PERCOLATION, RUNOFF, AND DEFICIT IRRIGATION

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Eastern Snake Plain Aquifer Model Enhancement Project Scenario
Document DDW-002 Final As-Built

DESIGN DOCUMENT OVERVIEW

Design documents are a series of technical papers addressing specific design topics on the Eastern Snake Plain Aquifer Model Enhancement Project. Each design document will contain the following information: topic of the design document, how that topic fits into the whole project, which design alternatives were considered and which design alternative is proposed. In draft form, design documents are used to present proposed designs to reviewers. Reviewers are encouraged to submit suggested alternatives and comments to the design document. Reviewers include all members of the Eastern Snake Hydrologic Modeling (ESHM) Committee as well as selected experts outside of the committee. The design document author will consider all suggestions from reviewers, update the draft design document, and submit the design document to the Eastern Snake Plain Model Enhancement Project Model Upgrade Program Manager. The Program Manager will make a final decision regarding the technical design of the described component. The author will modify the design document and publish the document in its final form in .pdf format on the ESPAM web site.

The goal of a draft design document is to allow all of the technical groups which are interested in the design of the ESPAM Enhancement to voice opinions on the upgrade design. The final design document serves the purpose of documenting the final design decision. Once the final design document has been published for a specific topic, that topic will no longer be open for reviewer comment. Many of the topics addressed in design documents are subjective in nature. It is acknowledged that some design decisions will be controversial. The goal of the Program Manager and the modeling team is to deliver a well-documented, defensible model which is as technically representative of the physical system as possible, given the practical constraints of time, funding and manpower. Through the mechanism of design documents, complicated design decisions will be finalized and documented.

Final model documentation will include all of the design documents, edited to ensure that the “as-built” condition is appropriately represented. This is the final as-built document for Percolation, Runoff, and Deficit Irrigation.

INTRODUCTION

Recharge from surface-water irrigation is the largest component of aquifer recharge on the Eastern Snake River plain, supplying about 60% of the total aquifer recharge. Net ground-water withdrawals for irrigation represent about 14% of the total aquifer discharge, second only to spring flows (Garabedian 1992). Because neither net recharge nor net withdrawals can be directly measured, these are calculated using elements of the surface-water budget. The calculations involve diversion volumes that are large relative to the overall aquifer water budget (see Design Document DDW-018).

For the Model Enhancement Project, water-budget information was spatially organized using a Geographic Information System (GIS) application, and calculations performed in a FORTRAN-language computer application. This document addresses the algorithms and assumptions that were used in the FORTRAN application to calculate net recharge from surface-water irrigation and net withdrawal from ground-water irrigation.

The calculation for net recharge from surface-water irrigation can be summarized as follows:

Field Delivery = Diversions - Canal Leakage - Return Flows

Net Recharge (surface)=
(Field Delivery + Precipitation) - (ET x Adjustment Factor)

The calculation for net recharge from ground-water irrigation (typically a negative recharge, or net withdrawal) is:

Net Recharge (ground) = Precipitation - (ET x Adjustment Factor)

These are commonly used and accepted methods (Burt 1999) and are the methods used by the US Geological Survey (Garabedian 1992) and Idaho Department of Water Resources (1997) in former Snake Plain modeling efforts. The ET adjustment factor is an innovation added in this effort to accommodate differences between potential and actual crop conditions. In this paper, these will be called the "default" methods. Concern has been expressed that these calculations may under-estimate net recharge from surface-water irrigation when deficit irrigation occurs on furrow-irrigated farms, and to a lesser extent with sprinklers. There is also concern that this calculation may over-estimate net aquifer withdrawals from ground-water irrigation.

The procedure for calculating net recharge from irrigation was first used in the calibration of parameters to represent aquifer characteristics. While recharge from irrigation was calculated for each stress period of the calibration period, the outcome of calibration is a single set of parameters. The goal of the modeling project is to produce a regional model. It will be important that the model is able to adequately predict regional-scale response to various real or hypothetical stresses. This requires that the calibrated aquifer parameters in aggregate accurately reflect actual characteristics on a regional scale. For this reason was vital that over the calibration period, the procedure for calculating net recharge produce an estimate that is unbiased in the long run. To the extent that data were available, it was also desirable to reflect nuances of temporal and spatial distribution of recharge from irrigation, to allow a finer spatial resolution and tighter confidence intervals for calibrated aquifer characteristics.

A second and significantly different use of the procedure for calculating net recharge from irrigation will be in applying the model to various real-life or hypothetical scenarios. This is not a *calibration* question but an *application* question. Proposed scenario recharge data will be applied to a calibrated set of aquifer characteristics in order to predict aquifer head and river reach gains. For this use of the procedure, it is vital that the procedure be able to represent the desired recharge regimes that users may wish to test.

This paper summarizes and analyzes the concerns that have been raised, in light of the two distinct uses of the recharge calculation procedure. The analysis indicates that appropriate calculation of return flows and adjustment factors will allow the default methods to give acceptable results.

CONCERNS EXPRESSED

Concerns With Default Method

Several specific concerns were expressed:

1. If the water supply deficit is severe, (ET x Adjustment Factor) could exceed (Diversions + Precipitation), resulting in a calculated "negative" net recharge.

2. Not all precipitation should be considered as part of the water supply; some fraction of precipitation is non-effective and does not contribute to recharge. Some precipitation may contribute to runoff.

3. The possibility of simultaneous deficit irrigation and deep percolation could indicate that adjustment factors should be smaller than perhaps contemplated. An incorrect adjustment factor could bias results.

4. The default method results in zero aquifer recharge under conditions of deficit irrigation from surface sources.

5. The default method assumes that all wells pump 100% of the crop demand plus losses.

6. If returns are the same fixed percentage of diversions in wet and in dry years, deficit-irrigation scenarios may not be correctly represented.

7. The default method does not differentiate between return flows from surface sources and return flows from ground water sources.

Alternate Calculation Method

An alternate method of calculation has been proposed which relies on "Maximum Farm Efficiency." Conceptually, this is an upper limit of efficiency which will not be exceeded, even with deficit irrigation. The proposed calculation, which will be called the “alternate method” in this paper, is:

Consumptive Irrigation Requirement = ET x Adjustment Factor
Field Delivery = Diversions - Canal Leakage
Alternate Consumptive Use = Field Delivery x Maximum Farm Efficiency
Consumptive Use = The lesser of Consumptive Irrigation Requirement
and Alternate Consumptive Use
Loss = Field Delivery - Consumptive Use
Loss is partitioned between percolation and runoff

It is anticipated that the partition of loss to percolation and runoff would rely upon the same return flow calculations as the default method. The analyses below apply the same return flow calculations to both methods.

ANALYSIS

These concerns and the alternate proposal were analyzed by reviewing the conceptual model of furrow irrigation losses, appropriate literature, and field data from a seven-year study in Colorado.

The analysis focuses on the hydrologic fate of irrigation water. This is a quantification of the net movement of water into or out of the aquifer, associated with irrigation practices.

Conceptual Furrow Irrigation Relationships

With furrow irrigation, water is introduced at the top of the field and begins simultaneously moving into the root zone and flowing down the field. Runoff begins when the stream reaches the end of the field, and percolation begins when the root zone is saturated.[1] Figure 1 illustrates this process, with successive blue lines indicating the hypothetical wetting front as time passes. Figure 2 represents a deficit irrigation scenario with appropriate run lengths, and Figure 3 represents deficit irrigation with high-infiltration soils and long runs. It is important to note that these represent field-level relationships. Runoff from a field is a different concept than return flows to a river, because much field runoff is later utilized by down-slope irrigators, rather than returning to the river. These

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[1] Some percolation can occur before the soil is saturated, due to preferential pathways (Lentz 2002).

figures represent a single irrigation event. Because of changes in rooting depth and soil surface conditions, successive events in the same field have different characteristics over any given season (Burt and Styles, 2002). The overall effect of an irrigation season is the integrated effect of individual irrigation events.

Figure 1

Conceptual Furrow Irrigation

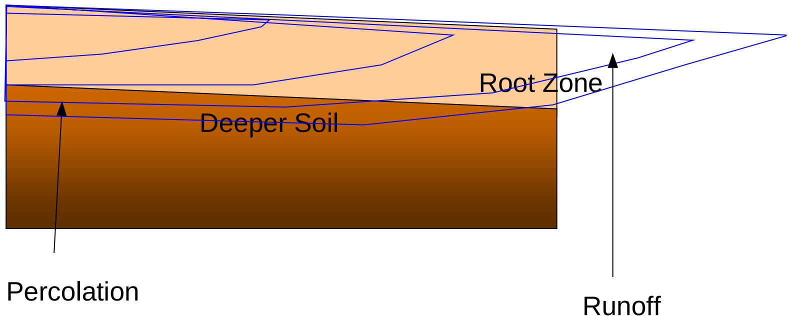


Figure 2

Deficit Irrigation and Runoff

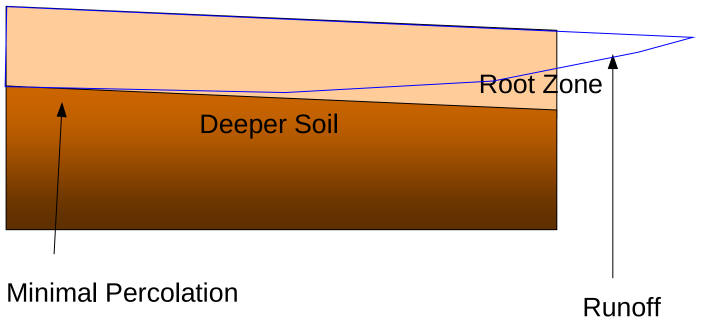
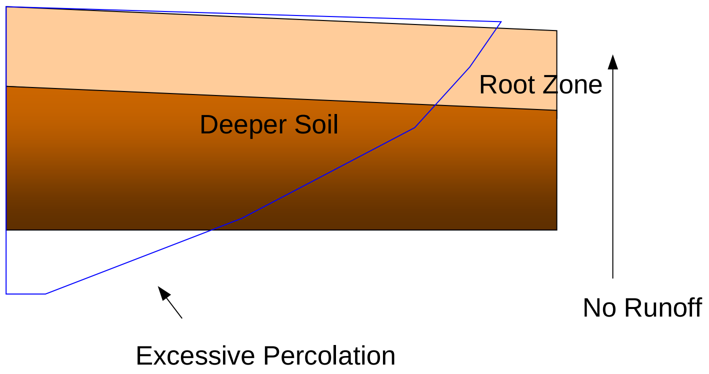


Figure 3

Deficit Irrigation and Percolation

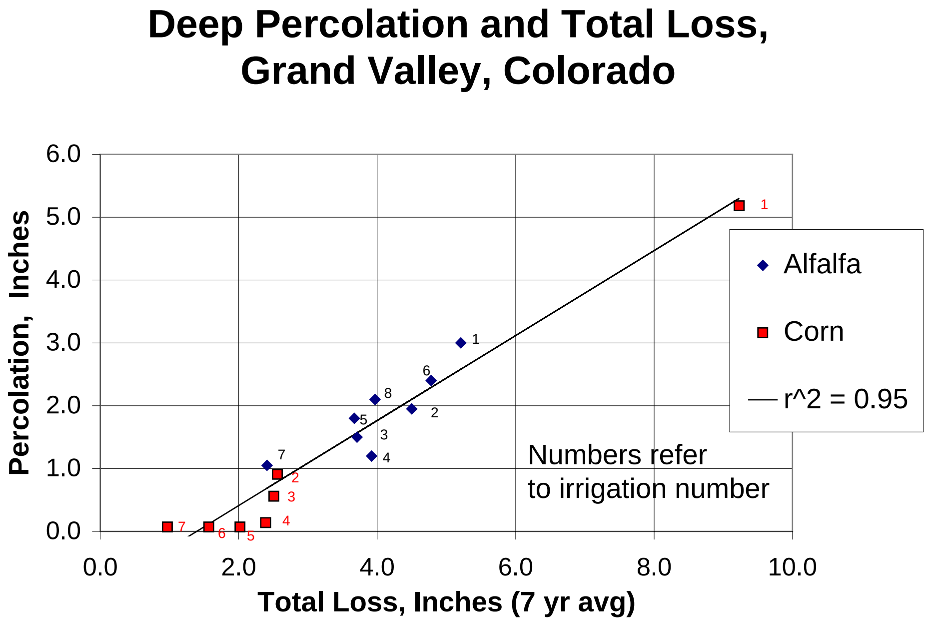


The effect is probably exaggerated, but Figure 3 shows that percolation can occur simultaneously with deficit irrigation. This has been observed in the field (Lentz 2002, Burt and Styles 2002). When the concern was raised, the scenario in Figure 3 was presented as the most likely. However, if the furrow system is at all matched to the soils and crops, "the too-deep loss is a small amount... because intake rate decreases with time and very little is infiltrating towards the end of the irrigation" (Merriam 1977). Economic theory would suggest that the remaining surface-irrigated farms are likely to be those which are most suited to the practice, indicating that the Merriam statement is often applicable. The next section presents field data that support Merriam's opinion.

Field Data

Figure 4 shows the results of a seven-year study on a furrow irrigation system in Grand County, Colorado (Andrews 1995). The soil was a fine silt loam. Data are not given regarding slope, soil depth, and run length, but it is assumed that this is an appropriately designed and operated system. Each point on the chart shows the average ratio of percolation (vertical axis) to total loss (horizontal axis) for a given irrigation. The crop is identified by the shape of the marker, and the label indicates the irrigation number. These data correspond to the conceptual models in Figures 1 through 3, in that they represent field runoff, not returns to source.

Figure 4
Field Data



The good fit of the regression line indicates that over a wide range of values, a fixed partition of total loss to percolation and runoff is appropriate. However, the regression line does not go through the origin. At lower loss values (which are the values of interest in predicting simultaneous percolation and deficit irrigation), the fixed relationship fails. Since negative percolation is impossible,[2] the actual relationship must be non-linear at low loss levels. It is important to note that percolation approaches zero before total losses do. This corresponds to the conceptual model in Figures 1 and 2, and the Merriam observation.

The maximum efficiencies obtained for each irrigation, over the seven years, range from 36 percent (irrigation 8, alfalfa) to 90 percent (irrigation 7, alfalfa). Minimum efficiencies range from 21 to 45 percent. This underscores the difficulty in estimating a single efficiency parameter.

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[2] Deep-rooted crops can extract shallow groundwater, making overall negative recharge a possibility (Lentz 2002). However, this not percolation; percolation is a direct result of the irrigation event and cannot be negative.

Sprinkler Systems

Experience, aerial photos, and published sources (Merriam 1977, USDA 1993) indicate that large volumes of runoff from sprinkler systems are rare.[3] Potential errors from sprinkler runoff are associated with errors in representing return flows to the river, and either method is susceptible to this danger.

Likewise, well-managed sprinkler systems "should not produce" deep percolation (USDA 1993).[4] While this is perhaps an optimistic assessment, it is true relative to gravity irrigation, and approaches absolute truth under conditions of increasing deficit irrigation. The scenario of concern, percolation with deficit irrigation, is less likely with sprinklers. Should it occur, the default calculation will correctly indicate it, as long as the ET adjustment factor is correct (though this will not be an easy parameter to estimate). The alternate method could also correctly indicate percolation with deficit irrigation, but again, this requires correct estimation of parameters. It is important to note that the alternate method requires the estimation of not only the ET adjustment factor but also the additional efficiency parameter.

Analysis of Alternate Method

The alternate method requires the estimation of an additional parameter - the Maximum Farm Efficiency - which is at least as difficult to determine as the ET adjustment factor that both methods require. Literature and the Colorado test data indicate that efficiency does not remain constant as deficit conditions are approached: "Runoff and percolation can be eliminated by severely underwatering, but an E_a [application efficiency] near 100 percent can result" (USDA 1993). "It is possible to obtain a very high AE [application efficiency] in a field by under-irrigating" (Burt et al 1997). The deficiency of the alternate method will be in these conditions of irrigation deficit, which are exactly the conditions that precipitated the concerns with the default method. Published “maximum” efficiency values describe the maximum attainable efficiency *for adequate irrigation* and therefore do not apply to the deficit-irrigation conditions of concern here.

The alternate method requires knowledge of diversion volume for all calculations. The data for ground-water diversion volume do not cover the entire study period, and estimating the earlier years would introduce an additional error opportunity into the process.

Despite these difficulties, the alternate method does match the conceptual model, and also produces exact results when known parameters are used. The vital questions

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[3] Some pivot and linear systems on low-intake soils produce localized runoff, but nearly all of this remains within the irrigated field and therefore is correctly represented by the default method.

[4] This does not mean that sprinkler systems are 100% efficient, but that relative to gravity irrigation more of the losses are to the atmosphere (direct evaporation and wind drift).

are whether it is better than the default method, and whether it is a sufficient improvement to warrant estimating additional parameters.

Deficit Irrigation

Deficit irrigation can refer to a chronic shortage of water that occurs on a regular basis, due to water supply factors, irrigation system capacity or management practices. This type of deficit should be correctly indicated by either method because it will be reflected in the empirical data used in calculating adjustment factors and efficiency parameters.

Deficit irrigation can also refer to a temporary shortage of water due to water supply factors. The quantity of water applied at each irrigation may be reduced, or the number of irrigations in a season may be reduced. The first response makes the most sense agronomically because it maximizes the amount of the limited supply delivered to the root zone and minimizes the amount delivered to percolation. The operation of the default method assumes this first response by allocating delivered water first to crop needs and then to percolation. If this first response dominates actual irrigator behavior, the default method is preferable, because under deficit irrigation the alternate method allocates a fixed fraction of delivered water to percolation regardless of the level of available supply.

With furrow and border irrigation there is a practical lower limit to the minimum quantity of water that can be applied in a single irrigation, so the second response also has merit. A naïve analysis suggests that the alternate method would be more appropriate in this situation, if one assumes that the individual irrigations have similar characteristics to corresponding irrigations in a normal year. However, even irrigations of the same magnitude, on the same date, have different efficiency and percolation characteristics under normal and deficit conditions. This is due to the difference in antecedent moisture condition and expected follow-up irrigation. Irrigation application efficiency may be defined as the ratio of the water delivered to the target to the total water applied. The target may be defined as either the depletion that has occurred since the last irrigation, or as the water required to be stored in the root zone to meet ET until the next irrigation. In either case, it is clear that a change in irrigation frequency will change the target (and therefore the actual irrigation efficiency) of an individual irrigation event. Furthermore, in Idaho the last irrigation event on small grains is typically unnecessary (Hopkins 2002), so the water actually supplying crop needs and therefore the actual efficiency is near zero. This is the irrigation most likely to be omitted in a water-short year, and its omission alone would significantly change the integrated efficiency and percolation characteristics of the full irrigation season.

It is important to consider deficit irrigation in light of both uses of these recharge calculations. For model calibration, a more-correct representation of a few seasons of low water supply in the calibration period could improve the nuances of spatial representation of aquifer characteristics, but in the context of regional modeling the differences would likely be minor. For scenario generation, any desired recharge calculation can be accomplished using either method, by selecting appropriate parameters.

Comparison Test of Methods

To test the two calculation methods, a computer spreadsheet was constructed which calculated depth of application, percolation, runoff, and delivery to target for a furrow irrigation event. An exponential algorithm (Burt and Styles 2002) was used to calculate inflow into the soil:

$$\text{Depth Infiltrated (inches)} = K * [\text{Time (minutes)}]^{N}$$

> Where “Time” represents opportunity time, or the time that the soil surface at a given point is covered with water. Because water in the furrow advances and recedes at different rates, this time is different at every point along the length of the furrow. It is typically highest at the top of the field and lowest at the bottom.

The spreadsheet accepted inputs of irrigation target depth, furrow length, furrow width, wetted fraction, advance time, set time, parameter K, and recession time. The spreadsheet set exponent N according to the user-selected parameter K, based on an empirical relationship that has been developed between K and N for agricultural soils (ITRC 2001). A mass balance equation solved for the required inflow rate to produce the specified opportunity time indicated by the advance time, recession time, and furrow length. The output of the spreadsheet was irrigation efficiency, ET adjustment factor, percolation depth, depth of deficit, and depth of runoff. Using the spreadsheet, various combinations of target depth, furrow length, parameters K and N, and advance and recession time were used. For each combination, a series of irrigation events was tested, starting with an excessive irrigation event and then incrementally scaling back set time into deficit conditions. While the relative magnitudes of deficit, runoff and percolation differed, all the tested combinations showed patterns similar to the illustration in Figure 5.

Figure 5
Runoff, Percolation, and Deficit

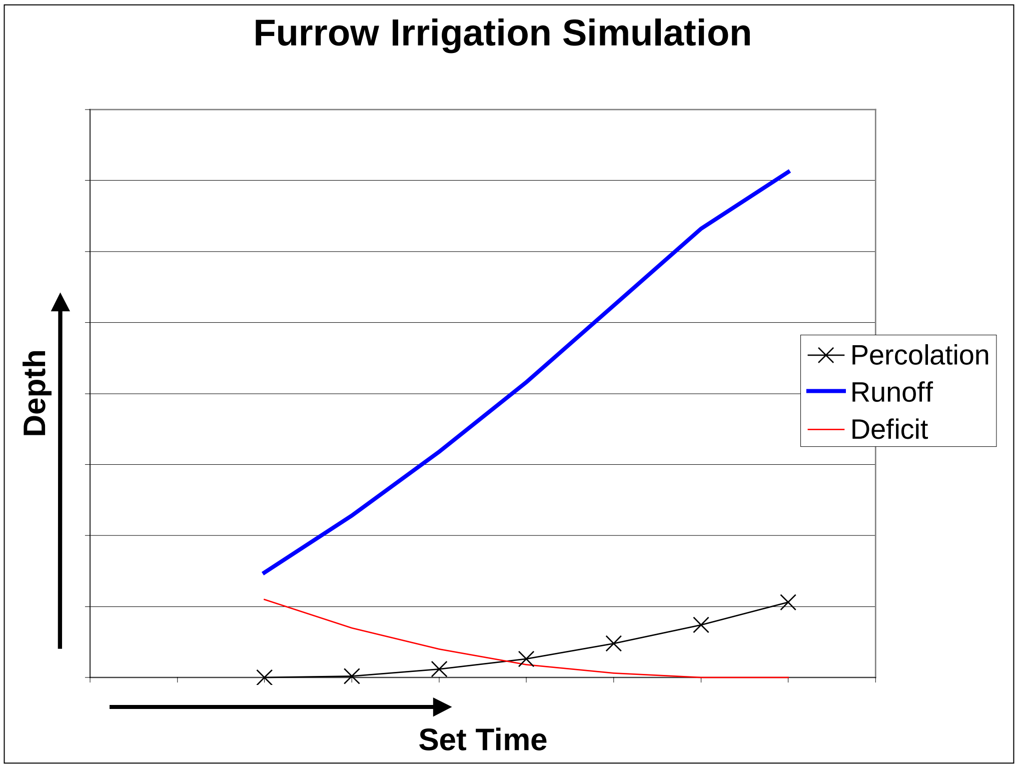
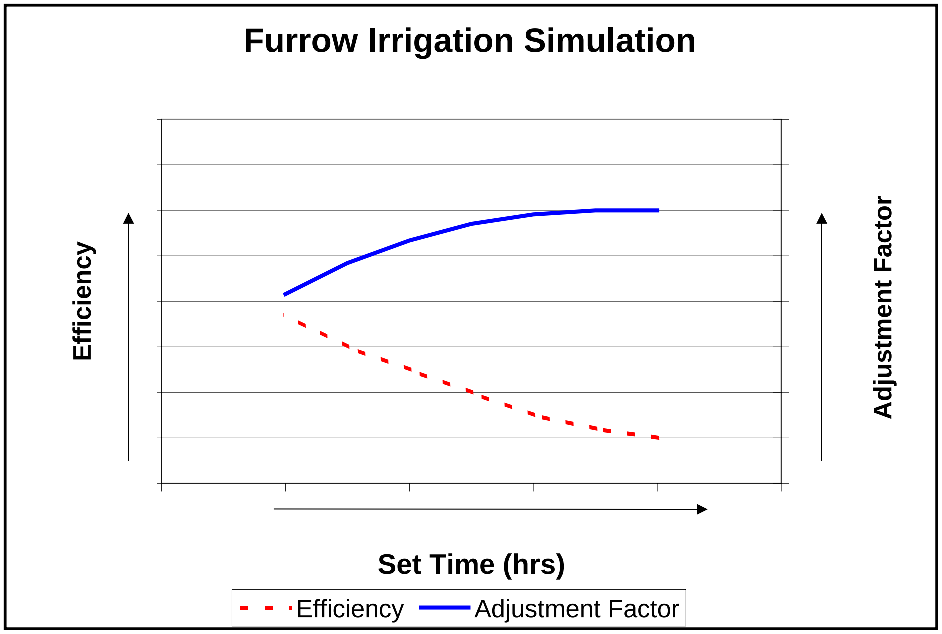


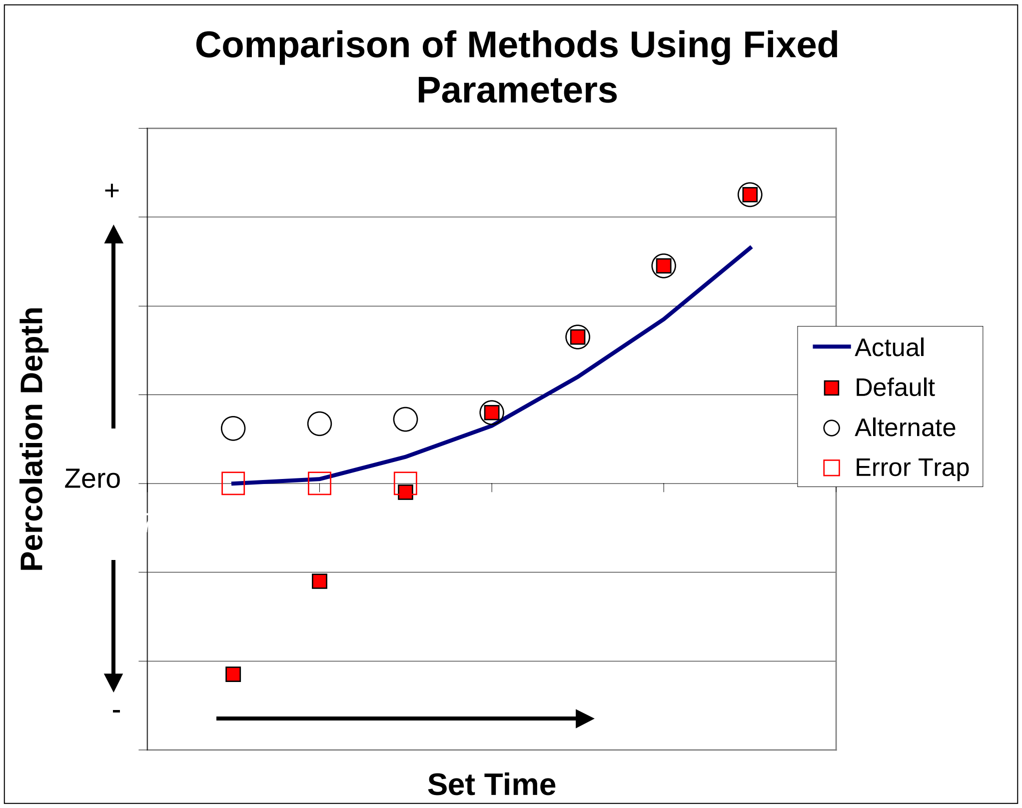
Figure 6 shows that neither the ET adjustment factor nor the irrigation efficiency remain constant. The relative magnitude of efficiency and adjustment factor depended on the specific hypothetical field conditions, but the pattern of increasing adjustment factor and decreasing efficiency was common to all simulations.

Figure 6
Irrigation Efficiency and Adjustment Factor



These simulations were used to create a table of known results, to test the two calculation methods. Parameters were adjusted so that both methods gave exact results at a common set time, and those sets of parameters were applied over the range of set times. When fixed parameters were used for a range of set times, both methods tended to over-estimate percolation at longer set times. At shorter set times (increasing deficit irrigation), the alternate method over-estimated percolation and the default method under-estimated. An error trap eliminating negative recharge greatly reduced the magnitude of the default method's errors. Figure 7 illustrates the results.

Figure 7
Comparison of Methods



It is true that both methods can exactly reproduce the results, if all the parameters are known. It is also true that knowing the parameters is impossible, and testing estimates nearly so. In the context of calibrating a set of aquifer characteristics from a multi-year data set, the default method with error trap appears to offer offsetting errors in dry and wet years, while the alternate method appears always biased towards over-estimating recharge. In the context of scenario generation, either method allows parameters to be selected to produce a desired recharge regime.

RESPONSE TO CONCERNS WITH DEFAULT METHOD

Brief responses to the concerns are outlined below.

1. If the water supply deficit is severe, (ET x Adjustment Factor) could exceed (Diversions + Precipitation), resulting in a calculated "negative" net recharge.

   This calculation will only result in a negative net recharge if the adjustment factor is incorrect. In the case of a constructed scenario, the user is free to set the adjustment factor to any desired level to simulate the hypothetical event being tested. The alternate method will suffer from the same limitation; irrigation efficiency also changes year-to-year and use of an average value will misrepresent some individual years.

In the case of model calibration, data limitations required the use of average parameters, which were expected to under-estimate recharge in some years and over-estimate recharge in other years. Most of the surface-water irrigation entities within the model boundary included areas of mixed-source lands with supplemental ground-water supplies. For these areas, it was assumed that in periods of low surface-water supply, ground-water would be pumped to satisfy crop demand. The default calculation is adequate for this situation.

After initial diversion volumes were calculated for all irrigation entities for the calibration period, year-by-year diversion depths were calculated. One entity - IESW007, in the Richfield area - showed implied negative net recharge, without adequate supplemental ground water supplies. This corresponds to operation of the error trap in Figure 7. For that entity, offsetting volumes were applied to the model using the Fixed Point function of the recharge tools to correct the water balance in dry years.

An incorrect adjustment factor is not the only blunder that could result in a calculated negative net recharge. Incorrect return-flow data, incorrect assignment of lands to irrigation entities, and incorrect calculation of ground water to surface water ratios could also result in a calculated negative recharge. Tapping of shallow ground water by deep-rooted crops could result in an actual negative net recharge. Any of these factors would affect any calculation method. For these reasons, final water-budget quality control included analysis of calculated diversion depth by model cell, by stress period, and by budget component. This allowed refinement of the assignment of diversions to entities, correction for dry years in IESW007, and refinement of the calculation of recharge on non-irrigated lands in cells where wetlands were present.

2. Not all precipitation should be considered as part of the water supply; some fraction of precipitation is non-effective and does not contribute to recharge. Some precipitation may contribute to runoff.

   This question applies equally to the default method and to the alternate method. If an adjustment to precipitation is required, it can be applied to either method. Year-round precipitation was included in the recharge calculations because winter time precipitation that exceeds ET eventually fills the soil profile or percolates through the soil to contribute to recharge. Soil storage of winter-time precipitation may account for a significant fraction of a deep-rooted crop's summertime water requirements (Allen 2002).

It is true that some rainfall events may result in return flows to the river. Because the return flow lag factors are empirically based, any historic rainfall component of return flows is correctly represented, though it is not explicitly labeled as rainfall.

In the contexts of calculating runoff from precipitation events and calculating actual infiltration of rainfall into the root zone, the concept of effective precipitation is important. Ponce (1989) estimates that only 75% of annual rainfall is available to contribute to surface runoff or percolation. It has been suggested that the first 0.20 inches (Luke et al 1998) to 0.25 inches (Burt and Styles 2002) of an individual rainfall event are intercepted by the leaves and soil surface and do not penetrate the root zone. However, for much of the winter (Wright 1993) and for much of the growing season (Allen et al 1998) evapotranspiration is energy limited. While raindrops that evaporate from crop leaves or snowflakes that sublimate from the surface never physically penetrate the root zone, the energy consumed in evaporation is no longer available to drive evaporation from the soil surface nor transpiration from the leaf. Under energy-limiting situations, the net water-balance effect is as if part or all of the precipitation were applied directly to the root zone.

Preliminary analysis of SEBAL (Morse et al 1999) evapotranspiration estimates suggests that the ET adjustment factors used in calibration are appropriate. These are 1.05 for all sprinkler-irrigated lands and 1.00 for all gravity irrigated lands. The SEBAL estimates are based on multiple satellite images for the years 2000 and 2002. If some part of precipitation is non-effective (that is, does not reduce crop irrigation requirement), it must increase total evapotranspiration viewed by the satellite. The effect will be empirically incorporated into the ET adjustment factors. Precipitation events have been observed to increase the SEBAL-indicated evapotranspiration on dry rangeland (Allen 2002), and to briefly increase indicated ET on irrigated grassland (Morse et al 1999). The general agreement between SEBAL and the adjustment factors used suggest that non-effective precipitation is not a large source of bias in the calibration data.

3. The possibility of simultaneous deficit irrigation and deep percolation could indicate that adjustment factors should be smaller than perhaps contemplated. An incorrect adjustment factor could bias results.

   This concern applies equally to the default method and the alternate method, because both methods rely upon the adjustment factor. Incorrect parameters in any calculation will result in erroneous results.

4. The default method results in zero aquifer recharge under conditions of deficit irrigation from surface sources.

This is only true if an inappropriate adjustment factor is selected. Any method is subject to errors from inappropriate parameters. As reported above, corrections were made for the one surface-water entity where calculated diversion depths suggested a deficit-irrigation condition.

5. The default method assumes that all wells pump 100% of the crop demand plus losses.

   As with item four, this is only true if an inappropriate adjustment factor is selected.

6. If returns are the same fixed percentage of diversions in wet and in dry years, deficit-irrigation scenarios may not be correctly represented.

   This is a valid concern that affects both methods equally. Every effort was made to calculate appropriate return flows given the available data and resources. It is important to remember that the calibrated aquifer parameters reflect the integrated effect of many stress periods, smoothing the effects of higher and lower return-flow years. For construction of scenarios, the user can set return flows to represent the desired hypothetical conditions.

7. The default method does not differentiate between return flows from surface sources and return flows from ground water sources.

   This concern affects both methods. Since the return flow calculations are empirically based, any historical contribution of ground water to returns is correctly represented, even if the source of the returning water is not known precisely. Calculations in the appendix illustrate the limited effect of this simplification.

All calculation methods are subject to limitations. The vital question is whether the default method is capable of representing the physical processes. The tests described above show that if the parameters in the calculation are set to the known values, the default method produces exact results. The method is also capable of adequately representing a range of hypothetical situations with reasonable estimated parameters.

CONCLUSIONS

The concerns expressed are valid. The recharge calculations for model calibration included careful consideration of parameters, and careful error checking. Both calculation methods are capable of reproducing exact results with exact parameters. The default method gives good results with reasonable estimated parameters, over a wide variety of hypothetical situations. The alternate method requires the estimation of more parameters and the estimation of ground-water pumping volumes for years where data are not available. Its step function tends to bias results towards excess recharge.

DESIGN DECISION

Diversion, canal leakage, and return flow data were provided to the FORTRAN program in table form, by irrigation entity. The GIS application identified to the FORTRAN program the number of square feet of each entity for each model cell, and point the FORTRAN program to the appropriate data tables. The FORTRAN program will allocate total field delivery by entity to all the cells served, proportionately to area served.

Precipitation will be delivered to the GIS application in a grid format, to the highest spatial resolution available in the original data. The GIS application will sum the precipitation by cell and deliver the value by model cell to the FORTRAN program.

The GIS tool will use county-wide crop mix for each year, nearest-weather-station Allen-Brockway ET by crop (Allen and Brockway 1983), and ET adjustment factor by irrigation entity, to calculate the ET rate for each entity having irrigated lands within the cell.

The FORTRAN program will calculate recharge by model cell from these input data, according to these algorithms:

Surface-water irrigation:

Field Delivery = Diversions - Canal Leakage - Return Flows

Net Recharge (surface)=
(Field Delivery + Precipitation) - (ET x Adjustment Factor)

Ground-water Irrigation:

Net Recharge (ground) = Precipitation - (ET x Adjustment Factor)

Instances of negative recharge from surface water irrigation were individually examined. For irrigation entity IESW007, corrections were made to the recharge data sets using the Fixed Point function of the recharge tools. GIS illustrations and tables of recharge depth by irrigation entity were generated to allow review of recharge rates associated with all ground-water and surface-water irrigation.

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[5] It is anticipated that the soon-to-be-released update of this report will be utilized.

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APPENDIX:

RETURN FLOWS FROM GROUND WATER

The default calculation method uses empirically-derived return flow ratios that relate all return flows to specific surface diversions, regardless of actual water source. The impact of this simplification is evaluated by constructing a "known" hypothetical, and testing the results of the default methods.

The scenario is a 275-acre tract, 250 acres irrigated from surface sources and 25 acres irrigated from ground-water sources. Canal losses and precipitation are zero, application rates are a uniform four feet, and consumptive use is two feet. Actual return flows are ten percent of diverted volume. The known values are shown in table A1:

Table A1
Known Return Flows and Recharge
(acre feet)

	Surface Source	**GW Source**	**Total**
Diversions	1000	100	1100
Returns	100	10	110
Net Application[6]	900	90	990
ET	500	50	550
Percolation[7]	400	40	440
Net Aquifer Effect[8]	400	-60	340

Because the default method return flows are empirically determined, the calculation would use an 11% return rate (110 acre feet of observed returns divided by 1000 acre feet of surface diversions). Table A2 shows the calculated results:

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[6] Diversions - returns

[7] Net application - ET

[8] For surface source, net effect = percolation. For ground-water source, net effect = (gross diversion - percolation).

Table A2
Default Calculation of Return Flows and Recharge
(acre feet)

	Surface Source	**GW Source**	**Total**
Diversions	1000	100	1100
Returns	110	0	110
Net Application	890	100	990
ET	500	50	550
Percolation	390	50	440
Net Aquifer Effect	390	-50	340

Note that the default method slightly under-estimates net recharge from surface water, offset by an equal under-estimate of net depletion from ground water. From a water budget standpoint, the important result is that the total net effect is correct. As long as the ground-water lands that produce return flows are scattered among surface-water lands (which is the case in this study), the cell-by-cell distribution will be approximately correct, as well.

This analysis also raises an issue with the construction of a prediction scenario. If the scenario is to stop application of ground water, appropriately the river returns that actually accrued from the ground water should also be stopped. If the default results are used without adjustment, the predicted results indicate ground-water withdrawals would be reduced by 50 units, instead of 60. Likewise, the predicted results would not acknowledge the decrease in return flows to the river. However, such a change would not occur in isolation. Surface water would be moved to different and perhaps more acres, affecting not only recharge but also timing, magnitude, and location of returns. Neither the default method, the alternate method, nor any other method, can be used without a great deal of forethought in describing hypothetical scenarios for predictive testing.