A Steady-State Water Budget Accounting Model for the Carbonate Aquifer System in White Pine County, Nevada, and Adjacent Areas in Nevada and Utah

K.W. Lundmark
G.M. Pohll
R.W.H. Carroll

June 2007

DHS Publication No. 41235

Prepared by

Desert Research Institute, Nevada System of Higher Education

Prepared for

U.S. Department of the Interior

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Groundwater budgets for a 12-basin carbonate aquifer study area in White Pine County, Nevada, and adjacent areas in Nevada and Utah were evaluated using a steady-state groundwater mass-balance accounting model. The groundwater budgets for study area basins include recent, independent estimates for groundwater recharge from precipitation and groundwater discharge as evapotranspiration which were developed for the Basin and Range Carbonate Aquifer System (BARCAS) study. The discrete-state compartment (DSC) model was coupled with the shuffled complex evolution (SCE) optimization algorithm to allow for optimization of both direction and magnitude of flow between basins. Deuterium was used as a conservative tracer in the mass-balance model. Characteristic deuterium values for groundwater recharge and for regional groundwater were determined from a geochemical database compiled for the study area. The objective function for model optimization was varied to include either deuterium values or a combination of deuterium values and basin groundwater evapotranspiration discharge estimates. Uncertainty of the accounting model predictions was evaluated by performing a Monte Carlo simulation on the groundwater recharge inputs to the model. When optimized based on only deuterium values, model-predicted rates for groundwater discharge from the model domain for multiple basins differed significantly from estimated groundwater evapotranspiration rates. Incorporation of target discharge values in the model's objective function yielded basin discharge rates which better agreed with the BARCAS study groundwater budgets and helped to assess the presence and direction of interbasin groundwater flow within and out of the study area.

THIS PAGE INTENTIONALLY LEFT BLANK

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Federal legislation (Section 131 of the Lincoln County Conservation, Recreation, and Development Act of 2004) was enacted in December 2004 that directed the Secretary of Interior, through the U.S. Geological Survey, the Desert Research Institute, and a designee from the State of Utah, to conduct a water resources study of the alluvial and carbonate aquifers in White Pine County Nevada and surrounding areas in Nevada and Utah. The main objectives of the study, termed the Basin and Range Carbonate Aquifer System (BARCAS) study, were to evaluate the following hydrogeologic characteristics: (1) the extent, thickness, and hydrologic properties of aquifers, (2) the volume and quality of water stored in aquifers, (3) subsurface geologic structures controlling ground-water flow, (4) ground-water flow direction and gradients, and (5) the distribution and rates of recharge and discharge.

Hydrographic areas in White Pine County are the primary focus of the study, covering approximately 90 percent of White Pine County (Figure 1). The 12-basin study area includes basins such as Cave Valley, Lake Valley, Snake Valley, and Spring Valley where groundwater development has been proposed by the Southern Nevada Water Authority (SNWA) as part of the Clark, Lincoln, and White Pine Counties Groundwater Development Project (SNWA, 2006).

This report is one in a series of reports related to the BARCAS study and is specifically focused on water budgets and the development of a conceptual description of groundwater flow in the study area. A complete overview of the BARCAS project was developed by Welch and Bright (2007). To help evaluate basin and regional water budgets, a mass-balance groundwater accounting model was developed and applied to the BARCAS study area. The groundwater accounting model incorporates recent, independent estimates for groundwater recharge from precipitation and groundwater discharge as evapotranspiration which were developed for the BARCAS study and provides estimates for interbasin groundwater flow rates based on the fluxes of a conservative tracer.

The groundwater accounting model synthesizes results from multiple tasks of the BARCAS project, including potentiometric surface, hydrogeologic interpretations, and groundwater recharge and evapotranspiration estimates. Consequently, revisions to any of these components of the BARCAS study, in particular to groundwater recharge and evapotranspiration estimates, will affect the groundwater accounting model. The groundwater accounting model inputs are based on BARCAS study results which were available at the time of preparation of this report.

WATER BUDGETS

One of the most basic ways to quantitatively evaluate the movement of groundwater through an aquifer system is through the water budget for the system. Water budgets may be developed for systems of any size and for this study are useful at both basin and regional scales. The fundamental equation for a water budget (or water balance) is the sum of inputs minus the sum of outputs equals the change in storage of the system:

$$\sum Inputs - \sum Outputs = \Delta Storage$$

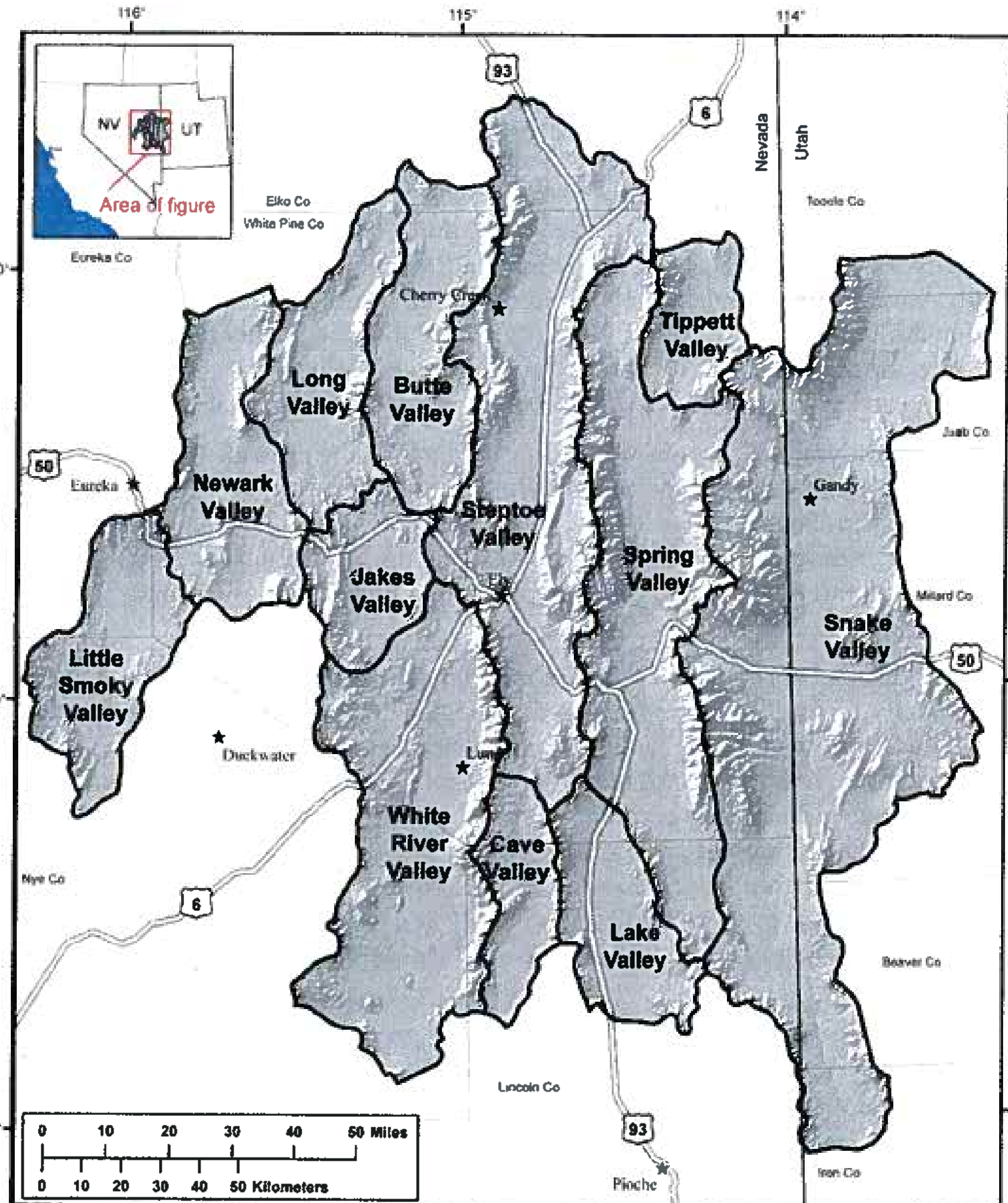


Figure 1. Study area showing twelve associated basins

If the system is assumed to be at steady state, then the change in storage is zero and the water budget becomes:

$$\sum Inputs = \sum Outputs$$

For a groundwater system, inputs may include direct recharge from precipitation, indirect recharge of precipitation from surface water runoff, groundwater inflow from outside the system boundary, or recharge from anthropogenic sources. Groundwater outputs may include discharge as springs, discharge to surface water bodies, loss to the atmosphere by evapotranspiration (ET), groundwater outflow to outside the system boundary, and pumping for domestic, agricultural, industrial, and mining uses. Considering that for basins within the BARCAS area the primary groundwater inputs are recharge from precipitation and interbasin groundwater inflow and that the primary outputs are discharge as groundwater ET and interbasin groundwater outflow, a simplified water budget may be expressed as:

$$Recharge_{precip} + GW_{inflow} = Discharge_{GWET} + GW_{outflow}$$

Work completed for the BARCAS discharge task and recharge task determined rates for discharge by ET from groundwater and recharge from precipitation (Welch and Bright, 2007). Groundwater ET discharge was estimated by first calculating the total ET for each basin or sub-basin then subtracting the amount of precipitation to yield the groundwater discharge component of the total ET rate. Recharge estimates include both in-place recharge occurring within the mountain areas as well as infiltration of surface water runoff to become recharge. Recharge estimates were initially developed using a spatially-distributed Basin Characterization Model (BCM) with monthly climate data from 1970 to 2004. The long-term average recharge rates presented in the BARCAS summary report (Welch and Bright, 2007) were estimated using a power function regression relating annual recharge to annual precipitation for the years 1970 to 2004 and then extrapolating or interpolating to average annual precipitation for the period 1895 to 2006 (Flint and Flint, 2007). The two sets of recharge estimates are referred to as “BCM 1970-2004” and “Power Function 1895-2006” within this report. The BCM 1970-2004 recharge rates used for groundwater accounting modeling are preliminary BCM modeling results and are greater than the final BCM recharge rates reported by Flint and Flint (2007).

The estimated BCM 1970-2004 and Power Function 1895-2006 recharge rates and groundwater ET discharge rates for the 12 basins of the BARCAS study are presented in Table 1. BCM 1970-2004 recharge rates are greater than Power Function 1895-2006 rates for all study area basins. Total recharge to the study area is greater than total groundwater ET discharge, indicating that groundwater outflow is occurring from the study area. Recharge rates from the BCM 1970-2004 and Power Function 1895-2006 methods are greater than discharge for all basins except Newark Valley, Snake Valley, and White River Valley, indicating that a net groundwater outflow is occurring from most basins in the study area. Recharge by both methods is less than groundwater ET discharge White River Valley, while for Newark Valley and Snake Valley the groundwater ET discharge rates are between the BCM 1970-2004 and Power Function 1895-2006 recharge rates.

The imbalance between recharge and groundwater ET discharge within study area is balanced by groundwater flow within and out of the study area. Groundwater flow may occur as interbasin flow between basins within the study area or as groundwater flow out of the study area. Groundwater pumping is another type of groundwater discharge which may occur within the study area, however groundwater pumping was not included in the water budget due to the temporal nature of pumping (versus a steady-state water budget). The omission of groundwater pumping may have some impact on the water budget for the study area.

Table 1. BARCAS recharge and groundwater evapotranspiration discharge estimates. (All values are acre-feet/year, rounded to the nearest 100 acre-feet/year.)

Basin	Recharge: Power Function 1895-2006	Recharge: BCM* 1970-2004	Groundwater ET**
Butte Valley	35,300	40,400	11,900
Cave Valley	10,900	15,600	1,600
Jakes Valley	15,700	17,700	900
Lake Valley	13,100	17,900	6,100
Little Smoky Valley	4,500	6,600	4,000
Long Valley	24,700	32,100	1,200
Newark Valley	21,200	27,000	26,100
Snake Valley	111,300	133,100	132,200
Spring Valley	93,100	103,400	75,600
Steptoe Valley	154,000	168,600	101,500
Tippett Valley	12,400	13,800	1,700
White River Valley	35,300	47,800	76,700
Total	531,500	624,000	439,500

*Basin Characterization Model
**evapotranspiration

INTEGRATED WATER ACCOUNTING MODEL

To help verify tabulated water budgets and evaluate interbasin groundwater flows, a steady-state groundwater accounting model was developed and applied to the study area. Groundwater accounting is accomplished via a simplified mass-balance mixing model which utilizes accounting "cells" from which input and outputs are defined, rather than the standard groundwater flow equation used in typical numerical simulations. The mass-balance model has the same fundamental equation as the water budget:

$$\sum Inputs - \sum Outputs = \Delta Storage$$

As with the water budget, the assumption of a steady state removes the storage term from the equation, giving:

$$\sum Inputs = \sum Outputs$$

The difference is that in a mass-balance model the mass flux of a substance (or tracer) moving in and out of the system is used, whereas in a water budget volumes of water moving in and out of the system are used. Considering that the mass flux of a tracer in water may be calculated as its concentration (mass per volume) times the flow rate (volume per time), the mass-balance approach may be viewed as a water budget modified to include concentrations, and the general equation may be expressed as:

$$\sum_{i=1}^{N_{in}} (Q_{in\,i} \times C_{in\,i}) = \sum_{j=1}^{N_{out}} (Q_{out\,j} \times C_{out\,j})$$

where Q_{in} and C_{in} represent the flow rate (volume/time) and concentration (mass/volume) for each of N_{in} inputs and Q_{out} and C_{out} represent the flow rate and concentration for each of N_{out} outputs.

The benefit of this approach is that if characteristic tracer concentrations vary between different model inputs and between different "cells" within the system, then modeling the movement of the tracer within the system can provide information on magnitudes and directions of water flow. In this way, groundwater chemistry data are used to help constrain the water budget and may provide information on the mixing patterns and source areas for groundwater in the carbonate aquifer system.

DEUTERIUM AS A GROUNDWATER TRACER

The stable isotope deuterium (^2H, D) is a nearly ideal tracer for groundwater investigations because 1) it is part of the water molecule and is therefore generally not affected by reactions with geologic materials, and 2) it displays natural variability as a result of the processes of evaporation and precipitation of water (Sadler, 1990). The ratio of deuterium to protium (^1H) in a water sample is typically referenced to the Vienna Standard Mean Ocean Water (VSMOW) standard by the equation

$$\delta D = \frac{\left(\frac{^2H}{^1H}\right)_{sample} - \left(\frac{^2H}{^1H}\right)_{VSMOW}}{\left(\frac{^2H}{^1H}\right)_{VSMOW}} \times 1{,}000$$

where δD is the ratio, expressed as per mil (‰), of the difference between the $D/^1H$ ratios of the sample and the reference to the $D/^1H$ ratio of the reference. Analytical error for δD analyses is approximately 1 ‰.

Freshwater systems are typically depleted in deuterium compared to oceanic waters and consequently have negative δD values. The process by which water becomes enriched in heavier isotopes (isotopically heavier, more positive δD values) or depleted in heavy isotopes (isotopically lighter, more negative δD values) is referred to as fractionation. Isotopic fractionation of water molecules occurs through a variety of processes. When water evaporates, the resultant water vapor will be isotopically lighter than the liquid water; when water vapor condenses as precipitation, the resultant liquid water is isotopically heavier than the vapor (Drever, 1997). Variability in isotopic composition of precipitation has been attributed to multiple effects, as summarized by Hershey and Mizell (1995):

- *temperature effect* – fractionation during the formation of precipitation from clouds is controlled by the temperature at which changes in physical state occur
- *continental effect* – precipitation tends toward more negative δ values further away from the ocean
- *altitude effect* – precipitation becomes lighter (more negative δ values) at higher altitudes
- *latitude effect* – precipitation becomes lighter (more negative δ values) at higher latitudes
- *amount effect* – the greater the amount of precipitation, the more negative the δ values

In addition, storm-to-storm variation in δD occurs, but mixing during the recharge process causes smoothing toward the mean value (Gat, 1981, Darling and Bath, 1988). Because evaporation changes δD values, any study using deuterium as a conservative tracer should only examine a deep groundwater system that is minimally impacted by evaporative processes. The characteristic δD value for recharge is defined with groundwater springs in recharge source areas, as opposed to using precipitation δD values that are highly variable and could be significantly altered by pre-recharge evaporation. Groundwater springs in recharge areas represent surface expressions of precipitation which has recharged, and may be assumed to average out storm-to-storm, seasonal, yearly, and small geographic variations in the isotopic composition of precipitation (Ingraham and Taylor, 1991). Assuming the effects of past climate regimes on deuterium signatures are negligible and that alteration of the signature does not occur through processes such as evaporation, then δD is simply a function of geographic location and is therefore treated as a conservative tracer (Sadler, 1990).

The mass balance equation developed in the previous section expressed a mass flux as the product of a tracer's concentration (mass per volume) times a volumetric flow rate. A δD value is not technically a concentration because it represents a difference between a water sample and VSMOW rather than an amount of D per volume or mass of water. However, δD can be treated as a concentration because it scales linearly with concentration and thus will not cause a difference in mass balance model results versus use of an actual D concentration.

DISCRETE-STATE COMPARTMENT MODEL

The groundwater accounting model developed and applied to the BARCAS study area is a modified Discrete-State Compartment (DSC) model. This accounting-type model uses water budget and environmental tracer values to perform iterative water and mass-balance calculations for the system which is modeled as a network of compartments (or "cells"). The model is calibrated by comparing simulated concentrations of the selected environmental tracer to observed values at each iteration.

Model Background

The DSC model was originally developed by Campana (1975) as a tool to model the mass of any groundwater tracer (i.e., groundwater constituents or environmental isotopes) via mixing cell mass-balance equations. Subsequent use of the DSC model has occurred in several groundwater studies of eastern Nevada (Feeney et al., 1987; Karst *et al.*, 1988; Roth and Campana 1989; Sadler 1990; Kirk and Campana 1990; Campana *et al.*, 1997; Calhoun 2000; Earman and Hershey, in review). The DSC model is advantageous for use in this study because it may be applied to systems lacking sufficient information on aquifer properties necessary to define a rigorous finite-difference or finite-element numerical groundwater model.

The DSC model is a mixing-cell model that represents groundwater systems as a network of interconnected cells. Both water and tracer movements are governed by a set of recursive conservation of mass equations in which the volumetric flux of water and associated mass flux of a tracer are tracked. Whereas the original DSC model allowed for transient simulations and the use of nonconservative tracers, the DSC model used for this study was modified to simulate only steady-state conditions of a conservative tracer (Carroll and Pohll, in press). Consequently, values are not necessary for cell volumes and source/sink rates (e.g., decay rates, reaction rates, adsorption/desorption coefficients). Model inputs include the number of cells, rates and concentrations for recharge, connections between cells, and cell ranks. A conceptual representation of a DSC model framework and components is provided in Figure 2. Conceptually, one can envision the cell's rank as a surrogate for the cell's groundwater head. Flow will only occur from a cell with higher groundwater levels (*i.e.*, higher rank) to a cell with relatively lower groundwater levels (*i.e.*, lower rank). Flow directions between connected cells may either be specified or left unspecified. If flow directions are left unspecified, ranks for these cells are varied during model optimization to determine flow direction.

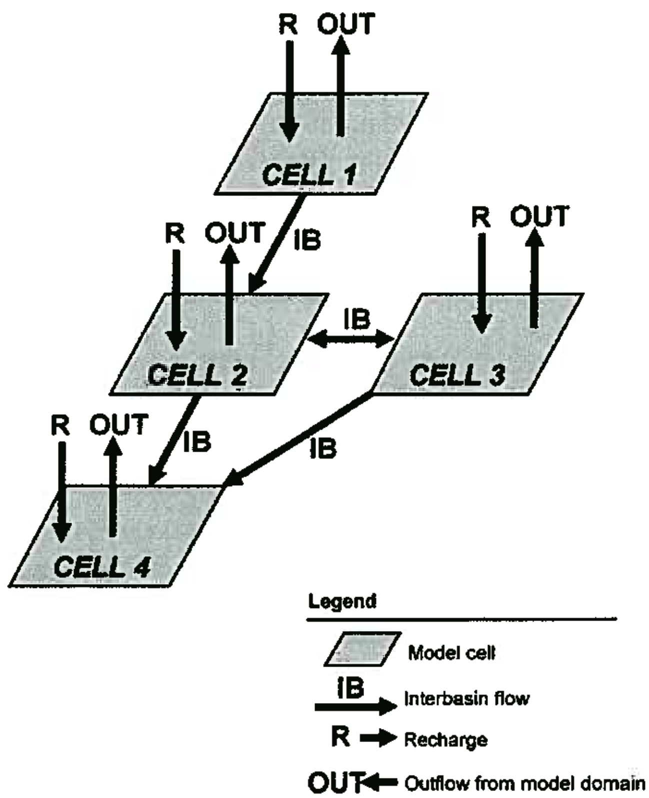


Figure 2. Discrete-state compartment (DSC) model components.

The-steady state assumption requires that volume and mass discharging from a cell are equal to all inputs of volume and mass to that cell. The algorithm of an instantaneously mixed cell may be expressed as:

$$C_i = \frac{\overbrace{\sum_{j=1}^{N}\left(Q^r_{i,j}C^r_{i,j}\right)}^{\text{Mass from recharge}} + \overbrace{\sum_{k=1}^{D}\left(f_{k,i}Q^d_k C^d_k\right)}^{\text{Mass from GW inflow}}}{\underbrace{\sum_{j=1}^{N}\left(Q^r_{i,j}\right)}_{\text{Recharge rate}} + \underbrace{\sum_{k=1}^{D}\left(f_{k,i}Q^d_k\right)}_{\text{GW inflow rate}}}$$

where C_i is the steady-state modeled concentration for cell i, $Q^r_{i,j}$ is the recharge rate for the j^{th} recharge to cell i, $C^r_{i,j}$ is the tracer concentration for the j^{th} recharge to cell i, N is the number of recharge inputs to cell i, Q^d_k is the total discharge from cell k, $f_{k,i}$ is the fraction of flow Q^d_k discharging from cell k to cell i, C^d_k is the steady-state modeled concentration for cell k, and D is the number of cells discharging to cell i. Discharge can occur to another cell (as interbasin groundwater flow within the model domain) or out of the model domain (as evapotranspiration or interbasin groundwater flow out of the model domain). Therefore,

$$\sum_{h=1}^{P} f_{i,h} + f_{i,out} = 1.0$$

where P is the number of outflows to adjacent cells from cell i, $f_{i,h}$ is the fraction of flow and mass discharged from cell i and received by cell h, and $f_{i,out}$ is the fraction of flow and mass discharged from cell i out of the model domain.

Model Optimization

For this study, optimization (or calibration) is synonymous with minimizing an objective function that defines the overall error between observed and predicted values for each cell of the model. Optimization of the DSC model has traditionally been performed by manually adjusting cell-to-cell and boundary fluxes until modeled tracer concentrations in each cell best approximated observed values. The DSC model developed and applied for this study was coupled to the Shuffled Complex Evolution (SCE) optimization algorithm (Duan *et al.*, 1992) to allow for rapid and automated model optimization.

During model optimization, flow fractions ($f_{i,h}$ and $f_{i,out}$) and cell ranks are adjusted until the predicted cell tracer concentrations and/or outflows best match observed cell tracer concentrations and/or outflows. The parameters $f_{i,h}$ and $f_{i,out}$ effectively control the volume of water and mass of tracer moving between model cells and out of the model domain. If all flow directions are specified, then $f_{i,h}$ and $f_{i,out}$ are the only parameters adjusted during model optimization. If the direction of flow between cells is unknown or ambiguous, the cells' ranks are adjusted and the fraction of flow from the lower (ranked) cell to the higher (ranked) cell is automatically set to zero.

BARCAS DSC MODEL

Model Description

The DSC model developed and applied for BARCAS is a single-layer model of regional and deep intermediate groundwater. For the context of the model, regional groundwater is defined as having long flowpaths spanning multiple hydrographic areas, discharge far from recharge, long travel times, and deep circulation. Deep-intermediate groundwater is considered to be groundwater that does not traverse multiple basins; however, this water does flow to sufficient depths to allow for heating and/or mixing with regional-type groundwater. Both regional groundwater and deep-intermediate groundwater are important to the study because these are the groundwater types that may be representative of the regional carbonate-rock aquifer.

Local groundwater systems, including shallow alluvial groundwater and perched aquifers within mountain blocks, were not included as cells in the DSC model. Local groundwater systems were not included as DSC model cells due to an insufficient amount of data to support the increased optimization parameters associated with a multi-layer model. However, groundwater samples collected from local systems were used to estimate characteristic recharge δD values.

The following sections describe the specific assumptions and input parameters associated with the BARCAS DSC model.

Model Assumptions

The following assumptions were made for the groundwater accounting model (modified from Sadler [1990]):

1. The system is at steady state.
2. Deuterium is a conservative tracer.
3. The regional aquifer system may be represented as a series of cells, each of which contains a characteristic deuterium concentration for the fully mixed cell (sufficient data do not exist to subdivide into smaller cells).
4. The δD values used for calibration are representative of the δD content of regional / deep-intermediate groundwater in the study area.
5. δD of recharge to the regional / deep-intermediate aquifer is related to the δD values for springs, shallow wells, and some surface water within recharge areas and downgradient of recharge areas.
6. Recharge rates and δD values have remained constant for a sufficient period of time for steady-state conditions to be observed for the system. This assumption does not imply that short-term fluctuations in recharge rates or values do not occur; however, these fluctuations are assumed to be smoothed out (integrated) over time to yield the estimated average value.
7. Groundwater input to the study area does not occur as interbasin groundwater flow from outside the study area. This assumption implies that the only groundwater input to the system occurs as recharge from precipitation. Water budgets presented in previous reports identified "some" groundwater inflow to Little Smoky Valley from Stevens Basin and Antelope Valley (Rush and Everett, 1966) and unspecified amounts of groundwater inflow to Snake Valley from Pine Valley and Wah Wah Valley (Harrill *et al.*, 1988). Groundwater inflow from outside the study area to Little Smoky Valley and Snake Valley was not modeled due to the unspecific nature of estimates for inflow reported in previous studies.

Model Inputs

Head Rankings

Model cells were assigned head rankings from 1 (lowest head) to 20 (highest head) based on the regional potentiometric surface map generated under the BARCAS groundwater flow task (Welch and Bright, 2007). Head rankings were assigned by calculating the average regional aquifer potentiometric elevation in each cell. Average elevations were determined by performing a simple interpolation of contour lines to generate a continuous potentiometric surface, then calculating the average value using ARCMap 9 geographic information system (GIS) software. Average heads ranged from 4,420 feet above mean sea level (amsl) for the northeast portion of Snake Valley to 6,440 feet amsl for the southern portion of Steptoe Valley. Average heads and head rankings are listed in Table 2 and shown on Figure 3.

Cell Connectivity

Potential interbasin groundwater flows were determined based on the hydrographic area boundary classifications determined for the geology task and the regional potentiometric surface contours (Welch and Bright, 2007). Boundary classifications for probable flow (green) or possible flow (yellow) were compared to the potentiometric surface in adjacent basins. If a gradient was present, then a potential interbasin flow was identified. If interbasin flow was possible based on the hydrographic boundary classification, but a gradient between basins was not apparent based on the regional potentiometric surface, then a potential interbasin flow was identified with an undetermined direction. If a basin boundary was classified as flow not likely (red) or if a groundwater mound was present, no potential flow was identified. Potential interbasin groundwater flows were used to establish the cell network for the DSC model and are shown in Figure 3.

Interbasin groundwater flow out of the model domain are not shown on Figure 3 nor are these flows explicitly listed in the model's input or output. The DSC model predicts one rate for outflow from the model domain for each cell and this outflow rate is not divided into components of interbasin groundwater outflow from the model domain and discharge from the model domain as groundwater ET.

Recharge Rate

Recharge rates for each cell were determined from the recharge estimates calculated for the BARCAS recharge task using the BCM and Power Function methodology (Flint and Flint, 2007). Recharge rates for sub-basins were summed, as necessary, to yield net recharge rates for the DSC model cells. The assumed ratio of 15 percent of runoff becoming recharge was maintained for cell recharge estimates for consistency with the BARCAS recharge task. Calculations also assumed that topographic basin boundaries were representative of hydrographic area boundaries. Recharge rates in acre-feet/year for each cell are presented on Table 2.

Table 2. BARCAS DSC model cell input parameters and calibration criteria. (Recharge and groundwater evapotranspiration rates are rounded to the nearest 100 acre-feet per year.)

		Head Rank		Recharge			Groundwater ET			Observed (calibration) values				
Cell	Name	Average Head (ft)	Rank	Power Function 1895-2006 rate (afy)	BCM 1970-2004 rate (afy)	δD (‰)	Rate (afy)	Standard deviation, sGW ET (afy)	Inverse standard deviation, 1/sGW ET (afy-1)	δD (‰)	Standard deviation (‰)	Confidence interval, *ci* (‰)	Inverse confidence interval, 1/*ci* (‰-1)	Weight (‰-1)
1	Snake Valley - South	5,490	5	41,700	49,100	-107	21,000	4,100	2.4E-04	-111	1.60	1.06	0.94	0.94
2	Lake Valley	5,710	9	13,100	17,900	-105	6,100	4,400	2.3E-04	-111	2.26	2.25	0.44	0.44
3	Cave Valley	5,610	6	10,900	15,600	-107	1,600	800	1.2E-03	-104	3.16	3.63	0.28	0.28
4	Spring Valley - South	5,760	7	25,100	30,600	-108	26,900	4,100	2.4E-04	-110	2.06	1.45	0.69	0.69
5	White River Valley - South	5,150	3	10,300	15,700	-107	65,500	15,400	6.5E-05	-115	5.63	2.88	0.35	0.35
6	Little Smoky Valley	5,970	12	4,500	6,600	-121	4,000	500	1.8E-03	-120	2.22	4.07	0.25	0.25
7	White River Valley - North	5,740	8	25,000	32,100	-113	11,200	1,600	6.2E-04	-120	4.29	3.02	0.33	0.33
8	Snake Valley - Central	5,180	4	28,100	34,200	-113	39,000	9,400	1.1E-04	na	--	--	--	0
9	Steptoe Valley - South	6,440	20	27,000	35,100	-114	3,600	400	2.7E-03	-118	3.06	9.29	0.11	0.11
10	Jakes Valley	6,180	16	15,700	17,700	-119	900	100	1.1E-02	na	--	--	--	0
11	Steptoe Valley - Central	6,490	19	63,300	64,100	-117	41,000	5,600	1.8E-04	-123	0.71	8.98	0.11	0.11
12	Newark Valley	5,980	13	21,200	27,000	-122	26,100	5,800	1.7E-04	-122	nc	--	--	0.1
13	Butte Valley	6,190	18	35,300	40,400	-122	11,900	8,700	1.2E-04	na	--	--	--	0
14	Snake Valley - North	4,960	2	38,300	45,900	-117	54,800	12,400	8.0E-05	-118	4.47	3.37	0.30	0.30
15	Spring Valley - Central	5,970	11	54,700	60,000	-118	47,000	10,200	9.8E-05	-123	1.78	3.27	0.31	0.31

Table 2. BARCAS DSC model cell input parameters and calibration criteria. (Recharge and groundwater evapotranspiration rates are rounded to the nearest 100 acre-feet per year) (continued).

		Head Rank		Recharge			Groundwater ET			Observed (calibration) values				
Cell	Name	Average Head (ft)	Rank	Power Function 1895-2006 rate (afy)	BCM 1970-2004 rate (afy)	δD (‰)	Rate (afy)	Standard deviation, *s*GW ET (afy)	Inverse standard deviation, 1/*s*GW ET (afy-1)	δD (‰)	Standard deviation (‰)	Confidence interval, *ci* (‰)	Inverse confidence interval, 1/*ci* (‰-1)	Weight (‰-1)
16	Spring Valley - North	6,000	14	13,300	12,800	-121	1,700	200	4.2E-03	-126	nc	--	--	0.1
17	Snake Valley - Northeast	4,420	1	3,200	3,900	-122	17,400	6,400	1.6E-04	-111	0.00	0.00	nc	0.5
18	Tippett Valley	5,790	10	12,400	13,800	-122	1,700	900	1.2E-03	-122	0.95	2.90	0.34	0.34
19	Long Valley	6,070	17	24,700	32,100	-123	1,200	1,700	5.7E-04	-129	2.12	26.95	0.04	0.1
20	Steptoe Valley - North	6,050	15	63,700	69,400	-123	56,900	16,300	6.1E-05	-128	3.30	2.94	0.34	0.34

Abbreviations: afy, acre-feet per year; BCM, Basin Characterization Model; ET, evapotranspiration; ft, feet; GW, groundwater; na, not available; nc, not calculable; ‰, permil.

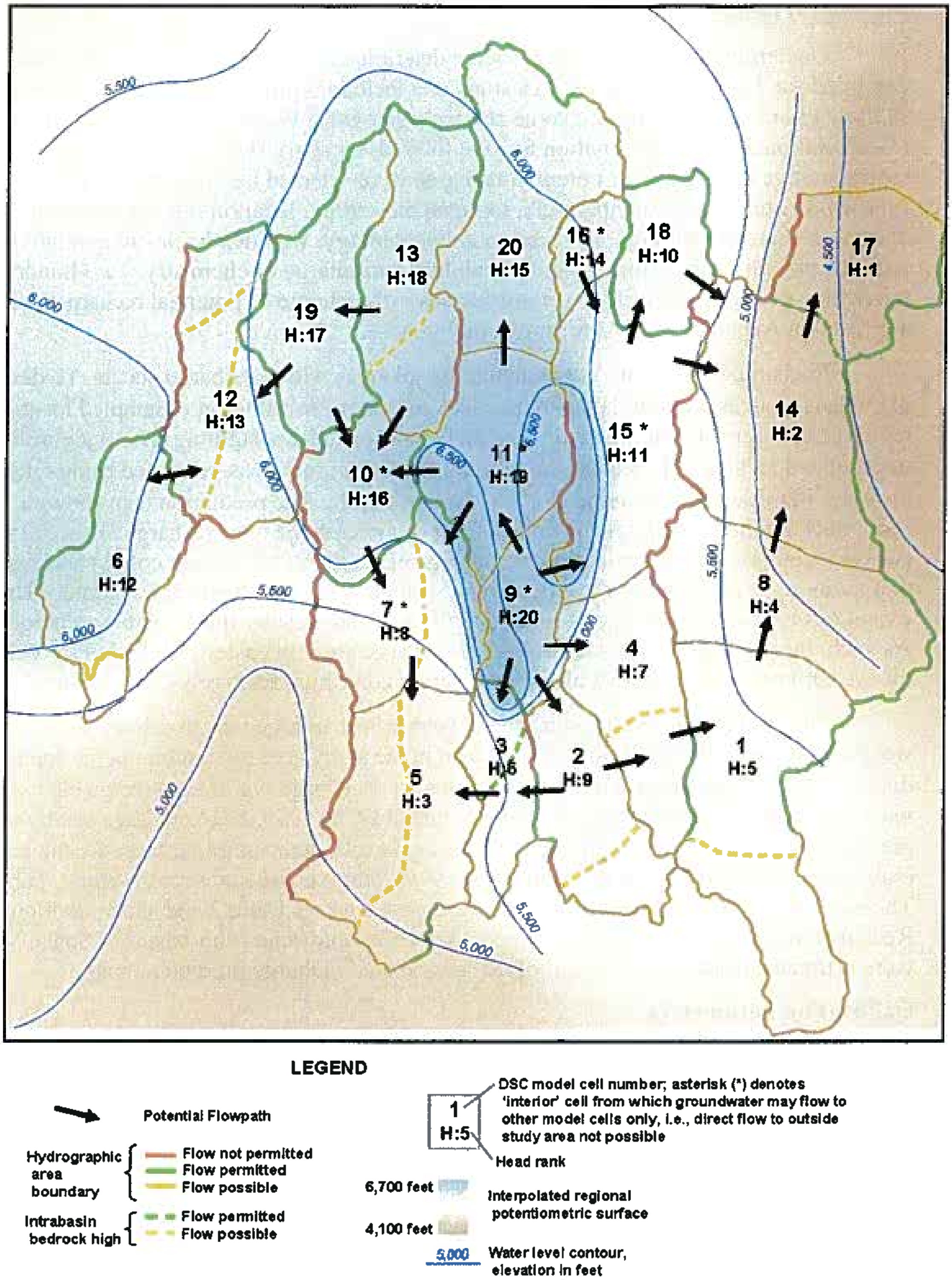


Figure 3. Regional potentiometric surface, hydrogeologic boundary classifications, and DSC model cell network and head ranks.

Recharge δ-Deuterium Values

Deuterium values for recharge were determined from a geochemistry database compiled for Task 6 of the BARCAS study and include samples collected from springs, shallow groundwater wells, and some surface water sites. Water data were queried from the USGS National Water Information System (NWIS) database (USGS, 2006). Sites representative of recharge or potential recharge were selected based on one or more of the following criteria: water temperature, topographic setting, location relative to recharge areas, discharge characteristics (springs), surrounding geology, well depth, elevation relative to regional potentiometric surface, and variability in discharge or chemistry. Two-hundred thirty nine sites were identified as representative of recharge or potential recharge; these sites are listed in Appendix A and are shown on Figure 4.

Recharge δD data are not available for all areas where recharge occurs. To determine δD values in areas without data and to calculate deuterium values at unsampled locations, the recharge data set was interpolated using an inverse distance weighting (IDW) algorithm. The interpolated recharge δD prediction map, shown in Figure 4, was generated using GIS and provides δD values for recharge at a 890-foot grid scale. The prediction map shows a pronounced trend in recharge δD values from isotopically heavier recharge δD in the south (warmer colors) to isotopically lighter recharge δD in the north (cooler colors) and suggests that at the scale of the study area, deuterium content is most influenced by latitude. The extent of the prediction map was limited to the east and west by the available recharge data. As such, the prediction map does not cover recharge areas in eastern Little Smoky Valley and the western portion of Snake Valley. These areas contribute relatively little recharge.

The final step in determining the δD value for recharge was to calculate a recharge-weighted average for each basin or sub-basin in the study area by combining the spatially-distributed BCM recharge and δD prediction map. Recharge-weighted average δD values were determined by multiplying the total potential BCM 1970-2004 recharge rate by the predicted recharge δD value for each 890-foot grid cell, then summing these for the entire (sub)basin, then dividing by the total BCM 1970-2004 recharge rate for the entire (sub)basin. The resulting recharge-weighted averages are presented on Table 2 and shown in Figure 4. Recharge-weighted averages for Little Smoky Valley and select sub-basins of Snake Valley were estimated based on the extent of the interpolated recharge prediction map.

Calibration Parameters

Observed δ-Deuterium Values

Observed δD values were also determined from the geochemical database compiled for Task 6 of the BARCAS study. Waters representative of regional or deep-intermediate groundwater were identified based on water temperature, surrounding geology, depth of the regional potentiometric surface, deuterium composition relative to nearby recharge, previous reports identifying regional and large springs of the Basin and Range province (Bedinger *et al.*, 1985; Harrill *et al.*, 1988), and results from a geochemical evaluation of dissolved gases within groundwater samples collected for the BARCAS study (Hershey *et al.*, 2007). Regional or deep-intermediate groundwater generally had temperatures greater than about 20° C. A total of 84 sites were identified as representative of regional / deep-intermediate groundwater (Appendix B). Regional/deep-intermediate groundwater sample locations are shown in Figure 5.

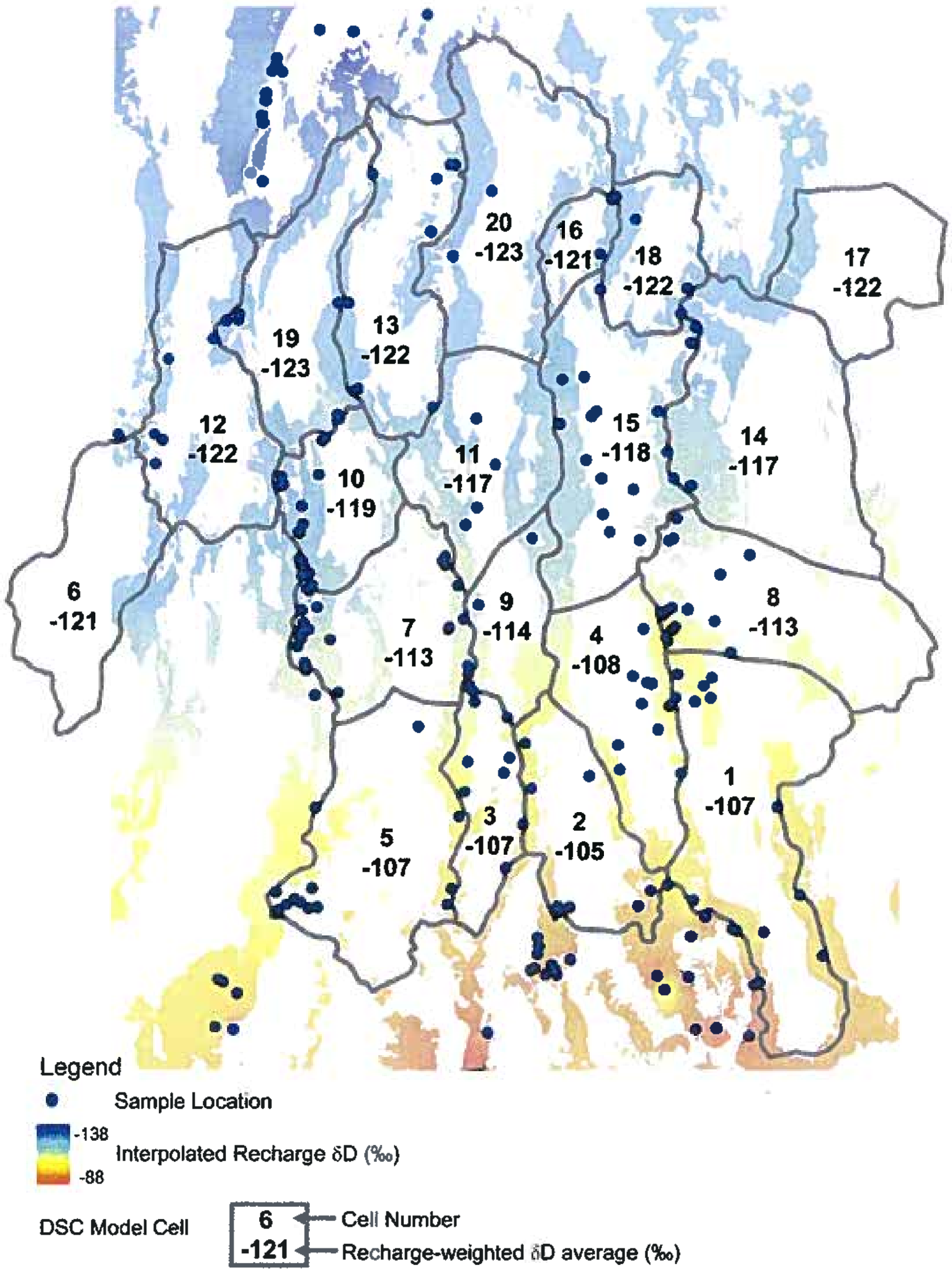


Figure 4. Recharge deuterium sample locations, inverse distance weighted (IDW) interpolated recharge deuterium values, and recharge-weighted basin average recharge deuterium values.

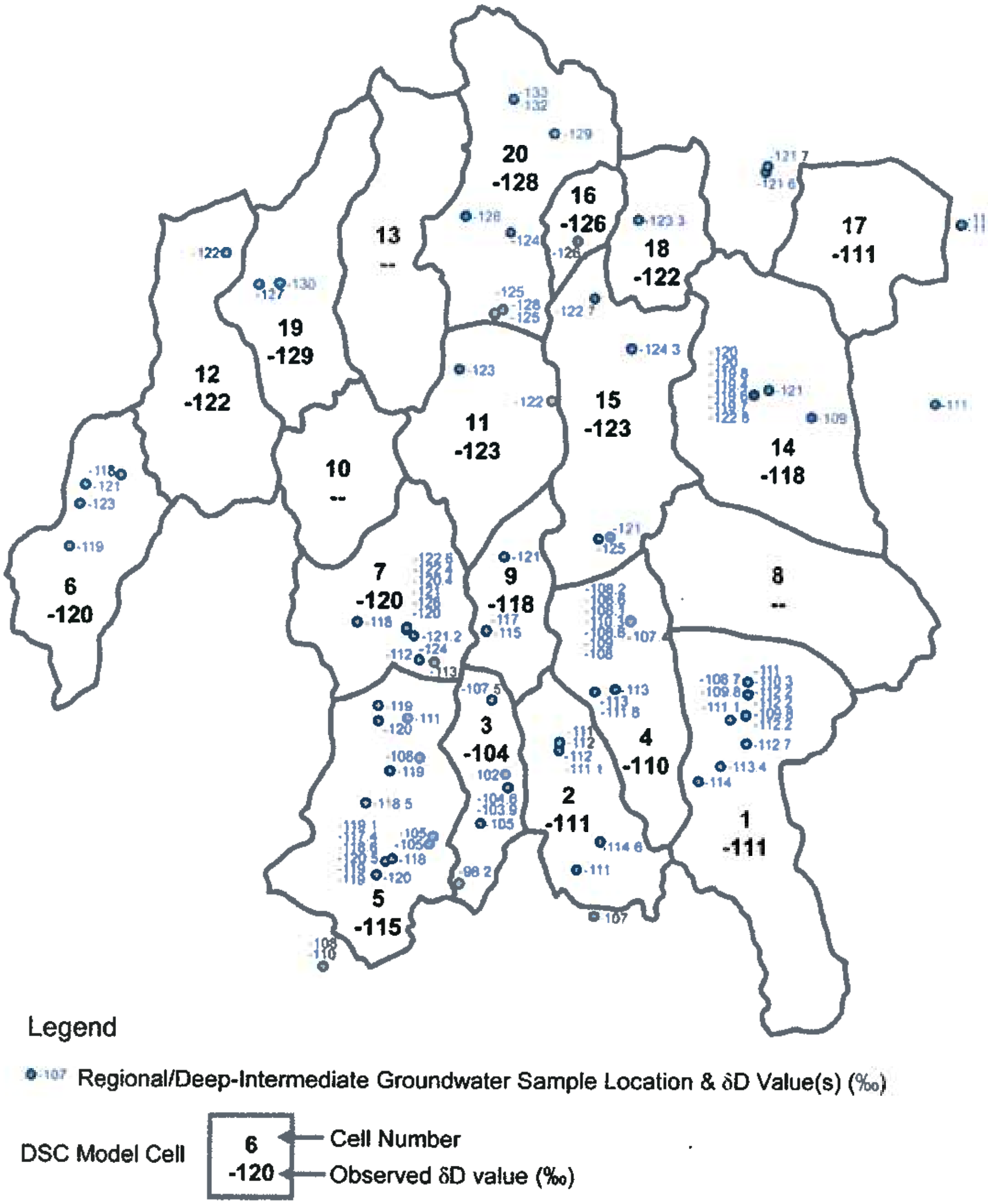


Figure 5. Regional/deep-intermediate groundwater deuterium sample locations and DSC model calibration (observed) deuterium values.

Observed δD values for each cell were determined by computing the average of all δD values for applicable sites (Figure 5). No appropriate δD data were identified for Butte Valley, Jakes Valley, and the central portion of Snake Valley; therefore, observed δD values were not calculable for the cells corresponding to these basins. Observed δD values for DSC model cells are presented in Table 2.

Observation Weights

During model optimization, the errors between observed and predicted δD values for each cell are incorporated into an overall objective function using weighting criteria. The weighting criteria account for differing uncertainty in observed δD values and for most model cells are calculated as:

$$w_{c_i} = \frac{1}{\left(t_{0.05,n_i-1} \frac{s_i}{\sqrt{n_i - 1}} \right)}$$

where w_{c_i} is the observed δD value weight for cell *i*, *n* is the number of regional / deep-intermediate-type groundwater samples associated with cell *i*, s_i is the standard deviation of observed values, and *t* is the Student t-statistic with $\alpha = 0.10$ and $df = n_i - 1$. The denominator for this weight function is analogous to one-half the 90-percent confidence interval about the observed mean, giving the δD weight units of ‰$^{-1}$.

This weight function effectively takes into account both the number and the variability of data points used for calculating the observed concentration values (Carroll and Pohll, in press) and assumes that the variance in the observed concentration for a given cell is independent from observed variance in other cells' concentrations. This approach is consistent with the approach described by Hill (1998), who suggests that weights should be proportional to the inverse of the variance-covariance matrix. The inverse variance gives greater weight to more accurately observed values and lower weight to less accurately observed values. The inverse variance also effectively normalizes observed values such that one can use different parameters in the objective function.

Observed δD value weights for DSC model cells are presented in Table 2. Observed value δD weights were calculated as described above with the following exceptions:

- Butte Valley, Jakes Valley, and the central portion of Snake Valley had no observed δD values; therefore, the weights for these cells were set to zero.
- Calculation of standard deviation and confidence interval for observed δD values was not possible for Newark Valley and the northern portion of Spring Valley because only one regional / deep-intermediate-type groundwater δD sample was identified for each of these cells ($n = 1$ sample). Observed δD value weights for these cells were assumed to be 0.1 ‰$^{-1}$ to reflect relatively low confidence in the associated observed δD values.
- Calculation of the inverse confidence interval was not possible for the northeastern portion of Snake Valley due to a zero standard deviation for the observed δD values for this cell ($n = 2$ samples). The observed δD value weights for the northeastern portion of Snake Valley was assumed to be 0.5 ‰$^{-1}$ to reflect an intermediate confidence in the associated observed δD value.

- The calculated inverse confidence interval for Long Valley (0.04 ‰$^{-1}$) was about two orders of magnitude less than inverse confidence intervals calculated for other cells. The observed δD value weight for Long Valley was assumed to be 0.1 ‰$^{-1}$ to reflect low confidence the observed δD value while keeping the error contribution from this cell to the overall objective function within the same order of magnitude as other cells in the model.

Groundwater Discharge Weights

For some model runs, optimization included a comparison of groundwater outflow from each cell to the groundwater ET rates calculated under the BARCAS Discharge Task (Welch and Bright, 2007). In these cases, the BARCAS groundwater ET rates represent hypothetical minima for outflow rates from cells in the model. Standard deviations associated with the groundwater ET estimates for each basin and sub-basin were also calculated under the Discharge Task (Zhu *et al.*, 2007). Groundwater ET rates and their associated standard deviations are shown in Table 2.

For cell outflows, weights were calculated as the inverse of the standard deviation of the groundwater ET rate (s_{GWET}):

$$w_{Q_i} = \frac{1}{s_{GWET}}$$

where w_{Q_i} is the groundwater ET rate weight with units of (acre-feet/year)$^{-1}$.

Objective Functions

Weighted root mean squared error (wRMSE) or variations thereof were used as objective functions for model optimization. To target δD values and discharge rates, the model was run using three optimization scenarios: C, O, and O*. Scenario C optimized the model based on target concentrations only. Scenarios O and O* both optimized the model based on target concentrations and groundwater ET rates. The O scenario penalized the model if a basin's discharge out of the model domain was less than the groundwater ET rate, while the O* scenario incorporated more rigorous constraints on discharge rates for cells in the interior of the model domain. The weight terms for both concentration and outflow are squared when used in the objective function(s) to become the dimensionally correct inverse variance term suggested by Hill (1998).

Each optimization scenario had a specific objective function. The optimization scenarios and associated objective functions are described below.

Optimization Scenario C

Under scenario C, the model was optimized based on concentration only. This approach is consistent with traditional applications of the DSC model. The objective function for scenario C is expressed as:

$$wRMSE_c = \left(\frac{\sum_{i=1}^{N} w_{c_i}^2 (Co_i - Cp_i)^2}{N} \right)^{0.5}$$

where Co_i and Cp_i are the observed and predicted concentrations in cell i, respectively, N is the number of cells being modeled, and w_{c_i} is the weight assigned to cell i for the observed concentration.

Optimization Scenario O

Model optimization scenario O included both concentration and outflow in the objective function. Scenario O penalized the model if a basin's discharge out of the model domain was less than the groundwater ET rate. The objective function for scenario O is modified as follows:

$$wRMSE_o = \left(\frac{\sum_{i=1}^{N} w_{c_i}^2 (Co_i - Cp_i)^2 + \sum_{i=1}^{N} \begin{cases} w_{Q_i}^2 (Q_{ET_i} - Q_{out_i})^2 ; \text{if } Q_{out} < Q_{ET} \\ 0 \qquad\qquad ; \text{if } Q_{out} \geq Q_{ET} \end{cases}}{2N} \right)^{0.5}$$

where Q_{ET_i} and Q_{out_i} are the groundwater ET rate from the BARCASS discharge task and the cell outflow predicted by the DSC model, respectively, and w_{Q_i} is the weight assigned to the groundwater ET rate.

*Optimization Scenario O**

Given the extent of the study area, the assumed DSC model cell connectivity, and/or the interpreted hydrogeologic boundaries, direct groundwater outflow out of the model domain is not possible for cells 4 (Spring Valley-South), 7 (White River Valley-North), 9 (Steptoe Valley-South), 10 (Jakes Valley), 11 (Steptoe Valley-Central), 15 (Spring Valley-Central), and 16 (Spring Valley-North) (Figure 3). For example, northern White River Valley is surrounded by other DSC model cells to the north, east and south and by a geologic structure to the west through which groundwater flow is not likely. For these cells, groundwater output from the model domain should only consist of groundwater ET. To deter excessive predicted outflow rates for these cells, the objective function was modified for scenario O*.

Model optimization scenario O* included both concentration and outflow in the objective function. Scenario O* incorporated more rigorous constraints on discharge rates for interior cells by penalizing the model for any difference between discharge out of the model domain and groundwater ET rates for basins in the interior of the model domain. Under this scenario, the objective function is expressed as:

$$wRMSE_o = \left(\frac{\sum_{i=1}^{nl} w_{c_i}^2 (Co_i - Cp_i)^2 + \sum_{i=1}^{N} \begin{cases} w_{Q_i}^2 (Q_{ET_i} - Q_{out_i})^2 & \text{if } Q_{out} < Q_{ET} \\ 0 & \text{if } Q_{out} \geq Q_{ET} \\ w_{Q_i}^2 (Q_{ET_i} - Q_{out_i})^2 & \text{if } Q_{out} \neq Q_{ET}, \text{int} \end{cases}}{2N} \right)^{0.5}$$

where different criteria apply to interior (int) model cells.

Uncertainty Analysis

To evaluate the effects of uncertainty of recharge rates and concentrations, a Monte Carlo uncertainty analysis was performed using the model inputs of the DSC model. Model uncertainty is also illustrated via the deterministic model results using different recharge estimates (1895-2006 Power Function and 1970-2004 BCM) and the different model optimization scenarios (scenarios C, O, and O*). A more rigorous evaluation of model uncertainty, including effects of uncertainty for recharge deuterium estimation methods and groundwater evapotranspiration rate and a more thorough evaluation of recharge rates and optimization approaches may be found in Lundmark (2007).

The uncertainty analysis was performed by random sampling from uniform distributions of potential recharge rates and δD values for each model cell for a given realization, then running the model to achieve the best fit for that realization. The process is then repeated with new random values selected for each cell's recharge rate and δD value. A total of 1,000 realizations were performed in this fashion.

Recharge rates were varied by keeping the amount of potential in-place recharge constant and adjusting the portion of runoff becoming recharge between 0 percent and 30 percent. Recharge δD values were varied by ± 1.5‰. This factor was selected based on the typical analytical variability of deuterium analyses (± 1‰) and the variability of δD values for groups of samples from within zones of high recharge rates. Uniform distributions were assumed for recharge rates and δD values based on insufficient data to support the selection of more specific distributions.

Target groundwater ET rates were kept constant in the Monte Carlo uncertainty analysis; therefore, uncertainty associated groundwater ET rate estimates are not incorporated in the uncertainty analysis. This may limit the predicted uncertainty bounds for interbasin flow estimates.

MODEL RESULTS

Model results are presented for deterministic model runs and stochastic (Monte Carlo) simulations. Deterministic model runs each include one set of model output, whereas the stochastic simulation includes 1,000 realizations of model output, or one set of output for each of the 1,000 realizations. DSC model output includes fractional and volumetric groundwater flow rates between model cells and out of the model domain that best satisfied the calibration criteria. Model output also includes predicted cell concentrations (δD values) and objective function values. Values calculated from model output include the component of groundwater flow out of the model domain for each model cell and net basin water budgets.

Deterministic Model Results

The DSC model was run using three optimization scenarios and two sets of recharge estimates, generating six sets of deterministic model results (Table 3). Comparisons between these sets of model results illustrate the effects of optimization criteria and recharge estimation method.

Table 3. DSC model deterministic results summary. (Volumetric rates are rounded to the nearest 100 acre-feet per year. C, O, and O* identify DSC model optimization scenarios.)

Observed and predicted δD values (‰)

			Power Function 1895-2006			BCM 1970-2004		
			C	O	O*	C	O	O*
Cell	Basin	Observed	Predicted			Predicted		
1	Snake V-S	-111	-108.8	-108.1	-108.2	-108.8	-108.3	-108.3
2	Lake V	-111	-111.1	-110.7	-110.4	-111.0	-110.6	-110.5
3	Cave V	-104	-107.0	-107.0	-107.0	-107.0	-107.0	-107.0
4	Spring V-S	-110	-109.9	-109.6	-109.6	-109.9	-109.6	-109.6
5	White River V-S	-115	-115.0	-115.4	-116.1	-115.0	-115.0	-116.0
6	Little Smoky V	-120	-121.0	-121.0	-121.0	-121.0	-121.0	-121.0
7	White River V-N	-120	-119.5	-118.9	-118.2	-119.5	-119.1	-118.5
8	Snake V-C	na	-109.6	-109.8	-109.8	-109.7	-109.8	-109.8
9	Steptoe V-S	-118	-114.0	-114.0	-114.0	-114.0	-114.0	-114.0
10	Jakes V	na	-121.7	-121.5	-120.5	-121.8	-121.7	-121.0
11	Steptoe V-C	-123	-117.0	-117.0	-117.0	-117.0	-117.0	-117.0
12	Newark V	-122	-121.9	-122.2	-122.2	-122.0	-122.0	-122.0
13	Butte V	na	-122.0	-122.0	-122.0	-122.0	-122.0	-122.0
14	Snake V-N	-118	-112.8	-113.2	-114.0	-112.8	-112.8	-113.5
15	Spring V-C	-123	-118.6	-118.5	-118.5	-118.5	-118.5	-118.5
16	Spring V-N	-126	-121.0	-121.0	-121.0	-121.0	-121.0	-121.0
17	Snake V-NE	-111	-112.9	-114.0	-114.5	-112.9	-113.3	-113.8
18	Tippett V	-122	-122.0	-122.0	-121.6	-122.0	-122.0	-121.7
19	Long V	-129	-123.0	-123.0	-123.0	-123.0	-123.0	-123.0
20	Steptoe V-N	-128	-123.0	-123.0	-123.0	-123.0	-123.0	-123.0

Cell-to-cell fluxes (acre-feet/year)

From		To		Power Function 1895-2006			BCM 1970-2004		
Cell	Basin	Cell	Basin	C	O	O*	C	O	O*
1	Snake V-S	8	Snake V-C	106,800	54,400	54,500	132,700	77,500	77,800
2	Lake V	3	Cave V	0	0	0	0	0	0
2	Lake V	4	Spring V-S	40,100	32,200	29,200	53,000	41,900	41,200
3	Cave V	5	White River V-S	10,800	9,300	9,300	11,400	13,500	14,000
4	Spring V-S	1	Snake V-S	65,200	33,000	33,000	83,600	49,300	49,400
6	Little Smoky V	12	Newark V	300	200	100	600	400	1,300
7	White River V-N	5	White River V-S	37,000	45,700	85,100	48,400	56,500	110,800
8	Snake V-C	14	Snake V-N	134,900	46,100	46,300	166,700	73,300	73,900

Table 3. DSC model deterministic results summary. (Volumetric rates are rounded to the nearest 100 acre-feet per year. C, O, and O* identify DSC model optimization scenarios.) (continued).

Cell-to-cell fluxes (acre-feet/year) (continued)

From		To		Power Function 1895-2006			BCM 1970-2004		
Cell	Basin	Cell	Basin	C	O	O*	C	O	O*
9	Steptoe V-S	2	Lake V	27,000	22,700	19,900	35,100	28,700	28,100
9	Steptoe V-S	3	Cave V	0	0	0	0	0	0
9	Steptoe V-S	4	Spring V-S	0	700	3,500	0	2,800	3,400
9	Steptoe V-S	11	Steptoe V-C	0	0	0	0	0	0
9	Steptoe V-S	15	Spring V-C	0	0	0	0	0	0
10	Jakes V	7	White River V-N	75,700	57,400	63,100	90,200	76,400	76,500
11	Steptoe V-C	7	White River V-N	0	0	8,200	0	0	13,300
11	Steptoe V-C	10	Jakes V	0	0	14,000	0	0	9,700
11	Steptoe V-C	20	Steptoe V-N	0	0	0	0	0	0
12	Newark V	6	Little Smoky V	0	0	0	0	0	0
13	Butte V	10	Jakes V	35,300	23,700	15,700	40,400	28,700	23,800
13	Butte V	19	Long V	0	0	0	0	0	0
14	Snake V-N	17	Snake V-NE	218,600	33,700	47,200	270,500	70,700	87,300
15	Spring V-C	14	Snake V-N	45,100	2,700	16,500	57,800	6,000	22,100
15	Spring V-C	18	Tippett V	0	100	1,700	0	0	1,200
16	Spring V-N	15	Spring V-C	13,300	11,600	11,600	12,800	11,100	11,100
18	Tippett V	14	Snake V-N	400	0	0	0	0	0
19	Long V	10	Jakes V	24,700	18,900	18,700	32,100	30,900	26,200
19	Long V	12	Newark V	0	4,600	4,800	0	0	1,600

Output from study area[1] (acre-feet/year)

		Power Function 1895-2006			BCM 1970-2004		
Cell	Basin	C	O	O*	C	O	O*
1	Snake V-S	100	20,300	20,200	0	20,900	20,700
2	Lake V	0	3,600	3,700	0	4,800	4,700
3	Cave V	100	1,600	1,600	4,200	2,100	1,600
4	Spring V-S	0	25,000	25,000	0	26,000	25,900
5	White River V-S	57,500	65,200	104,700	81,400	85,600	140,500
6	Little Smoky V	4,200	4,300	4,400	6,000	6,200	5,300
7	White River V-N	63,600	36,700	11,200	73,900	52,100	11,200
8	Snake V-C	0	36,500	36,300	100	38,400	38,100
9	Steptoe V-S	0	3,600	3,600	0	3,600	3,600
10	Jakes V	0	900	900	0	900	900
11	Steptoe V-C	63,300	63,300	41,200	64,100	64,100	41,100
12	Newark V	22,600	26,000	26,200	27,900	27,400	29,900
13	Butte V	0	11,600	19,600	0	11,700	16,600
14	Snake V-N	0	53,300	54,000	0	54,500	54,700
15	Spring V-C	22,900	63,500	48,100	15,000	65,000	47,700
16	Spring V-N	0	1,700	1,700	0	1,700	1,700
17	Snake V-NE	221,700	37,000	50,500	274,200	74,600	91,200
18	Tippett V	12,000	12,400	14,000	13,800	13,800	15,100
19	Long V	0	1,200	1,300	0	1,200	4,500
20	Steptoe V-N	63,700	63,700	63,700	69,400	69,400	69,400

Table 3. DSC model deterministic results summary. (Volumetric rates are rounded to the nearest 100 acre-feet per year. C, O, and O* identify DSC model optimization scenarios.) (continued).

Groundwater outflow from study area[2] (acre-feet/year)

		Power Function 1895-2006			BCM 1970-2004		
Cell	Basin	C	O	O*	C	O	O*
1	Snake V-S	-20,900	-700	-800	-21,000	-100	-300
2	Lake V	-6,100	-2,500	-2,400	-6,100	-1,300	-1,400
3	Cave V	-1,500	0	0	2,600	500	0
4	Spring V-S	-26,900	-1,900	-1,900	-26,900	-900	-1,000
5	White River V-S	-8,000	-300	39,200	15,900	20,100	75,000
6	Little Smoky V	200	300	400	2,000	2,200	1,300
7	White River V-N	52,400	25,500	0	62,700	40,900	0
8	Snake V-C	-39,000	-2,500	-2,700	-38,900	-600	-900
9	Steptoe V-S	-3,600	0	0	-3,600	0	0
10	Jakes V	-900	0	0	-900	0	0
11	Steptoe V-C	22,300	22,300	200	23,100	23,100	100
12	Newark V	-3,500	-100	100	1,800	1,300	3,800
13	Butte V	-11,900	-300	7,700	-11,900	-200	4,700
14	Snake V-N	-54,800	-1,500	-800	-54,800	-300	-100
15	Spring V-C	-24,100	16,500	1,100	-32,000	18,000	700
16	Spring V-N	-1,700	0	0	-1,700	0	0
17	Snake V-NE	204,300	19,600	33,100	256,800	57,200	73,800
18	Tippett V	10,300	10,700	12,300	12,100	12,100	13,400
19	Long V	-1,200	0	100	-1,200	0	3,300
20	Steptoe V-N	6,800	6,800	6,800	12,500	12,500	12,500

Objective function values (unitless)	Power Function 1895-2006			BCM 1970-2004		
	C	O	O*	C	O	O*
wRMSEc	0.854	0.964	0.978	0.850	0.926	0.936
wRMSEo	3.010	0.691	0.701	3.005	0.657	0.665
wRMSEo*	5.854	2.629	0.701	6.703	4.013	0.665

Net interbasin inflow (acre-feet/year)	Power Function 1895-2006			BCM 1970-2004		
	C	O	O*	C	O	O*
Butte V	--	--	--	--	--	--
Cave V	0	0	0	0	0	0
Jakes V	60,000	42,600	48,400	72,500	59,600	59,700
Lake V	27,000	22,700	19,900	35,100	28,700	28,100
Little Smoky V	0	0	0	0	0	0
Long V	0	0	0	0	0	0
Newark V	300	4,800	4,900	600	400	2,800
Snake V	110,700	35,700	49,500	141,400	55,300	71,500
Spring V	40,100	32,900	32,800	53,000	44,700	44,700
Steptoe V	--	--	--	--	--	--
Tippett V	0	100	1,700	0	0	1,200
White River V	86,500	66,800	80,600	101,600	90,000	103,900

Table 3. DSC model deterministic results summary. (Volumetric rates are rounded to the nearest 100 acre-feet per year. C, O, and O* identify DSC model optimization scenarios.) (continued).

Net interbasin outflow within study area (acre-feet/year)	Power Function 1895-2006			BCM 1970-2004		
	C	O	O*	C	O	O*
Butte V	35,300	23,700	15,700	40,400	28,700	23,800
Cave V	10,800	9,300	9,300	11,400	13,500	14,000
Jakes V	75,700	57,400	63,100	90,200	76,400	76,500
Lake V	40,100	32,200	29,200	53,000	41,900	41,200
Little Smoky V	300	200	100	600	400	1,300
Long V	24,700	23,500	23,500	32,100	30,900	27,700
Newark V	0	0	0	0	0	0
Snake V	--	--	--	--	--	--
Spring V	110,300	35,800	51,200	141,400	55,400	72,800
Steptoe V	27,000	23,500	45,600	35,100	31,600	54,600
Tippett V	400	0	0	0	0	0
White River V	--	--	--	--	--	--
Net interbasin outflow from study area (acre-feet/year)	Power Function 1895-2006			BCM 1970-2004		
	C	O	O*	C	O	O*
Butte V	-11,900	-300	7,700	-11,900	-200	4,700
Cave V	-1,500	0	0	2,600	500	0
Jakes V	-900	0	0	-900	0	0
Lake V	-6,100	-2,500	-2,400	-6,100	-1,300	-1,400
Little Smoky V	200	300	400	2,000	2,200	1,300
Long V	-1,200	0	100	-1,200	0	3,300
Newark V	-3,500	-100	100	1,800	1,300	3,800
Snake V	89,600	14,800	28,700	142,100	56,100	72,500
Spring V	-52,700	14,700	-800	-60,600	17,100	-300
Steptoe V	25,500	29,000	6,900	32,000	35,500	12,500
Tippett V	10,300	10,700	12,300	12,100	12,100	13,400
White River V	44,400	25,300	39,100	78,600	61,000	75,000

Abbreviations: BCM, Basin Characterization Model; C, central; N, north; na, not available; NE, northeast; S, south; V, valley; wRMSE, weighted root mean squared error; ‰, permil

[1] Output from study area includes groundwater evapotranspiration and groundwater outflow from the study area

[2] Calculated by subtracting groundwater evapotranspiration from total output from the study area

Predicted cell δD values were not a function of optimization criteria for six models cells: cell 3 (Cave Valley), cell 9 (Steptoe Valley-South), cell 11 (Steptoe Valley-Central), cell 16 (Spring Valley-North), cell 19 (Long Valley), and cell 20 (Steptoe Valley-North). For these cells, the differences (errors) between predicted and observed δD values range from -3‰ (Cave Valley) to +6‰ (Long Valley, Steptoe Valley - Central). For the remaining 14 model cells, predicted cell δD values were affected by optimization criteria and the absolute errors between predicted and observed δD values range from 0‰ (Newark Valley, Tippett Valley) to 5.2‰ (Snake Valley - North). The largest effect of optimization criteria on predicted δD values is for Snake Valley-North using Power Function 1895-2006 recharge rates, where the error between predicted and observed δD values ranges from 5.2‰ (scenario C) to 4.0‰ (scenario O*). The error between predicted and observed δD values usually increases from scenarios C to O to O*. As an indicator for overall goodness of predicted δD values, wRMSEc objective functions range from 0.854 to 0.964 for Power Function 1895-

2006 recharge rates and from 0.850 to 0.936 for BCM 1970-20004 recharge rates, suggesting that the three optimization scenarios yield reasonably similar predicted δD values.

Under scenario C, predicted rates of groundwater outflow (combination of groundwater flow out of the study area and discharge as groundwater ET) appeared significantly lower than the estimated groundwater ET rates for selected basins (Table 3). For both Power Function 1895-2006 and BCM 1970-2004 recharge rates, the DSC model predicted 100 acre-feet per year or less outflow for 10 of the 20 model cells under optimization scenario C, implying that groundwater outputs for these basins are entirely interbasin groundwater outflow and that no groundwater ET discharge occurs. Conversely, under scenario C the DSC model predicted outflow rates for Steptoe Valley-Central (cell 11) and White River Valley-North (cell 7) sub-basins which are significantly greater than the groundwater ET discharge estimates for these sub-basins which have no outlet for interbasin groundwater outflow to outside the study area given the assumed cell configuration and hydrogeologic boundaries of the sub-basins.

To deter model-predicted outflow rates which were significantly less than the groundwater ET discharge estimates, the objective function was modified to include both concentration and outflow criteria for scenario O. Under this scenario, an iteration was penalized if a cell's outflow rate was less than the estimated groundwater ET rate. Predicted outflow rates under optimization scenario O compare more favorably with the estimated groundwater ET rates, with rates for outflow from the model domain being greater than or equal to net basin groundwater ET rates for most model cells (Table 3). On a net-basin basis, Lake Valley and Spring Valley are the only basins for which output from the model domain was less than the groundwater ET rate (Table 4). Outflow rates which are significantly greater than groundwater ET discharge rates are predicted under optimization scenario O for the internal model cells Steptoe Valley-Central, White River Valley-North, and Spring Valley-Central.

Direct interbasin groundwater outflow out of the model domain is not possible for Jakes Valley, White River Valley-North, Steptoe Valley-Central, Steptoe Valley-South, Spring Valley –North, Spring Valley-Central, and Spring Valley-South (Figure 3). For these cells, predicted outflow from the model domain should represent only discharge as groundwater ET. To deter predicted outflow rates from significantly exceeding groundwater ET discharge estimates for interior cells, the scenario O*objective function penalized the model if interior cells' outflow rates were greater than or less than the estimated groundwater ET rates. Other cells were assessed using the same criteria as scenario O. Model results shown in Table 3 suggest that optimization scenario O* was successful at reducing predicted outflow rates for interior model cells. *Scenario O* was identified as the preferred optimization scenario given its most realistic distribution of outflows from the model domain and the adequacy of the associated predicted δD values.*

A summary of interbasin groundwater flow rates under optimization scenario O* are shown on Figure 6 for Power Function 1895-2006 recharge rates and Figure 7 for BCM 1970-2004 recharge rates. A comparison between wRMSEc and wRMSEo* values between the scenario O* results for the Power Function 1895-2006 and BCM 1970-2004 model runs (Table 3) suggest that the BCM 1970-2004 recharge rates yielded a slightly better fit for predicted δD values (based on a lower wRMSEc) and a better overall fit (based on a lower wRMSEo*).

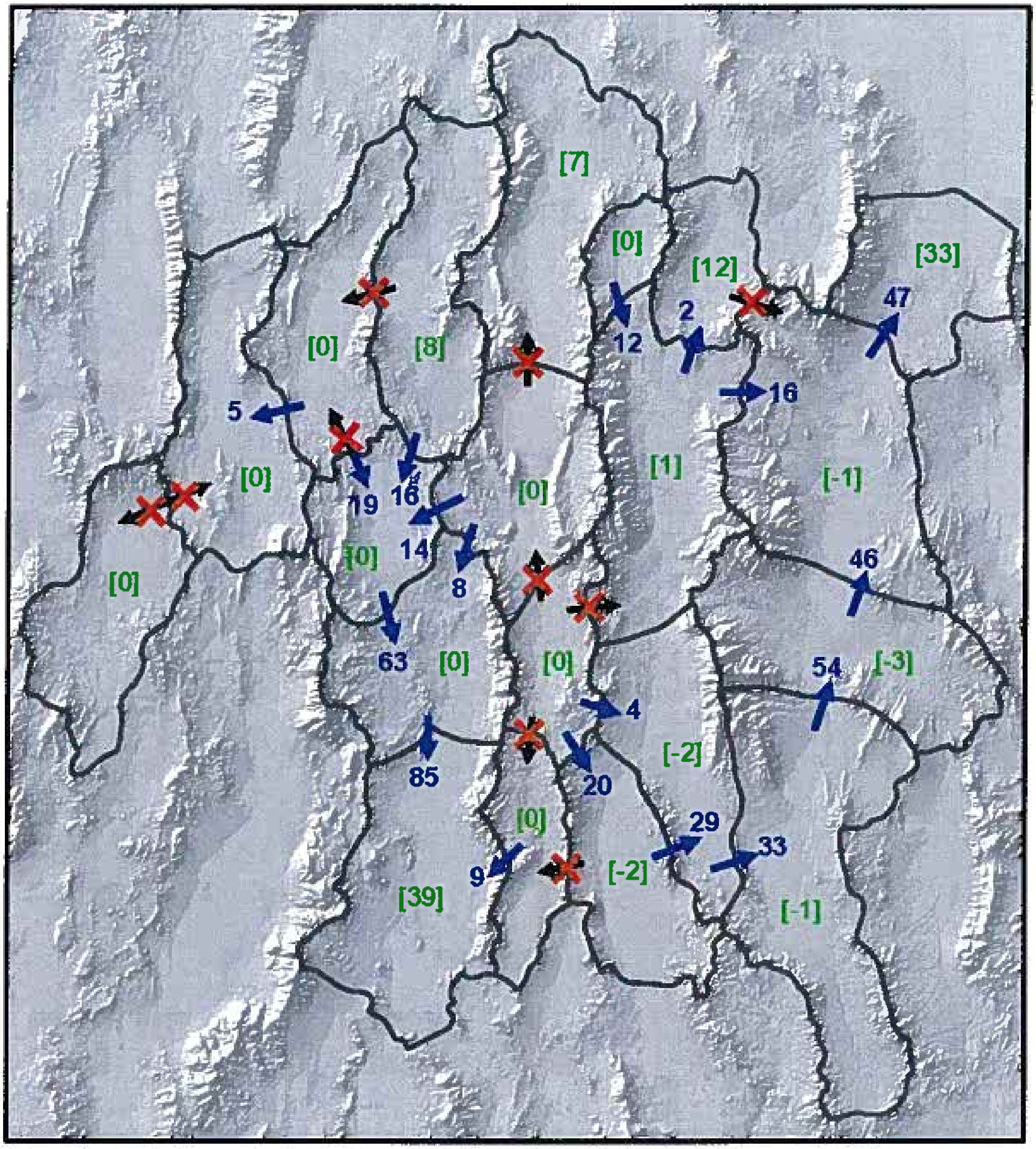
Table 4. BARCAS water budget and DSC model summary. (All values are acre-feet/year, rounded to the nearest 100 acre-feet/year. Results are from the O* optimization scenario using either Power Function 1895-2006 or BCM 1970-2004 recharge values.)

	Inputs				Outputs				Components of Output from Study Area		
	Total Recharge		Interbasin Groundwater Inflow		Interbasin GW Outflow (within study area)		Output from Study Area [1]			Interbasin GW Outflow (out of study area) [2]	
Basin	Power Function 1895-2006	BCM 1970-2004	Power Function 1895-2006	BCM 1970-2004	Power Function 1895-2006	BCM 1970-2004	Power Function 1895-2006	BCM 1970-2004	GW ET	Power Function 1895-2006	BCM 1970-2004
Butte Valley	35,300	40,400	--	--	15,700	23,800	19,600	16,600	11,900	7,700	4,700
Cave Valley	10,900	15,600	0	0	9,300	14,000	1,600	1,600	1,600	0	0
Jakes Valley	15,700	17,700	48,400	59,700	63,100	76,500	900	900	900	0	0
Lake Valley	13,100	17,900	19,900	28,100	29,200	41,200	3,700	4,700	6,100	-2,400	-1,400
Little Smoky Valley	4,500	6,600	0	0	100	1,300	4,400	5,300	4,000	400	1,300
Long Valley	24,700	32,100	0	0	23,500	27,700	1,300	4,500	1,200	100	3,300
Newark Valley	21,200	27,000	4,900	2,800	0	0	26,200	29,900	26,100	100	3,800
Snake Valley	111,300	133,100	49,500	71,500	--	--	160,900	204,700	132,200	28,700	72,500
Spring Valley	93,100	103,400	32,800	44,700	51,200	72,800	74,800	75,300	75,600	-800	-300
Steptoe Valley	154,000	168,600	--	--	45,600	54,600	108,400	114,000	101,500	6,900	12,500
Tippett Valley	12,400	13,800	1,700	1,200	0	0	14,000	15,100	1,700	12,300	13,400
White River Valley	35,300	47,800	80,600	103,900	--	--	115,800	151,700	76,700	39,100	75,000

Abbreviations: BCM, Basin Characterization Model; ET, evapotranspiration; GW, groundwater

[1] Output from study area includes GW ET and groundwater outflow from the study area

[2] Calculated by subtracting basin GW ET from total basin output from the study; a negative value indicates GW ET rate not satisfied by model-predicted output from the study area.



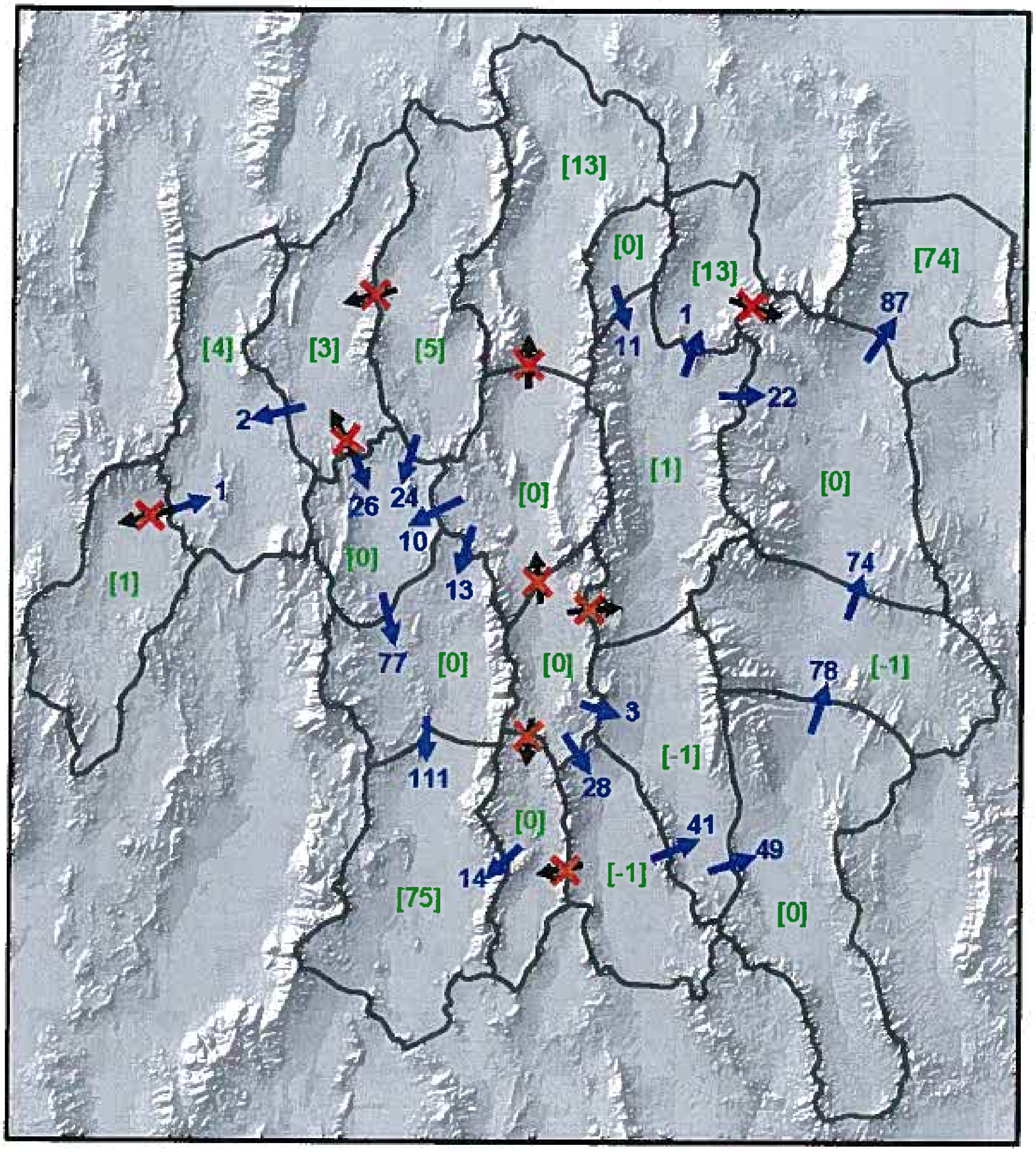
LEGEND

4 Model-predicted flow, x1,000 acre-feet per year

No flow or less than 500 acre-feet per year flow predicted by model

[8] Groundwater outflow from model domain, x1,000 acre-feet per year, calculated by subtracting groundwater ET from model-predicted net output from model domain; negative value indicates groundwater ET rate not satisfied by model-predicted output from model domain

Figure 6. Summary of BARCAS DSC model intrabasin and interbasin groundwater flow rates using long-term (1895-2006) recharge rates.



LEGEND

4 Model-predicted flow, x1,000 acre-feet per year

No flow or less than 500 acre-feet per year flow predicted by model

[8] Groundwater outflow from model domain, x1,000 acre-feet per year, calculated by subtracting groundwater ET from model-predicted net output from model domain; negative value indicates groundwater ET rate not satisfied by model-predicted output from model domain

Figure 7. Summary of BARCAS DSC model intrabasin and interbasin groundwater flow rates using recent (1970-2004) recharge rates.

Monte Carlo Uncertainty Analysis

The results for the Monte Carlo uncertainty analysis are presented in Tables 5 and 6. Each realization generated a set of interbasin groundwater flows and outflows for the model cells. For each cell, the 1,000 simulated interbasin inflows, interbasin outflows, and outflows from the model domain were sorted in ascending order. The 26th and 975th values from the sorted results were identified as the lower confidence limit (LCL) and upper confidence limit (UCL) for the 95-percent confidence interval, respectively. Similar calculations were performed to yield 95-percent confidence intervals for net basin interbasin inflow and outflow for Snake Valley, Spring Valley, Steptoe Valley, and White River Valley, which are each composed of multiple model cells. The error bars on Figures 8 and 9 display the 95-percent confidence intervals for interbasin inflow and outflow for the study area basins.

As expected, the deterministic values from the DSC model fell within the 95-percent confidence intervals for all water budget components of all basins. The differences between UCL and LCL values for interbasin groundwater inflow rates were greater than 20,000 acre-feet/year for Jakes Valley, Long Valley, Snake Valley, Tippett Valley, and White River Valley. Jakes Valley, Long Valley and Spring Valley had a difference of greater than 20,000 acre-feet/year between UCL and LCL values for interbasin groundwater outflow, while Snake Valley, Tippett Valley, and White River Valley each had ranges of outflow from the study area of 24,000 acre-feet/year or more. The results of the Monte Carlo uncertainty analysis suggest that Snake Valley is the basin which exhibits the greatest uncertainty in water budget components.

Table 5. DSC model Monte Carlo uncertainty analysis results summary. (Volumetric rates are rounded to the nearest 100 acre-feet per year.)

Cell-to-cell fluxes (acre-feet/year)

From		To			95% Confidence Interval	
Cell	Basin	Cell	Basin	Deteministic	Lower	Upper
1	Snake V-S	8	Snake V-C	54,500	47,300	62,400
2	Lake V	3	Cave V	0	0	0
2	Lake V	4	Spring V-S	29,200	20,500	35,700
3	Cave V	5	White River V-S	9,300	8,400	10,100
4	Spring V-S	1	Snake V-S	33,000	27,800	38,500
6	Little Smoky V	12	Newark V	100	0	500
7	White River V-N	5	White River V-S	85,100	71,800	96,600
8	Snake V-C	14	Snake V-N	46,300	37,900	55,200
9	Steptoe V-S	2	Lake V	19,900	12,700	24,500
9	Steptoe V-S	3	Cave V	0	0	0
9	Steptoe V-S	4	Spring V-S	3,500	0	11,000
9	Steptoe V-S	11	Steptoe V-C	0	0	0
9	Steptoe V-S	15	Spring V-C	0	0	0
10	Jakes V	7	White River V-N	63,100	46,100	70,100
11	Steptoe V-C	7	White River V-N	8,200	4,800	20,800
11	Steptoe V-C	10	Jakes V	14,000	2,800	17,100
11	Steptoe V-C	20	Steptoe V-N	0	0	0
12	Newark V	6	Little Smoky V	0	0	6,100

Table 5. DSC model Monte Carlo uncertainty analysis results summary. (Volumetric rates are rounded to the nearest 100 acre-feet per year.) (continued)

Cell-to-cell fluxes (acre-feet/year) (continued)

From		To			95% Confidence Interval	
Cell	Basin	Cell	Basin	Deterministic	Lower	Upper
13	Butte V	10	Jakes V	15,700	200	24,300
13	Butte V	19	Long V	0	0	20,300
14	Snake V-N	17	Snake V-NE	47,200	27,200	59,800
15	Spring V-C	14	Snake V-N	16,500	0	25,900
15	Spring V-C	18	Tippett V	1,700	0	23,600
16	Spring V-N	15	Spring V-C	11,600	10,800	12,600
18	Tippett V	14	Snake V-N	0	0	0
19	Long V	10	Jakes V	18,700	8,700	30,700
19	Long V	12	Newark V	4,800	3,300	17,500

Discharge from study area[1] (acre-feet/year)

			95% Confidence Interval	
Cell	Basin	Deterministic	Lower	Upper
1	Snake V-S	20,200	19,700	20,700
2	Lake V	3,700	2,400	4,800
3	Cave V	1,600	1,600	1,600
4	Spring V-S	25,000	23,800	25,900
5	White River V-S	104,700	90,900	116,100
6	Little Smoky V	4,400	4,000	10,200
7	White River V-N	11,200	11,200	11,200
8	Snake V-C	36,300	34,500	37,900
9	Steptoe V-S	3,600	3,600	3,600
10	Jakes V	900	900	900
11	Steptoe V-C	41,200	41,000	41,200
12	Newark V	26,200	25,900	37,700
13	Butte V	19,600	11,500	27,000
14	Snake V-N	54,000	52,700	54,500
15	Spring V-C	48,100	47,000	48,600
16	Spring V-N	1,700	1,700	1,700
17	Snake V-NE	50,500	29,500	63,100
18	Tippett V	14,000	11,600	36,100
19	Long V	1,300	1,200	11,600
20	Steptoe V-N	63,700	59,500	67,900

Groundwater outflow from study area[2] (acre-feet/year)

			95% Confidence Interval	
Cell	Basin	Deterministic	Lower	Upper
1	Snake V-S	-800	-1,300	-300
2	Lake V	-2,400	-3,700	-1,300
3	Cave V	0	0	0
4	Spring V-S	-1,900	-3,100	-1,000
5	White River V-S	39,200	25,400	50,600
6	Little Smoky V	400	0	6,200
7	White River V-N	0	-100	0
8	Snake V-C	-2,700	-4,500	-1,100
9	Steptoe V-S	0	0	0
10	Jakes V	0	0	0

Table 5. DSC model Monte Carlo uncertainty analysis results summary. (Volumetric rates are rounded to the nearest 100 acre-feet per year.) (continued).

Groundwater outflow from study area[2] (acre-feet/year) (continued)

Cell	Basin	Deterministic	95% Confidence Interval Lower	95% Confidence Interval Upper
11	Steptoe V-C	200	0	200
12	Newark V	100	-200	11,600
13	Butte V	7,700	-400	15,100
14	Snake V-N	-800	-2,100	-300
15	Spring V-C	1,100	-100	1,600
16	Spring V-N	0	0	0
17	Snake V-NE	33,100	12,100	45,700
18	Tippett V	12,300	9,900	34,400
19	Long V	100	0	10,400
20	Steptoe V-N	6,800	2,600	11,000

Objective function values	Deterministic	95% Confidence Interval Lower	95% Confidence Interval Upper
wRMSEo*	0.70	0.62	0.82

Net interbasin inflow (acre-feet/year)

Basin	Deterministic	95% Confidence Interval Lower	95% Confidence Interval Upper
Butte V	--	--	--
Cave V	-	0	0
Jakes V	48,400	31,100	55,400
Lake V	19,900	12,700	24,500
Little Smoky V	-	0	6,100
Long V	-	0	20,300
Newark V	4,900	3,400	17,700
Snake V	49,500	30,900	60,200
Spring V	32,800	29,600	36,200
Steptoe V	--	--	--
Tippett V	1,700	0	23,600
White River V	80,600	67,400	91,600

Net interbasin outflow within study area (acre-feet/year)

Basin	Deterministic	95% Confidence Interval Lower	95% Confidence Interval Upper
Butte V	15,700	8,500	25,200
Cave V	9,300	8,400	10,100
Jakes V	63,100	46,100	70,100
Lake V	29,200	20,500	35,700
Little Smoky V	100	0	500
Long V	23,500	15,200	40,600
Newark V	--	0	6,100
Snake V	--	--	--
Spring V	51,200	41,700	62,600
Steptoe V	45,600	40,600	50,500
Tippett V	--	0	0
White River V	--	--	--

Table 5. DSC model Monte Carlo uncertainty analysis results summary. (Volumetric rates are rounded to the nearest 100 acre-feet per year.) (continued).

Net output from study area[1] (acre-feet/year)		95% Confidence Interval	
Basin	Deterministic	Lower	Upper
Butte V	19,600	11,500	27,000
Cave V	1,600	1,600	1,600
Jakes V	900	900	900
Lake V	3,700	2,400	4,800
Little Smoky V	4,400	4,000	10,200
Long V	1,300	1,200	11,600
Newark V	26,200	25,900	37,700
Snake V	160,900	138,300	174,100
Spring V	74,800	73,100	75,800
Steptoe V	108,400	104,200	112,500
Tippett V	14,000	11,600	36,100
White River V	115,800	102,100	127,300

Abbreviations: BCM, Basin Characterization Model; C, central; N, north; na, not available; NE, northeast; S, south; V, valley; wRMSE, weighted root mean squared error; ‰, permil

[1] Output from study area includes GW ET and groundwater outflow from the study area

DISCUSSION

The DSC model developed and applied to the BARCAS study area produces a balanced water budget which includes groundwater recharge, groundwater ET discharge, and interbasin groundwater flow components. The study area water budget was evaluated through the mass-balance modeling of a conservative tracer (deuterium). Interbasin flow locations and rate ranges were determined by varying the optimization criteria of the model to allow for increasing constraint on discharge predictions. Results from optimization scenario O* appear to be most realistic given the unrealistic discharge (ET) rates and interbasin flow rates for some basins under scenarios C and O, as described in the results section. The DSC model was completed using recharge rates representative of long-term average conditions and of more recent conditions by using the Power Function 1895-2006 and BCM 1970-2004 recharge rates, respectively.

Interbasin groundwater inflow and outflow rates calculated by the DSC model using Power Function 1895-2006 recharge rates along with interbasin flow rates from previous studies are presented in Figure 8 (inflow) and Figure 9 (outflow). Results from the Monte Carlo uncertainty analysis are shown in Figures 8 and 9 as error bars on the inflow and outflow rates. Groundwater inflow rates calculated from the DSC model for the BARCAS study were generally higher than estimates from previous studies, with inflow rates for Jakes Valley, Lake Valley, Snake Valley, Spring Valley, and White River Valley being much higher than the previous studies' estimates. Groundwater outflow rates calculated from the DSC model are generally comparable to estimates from previous studies with the exception of Spring Valley and Steptoe Valley, where the DSC model predicted much higher rates than previous studies. These higher outflow rates are reasonable given that the BCM recharge predictions developed for BARCAS study for Snake Valley, Spring Valley, Steptoe Valley, and Tippett Valley are greater than or equal to the upper range of previous recharge estimates (Welch and Bright, 2007).

Table 6. BARCAS basin water budgets based on Monte Carlo uncertainty analysis results. (All values are acre-feet/year, rounded to the nearest 100 acre-feet/year. Model results reflect O* optimization scenario.)

	Inputs				Outputs				Components of Output from Study Area		
	Power Function 1895-2006 Recharge Range[1]		Interbasin GW Inflow 95% Confidence Interval		Interbasin GW Outflow (within study area) 95% Confidence Interval		Output from Study Area[2] 95% Confidence Interval		GW	Interbasin GW Outflow (out of study area)[3] 95% Confidence Interval	
Basin	Low	High	Lower	Upper	Lower	Upper	Lower	Upper	ET	Lower	Upper
Butte Valley	33,400	37,300	--	--	8,500	25,200	11,500	27,000	11,900	-400	15,100
Cave Valley	10,000	11,700	0	0	8,400	10,100	1,600	1,600	1,600	0	0
Jakes Valley	14,800	16,500	31,100	55,400	46,100	70,100	900	900	900	0	0
Lake Valley	10,300	15,900	12,700	24,500	20,500	35,700	2,400	4,800	6,100	-3,700	-1,300
Little Smoky Valley	4,200	4,700	0	6,100	0	500	4,000	10,200	4,000	0	6,200
Long Valley	23,500	25,800	0	20,300	15,200	40,600	1,200	11,600	1,200	0	10,400
Newark Valley	19,500	22,900	3,400	17,700	0	6,100	25,900	37,700	26,100	-200	11,600
Snake Valley	94,100	128,500	30,900	60,200	--	--	138,300	174,100	132,200	6,100	41,900
Spring Valley	79,500	106,800	29,600	36,200	41,700	62,600	73,100	75,800	75,600	-2,500	200
Steptoe Valley	143,600	164,500	--	--	40,600	50,500	104,200	112,500	101,500	2,700	11,000
Tippett Valley	11,500	13,200	0	23,600	0	0	11,600	36,100	1,700	9,900	34,400
White River Valley	32,800	37,600	67,400	91,600	--	--	102,100	127,300	76,700	25,400	50,600

Abbreviations: ET, evapotranspiration; GW, groundwater

[1] Recharge range calculated as in-place recharge plus 0% runoff (low value) or 30% runoff (high value)

[2] Output from study area includes GW ET and GW outflow from the study area

[3] Calculated by subtracting basin GW ET from total basin output from the study; a negative value indicates GW ET rate not satisfied by model-predicted output from the study area.

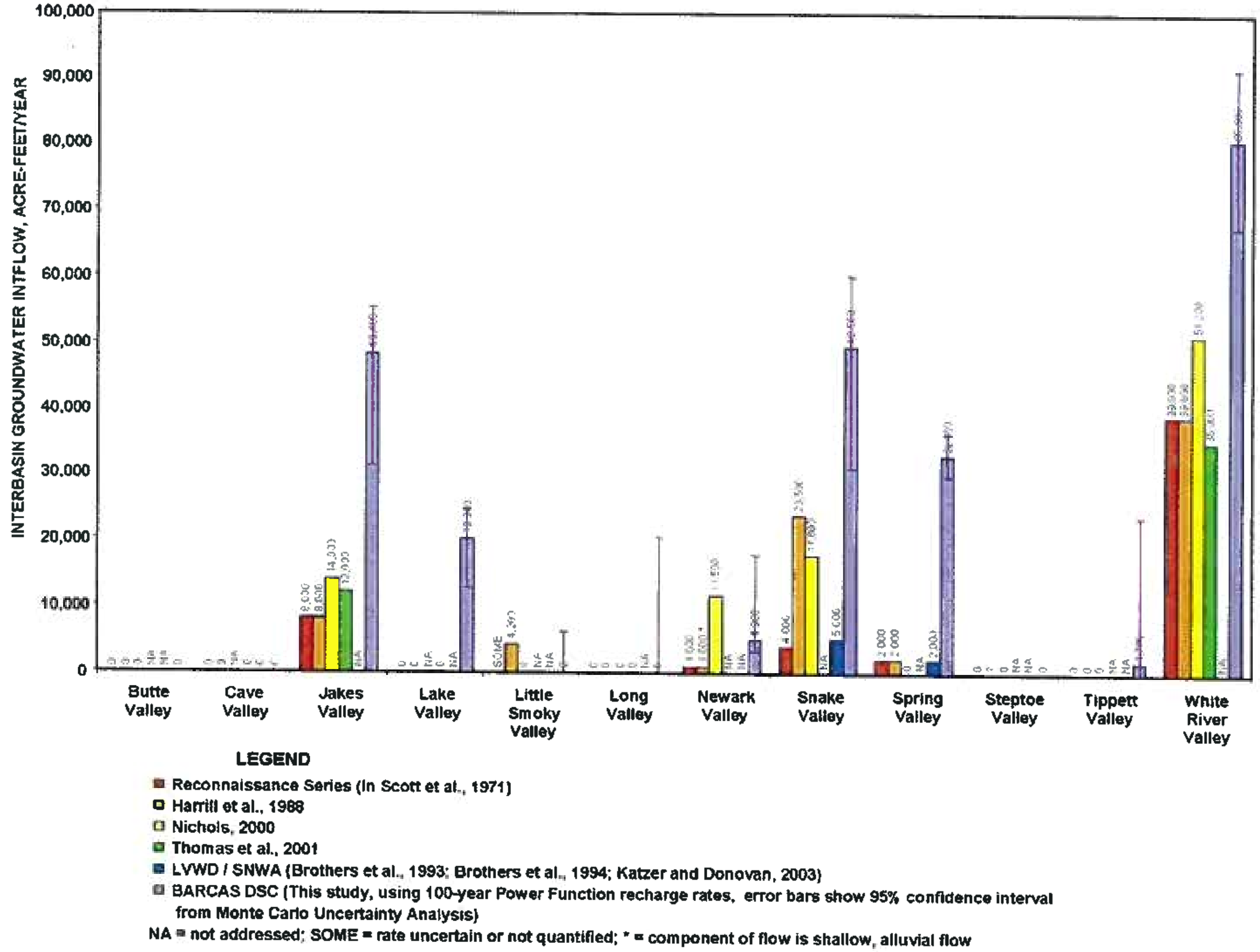


Figure 8. Summary of interbasin groundwater inflow rates for BARCAS and previous studies.

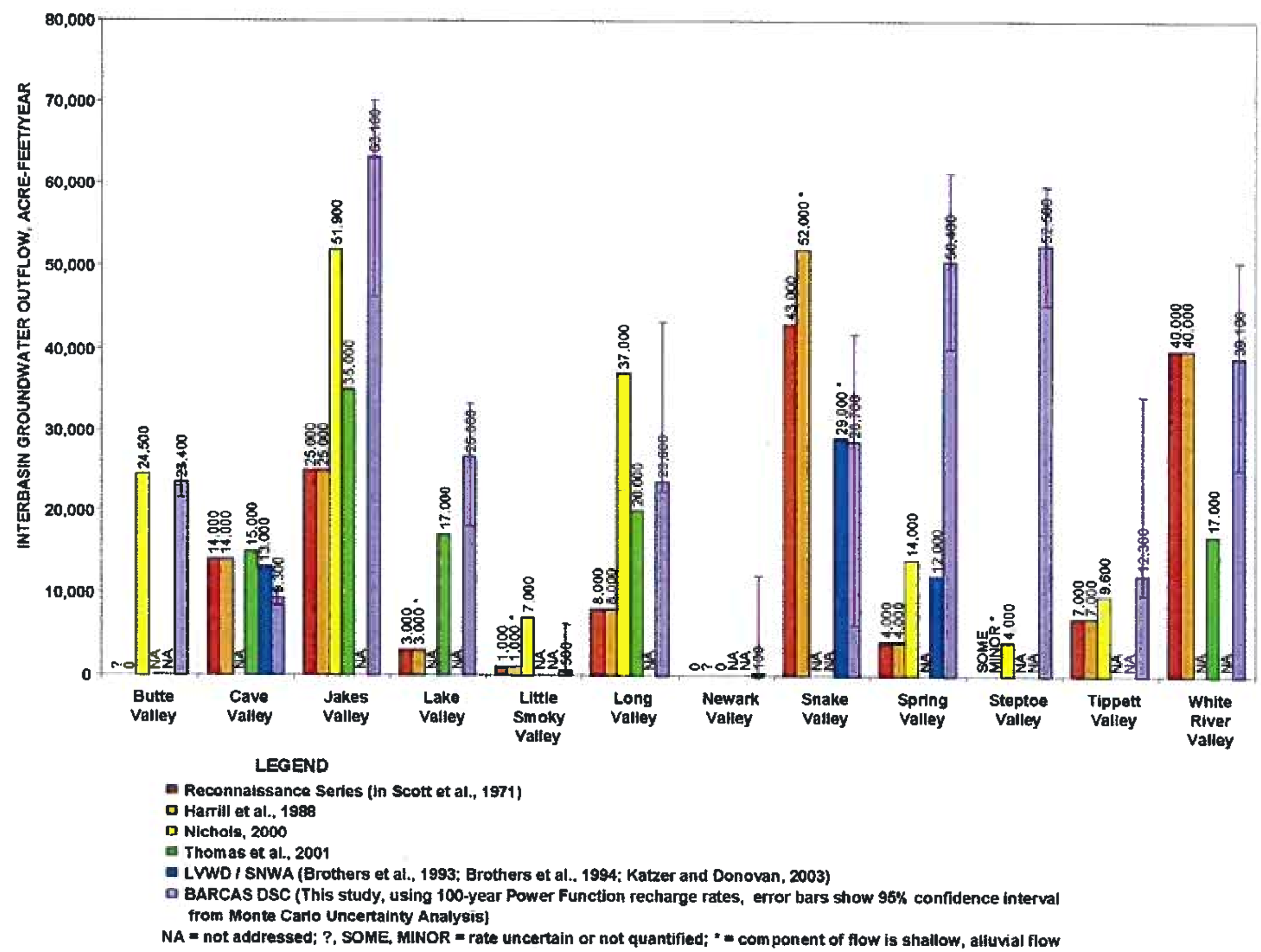


Figure 9. Summary of interbasin groundwater outflow rates for BARCAS and previous studies.

Results from the DSC model suggest that multi-basin groundwater flow systems discharge from the southern portion of White River Valley and the northeast portion of Snake Valley, the sub-basins having lowest average potentiometric surfaces within the study area. The flow system comprising Butte Valley, Long Valley, Jakes Valley, Steptoe Valley, Cave Valley, and White River Valley and discharging from the southern portion of White River Valley is consistent with the White River Regional Flow System, which has been described previously (Eakin, 1966, Kirk and Campana, 1990, Thomas *et al.*, 2001), with the exception of Butte Valley and Steptoe Valley which have not been included previously. The system comprising the southern portion of Steptoe Valley, Lake Valley, Spring Valley, and Snake Valley includes components that have been described previously (*e.g.*, flow from the southern portion of Spring Valley into Snake Valley as described by Hood and Rush [1965] and Harrill *et al.* [1988]) as well as new potential flowpaths, notably flow from the southern portion of Steptoe Valley into Lake Valley and Spring Valley and flow from Lake Valley into Spring Valley.

The southern portion of Steptoe Valley is an important area because it has the highest average potentiometric surface within the study area, receives 27,000 acre-feet/year groundwater recharge, and has a relatively low estimated groundwater ET discharge rate of less than 4,000 acre-feet/year, resulting in about 23,000 acre-feet/year of excess groundwater input which must be accounted for as interbasin groundwater outflow. Based on the available δD data for Steptoe Valley, groundwater from the southern portion of Steptoe Valley (recharge δD = -114 ‰) does not appear to travel as intrabasin flow to the central portion of Steptoe Valley where δD values for recharge (δD = -117 ‰) and the observed δD value for the cell (δD = -123 ‰) are both isoptopically lighter. Groundwater recharge occurring in the southern portion of Steptoe Valley may travel south and east as interbasin flow to Lake Valley and the southern portion of Spring Valley, where the observed δD values (-111 ‰ and -110 ‰, respectively) are isotopically lighter than the intrabasin recharge occurring to these (sub)basins (-105 ‰ and -108 ‰, respectively). A similar condition exists within central Steptoe Valley, where recharge exceeds groundwater ET discharge by greater than 22,000 acre-feet/year and this relatively large surplus of recharge does not appear to move north within Steptoe Valley based on the available deuterium data. Other model cells with a surplus of greater than 20,000 acre-feet/year recharge include Butte Valley, Long Valley, Snake Valley-South, and White River – North.

Rates of groundwater discharge from the study area as interbasin flow, calculated as the total outflow from the model domain minus the groundwater ET rate, were constrained for interior model cells under optimization scenario O*. While the elevated rates of interbasin outflow from the study area for interior cells under optimization scenarios C and O were interpreted to be unrealistic given the model configurations and assumptions, the elevated outflow rates from interior model cells may be an indication that model assumptions and/or inputs are not representative of the system. For example, the elevated outflow rates from interior model cells under scenarios C and O may indicate 1) groundwater recharge rates are overestimated, 2) groundwater ET rates underestimate actual discharge, 3) available stable isotope (deuterium) data do not fully characterize recharge or regional aquifer characteristics, or 4) groundwater discharge occurs in a manner that is not manifested in available deuterium data for adjacent basins (*i.e.*, the perfect mixing assumption of the DSC model may not be adequate for describing the aquifer system).

Butte Valley, the northern portion of Spring Valley, and the southern portion of Steptoe Valley are "upgradient" cells that do not have potential inflow from any other model cell. As upgradient cells, the only input to each cell is precipitation recharge, therefore the observed δD values should equal the recharge δD values. Observed δD values are 4 ‰lighter (more negative) than recharge for the southern portion of Steptoe Valley and 5 ‰ lighter for the northern portion of Spring Valley. An observed deuterium value for Butte Valley was not calculable because no appropriate δD data were identified for this basin; however, the observed value for Long Valley, which is located adjacent and east of Butte Valley, is isotopically lighter than any recharge δD values for model cells. The differences between observed δD values for these cells compared to recharge δD values suggest that 1) there are errors associated with the assumed δD values, 2) these cells receive groundwater input from adjacent model cells, or 3) a different model or set of assumptions is necessary to explain the observed and recharge δD values.

Because the DSC model integrates data from multiple aspects of the BARCAS study, results from the model have a substantial amount of associated uncertainty. The interpreted hydrogeologic boundary classifications, regional potentiometric surface map, recharge and discharge rates all have associated uncertainties. Moreover, deuterium values for model inputs were calculated from a geochemical database which was relatively sparse for several basins, most notably Butte Valley and Jakes Valley for which no appropriate deuterium data were identified for the regional aquifer. The deterministic model results each represent a single solution which was obtained when the model was optimized for a given set of input parameters. The optimal or best model is determined based on a minimum difference (residual) between the simulated and observed deuterium concentrations and ET rates. It is important to note that other models may yield similar residuals yet have different flow patterns and that the deuterium data may not provide enough information to constrain these various flow solutions. For example, groundwater outflow from Cave Valley or Lake Valleys may be possible, but wasn't simulated by the optimal model solution based on the current DSC model extent and the available deuterium data.

To evaluate the uncertainty associated with the accounting model, the Monte Carlo uncertainty analysis was performed by randomly sampling from distributions of potential recharge rates and deuterium values for each model cell. Results from the Monte Carlo uncertainty analysis show that for the assumed potential variability in recharge flux, Snake Valley displayed the highest uncertainty for water budget components of interbasin groundwater fluxes. In addition to the Monte Carlo uncertainty analysis results, another indicator of model uncertainty is provided by inspection of the model-predicted groundwater flows within and out of the study area shown for long-term (1895 to 2006) and recent (1970 to 2004) average annual recharge estimates shown on Figures 6 and 7. The variation between model-predicted groundwater fluxes shown for these recharge conditions illustrate that while the regional flow patterns for the study area predicted by the DSC model are consistent, the rates of groundwater flow within and out of the study vary in a non-linear fashion.

RECOMMENDATIONS FOR FUTURE RESEARCH

The groundwater accounting model developed for this study met the objective of evaluating basin and regional groundwater budgets using estimates for groundwater recharge and discharge developed for the BARCAS project. Additional research could improve the predictive capability of the model and the interpretation of model results, especially with respect to areas with sparse or no deuterium data for recharge or regional groundwater. The following are recommendations for future research:

- Groundwater samples representative of the regional aquifer could be collected for chemical and isotopic analysis from (sub)basins with no data (Jakes Valley, Butte Valley, central Snake Valley) or limited data (Newark Valley, central Steptoe Valley, southern Steptoe Valley, northeast Snake Valley)
- Additional samples from recharge areas could be collected for chemical and isotopic analysis. Deuterium data are sparse for multiple recharge areas, notably the ranges in the northwest corner of the study area (Needles, Pancake, and Maverick Springs ranges and Butte Mountains), along the southern portion of the Schell Creek Range, and from eastern areas (Deep Creek and Confusion ranges).
- The model domain could be expanded to include hydrographic areas which are adjacent to the BARCAS study area. The expanded model domain could allow for evaluation of the direction and rates of interbasin groundwater outflow from the BARCAS study area. While the current model does incorporate a driver for achieving minimum outflows under certain optimization scenarios, there do not exist explicit sinks for water (or tracer) outside of the study area boundary. For this reason, calculated discharges from the study result from drivers within the study area, rather than drivers (constraints) at the model boundaries. For example, Lake Valley is generally predicted to not have significant outflow from the study area because fluxes of water (and tracer) from this cell are pulled into southern Spring Valley and southern Snake Valley and there is no "competition" from outside the study area for Lake Valley's groundwater. This condition illustrates a potential limitation of the current model for predicting flow to outside the study area.
- The DSC model structure could be modified to explicitly include a specified component for discharge from the model domain (e.g. a groundwater ET discharge rate) for each mixed cell. Currently, target groundwater ET discharge rates are used only in objective function calculations when outflow is included as optimization criteria. Modifying the model to include a specified discharge component for each mixed cell would allow for model optimization using a single objective (deuterium values) compared to the multiple objective optimization used in this study for scenarios which include target groundwater ET outflows.
- A more rigorous evaluation of uncertainty associated with recharge δD values could improve the uncertainty analysis and the resulting description of model sensitivity to assumed recharge δD values. Model uncertainty related to observed δD values could also be evaluated by incorporating distributions for cell observed δD values into the Monte Carlo uncertainty analysis.
- Deuterium value inputs or DSC model cell connectivity could be re-evaluated for the upgradient cells associated with the northern portion of Spring Valley and the southern portion of Steptoe Valley. For these cells, the difference between the observed deuterium values for these cells compared the recharge deuterium values

indicates that either there are errors associated with the assumed deuterium values or these cells receive groundwater input from adjacent model cells.

- Cell input and output fluxes could be checked using chloride data for samples collected from wells and springs. Assuming there are no mineral sinks for chloride in the flow system, chloride may acts as another conservative tracer and could be used to help validate mix ratios predicted by the deuterium-calibrated DSC model. Possible flowpaths identified for the DSC model could also be evaluated using a geochemical modeling program such as NETPATH (Plummer et al. 1991). Geochemical modeling using NETPATH was completed for a subset of interbasin and intra basin flowpaths as part of the BARCAS study; however, results from this geochemical modeling were not available during the DSC model development.
- The appropriateness of the steady-state assumption could be evaluated to estimate model sensitivity to temporal variability in recharge rates, recharge deuterium values, and/or groundwater ET discharge rates. Recharge estimates developed for the BARCAS study suggest that average annual precipitation and associated recharge is greater for the recent period of record (1970 to 2004) than for the long-term average (1895 to 2006). Temporal variability could be estimated or generated synthetically to represent potential annual or long-term changes in recharge rates, recharge deuterium signatures, and groundwater ET discharge rates including ET and pumping. A modified DSC model could be developed to evaluate the impacts of temporal variability on the water budget components; however, the revised model would require estimates for cell (basin) volumes.

REFERENCES

Bedinger, M.S., J.R. Harrill, W.H. Langer, J.M. Thomas, and D.A. Mulvihill. 1985. Maps showing ground-water levels, springs, and depth to ground water, Basin and Range Province, Nevada: U.S. Geological Survey Water-Resources Investigations Report 83-4119-B.

Brothers, K., T.S. Buqo, and J.V. Tracy. 1993. Hydrology and Steady State Ground-water Model of Snake Valley, East-Central Nevada, and West-Central Utah. LVWD Report No. 9.

Brothers, K., T.S. Buqo, J.V. Tracy, M. Stock, C. Bentley, A. Zdon. and J. Kepper. 1993. Hydrology and Steady State Ground-water Model of Cave Valley, Lincoln and White Pine Counties, Nevada. LVWD Report No. 11.

Brothers, K., A.J. Bernholtz, T.S. Buqo, and J.V. Tracy. 1994. Hydrology and Steady State Ground-water Model of Spring Valley, Lincoln and White Pine Counties, Nevada. LVWD Report No. 13.

Calhoun, S.C. 2000. Regional groundwater flow at the Nevada Test Site using stable isotopes and trace element chemistry, Hydrologic Sciences Program, University of Nevada, Reno, Master's Thesis.

Campana, M.E. 1975. Finite-state models of transport phenomena in hydrologic systems, University of Arizona, Tuscon. PhD Dissertation.

Campana, M.E., W.R. Sadler, N.L. Ingraham and R.L. Jacobson. 1997. A deuterium-calibrated compartment model of transient flow in a regional aquifer system. *Tracer Hydrology 97*. A. Kranjc: 389-496.

Carroll, R.W.H. and G.M. Pohll. In press. A User's Manual for the Discrete-state Compartment Model-Shuffled Complex Evolution (DSCM-SCE). Division of Hydrologic Sciences, Desert Research Institute.

Darling, W.G. and A.H. Bath. 1988. A stable isotope study of recharge processes in the English Chalk. *Journal of Hydrology* 101: 31-46.

Drever, J.I. 1997. *The Geochemistry of Natural Waters: Surface and Groundwater Environments - 3rd ed.* Upper Saddle River, New Jersey, Prentice-Hall, Inc.

Duan, Q., S. Sorooshian, and V. Gupta. 1992. Effective and efficient global optimization for conceptual rainfall-runoff models. *Water Resources Research* 28(4): 1015-1031.

Eakin, T.E. 1966. A regional interbasin ground-water system in the White River area, southeastern Nevada. *Water Resources Research* (2): 251-271.

Earman, S. and R. Hershey. In review. Groundwater recharge estimates for basins in south-central Nevada (eastern Nevada Test site and vicinity) developed using a deuterium-calibrated discrete-state compartment model. Division of Hydrologic Sciences, Desert Research Institute.

Epstein, B.J. 2004. Development and Uncertainty Analysis of Empirical Recharge Prediction Models for Nevada's Desert Basins. Hydrologic Sciences Program, University of Nevada, Reno, Master's Thesis.

Feeney, T.A., M.E. Campana, and R.L. Jacobson. 1987. A Deuterium-Calibrated Groundwater Flow Model of the Western Nevada Test Site and Vicinity. Desert Research Institute Water Resources Center Publication 45057.

Flint, A.L., and L.E. Flint. 2007. Application of the basin characterization model to estimate in-place recharge and runoff potential in the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2007-5099.

Gat, J.R. 1981. Groundwater, in Stable Isotope Hydrology, Deuterium and Oxygen-18 in the Water Cycle. Ed. J.R. Gat and R. Gonfiantini. Technical Report Series No. 210, pp. 223-240. IAEA, Vienna.

Harrill, J.R., J.S. Gates, and J.M. Thomas. 1988. Major ground-water flow systems in the Great Basin region of Nevada, Utah, and adjacent states: U.S. Geological Survey Hydrologic Investigations Atlas HA-694-C.

Hershey, R.L., B.F. Lyles, S. Earman, J.M. Thomas, and K.W. Lundmark. 2007. DRAFT - Ground-water Chemistry Interpretations Supporting the Basin and Range Regional Carbonate-rock Aquifer System (BARCAS). Division of Hydrologic Sciences, Desert Research Institute, Publication No. 41230.

Hershey, R.L., and S.A. Mizell. 1995. Water Chemistry of Spring Discharge from the Carbonate-rock Province of Nevada and California: Desert Research Institute, Water Resources Center, Publication No. 41140, 42 p.

Hill, M.C. 1998. Methods and guidelines for effective model calibration: U.S. Geological Survey Water-Resources Investigations Report 98-4005.

Hood, J.W., and F.E. Rush. 1965. Water-resources Appraisal of the Snake Valley Area, Nevada and Utah. Nevada Department of Conservation and Natural Resources Ground Water Reconnaissance Series Report No. 34.

Ingraham, N.L., and B.E. Taylor. 1991. Ligth Stable Isotope Systematics of Large-Scale Hydrologic Regimes in California and Nevada. Water Resources Research, 27(1): 77-90.

Karst, G.B., M.E. Campana, and R.L. Jacobson. 1988. A mixing-cell model of the hydrothermal flow system, northern Dixie Valley, Nevada. *Transactions, Geothermal Resources Council* 12: 167-174.

Katzer, T., and D.J. Donovan. 2003. Surface Water Resources and Basin Water Budget for Spring Valley, White Pine and Lincoln Counties, Nevada. Las Vegas Valley Water District.

Kirk, S.T., and M.E. Campana. 1990. A Deuterium-calibrated Groundwater Flow Model of a Regional Carbonate-alluvial System. *Journal of Hydrology*, (119) 357-388.

Lundmark, K.W. 2007. Regional Water Budget Accounting and Uncertainty Analysis Using a Deuterium-Calibrated Discrete State Compartment Model: White Pine County, Nevada, and Adjacent Areas in Nevada and Utah. Hydrologic Sciences Program, University of Nevada, Reno, Master's Thesis.

Nichols, W.D. 2000. Regional Ground-water Evapotranspiration and Ground-water Budgets, Great Basin, Nevada, Chapter C. Regional Ground-water Budgets and Ground-water Flow, Eastern Nevada. U.S. Geological Survey Professional Paper 1628.

Plummer, L.N., D.L. Prestemon, and D.C. Thorstenson. 1991. An interactive code (NETPATH) for modeling *net* geochemical reactions along a flow*path*. U.S. Geological Survey Water-Resources Investigation Report 91-4078.

Roth, J.G. and M.E. Campana. 1989. A Mixing-cell Model of the Railroad Valley Regional Groundwater Flow System, Central Nevada. Desert Research Institute Water Resources Center Publication 41123.

Rush, F.E. and D.E. Everett, 1966. Water Resources Appraisal of Little Fish Lake, Hot Creek, and Little Smoky Valleys, Nevada. Nevada Department of Conservation and Natural Resources Ground Water Reconnaissance Series Report No. 38.

Sadler, W.R. 1990. A Deuterium-Calibrated, Discrete-State Compartment Model of Regional Groundwater Flow, Nevada Test Site and Vicinity. Hydrologic Sciences Program, University of Nevada, Reno, Master's Thesis.

Scott, B.R., T.J. Smales, F.E. Rush, and A.S. Van Denburgh. 1971. Nevada's water resources: Nevada Division of Water Resources, Water for Nevada Report 3.

Southern Nevada Water Authority. 2006. Southern Nevada Water Authority Clark, Lincoln, and White Pine Counties Groundwater Development Project Draft Conceptual Plan of Development. Prepared for U.S. Bureau of Land Management.

Thomas, J.M., S.C. Calhoun, and W.B. Apambire. 2001. A Deuterium Mass-balance Interpretation of Groundwater Sources and Flows in Southeastern Nevada. Division of Hydrologic Sciences, Desert Research Institute, Publication No. 41169.

U.S. Geological Survey, 2006, National Water Information System (NWISWeb) data available on the World Wide Web, accessed September 12, 2006, at URL *http://waterdata.usgs.gov/nv/nwis/nwis*.

Welch, A.H., and D.J. Bright (eds.). 2007. Water resources of the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah—Draft Report: U.S. Geological Survey Open-File Report 2007-1156.

Zhu, J., M.H. Young, and M.E. Cablk. 2007. Uncertainty Analysis of Estimates of Ground-Water Discharge by Evapotranspiration for the BARCAS Study Area. Desert Research Institute, Division of Hydrologic Sciences Publication No. 41234.

APPENDIX A. DEUTERIUM DATA FOR RECHARGE SAMPLES.

(SW = surface water, GW = groundwater other than spring)

NWIS Site Number	NWIS Site Name	Latitude (NAD83)	Longitude (NAD83)	Site Type	Sample Date	δD (‰)
9415515	WATER CANYON CREEK NEAR PRESTON, NV	38.98772041	-114.9583496	SW	10/24/2003	-109.5
					10/24/2003	-112.7
10243740	MCCOY CREEK NEAR MCGILL, NV	39.37410747	-114.5283424	SW	5/28/1992	-118
373255114102301	204 S05 E70 04BA 1	37.54858007	-114.1738696	GW	6/3/1985	-95
373953113400801	(C-36-16)20ABB- 2	37.66469578	-113.6696877	GW	1/1/1981	-94.5
374441114252801	203 S02 E67 25DABB1	37.74468711	-114.4252681	GW	6/4/1985	-101
374607114242501	203 S02 E68 18DD 1	37.76857579	-114.4077676	GW	6/4/1985	-101
374934114555201	181 S01 E63 33 1 RATTLESNAKE SPRING	37.82608333	-114.9311111	Spring	3/24/2004	-97.3
375136114192001	198 S01 E68 13DB 1 SPRING	37.85996364	-114.3230425	Spring	4/8/1985	-98
					4/8/1985	-104
375140114191801	198 S01 E68 13 1 MVW ABOVE DELMUE SPRING	37.86107474	-114.3224869	SW	4/8/1985	-98
375140115115601	171 S01 E60 13 1 SEAMAN SPRING	37.86119444	-115.1987778	Spring	6/25/2004	-99
375310114181701	198 S01 E69 06DB 1	37.88607445	-114.3055419	GW	6/5/1985	-92
375406114333701	202 N01 E66 34 1 CONNOR SPRING	37.90163889	-114.5602222	Spring	6/24/2004	-100.6
375410114333801	202 N01 E66 34ACD 1 BIG TREES SPRING	37.90274073	-114.5613851	Spring	6/24/2004	-102.3
375429114325601	202 N01 E66 35BB 1 PINE SPRING	37.90801849	-114.5497179	Spring	4/7/1985	-99
					6/24/2004	-99
375443114550501	181 N01 E63 28CC 1 BLACK ROCK SPRING	37.91190416	-114.9188999	Spring	3/22/1988	-94
					3/23/2004	-93.6
375452114322501	203 S01 E66 26 1 LIME SPRING	37.91440734	-114.5411064	Spring	6/24/2004	-99.9
375501114550701	181 N1 E63 28 1 UNNAMED SPRING--NR BLACKROC	37.91694444	-114.9186111	Spring	3/23/2004	-94.3
375507114322901	202 N01 E66 26AD 1 DEADMAN SPRING	37.91857396	-114.5422176	Spring	3/23/2004	-86.9
					3/23/2004	-88.7
375516114325601	202 N01 E66 26BAC 1 HIGHLAND SPRING	37.92107391	-114.5497179	Spring	6/24/2004	-99.6
					5/1/2005	-99.3
375609114531601	181 N01 E63 22 1 HAMILTON SPRING	37.93572222	-114.8876389	Spring	3/23/2004	-93.1
380022114052301	201 N02 E70 25 1 TOBE SPRING	38.00608333	-114.0898056	Spring	5/20/2004	-98.6
380024114052301	201 N02 E70 25 1 TOBE SPRING 2	38.00675	-114.0896944	Spring	5/20/2004	-89.4
380136114144201	200 N02 E69 15 1 HORSETHIEF SPRING	38.02675	-114.2450278	Spring	5/20/2004	-93.7
					5/1/2005	-97.6
380140114110901	201 N02 E70 18C 1 MVW ABOVE EAGLE CANYON R	38.0277394	-114.1866484	SW	4/9/1985	-93
380155114514401	181 N02 E63 13 1 COYOTE SPRING	38.03186111	-114.8621944	Spring	5/1/2005	-95.2
380300115364201	172 N02 E57 07 1 SPRING	38.04994455	-115.6125327	Spring	7/31/1985	-95
380324115395301	172 N02 E56 10 1 UNNAMED SPRING 8	38.05666667	-115.6647222	Spring	7/2/2005	-104.4
380714114200001	202 N03 E68 14 1 UPPER TOWER SPRING	38.1205	-114.3334444	Spring	4/28/2004	-111.8
380731114035601	201 N03 E71 18A 1 SPRING BELOW REED SUMMIT	38.12523875	-114.0663662	Spring	5/21/2004	-92.2

APPENDIX A. DEUTERIUM DATA FOR RECHARGE SAMPLES (CONTINUED).

NWIS Site Number	NWIS Site Name	Latitude (NAD83)	Longitude (NAD83)	Site Type	Sample Date	δD (‰)
380752114031801	196 N03 E71 08 1 BARREL SPRING	38.13105556	-114.0550556	Spring	5/21/2004	-99
380805115355801	172 N03 E57 08 1 SPRING ABOVE ADAVEN	38.13466559	-115.6003093	Spring	7/31/1985	-103
380858114154501	201 N03 E69 04BCC 1 PARSNIP SPRING	38.14940491	-114.2633187	Spring	6/5/1985	-93.5
380912114211401	202 N03 E68 03 1 BLUE ROCK SPRING	38.15344444	-114.354	Spring	4/28/2004	-90.5
380941115383001	172 N04 E56 35 1 UNNAMED SPRING 7	38.16138889	-115.6416667	Spring	7/2/2005	-105.9
380946114390101	181 N04 E65 35 1 FOX CABIN	38.16266667	-114.6503333	Spring	6/29/2004	-103.5
380953114410101	181 N04 E65 33 1 SCOTTY SPRING	38.16477778	-114.68375	Spring	6/26/2004	-98.9
381002115391201	172 N04 E56 35 1 LOWER LITTLE CHERRY CR SP	38.16716289	-115.6541994	Spring	7/31/1985	-103
381033114392001	181 N04 E65 26 1 LOWER FAIRVIEW	38.17572222	-114.6555	Spring	6/29/2004	-97.5
381033114434201	181 N04 E65 30 1 BAILEY SPRING	38.17594444	-114.7282778	Spring	6/29/2004	-98.5
					5/1/2005	-97.9
381047114425701	181 N04 E65 29 1 FENCE SPRING	38.17977778	-114.7159444	Spring	6/29/2004	-97.4
381112114395801	181 N04 E65 22 1 UPPER FAIRVIEW	38.18658333	-114.6661944	Spring	6/29/2004	-97.7
381117113515901	(C-30-18)21ABC-S1	38.18805556	-113.8663889	Spring	11/19/2005	-102.3
381150114363101	202 N04 E66 20BB 1 WILDHORSE SPRING	38.19718104	-114.6094424	Spring	4/6/1985	-92.5
381246114422301	181 N04 E65 17 1 ROBINSON SPRING	38.21272222	-114.7063611	Spring	6/29/2004	-97.9
381358114412201	181 N04 E65 04DBD 1 LITTLE FIELD SPRING	38.23273571	-114.6902786	Spring	6/26/2004	-98.5
381437114150801	201 N05 E69 33D 1 CAMP CREEK	38.24357067	-114.2530408	SW	4/9/1985	-102
381453114022301	(C-29-20)36BBB-S1	38.24805556	-114.0397222	Spring	11/19/2005	-105.1
381506114421801	181 N05 E65 32AD 1 MELOY SPRING	38.25162423	-114.7058347	Spring	6/26/2004	-99.8
381517114070201	201 N05 E70 35 1 SOUTH MONUMENT SPRING	38.25480556	-114.1171111	Spring	5/21/2004	-102.3
381531114074901	201 N05 E70 27 1 LION SPRING	38.25863889	-114.1303333	Spring	5/21/2004	-104.2
381722114123201	201 N05 E69 14DDAD1 BURNT CANYON SPRING	38.2894034	-114.2097065	Spring	6/5/1985	-93
381838114390101	183 N05 E65 11AD 1 SPRING	38.31051215	-114.6511107	Spring	4/5/1985	-102
381840114380501	183 N05 E65 12 1 COTTONWOOD SPRING	38.31102778	-114.6346111	Spring	6/29/2004	-102.2
381905114241201	183 N05 E68 06C 2 WILSON CREEK	38.3180131	-114.4041578	SW	4/5/1985	-97.5
381911114362601	183 N05 E66 05CBCC1 LOWER PONY SPRING	38.31967882	-114.6080537	Spring	7/23/1981	-101
385020115172301	207 N11 E59 1CDAA1 SECRET SPRING	38.8388275	-115.2905789	Spring	6/16/1983	-110
385030114205901	184 N11 E68 0 SWALLOW CANYON, BELOW	38.8416152	-114.3505517	SW	6/14/1983	-112
385033114205201	184 N11 E68 0 SWALLOW CANYON, ABOVE	38.84244852	-114.3486072	SW	6/14/1983	-110
385040114213901	184 N11 E68 5DBAB1 LITTLE SWALLOW SPRING	38.84439288	-114.3616632	Spring	6/14/1983	-110
385057114534401	179 N11 E63 04 1 HOLE IN THE BANK SPR (D15)	38.84913889	-114.8956667	Spring	7/31/2005	-114.9
385105114101301	195 N11 E69 01 1 UNNAMED SPRING #2 (D10)	38.85147222	-114.1703611	Spring	7/28/2005	-105.4
385141114241301	184 N12 E67 36 1	38.86138889	-114.4036111	Spring	5/27/1992	-121
385145114161801	196 N12 E69 31 1 MUSTANG SPRING (D6)	38.86258333	-114.2717778	Spring	7/14/2005	-111.3
385233114535501	179 N12 E63 28 1 SECOND SAWMILL SPRING	38.87577783	-114.8994577	Spring	8/1/1985	-110

APPENDIX A. DEUTERIUM DATA FOR RECHARGE SAMPLES (CONTINUED).

NWIS Site Number	NWIS Site Name	Latitude (NAD83)	Longitude (NAD83)	Site Type	Sample Date	δD (‰)
385339115225801	173B N12 E59 18 1 SPRING BELOW CURRANT MTN	38.89410309	-115.3836382	Spring	6/15/1983	-107
					10/12/2003	-113.6
385344114535801	207 N12 E63 1 LONE PINE SPRING	38.89549977	-114.9002913	Spring	10/13/2003	-109.2
385402115225701	173B N12 E59 18 2 SNWMLT SP BLW DUCKWATER PK	38.90049195	-115.3833605	Spring	6/15/1983	-105
385434114063901	195 N12 E70 15CB 1 SPRING CREEK SPRING (D8)	38.90939309	-114.1116566	Spring	7/16/2005	-112.5
385436115231101	173B N12 E59 07 1 SADDLE SPRING	38.90993628	-115.3872497	Spring	6/15/1983	-116
385635114175401	195 N13 E68 36 1	38.94305556	-114.2983333	SW	9/1/1990	-96
					10/1/1990	-110
					6/1/1991	-109
					7/1/1991	-111
					8/1/1991	-108
					9/1/1991	-109
385636114175601	195 N13 E68 36 2	38.94333333	-114.2988889	SW	9/1/1990	-100
385657115243601	207 N13 E58 35 1 MONITORING SPRING WR1	38.94902778	-115.4100833	Spring	10/12/2003	-111.2
					3/23/2004	-113.3
					6/21/2004	-114
					9/22/2004	-115.7
					1/21/2005	-115.1
					5/21/2005	-112.3
					8/14/2005	-113.2
					11/5/2005	-113.8
385706114180901	195 N13 E68 35 1	38.95166667	-114.3025	SW	9/1/1990	-90
					10/1/1990	-88
					5/1/1991	-108
					6/1/1991	-105
					7/1/1991	-103
					8/1/1991	-96
					9/1/1991	-90
385752115184101	207 N13 E59 26 1 HALFWAY SPRING	38.96444444	-115.3113889	Spring	6/29/2005	-108.4
385804115235601	207 N13 E58 24 1 UNNAMED SPRING 1	38.96777778	-115.3988889	Spring	6/28/2005	-114.8
385805114170601	195 N13 E68 25 1	38.96805556	-114.285	SW	9/3/1916	-113
					8/1/1990	-108
					9/1/1990	-104
					10/1/1990	-110
					7/1/1991	-112
					8/1/1991	-108
					9/1/1991	-102

APPENDIX A. DEUTERIUM DATA FOR RECHARGE SAMPLES (CONTINUED).

NWIS Site Number	NWIS Site Name	Latitude (NAD83)	Longitude (NAD83)	Site Type	Sample Date	δD (‰)
385811114164601	195 N13 E69 30 2	38.96972222	-114.2794444	SW	8/1/1990	-93
					9/1/1990	-101
					10/1/1990	-104
					6/1/1991	-112
					8/1/1991	-105
					9/1/1991	-99
385823114221301	184 N13 E68 20 1 RAISED SPRING D36	38.97263889	-114.3704167	Spring	10/27/2005	-107.6
385831115240101	207 N13 E58 24 1 SADDLE SPRING	38.97541667	-115.4002222	Spring	10/12/2003	-115.7
					6/28/2005	-118.6
385832114162901	195 N13 E69 30 1	38.97555556	-114.2747222	SW	8/1/1990	-106
					9/1/1990	-105
					10/1/1990	-106
					5/1/1991	-111
					6/1/1991	-111
					7/1/1991	-106
					8/1/1991	-103
					9/1/1991	-102
385837115240201	207 N13 E58 24 1 UNNAMED SPRING 2	38.97694444	-115.4005556	Spring	6/28/2005	-114.9
385902114572401	207 N13 E62 03D 1 WATER CANYON	38.98383158	-114.9575162	SW	6/14/1983	-115
					8/23/1983	-117
385903115232501	207 N13 E59 18 1 UNNAMED SPRING 3	38.98416667	-115.3902778	Spring	6/28/2005	-113.1
385911114093101	195 N13 E70 19 1	38.98638889	-114.1586111	Spring	6/19/1992	-110
385935115223101	207 N13 E59 18 1 UNNAMED SPRING 6	38.99305556	-115.3752778	Spring	6/29/2005	-115.1
385942115232901	207 N13 E58 13 1 DEER SPRING	38.99494444	-115.3913056	Spring	10/12/2003	-118.9
					6/28/2005	-119.6
390010114184001	195 N13 E68 11CAC 1 THERESA LAKE FEEDER SPRING	39.00272358	-114.311942	Spring	8/1/1990	-104
					9/1/1990	-103
					10/1/1990	-106
					6/1/1991	-112
					7/1/1991	-107
					8/1/1991	-105
					9/1/1991	-102
390023115232601	207 N13 E59 7 1 UNNAMED SPRING 5	39.00638889	-115.3905556	Spring	6/29/2005	-120.4
390025114543801	207 N13 E63 08 1 WATER CANYON SPRING	39.00691667	-114.9106389	Spring	10/14/2003	-114.4
390032114185501	195 N13 E68 11 2	39.00888889	-114.3152778	SW	8/1/1990	-105
					9/1/1990	-108
					10/1/1990	-109
					6/1/1991	-110
					7/1/1991	-113

APPENDIX A. DEUTERIUM DATA FOR RECHARGE SAMPLES (CONTINUED).

NWIS Site Number	NWIS Site Name	Latitude (NAD83)	Longitude (NAD83)	Site Type	Sample Date	δD (‰)
390044114181301	195 N13 E68 11 1	39.01222222	-114.3036111	SW	8/1/1990	-111
					9/1/1990	-113
					6/1/1991	-114
					7/1/1991	-115
					8/1/1991	-113
					9/1/1991	-114
390049114174501	195 N13 E68 01 2	39.01361111	-114.2958333	SW	8/1/1990	-111
					9/1/1990	-112
					1/1/1991	-115
					6/1/1991	-115
					7/1/1991	-113
					8/1/1991	-113
					9/1/1991	-115
390055114141101	195 N13 E69 09 2	39.01527778	-114.2363889	SW	8/1/1990	-116
					9/1/1990	-106
					10/1/1990	-116
					5/1/1991	-117
390055114141401	195 N13 E69 09 1	39.01527778	-114.2372222	SW	8/1/1990	-115
					9/1/1990	-116
					10/1/1990	-119
					1/1/1991	-119
					5/1/1991	-118
					6/1/1991	-116
					7/1/1991	-118
					8/1/1991	-105
					9/1/1991	-118
390056114141001	195 N13 E69 09 3	39.01555556	-114.2361111	SW	8/1/1991	-117
					9/1/1991	-118
390112114165501	195 N13 E68 01 1	39.02	-114.2819444	SW	8/1/1990	-113
					9/1/1990	-110
					10/1/1990	-114
					1/1/1991	-110
					5/1/1991	-113
					6/1/1991	-115
					7/1/1991	-114
					8/1/1991	-114
					9/1/1991	-115
390211115233601	207 N14 E58 36 1 UNNAMED SPRING 4	39.03638889	-115.3933333	Spring	6/29/2005	-116.3
390223114514801	179 N14 E63 35A 1 WILLOW CREEK	39.03966459	-114.8641815	SW	8/22/1983	-119
					6/12/1984	-116
390228115205601	207 N14 E59 28 1 EASTER SPRING	39.04111111	-115.3488889	Spring	6/29/2005	-119.4

APPENDIX A. DEUTERIUM DATA FOR RECHARGE SAMPLES (CONTINUED).

NWIS Site Number	NWIS Site Name	Latitude (NAD83)	Longitude (NAD83)	Site Type	Sample Date	δD (‰)
390451115221701	207 N14 E59 17 1 LITTLE TOM PLAIN SPRING	39.08091667	-115.3715278	Spring	6/6/2005	-121.84
390512114553201	207 N14 E63 08 1 UPR TERRACE SPR FLTRD WR2	39.08663889	-114.9256389	Spring	10/13/2003	-111.3
					10/15/2003	-114.9
					4/26/2004	-89.9
					6/23/2004	-115.6
					9/22/2004	-114.4
					2/9/2005	-114.6
					5/21/2005	-113.7
					8/11/2005	-113.4
					11/6/2005	-113.7
390513115223901	207 N14 E59 07 1 BIG TOM PLAIN SPRING	39.087	-115.3773611	Spring	6/6/2005	-121.1
390542115214901	207 N14 E59 08 1 STOVE SPRING	39.09486111	-115.3635833	Spring	6/6/2005	-114.5
390543114081801	195 N14 E70 08DC 1 USGS-MX (SNAKE VALLEY S.)	39.09522364	-114.1391598	GW	7/16/2005	-113.2
390655115233201	173B N15 E58 36 1 SAGE HEN SPRING	39.11533333	-115.3921111	Spring	6/6/2005	-112.44
390718115220901	174 N15 E59 32 1 CIRCLE WASH SPRING	39.12169444	-115.3692778	Spring	6/6/2005	-114.5
390755115230401	174 N15 E59 30 1 SHELLBACK SPRING	39.13197222	-115.3843611	Spring	6/7/2005	-123.6
390802114574101	207 N15 E62 25CBBC1 SPRING	39.13382946	-114.962241	Spring	6/16/1983	-111
390818114025501	195 N15 E71 30CDDD1 CAINE SPRING	39.13838889	-114.0486389	Spring	12/12/2005	-114
390825115232201	174 N15 E58 25 1 UNNAMED SHELLBACK RIDGE SP	39.14038889	-115.3895278	Spring	6/7/2005	-123.59
390844114581201	207 N15 E62 23DCBD1 SOUTH SPRING	39.14549591	-114.9708526	Spring	6/17/1983	-111
390905115233401	174 N15 E58 24 1 UNNAMED HAYDEN CANYON SPR	39.15147222	-115.3926389	Spring	6/7/2005	-120.9
390922114574701	207 N15 E62 23AAAD1 NORTH SPRING	39.15605135	-114.9639081	Spring	6/17/1983	-113
390933115235601	174 N15 E58 13 1 UNNAMED STONE CABIN SPR	39.15911111	-115.3989167	Spring	6/7/2005	-114.16
391041114170601	195 N15 E68 12 1 ROCK SPRING D35	39.17783333	-114.2868611	Spring	10/26/2005	-113.7
391054114222801	184 N15 E68 08BCCB1 ROCK SPRING	39.18152778	-114.3743056	Spring	12/12/2005	-114
391101114162501	195 N15 E69 7 1 RABBIT BRUSH SPRING	39.18361111	-114.2736111	Spring	10/26/2005	-117.1
391135114414401	179 N15 E65 05A 1 STEPTOE CREEK	39.19299673	-114.6964008	SW	6/14/1983	-117
391212114274501	184 N16 E67 32 1 UNNAMED SPRING 14 D41	39.20341667	-114.4626111	Spring	12/13/2005	-121
391259115235301	174 N16 E58 36 1 ASPEN SPRINGS(SOUTH)	39.21627778	-115.398	Spring	6/7/2005	-120.89
391316115235701	174 N16 E58 25 1 UNMARKED ASPEN SPR NORTH	39.221	-115.3990556	Spring	6/7/2005	-119.29
391345114535501	179 N16 E63 29AAAA1 CITY OF ELY - SPRING	39.2291062	-114.899463	Spring	6/14/1983	-120
					8/5/2003	-117
391348114153901	195 N16 E69 19 1 UNNAMED SPRING	39.23	-114.2608333	Spring	10/26/2005	-115.7
391420115232001	174 N16 E58 24 1 CHICKEN SPRING	39.23886111	-115.3888611	Spring	6/7/2005	-122.02
391446114285801	184 N16 E66 34B 1 CLEVE CREEK	39.24605317	-114.4836165	SW	6/15/1983	-117
					8/22/1983	-119
391609114514601	179 N16 E63 10ADAC1 CITY OF ELY	39.2691059	-114.8636291	GW	7/6/1983	-120
391654115232401	174 N16 E58 01D 1 UPPER ILLIPAH CREEK	39.28160035	-115.3908663	SW	6/13/1983	-124

APPENDIX A. DEUTERIUM DATA FOR RECHARGE SAMPLES (CONTINUED).

NWIS Site Number	NWIS Site Name	Latitude (NAD83)	Longitude (NAD83)	Site Type	Sample Date	δD (‰)
					8/23/1983	-123
391810114232101	184 N17 E67 25 1	39.30277778	-114.3891667	Spring	6/18/1992	-116
391828114125901	195 N17 E69 28 1 UNNAMED SPRING 12 D33	39.30752778	-114.2160833	Spring	10/25/2005	-117.8
391932114160201	195 N17 E68 24 1 MUD SPRING D34	39.32575	-114.2671389	Spring	10/25/2005	-115.6
391949114290401	184 N17 E67 19 1 UNNAMED SPRING 17 D44	39.33027778	-114.4845	Spring	12/14/2005	-117.6
391950115271801	174 N17 E58 21BAC 1 SAND SPRING	39.33048818	-115.4558689	Spring	7/14/1981	-123
392001115263601	174 N17 E58 2AAB 1 WILD-HORSE SPRING	39.33354383	-115.4442019	Spring	7/14/1981	-129
392105115265901	174 N17 E58 9 1 TUNNEL SPRING	39.35138889	-115.4497222	Spring	7/1/2005	-118.3
392118115201201	174 N17 E59 09D 1 LOWER ILLIPAH CREEK	39.35493358	-115.3375319	SW	6/13/1983	-114
392212114481001	179 N17 E64 05BC 1	39.36993861	-114.8036284	GW	6/13/1984	-120
392300115493001	154 N18 E55 31CABC1 U.S. FERA	39.38604128	-115.8272723	GW	7/31/1987	-129
392318114170401	184 N18 E68 26 1 EIGHT MILE SPRING (D32)	39.38836111	-114.2843333	Spring	8/26/2005	-116.1
392609115192801	174 N18 E59 10 1 SAMMY SPRING	39.43597222	-115.3245278	Spring	5/24/2005	-117.6
392625115190801	174 N18 E59 10 1 INDIAN SPRING	39.44038889	-115.3188333	Spring	6/5/2005	-119.11
392634115482101	154 N18 E55 08CADA1	39.44270771	-115.8067167	GW	7/31/1987	-123
392721115494901	154 N18 E55 06 1	39.45583333	-115.8302778	Spring	7/31/1987	-125
392724115562001	155A N18 E54 06 1	39.45666667	-115.9388889	Spring	7/31/1987	-117
392740114361501	184 N18 E65 01 1	39.46111111	-114.6041667	SW	5/28/1992	-116
392842114303301	184 N19 E66 26 1 UNNAMED SPRING 16 D43	39.47852778	-114.509	Spring	12/14/2005	-122.9
392847114513601	179 N19 E63 26CCB 1	39.47965943	-114.8608538	GW	7/26/1983	-125
392905114183701	184 N19 E68 27 1 UNNAMED SPRING #5 (D31)	39.48483333	-114.3103056	Spring	8/26/2005	-116.9
392913115163201	174 N19 E59 25 1 DEER SPRING	39.48683333	-115.2755833	Spring	6/4/2005	-114.11
392920114294301	184 N19 E66 25 1	39.48888889	-114.4952778	SW	6/18/1992	-111
392945115165001	175 N19 E59 24 1 ROBBERS ROOST NO 2 SPRING	39.49597222	-115.2804722	Spring	6/4/2005	-112.01
393033114593501	178B N19 E62 16 1 UNNAMED SPRING 1	39.50919444	-114.9929722	Spring	5/24/2005	-118.9
393304115134801	178B N19 E60 04 1 SUMMIT SPRING	39.55108333	-115.23	Spring	6/4/2005	-120.8
393320115130501	178A N20 E60 33C 1 THIRTY MILE SPRING	39.55548849	-115.2189199	Spring	8/23/1983	-126
393347114361801	184 N20 E66 30DCC 1 KALAMAZOO CREEK SPRING WR6	39.56382751	-114.5925144	Spring	7/20/2004	-121.6
					9/21/2004	-118.5
					1/23/2005	-121.6
					5/23/2005	-118.6
					8/12/2005	-119.2
					10/5/2005	-120.6
					11/8/2005	-121
					12/13/2005	-120.1
393417114314101	184 N20 E66 27C 1 KALAMAZOO CREEK	39.57132804	-114.5289018	SW	6/14/1983	-124
					8/24/1983	-121
393759115471001	154 N20 E55 04 1	39.63305556	-115.7861111	Spring	7/31/1987	-120

APPENDIX A. DEUTERIUM DATA FOR RECHARGE SAMPLES (CONTINUED).

NWIS Site Number	NWIS Site Name	Latitude (NAD83)	Longitude (NAD83)	Site Type	Sample Date	δD (‰)
393838114121801	184 N20 E69 34 1 MIKES SPRING (D20)	39.64375	-114.2048889	Spring	8/23/2005	-122.5
394045115385701	154 N21 E56 22 1	39.67916667	-115.6491667	Spring	7/31/1987	-124
394051114112701	184 N21 E69 21 1 UNNAMED SPRING #1 (D21)	39.68077778	-114.1908889	Spring	8/23/2005	-122.7
394248114135901	185 N21 E68 12 1 GRASS VALLEY SPRINGS (D22)	39.71325	-114.233	Spring	8/23/2005	-124.3
394320115363601	175 N21 E56 01 1 UNNAMED NR LITTLE WILLOW	39.72236111	-115.6098611	Spring	6/5/2005	-125.9
394328115342301	175 N21 E57 05 1 WOODCHUCK SPRING	39.72452778	-115.5729722	Spring	6/5/2005	-119.56
394409115341301	175 N22 E57 33 1 MUD SPRING	39.73586111	-115.5703611	Spring	6/5/2005	-117.55
394528115162101	175 N22 E59 24 1 CABIN SPRING	39.75788889	-115.2724444	Spring	6/5/2005	-124.42
394529115143301	178B N60 E22 1 BUTTE SPRING	39.75816667	-115.2424722	Spring	5/24/2005	-120.4
394623114124101	185 N22 E69 19 1 CEDAR SPRING (D23)	39.77313889	-114.2114167	Spring	8/23/2005	-120.6
394631114283001	184 N22 E66 23 1 DIPPING TANK SPRING (D28)	39.77525	-114.4751111	Spring	8/25/2005	-121.5
395135114282201	184 N23 E66 24 1 ROCK SPRINGS (D29)	39.85983333	-114.4727778	Spring	8/25/2005	-119.1
395152114552601	179 N23 E62 13B 1 EGAN CREEK	39.86437812	-114.9247499	SW	8/24/1983	-126
					6/14/1984	-123
395523114592101	178B N24 E62 29 1 JOHNSON SPRING	39.92319444	-114.9892222	Spring	5/24/2005	-123.4
395617114213901	185 N24 E67 23 1 UNNAMED SPRING #4 (D27)	39.93802778	-114.36075	Spring	8/25/2005	-121.9
395916114260001	184 N24 E67 05 1 UNNAMED SPRING #2 (D25)	39.98783333	-114.4334167	Spring	8/24/2005	-121
395937114251501	185 N25 E67 32 1 UNNAMED SPRING #3 (D26)	39.99366667	-114.4207222	Spring	8/25/2005	-122.8
400054114480001	179 N25 E63 18D 1 GOSHUTE CREEK	40.01493292	-114.8008589	SW	6/15/1983	-122
					8/24/1983	-124
400243114580301	178B N25 E62 03D 1 SNOW CREEK	40.04520973	-114.9683636	SW	6/15/1983	-122
					8/24/1983	-125
400255115293801	176 N25 E57 13AD 1 STATION SPRING AT ORIFICE	40.04846071	-115.4948973	Spring	5/23/2000	-128
400339115095001	175 N25 E60 12 1 WHITE ROCK SPRING	40.06083333	-115.1638889	Spring	5/24/2005	-119.2
400405115314901	176 N25 E57 11BBBC1 FORT RUBY RANCH 1	40.06798832	-115.5311102	GW	5/2/2002	-129
400442114544101	178B N25 E62 01 1 LOWER SNOW CREEK SPRING	40.07836111	-114.9113889	Spring	5/24/2005	-120.9
					5/24/2005	-120.7
401105115292801	176 N27 E57 36AA 1 NINO SP AT FISH HATCHERY	40.1846938	-115.4918664	Spring	5/23/2000	-125
401205115301101	176 N27 E57 24DC 1 CAVE CREEK SPRING	40.20179377	-115.4960808	Spring	5/23/2000	-124
					1/11/2001	-122
					5/1/2002	-125
401412115285601	176 N27 E58 07BD 1 SP 0.89MI N BRESSMAN CABIN	40.23670759	-115.4832366	Spring	5/25/2000	-122
401515115284901	176 N27 E58 06BADD1	40.25406032	-115.481098	GW	5/25/2000	-125
401813115255201	176 N28 E58 15CCBB1 RUBY LAKE ESTATES 1	40.30359052	-115.4318755	GW	4/30/2002	-129
401822115274001	HARRISON PASS CR AT BEDROCK/ALLUVIAL CONTACT	40.30609338	-115.4620237	SW	9/19/2000	-122
401913115265701	176 N28 E58 09CBDB1 RUBY VALLEY STORE	40.320225	-115.4490944	GW	10/8/2002	-124

APPENDIX A. DEUTERIUM DATA FOR RECHARGE SAMPLES (CONTINUED).

NWIS Site Number	NWIS Site Name	Latitude (NAD83)	Longitude (NAD83)	Site Type	Sample Date	δD (‰)
402010115265001	176 N28 E58 04CBAC1	40.33604041	-115.4481046	GW	5/25/2000	-127
402343115125801	176 N29 E60 16BDBD1 BASQUE WELL NO 2	40.39520556	-115.2162028	GW	4/30/2002	-137
402360115190101	176 N29 E59 15BBBC1	40.39982816	-115.3177016	GW	5/25/2000	-139
					10/10/2002	-137
402555114591801	178A N30 E62 33CAC 1 USBLM	40.43187221	-114.9892021	GW	10/9/2002	-128
403334115155101	176 N31 E59 24ABBC1	40.55947911	-115.264989	GW	10/9/2002	-127
403958115121101	176 N32 E60 09DBDA1	40.66615061	-115.2039311	GW	5/1/2002	-122
404335115123801	176 N33 E60 21BDCD1	40.72657519	-115.2113884	GW	10/10/2002	-127

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B. DEUTERIUM DATA FOR REGIONAL / DEEP-INTERMEDIATE GROUNDWATER SAMPLES.

(GW = groundwater other than spring)

NWIS Site Number	Site Name	Latitude (NAD83)	Longitude (NAD83)	Site Type	Sample Date	δD (‰)
375346114133301	198 N01 E69 35CC 1 SPRING	37.89607437	-114.2266501	Spring	4/8/1985	-101
380531114534201	181 N03 E63 27CAA 1 USGS-MX (N. DRY LAKE)	38.09190245	-114.8958427	GW	6/19/2003	-107
380758115204601	172 N03 E59 10BD 1 USGS-MX (COAL VALLEY WELL)	38.13745091	-115.3397482	GW	1/15/1981	-110
					6/25/2003	-108
380845114533601	181 N03 E63 03DCC 1	38.14579063	-114.8941756	GW	12/10/1980	-108
381440114323301	202 N05 E66 35DC 1 DODGE WELL	38.24440284	-114.5433287	GW	6/7/1985	-107
381626114540801	180 N05 E63 20CC 1 SILVER KING WELL	38.27394444	-114.902111	GW	9/2/2005	-89.3
381943114562201	180 N06 E63 31DCAC1 LEWIS WELL	38.32871944	-114.9394833	GW	9/2/2005	-98.2
382105115104801	207 N06 E60 25BDAD1 MOON RIVER SPRINGS	38.35161611	-115.1816853	Spring	4/27/1982	-120
382120114352101	183 N06 E66 29ABC 1 LAKE VALLEY WELL	38.3555115	-114.5899978	GW	6/7/1985	-111
382259115090801	207 N06 E61 18AADA1 NDW - HOT CREEK SPRING	38.38300476	-115.1533508	Spring	5/20/1992	-119
					9/25/2004	-120.5
					1/24/2005	-119
					5/18/2005	-118.6
					8/14/2005	-117.4
					11/6/2005	-119.1
382318115075801	207 N06 E61 09CCBB1 HOT CREEK CAMPGROUND WELL	38.38828281	-115.1336279	GW	7/19/1981	-118
382513114312001	183 N07 E66 36C 1 USBLM - MUSTANG WELL	38.42023269	-114.5230515	GW	11/8/2005	-114.6
382517115012001	207 N07 E62 33BCCC1 FLAG SPRING 3	38.42133994	-115.0230685	Spring	1/17/1984	-105
382620115340801	173B N07 E57 28ACBD1 BULLWHACKER SPRING	38.43882565	-115.5697517	Spring	6/15/1983	-114
382624115004001	207 N07 E62 28ABDC1 BUTTERFIELD SPRING	38.43967317	-115.0116792	Spring	7/19/1981	-105
382807114521001	180 N07 E63 14BADD1 USGS-MX (CAVE VALLEY)	38.46856293	-114.8702855	GW	7/10/2003	-105
383114115123401	207 N08 E60 27D 1 USBLM	38.52050018	-115.2102965	GW	7/23/1986	-118.5
383116115324601	173B N08 E57 27DACC2 BITTERFIELD SPRING	38.52104626	-115.5469732	Spring	6/15/1983	-116
383307114471001	180 N08 E64 15BCBC1 USBLM	38.55189544	-114.7869502	GW	11/8/2005	-104.6
					11/8/2005	-103.9
383325114134901	196 N08 E69 15B 1	38.5571762	-114.2247106	GW	8/31/2005	-114
383346115313801	173B N08 E57 11DDB 1 BLUE EAGLE SPRINGS	38.56299073	-115.5283617	Spring	7/17/1981	-114
383458114473601	180 N08 E64 04ABDD1 USBLM	38.58300592	-114.7933397	GW	7/23/1986	-102
383533114102901	196 N08 E70 06B 1 USBLM - MONUMENT WELL	38.59162039	-114.1683206	GW	10/5/2005	-113.4
383540115081801	207 N09 E61 32DABC1 MOORMAN SPRING	38.59466729	-115.1391836	Spring	7/18/1981	-119
383607115023801	207 N12 E62 31D 1	38.85577647	-115.0461277	GW	7/23/1986	-112
383730115025201	207 N09 E62 19A 1 EMIGRANT SPRINGS	38.62494658	-115.0486255	Spring	7/18/1981	-108
383813114380901	183 N09 E65 13CBAA1	38.63686111	-114.63575	GW	5/20/1992	-112
					10/19/2005	-111.1

APPENDIX B. DEUTERIUM DATA FOR REGIONAL / DEEP-INTERMEDIATE GROUNDWATER SAMPLES (CONTINUED).

NWIS Site Number	Site Name	Latitude (NAD83)	Longitude (NAD83)	Site Type	Sample Date	δD (‰)
383826114051201	196 N09 E70 14DABD1 20A	38.64041667	-114.0867778	GW	10/5/2005	-112.7
383915114375901	183 N09 E65 12CA 1 SOUTH BIG SPRING	38.65411692	-114.6338912	Spring	4/4/1985	-111
383922114375901	183 N09 E65 12BD 1 NORTH BIG SPRING	38.65606134	-114.6338912	Spring	4/4/1985	-112
384152114075001	195 N10 E70 33ACBB1 BIG SPRING	38.69772997	-114.1313764	Spring	6/19/1992	-111
					1/22/2005	-112.2
					5/20/2005	-109.8
					7/13/2005	-112.2
					8/13/2005	-112.2
					11/8/2005	-110.3
384226114050601	195 N10 E70 25CBC 1 BARCASS 3A	38.70723012	-114.0859586	GW	7/14/2005	-111.1
384245115101601	207 N10 E61 19	38.7125	-115.1711111	GW	7/23/1986	-120
384309115045901	207 N11 E61 23AA 1	38.71911076	-115.0839049	GW	7/23/1986	-111
384331114043401	195 N10 E70 24BC 1 BARCASS 2A	38.72525767	-114.0769863	GW	7/14/2005	-120.8
384454115101701	207 N10 E61 07	38.74833333	-115.1713889	GW	7/23/1986	-119
384521114043801	195 N10 E70 12	38.75583333	-114.0772222	GW	9/1/2005	-109.8
384534114495301	180 N10 E64 06BDA 1 ROBBERS ROOST WELL	38.75928013	-114.8323709	GW	7/18/2005	-107.5
384620114313601	184 N11 E66 35DBAC1 (S. FOX FLOWING WELL)	38.77217133	-114.5275004	GW	7/6/1983	-113
					8/30/2005	-111.8
384640114280101	184 N11 E67 32AADA1 SPET1W	38.77766667	-114.4670556	GW	9/3/2005	-113
384702114034101	195 N11 E70 36BD 1 USGS-MX	38.7838401	-114.0622088	GW	9/1/2005	-108.7
384803115133001	207 N13 E60 33A 1 WILLIAM HOT SPRING	38.94771675	-115.2289117	Spring	4/29/1982	-118
385158115000401	207 N11 E62 04AABA1 LUND SPRING	38.849944	-115.0033487	Spring	4/27/1982	-113
385516114502101	179 N12 E63 12BDAB1	38.91994423	-114.8461237	GW	1/19/1981	-117
385521114503601	179 N12 E63 12AB 1 USGS - S STEPTOE MX WELL	38.9224442	-114.8441793	GW	7/16/2003	-115
385530115044601	207 N12 E61 12DBDD1 NICHOLAS SPRING	38.91244224	-115.0611289	Spring	4/27/1982	-124
385538115045701	207 N12 E61 02AC 1 COLD SPRINGS - PRESTON	38.92716391	-115.083352	Spring	7/16/1981	-121
					6/16/1983	-126
385540115045701	207 N12 E61 02ACAB1 PRESTON BIG SPRING	38.93355277	-115.0814075	Spring	9/25/2004	-122.6
					1/24/2005	-122.4
					5/21/2005	-120
					8/14/2005	-121.2
					11/6/2005	-120.4
385546114250501	184 N12 E67 02 1 CEDAR SPRINGS	38.92938889	-114.4181667	Spring	7/12/2005	-107.4
385613114250401	184 N12 E67 02ACBA1 USBLM (SHOSHONE POND WELL)	38.9363354	-114.4188885	GW	7/6/1983	-109
					5/27/1992	-108
					1/22/2005	-110.3
					5/20/2005	-108.1
					7/12/2005	-108.6
					8/12/2005	-108.6
					11/8/2005	-108.2

APPENDIX B. DEUTERIUM DATA FOR REGIONAL / DEEP-INTERMEDIATE GROUNDWATER SAMPLES (CONTINUED).

NWIS Site Number	Site Name	Latitude (NAD83)	Longitude (NAD83)	Site Type	Sample Date	δD (‰)
390352114305401	184 N14 E66 24BDDD1 USGS-MX (SPRING VALLEY N.)	39.0643885	-114.5158375	GW	12/12/2005	-83
390457116323401	140A N14 E47 02A 1 SPRING	39.08243092	-116.5436853	Spring	1/1/1974	-128
390541114471301	179 N20 E64 17DD 1	39.09466419	-114.7877914	GW	6/14/1984	-121
390753116051701	155A N15 E52 35C 1	39.13132019	-116.0889457	GW	7/31/1987	-119
390754114303001	184 N15 E66 25DCAD1 LAP&W SPRING VLY WELL 1	39.13160994	-114.5091715	GW	9/16/1982	-125
390807114282501	184 N15 E67 29	39.13527778	-114.4736111	GW	6/18/1992	-121
391410116032101	155A N16 E53 30B 1	39.23076394	-116.0567233	GW	7/31/1987	-123
391637116021801	155A N16 E53 08BCBB1 FISH CREEK SPRINGS	39.27687467	-116.0392233	Spring	7/17/1981	-121
391755115555401	155A N17 E54 31	39.29861111	-115.9316667	GW	7/31/1987	-118
392411113514301	(C-16-18)22CAB-S1	39.4030001	-113.8627673	Spring	8/26/1981	-109
392527113290901	(C-16-15)13BAB-S1	39.4241138	-113.4866457	Spring	8/25/1981	-111
392731114382801	179 N18 E65 03DA 1 MCGILL SPRING	39.45855027	-114.6419581	Spring	7/15/1981	-122
392737114021201	(C-15-19)31CBD-S1	39.46013795	-114.0376336	Spring	5/28/2003	-120
					9/24/2004	-119.6
					1/22/2005	-120
					5/23/2005	-119.4
					7/17/2005	-119.7
					8/12/2005	-119.8
					11/8/2005	-122.8
392815113593001	(C-15-19)31BC -S1	39.47077689	-113.9924936	Spring	8/26/1981	-121
393212114545001	179 N19 E63 05 1 SPRING	39.536603	-114.9147453	Spring	7/15/1981	-123
393442114231801	184 N20 E67 26ABBD1 USBLM	39.57632936	-114.4002863	GW	11/9/2005	-124.3
393946114482301	179 N21 E63 24 1 SPRING	39.66271357	-114.8072445	Spring	1/1/1974	-128
394001114482600	179 N21 E63 24 2 SPRING	39.66688019	-114.8080779	Spring	5/28/1992	-125
394031114465601	179 N21 E64 19BDAD1	39.67521356	-114.7830774	GW	6/14/84	-125
394149114302201	184 N21 E66 15DBDD1 WILLOW SPRING	39.69681667	-114.5060667	Spring	10/20/2005	-122.7
394427115304301	175 N22 E57 25CCCC1 WELL AT ALLIGATOR RIDGE	39.74076416	-115.512819	GW	4/24/1984	-127
394436115270401	175 N22 E58 28CCCA1 RAM. RES. WTR SUPPLY WELL	39.74326466	-115.4519839	GW	7/19/1985	-130
394859115363701	154 N23 E56 36DD 1	39.81631861	-115.6111573	GW	7/31/1987	-122
394949114331802	184 N23 E66 31AB 2	39.83021387	-114.5558515	GW	7/27/1983	-126
395027113234001	(C-11-14)23DCD-S1	39.8407204	-113.3952033	Spring	5/29/2003	-111
395029113233601	(C-11-14)23DDC-S1	39.8413315	-113.3941477	Spring	8/27/1981	-111
395116114451301	179 N23 E64 20AA 1 LAP&W STEPTOE WELL 1	39.85437879	-114.7544678	GW	9/16/1982	-124
395226114215401	185 N23 E67 14BA 1 TIPPET SPRING (D24)	39.8738261	-114.3658457	Spring	8/24/2005	-123.3
395342114532701	179 N23 E63 06 1 HOT SP, CHERRY CREEK	39.89493356	-114.8916938	Spring	1/1/1974	-128
395846113591101	(C-10-19)04DDC-1	39.97944444	-113.9863889	GW	10/4/2005	-121.6
395935113584601	(C- 9-19)34CCD- 1	39.99299352	-113.980002	GW	10/4/2005	-121.7
400119115274801	176 N25 E58 29ABDC2 RV-1 SHALLOW	40.02194444	-115.4633333	GW	8/20/2002	-121
400119115274802	176 N25 E58 29ABDC3 RV-1 DEEP	40.02194444	-115.4633333	GW	8/20/2002	-127
					9/10/2003	-127

APPENDIX B. DEUTERIUM DATA FOR REGIONAL / DEEP-INTERMEDIATE GROUNDWATER SAMPLES (CONTINUED).

NWIS Site Number	Site Name	Latitude (NAD83)	Longitude (NAD83)	Site Type	Sample Date	δD (‰)
400131115254501	176 N25 E58 27BAAA1 RV-2	40.02527778	-115.4291667	GW	8/20/2002	-127
400131115254501	176 N25 E58 27BAAA1 RV-2	40.02527778	-115.4291667	GW	8/20/2002	-127
					8/21/2002	-123
400458114371401	179 N26 E65 34DABA2	40.08271069	-114.6214112	GW	7/27/1983	-129
400954114442401	179 N27 E64 34DCC 1	40.1649314	-114.7408587	GW	4/21/1983	-133
					6/14/1983	-132