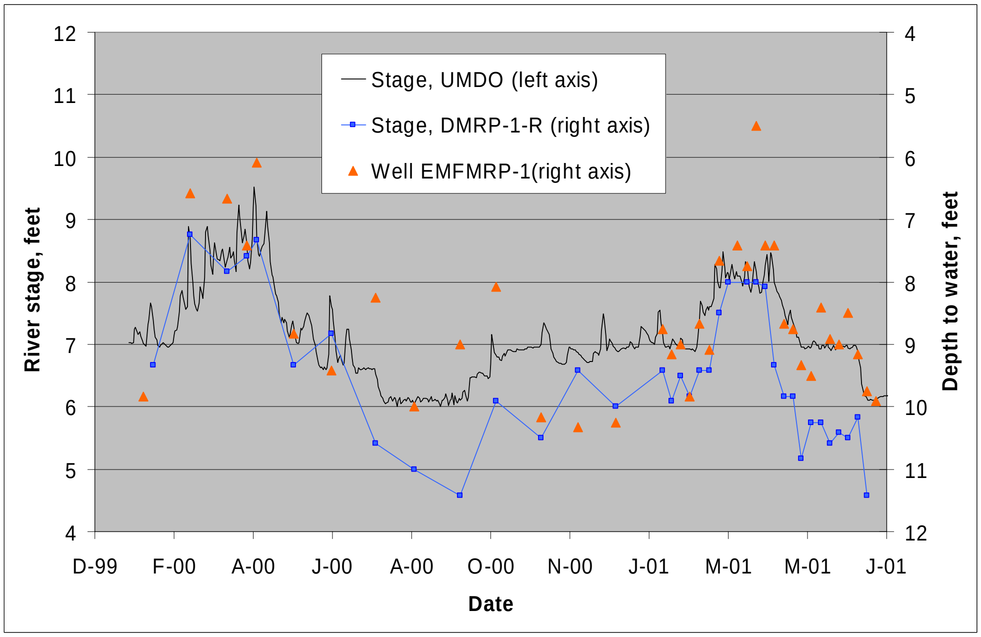
Interaction between stream temperature, streamflow, and groundwater exchanges in alpine streams
Constanz, J
Water Resources Research [Water Resour. Res.]. no. 7, pp.1609-1615. Jul 1998.

We suggest that a full search and discussion of the literature be included in the final report.

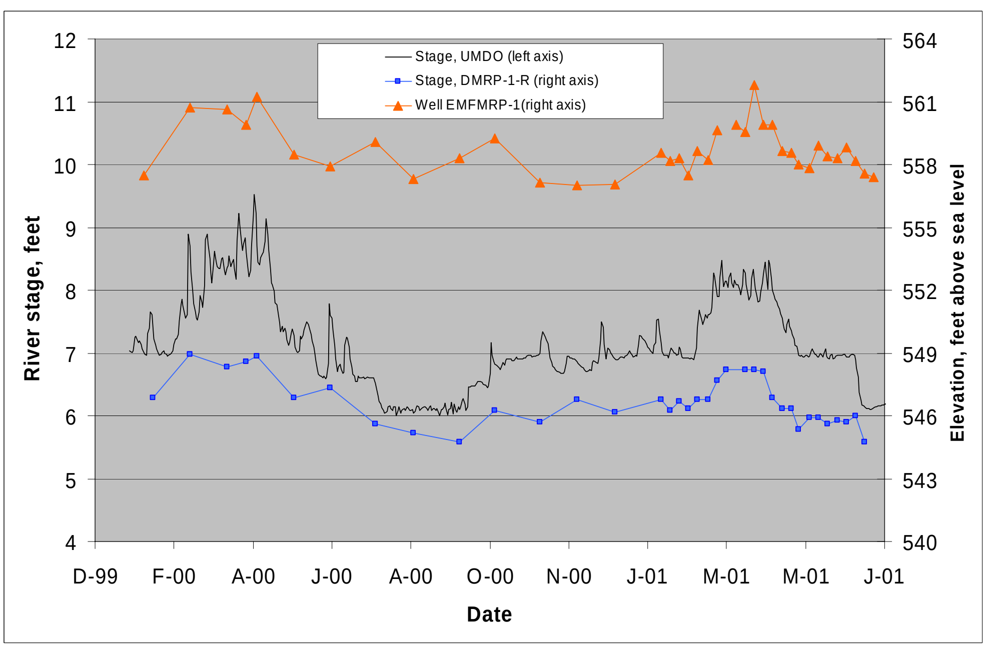
Stream depletion computations shown on page 23 are based on simplifying assumptions that need some support. The authors estimate that groundwater pumping to offset reductions in surface water availability for irrigation "could" have depleted streamflow by 20 cfs during the lowflow period. The first implicit assumption is that all groundwater pumped would have discharged to the river. Other possible fates for the groundwater are discharge to evapotranspiration (via wetlands created by an elevated water table) or subsurface outflow from the area. Subsurface outflow is especially likely if any of the groundwater pumped was from the deeper basalt aquifers. The stated assumption that all captured groundwater would have discharged to the river during the 150-day irrigation season cannot be justified. In fact this assumption is contrary to the finding presented later in the report that artificial recharge applied in the winter months would discharge to the river in late summer and early fall. If water applied in winter would not discharge until 6-8 months later, then groundwater pumped in the summer could not have discharged instantaneously to the river. In summary, the estimate of 20 cfs for streamflow depletion caused by pumping is extremely tenuous and is dependent on some assumptions that have not been justified.

The discussion of historic return flows (page 25) concludes that summer baseflow in the Echo Meadows reach has decreased from 45 cfs to 10 cfs since the 1970s. This is a critical piece of information inasmuch as it forms the basis of the need for the proposed artificial recharge project. A much more thorough discussion and presentation of data is warranted and the data that form the basis of the conclusion should be presented in graphical form. A reference is made to figure 2 of the draft progress report which apparently shows data collected by OWRD in 1985-86 and 1991-97 that indicates a reduction from 20 cfs to 10 cfs during this period. The actual figure number in the progress report is 5 (page 14), however, at least as presented in the figure it is impossible to discern a significant reduction in baseflow from the data. Another reference is made to "Ely (2000)" for data that support the reports contention that baseflow was reduced from 35 cfs in 1980 to 20 cfs in 1985-86. The Ely reference does not appear in "Cited References" on page 54 and could not be supplied by the authors for this review. Finally, the data used by Graham (2002) that is also cited to support a mean summer baseflow of 45 cfs in the "1940-1970s" should also be presented in this section. If there were one published report that presented a comprehensive interpretation of the return flow data, it could be cited and summarized to support this very important aspect of the hydrologic conditions in the Echo Meadows. However, since most of the discussion references draft and unpublished work, a more complete analysis should be presented in this report. That analysis should address the question of how the datasets, which were collected by different agencies and at different times and locations, were compared. The effects of variable climatic conditions should be considered as should the effects of measurement error at the various streamflow conditions during each measurement.

Groundwater and surfacewater level measurements are shown in figures 3-5 and discussed on pages 27-29. Figure 3 is presented as a representative hydrograph showing the relation between the water table elevation and the stage of the river. The 3-ft rise in the water table at well EMFMRP-1 from January through March 2000 is attributed to "irrigation and river stage". We question whether irrigation has any part in this rise inasmuch as the rise occurred prior to March 1st and significant Irrigation did not occur until at least mid-April. It is more likely that the rise is caused by the river stage which peaked in early April after a 2-3 ft rise. We plotted the stage measurements from the gage below the Dillon diversion (UMDO on the USBR web site) against the groundwater levels from well EMFMRP-1 (see below). The data in figure 4, "Umatilla River Stage", are labeled as DMRP-1-R; we plotted these data from the CD on the hydrograph below and discovered that the measurements are apparently "depth to water surface" below some datum. (Figure 4 does not have the y-axis labeled and does not define either of the two series of data displayed on the graph.) When these data are plotted together, it is readily apparent that stage at UMDO and the "depth" data at DMRP-1-R show similar trends to the well hydrograph for EMFMRP-1 as would be expected in a well only 100 ft from the river.




When presenting data from sites that have been surveyed, the authors are encouraged to convert all water level and stage measurements to a consistent datum (sea level) so that elevation relations between groundwater levels, and between groundwater levels and river stage may be determined. In the hydrograph below, the data from well EMFMRP-1 and river stage site DMRP-1-R have been adjusted to sea level using the reference elevations listed in Appendix A. When plotted in this way it is apparent that the water table is consistently about 12 feet above the river level. This gradient shows that groundwater discharges to the river throughout the year, although discharge during periods of high river stage is probably reduced due to the reduced lateral gradient toward the river.



The use of data loggers with pressure transducers is commendable. We suggest that more rigorous quality assurance procedures be put in place, however, to avoid the large discrepancies between the manually measured levels and those measured by the transducers. It is common to have discrepancies of 0.01-0.03 ft that can be caused by transducer drift or measurement error, but the magnitude of discrepancies shown in figure (up to 2 ft) suggest serious procedural problems. The difference of nearly 3 feet between the two manual measurements made on May 24, 2001 at well ERW-1 (figure 5) is of particular concern. If operator error is the cause, training should be given to insure that operators understand basic operation of equipment. Without better quality assurance these data can not be considered reliable and therefore can not be used to Interpret cause and effect relationships In the hydrologic system.

The hydrograph for ETW-1, which is described in paragraph 3 on page 29, does not appear in the report. The reference to "OSU, 1992" is not listed.

Missing from the analysis of water level changes is any long-term monitoring data that would support the authors' conclusion that reductions in recharge from irrigation have lowered the water table in the Echo Meadows area. The report should discuss the availability of any long-term monitoring well data in the alluvial aquifer. The OWRD has maintained a large monitoring network in the basin for many years and some of the wells may be in the alluvial aquifer. Even if the wells are not in the Echo Meadows area such data would provide support if they could show that long-term declines have occurred in other areas of the lower basin where improvements in irrigation efficiency have reduced recharge to the alluvial aquifer. At a minimum, the authors should compare present water levels in shallow domestic wells with levels that were reported by the driller when the well was constructed. If enough wells are visited, trends may become evident that would support the idea of long-term water table declines in the alluvial aquifer.

On page 32 the authors state that no recharge occurs at site DMRP-1 (figure 7) because "soil moisture from 4 to 8 feet do not fluctuate much during these years". Changes in soil moisture content are not necessary for moisture movement. Constant soil moisture content simply means that there is steady flow--no additional moisture is being added to or taken from storage in the soil column. This is the condition that is normally found at depth where seasonal fluctuations in soil moisture have been attenuated. The authors have misinterpreted steady soil moisture content as an indication of no flow and hence no recharge. All that is needed for recharge is a source of moisture and a potential gradient.

The temperature contour map (figure 9) appears to have been generated using automated methods. The "lower temperature trough" that is described is more likely an artifact of the lack of data in the northeast and southwest quadrants of the map area. The "high" temperatures in these areas result from unconstrained extrapolation by the contour program. The authors attribute the low temperature area to "colder surface water used for irrigation" which seems to conflict with other data shown than indicate surface water temperatures exceed groundwater temperatures. We suggest the authors either manually contour the data or use a mask to restrict the area.

**Groundwater Model Results**

The section of the report devoted to the groundwater model is incomplete. The authors should examine the report outline suggested in comments under the heading of "General Editorial

Comments" for a complete list of topics that should be addressed in the report with regard to the model. It is particularly important that the data and assumptions used in model development and calibration be documented and described because, as is repeatedly mentioned in the report, the model is "a critical element" of the project. Much of the information on the development of this model is found in another report by Graham that is not referenced in this report. Graham's report, "Lower Umatilla River Basin Groundwater Model, Principals Environmental Group, April 2003" was supplied as supplemental information for this review. While this report contains considerable information on the development of the model, it is essentially an unpublished manuscript at this time. (Our understanding is that the report will ultimately be published as the author's dissertation through Portland State University). We feel that the Echo Meadows report should stand alone and therefore strongly urge the authors to incorporate information from the model report and add to it as needed to provide the complete documentation of the model that is required by this report. Simply stating that the model "had a considerable amount of calibration, verification, and sensitivity work and the work was reviewed by the BOR, a contractor for the BIA and CTUIR" is insufficient considering that the primary conclusions of this report are based on the model results.

The following comments are organized under the major headings of the proposed outline for the simulation analysis part of the report.

**Approach**

The model used in this analysis is a regional-scale model that was calibrated using data for two time periods and temporal scales. The first period, from March 1991 through February 1992, used monthly stress periods. The second period, from 1947 through 1992, used annual stress periods. The first period is referred to by the authors as the calibration period while the second period is described as a verification period. However, model parameters were adjusted during the second period to improve the fit to observations and thus the second period was also a calibration period. Although it is not specifically stated in the report, the 1991-92 period was undoubtedly chosen for calibration of the regional BOR model because there is a wealth of data available that were collected as part of the OWRD-ODEQ hydrogeologic investigation. The Echo Meadows project has made a significant effort to collect data in the Echo Meadows area during the 2000-2002 period. However, relatively little of that data have been used to construct and calibrate the model. Only data that are independent of time, such as aquifer properties, are of value in calibrating the model for a period ten years before present. The OWRD-ODEQ study encompassed the entire lower Umatilla Basin and did not have the density of data collection sites within the Echo Meadows area that the present study has been able to establish. To maximize the benefit of the present data collection effort and expense, the model should be calibrated for the period 2000-2002 using the data from this study. Additional comments on the calibration of the model can be found in the following sections.

**Description of model**

**Discretization**

This model was originally developed to assess groundwater surface water relations throughout the lower basin in support of surface water modeling efforts for the BOR. The horizontal dimensions of grid cells are 0.25 mile (1,347 ft) per side and are uniform throughout the model. There are approximately 10 rows and 16 columns of cells within the 10 square-mile Echo Meadows area. In the vertical dimension, the model uses a single layer to represent the thickness of the alluvial sediments. The model grid resolution was designed to meet the needs of the BOR study which, as previously described, covered a much larger area and had much less data to use for calibration in the Echo Meadows area.

This horizontal grid resolution is very coarse for use in the analysis of artificial recharge in the Echo Meadows. There are, of course, economies in using existing models for an analysis and we believe that existing models should always be evaluated before developing new models. In this case, however, given the expense of collecting data at the detailed scale used, a finer-grid model is certainly warranted. The study would still benefit from the regional BOR model which could have been used to provide groundwater flows across the boundaries of a smaller, more detailed sub-regional scale model for the Echo Meadows area. There are some very good software packages available now that expedite the development of these "nested" models.

Based on the author's description of the lithology of the alluvial sediments, we are concerned that a two-dimensional (single layer) model may not adequately represent vertical groundwater flow dynamics of the system. A two-dimensional model cannot account for vertical groundwater movement—the implicit assumption is that recharge instantaneously reaches the water table and flows laterally as it moves through the aquifer to a point of discharge. In this representation, there is no variation in horizontal groundwater flow velocity with depth—all groundwater moves at the same average velocity whether it is at the water table or at the base of the aquifer. This assumption is valid if the lithology of the aquifer is relatively uniform (homogeneous) throughout its thickness and is rarely valid. Based on our understanding of the geology, and variability of the hydraulic properties reported in pump test data, we suspect the assumption is not valid in this case. Specifically, the report states (page 45) that there are finer grained sediments in the upper 15 feet of the aquifer that overlie coarser sands. Representing this system with a single model layer would not allow for the restriction of vertical and horizontal groundwater flow caused by the silty sands. Compensation for this conceptual error would lead to errors in model properties.

The present model grid configuration is adequate as a tool for illustrating the broad concept that some part of recharge to the alluvial aquifer in the Echo Meadows area will discharge to the Umatilla River. However, to make the best use of data collected by the study for calibration of the model, and to have a tool (model) that would ultimately be useful for predicting the results of recharge scenarios, we believe a more detailed representation of the aquifer system is required. The model grid should be redesigned to have a maximum grid cell dimension of 500 ft and a minimum of two layers.

**Boundary and initial conditions**

Boundary and initial conditions are not discussed in the report; information in the Graham (2003) report is the basis for the following comments.

Representation of lateral boundaries is not an issue because of the distance to any of the regional model boundaries from the Echo Meadows area.

The authors have made the assumption that the lower boundary between the basalt aquifers and the alluvial aquifers is essentially impermeable and represent it as a no-flow boundary. Justification is based on application of Darcy's law with assumed hydraulic gradient, area, and a range of vertical hydraulic conductivity. The resulting range of estimated upward vertical flux ranges from 1 to 100 cfs over the entire area covered by the alluvial aquifer. The authors cite a USGS model (Davies-Smith and others, 1987) in support of using the lower value of vertical hydraulic conductivity and thus leakage. The USGS model was a large-scale regional model calibrated using very sparse data on the vertical hydraulic gradient between the basalt and overlying alluvial aquifers. Vertical hydraulic conductance in models is scale dependent and therefore cannot be easily converted to smaller scale models. The report should provide some local information to support this contention as well. For example, what are the vertical hydraulic gradients between the basalt aquifers and the alluvial aquifer underlying the Echo Meadows area? Have any of the basalt wells been monitored and do they show any influence from irrigation? Finally, for boundaries that have significant uncertainty associated with them, as this one does, a sensitivity analysis should be performed to assess how much model results would be affected by errors in the representation of this boundary. A reasonable range of potential leakage should be applied to the model to simulate the effects on the model. This might demonstrate that, even if there is some leakage, it does not materially affect the results of the model.

Head-dependent flux boundaries represent rivers, drains, and canals adequately within the Echo Meadows area, however, the lack of resolution in the model grid does not allow for accurate location of the features. This is another reason for decreasing the grid cells size in the model

One hydrologic process that does not appear to be represented in the model is evapotranspiration from the water table. Some types of native vegetation (phreatophytes) as well as cultivated crops can obtain water from the saturated part of the aquifer. The authors state that they believe some crops in the Echo Meadows area obtain water via sub-irrigation from the water table. In addition, if the water table is within 5-10 ft of land surface, evaporation from bare soil can become a significant process for groundwater discharge. Modflow has a package (EVT) for simulating evapotranspiration from the water table as a linear function of the depth below land surface. We suggest the authors evaluate the potential importance of the process in this area.

Well discharge from the alluvial aquifer is accounted for by adjustment of the recharge rates to the model. This method works for two-dimensional flow systems wherein vertical groundwater movement can be ignored. As discussed above, we believe that this system may be heterogeneous, have a significant component of vertical flow, and need to be simulated with a multi-layer model. In this case, pumping should be represented with the Modflow well (WEL) package so that discharge can be simulated from the appropriate layer. The recharge (RCH) package cannot be used because recharge occurs only in the uppermost active model cell.

Perhaps the most important flux in the model is the estimated recharge from irrigation return flow. This input and how it was estimated is not described in the report. We referred to Graham (2003) but found the description cumbersome. A clear and concise discussion of this is a critical part of the conceptual model for the hydrologic system that belongs under the heading Hydrogeology>Water Budget>Recharge in the suggested outline.

There is no discussion of the initial head conditions that must be specified for the beginning of a transient simulation. We referred to Graham (2003) to learn that initial conditions for the 1991-92 simulation were generated by using Kriging (automated contouring methods) to estimate a water-table surface from 320 water levels, by using that surface as initial heads for a one-year “hot-start” simulation that used 1991-92 stress (pumping and recharge), and finally by using the heads at the end the “hot-start” as initial conditions for the “real” 1991-92 simulation. This is effectively like using the estimated water table surface as initial conditions and simulating 1991-92 stress for two years. This approach can lead to errors because the specified initial conditions (from the contoured data) are not consistent with the model parameters. Because of this, in the early part of a simulation there will be water level-changes that are not due to stresses in the model but due to the process of the initial water levels equilibrating to the parameters of the model. If a long enough period of time is simulated, these equilibrations will become less and less until they are zero. In this case, however, there is only one year of calibration data. Simply repeating the same one year of stress data only drives the simulation toward a steady-state solution that reflects the stress conditions for that year. There are three ways to avoid the problem: 1) identify a period when the system was at equilibrium, simulate that period, and use those heads for your initial conditions, 2) have a long enough period of calibration data that early changes in head due to equilibration will dissipate by the end of the simulation (only the later part of the period can be used for calibration), and 3) use a time-averaged steady-state approach to calibration.

The initial conditions for the 1947-92 period were not described in the report either, but Graham (2003) explained that the simulated 1991 heads were used. If there were some period during 1947-92 during which the groundwater system could be assumed to be at steady-state (i.e., no long-term changes in storage), then the stress from that period could be used to simulate the steady-state heads and those could be used as initial conditions for a transient simulation from that time forward. In this case, however, there is a long enough period of calibration data (1947-92) that the effects of inexact initial conditions should be insignificant in the later part of the period. Note that figure 14c shows a steep decline in the simulated return flow for the first 10 years of the simulation; the authors should carefully evaluate the simulation to determine if some of this response is due to equilibration to the initial conditions from the 1991 simulated heads which would likely be higher than the “true” 1947 heads and therefore result in increased return flows in early stress periods as water drained from the aquifer into the river.

**Hydraulic properties**

The hydraulic properties of concern in this model are the horizontal hydraulic conductivity, specific yield (storage coefficient), and river and drain conductance. A brief discussion of how the properties were derived from pump test and other data and how these values were modified during calibration is required. A table similar to the one in Graham (2003) should be included that summarizes the information.

It is unclear what value of specific yield was used in the calibrated model. On page 45 a value is 0.15 is cited, on page 49 a value of 0.2 is cited, and in Graham (2003, page 32) a value of 0.1 is cited. The authors should determine the correct value and make the text and reports consistent.

Hydraulic conductivity values used in the model are reported to be 400-800 ft/d on page 45 and Graham's values for coarse (Pscfc) materials are in agreement. Graham also lists a value for fine-grained (Pscff) materials of 200 ft/d, however, there is no distinction for fine-grained materials in the Echo Meadows report. The authors should clarify whether lower values were used for fine-grained materials in the Echo Meadows model. There should also be some explanation of why such large values of hydraulic conductivity were used to simulate the finer-grained materials. Hydraulic conductivity values of 200 ft/d for materials with significant components of silt-sized sediments would be suspect. The authors cite slug tests in the meadows area that yielded values less than 1 ft/d which would be more in keeping with a fine silty-sand.

**Calibration of model**

**Water budget**

An essential part of the evaluation of the calibration is a comparison between the estimated components of the water budget for the simulated area with the simulated components of the budget. The presentation of the conceptual model in the report should include estimates of each component of recharge and discharge to and from the model area for the calibration periods (1947-92 and 1991-92). These estimates should then be compared with the simulated values from the calibrated model. This gives the reader an overall assessment of the model's ability to represent the author's concept of the system.

**Goodness of fit: heads, flux**

This discussion is inadequate. Four wells are used for comparison of simulated and observed water levels and there is no indication of what time period was simulated to generate the contours in figure 13. We question why only four wells were used when the project monitored over 20 wells. Perhaps this is in part due to the fact that the model was calibrated for the 1991-92 period rather than the 2000-2002 period of this project. See comments above in "Approach". There are several more observations shown in figure 14-a, but there is no explanation of whether they are in the Echo Meadows area or not. The goodness-of-fit of a model can be much more accurately assessed if the observed head values are plotted versus the residual of simulated minus observed heads. The scale in simulated versus observed head plots tends to mask errors and make it difficult to identify bias toward positive or negative residuals.

There are no hydrographs of simulated and observed heads or fluxes to rivers for the 1991-92 calibration period. We suggest the authors include several examples to show the ability of the model to simulate the seasonal variation in head and flux to the river. It is our understanding that there are several wells that were monitored monthly during 1991-92 and there are monthly discharge measurements by OWRD for the 1991-97 period. Since the primary value of the model is to determine the best locations and recharge rates to insure increased groundwater discharge to the river at the critical low flow period, it is imperative that the model be able to simulate the seasonal variability of groundwater discharge to the river during the 1991-1992 calibration period.

The single hydrograph shown for the 1947-92 period has only a single observed value at the end of the period. This does not provide any means of evaluating the model's ability to simulate inter-annual variation in heads due to changes in recharge or discharge. The simulated heads during this period are shown at a scale that does not indicate any interannual variation that might be expected from variability in recharge due to irrigation, pumping, or stream flow conditions. The smooth gradual decline in head appears unrealistic and most likely an artifact of an oversimplified estimate of recharge and pumping discharge.

Figure 14c shows simulated "return flow", or groundwater discharge, to the Umatilla River from 1947 through 1992. The recharge input function for this simulation is not shown, but we assume that it would have trends similar to the historical diversions plot (figure 2). The authors should explain why simulated return flows to the river in the late 1950s (~32 cfs on figure 14c) are not the same as the simulated return flows in 1992 (~22 cfs) in spite of the fact that irrigation application rates are approximately the same (15,000 acre-ft/yr) for these periods. Also, why don't simulated return flows increase in response to the increase in irrigation applications from 1960 through the early 1970s? Instead, figure 4-b shows a continued decrease in return flow through this period.

The comparisons of irrigation diversions and simulated return flows on page 48 are apparently flawed. The report states that "as application volume diminished from 17-20,000 afy to less than 15,000 afy" the simulated return flows diminished from "about 45 cfs in the 1940s to about 22 cfs in the early 1990s". Implied in this is that a reduction of 2,000-5,000 afy of irrigation resulted in a reduction of 23 cfs in the mean annual return flow (groundwater discharge) to the river. There are two problems with this analysis. First, 2,000-5,000 afy are the equivalent of 2.8-6.9 cfs. Clearly this is much less than the 23 cfs reduction in return flow simulated by the model. Second, 2,000-5,000 afy is the reduction in applied irrigation water, not recharge. Even if it is assumed that flood irrigation was used, only about half of the applied water would become recharge and thus the reduction in recharge from a 2,000-5,000 reduction in diversions is probably less than 1,000-2,500 afy or 1.4-3.5 cfs. This is nearly an order of magnitude less than the simulated reduction in return flows. (Note that these are annualized mean return flows—as were simulated in the 1947-92 model.) This would indicate that there are other factors that have reduced return flows; one factor may be increased pumping from the alluvial aquifer.

The report states on page 48 that a 5-ft head decline in the area has resulted in the reduction of return flows and that by restoring that head, return flows will be restored to their "historic values". It further states that application of 1 acre-ft/acre of water will achieve this increase in head because the specific yield is 0.2. It is then concluded that addition of 9,600 acre-ft of artificial recharge will achieve the 5 ft head increase and result in "double to quadruple the flow of the Umatilla River during the low summer flow…". There are several problems with this analysis. First, Graham (2003) documents that the specific yield used in the model was 0.1, not 0.2. The value 0.1 is also cited in on page D-3 of this report. Thus, assuming the model specific yield value is correct, it would only require 0.5 acre-ft/acre to cause an increase in head of 5 ft and presumably only 4,800 acre-ft to achieve that increase over the project area. This means that, if 100 percent of the 4,800 acre-ft recharged the aquifer and discharged to the river during the summer low flow period, there would be an increase in baseflow of about 13 cfs. This is clearly a "best-case" scenario because recovery of the recharge will be expected to be significantly less than 100 percent and that water that does discharge to the river will not all discharge during the summer low flow period, particularly if it is applied evenly at a rate of 0.5 acre-ft/acre throughout the area.

**Simulation of artificial recharge**

**Hypothetical application**

Response functions are described in the report as "essentially linear", however, head changes in an unconfined aquifer in response to stress are inherently non-linear. This is due to the fact that changes in the saturated thickness of the aquifer change the transmissivity of the aquifer. Head-dependent boundary conditions (e.g., rivers, drains) also contribute to non-linearity. This is probably not an issue for this report since the response functions would not be used to predict the effects of recharge on groundwater discharge to the river.

A key factor in evaluating the efficiency of an artificial recharge project is determining the fraction of water applied that would be available as discharge to the river. In addition to the response curves, the authors should provide information on how much of the applied water reached the river as opposed to that discharging to drains, subsurface outflow from the Echo Meadows area, and if implemented in the model, evapotranspiration (see boundary condition comments).

**Trial application**

The word "trial" is misspelled throughout the report and on the data CD.

Data collection and presentation of data are inconsistent. Graphs have variable scales, units are not labeled, orientations vary, and manipulations have been made to the data that are not described.

Diurnal variations exceed the inflections caused by water applications in several of the monitoring sites. The trends are weak and are sometimes superimposed on longer-term trends with variability due to nearby pumping or other factors. In the future, monitoring should begin a few days prior to the start of the test at all sites to establish pre-test trends. There are techniques that can be used to remove these trends if they can be characterized before the test.

The recorder data in figure D-5 show a strong declining trend prior to the test, which continues immediately after the test for a few days and then sharply reverses. The authors should explain this if possible.

The recorder data in figure D-6 has been corrected by up to 5 feet at the end of the record. What is the reason?

The description of figure D-9 on page D-7 states that there is "no raise" in water level, yet the data show an increase of about 4 inches, one of the most significant changes measured. Table D-1 also lists a measured fluctuation of 0.29 feet for this well.

### Model uncertainty and limitations

A thorough discussion of model reliability and uncertainty is a necessary part of any simulation analysis, and particularly if the model is to be used for predictive purposes.