2005

The effects of small-scale heterogeneities on aquifer storage recovery systems

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The Effects of Small-Scale Heterogeneities on Aquifer Storage Recovery Systems

by

William C. Hutchings

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science
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Date of Approval:
September 23, 2005

Keywords: Homogeneous, heterogeneous, variable-density, equivalent freshwater heads, ASR cycles, recovery efficiency

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Acknowledgements

I would like to extend my sincerest appreciation to Dr. Vacher, Major Professor, for his persistence, creativity, and thoughtfulness in ensuring that I completed this program, following an absence from the program due to personal reasons that appeared to have concluded this endeavor. In addition, collaboration with Dr. Vacher to research the subject matter of this thesis with both constant and variable-density models provided a solid foundation from which to evaluate ASR systems. His relentless interest in the subject matter and attention to detail concerning the geology, modeling, and interpretation of the results has led to an increased understanding of the fundamentals of ASR systems.

My gratitude is extended to Dr. Stewart, Supervisory Committee Member, for his guidance and critical review of all aspects of this study that significantly improved the quality of this thesis. His knowledge of groundwater and solute transport modeling and its relevance to the evaluation of ASR systems improved the course and outcome of this study.

I would like to extend my appreciation to Dr. Langevin, Supervisory Committee Member, for his suggestions and recommendations on the important aspects of ASR systems that needed to be evaluated. Dr. Langevin, the author of SEAWAT 2000, provided critical review of the study and modeling results significantly improving the quality of the thesis.

I am grateful to HSA Engineers and Scientists, especially Nicholas Albergo, CEO, for providing the computer and accessories required to efficiently run both the constant and variable-density models.

I would also like to thank James Rumbaugh of Environmental Simulations, Inc. and the technical staff of Waterloo Hydrogeologic, Inc. for their custom software.
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The Effects of Small-Scale Heterogeneities on Aquifer Storage Recovery Systems

William C. Hutchings

ABSTRACT

Aquifer Storage Recovery (ASR) is a recently developed (circa 1970) method (in the U.S.A.) to reduce groundwater-pumping stresses by injecting treated wastewater or surface water during periods of low demand into an aquifer followed by its recovery during periods of high demand. This method has been successfully implemented in numerous locations across the U.S.A. and worldwide, mainly due to the cost savings provided by the use of an unlimited reservoir (aquifer) in which to store water compared to the costs to construct surface impoundments and the inherent problems with storing such water for extended periods of time under evaporative atmospheric conditions.

This study describes the use of a highly discretized, three-dimensional, variable-density, numerical model (SEAWAT 2000) that incorporates the vertical variation of hydraulic conductivities, measured foot by foot, from a continuous core collected from the upper Floridan aquifer in southwest Florida, to evaluate the effects of small-scale heterogeneities on a hypothetical ASR system well. In order to compare these effects to the more general case in which average hydraulic parameters are used to characterize flow zones, a model is constructed with average parameters taken from the heterogeneous case. This study attempts to determine whether aquifer heterogeneities influence the performance of ASR systems, compared to assumed homogeneous conditions, by quantifying differences in recovery efficiency, horizontal and vertical flow due to advection and dispersion, plume dimensions, and storage periods. The results of this study indicate that 1) the geometry of the injectate plume under homogeneous and heterogeneous conditions differ significantly; 2) background formation total dissolved solids (TDS) concentrations significantly control the quantity of potable water available
for recovery; 3) dispersion exhibits a strong control on vertical mixing; 4) multiple injection cycles are required to generate a plume of potable water for long term storage; and 5) the percent recoveries under homogeneous and heterogeneous conditions are generally similar only in low-salinity background concentrations, due to the absence of the effects of buoyancy. Although the percent recoveries of the systems modeled are similar, the success of an ASR well is strongly controlled by the existence of heterogeneities, which essentially determine the degree of horizontal and vertical mixing of the injectate with formation waters.

Heterogeneities result in varying groundwater and mass transport paths during injection and recovery periods. Presumably these variations would need to be considered when evaluating potential variations in groundwater quality due to mixing between formation and injected water. Understanding potential variations in groundwater quality and treatment alternatives due to the presence of ASR-associated geochemical conditions, e.g., elevated arsenic concentrations, may also be improved with a detailed heterogeneous numerical model.
Introduction

Aquifer Storage Recovery (ASR) is a recently developed method (circa 1970) to conserve groundwater by injecting treated wastewater into an aquifer during periods of low demand, storing it there, and recovering it later during periods of high demand. This method has been successfully implemented in numerous locations across the U.S.A. including Florida, Virginia, New Jersey, Texas, Colorado, California, and Oregon, and worldwide including Israel, England, the Netherlands, and Australia (Pyne 1995). The attraction of ASR is mainly due to cost savings provided by the use of an unlimited reservoir (aquifer) in which to store water compared to the costs to construct surface impoundments and the inherent problems with storing such water for extended periods of time above ground (Pyne 1995). The success of this technology is due also to the rather common geologic and hydrogeologic conditions in which this water-conserving technology can be implemented.

ASR systems are generally represented with numerical models that incorporate general primary heterogeneities such as permeable and impermeable units and secondary post-depositional solution features and fractures. Due to the difficulty in characterizing the hydraulic parameters associated with more complex environments, groundwater models constructed to simulate ASR systems generally use average hydraulic parameters for permeable units (flow zones) and for low-permeability confining units. Although these models have proved successful in interpreting the main features of ASR systems, such as groundwater composition during implementation of the injection-storage-recovery cycles and determining the recovery efficiency of the system (Huntley and Bottcher, 1997; Missimer et al., 2002), the potential effects of small-scale heterogeneities are generally not evaluated. These features are generally not able to be included in most regional groundwater flow and solute-transport models due to the inherent difficulties and costs associated with obtaining such data.
This thesis describes the use of a highly discretized, three-dimensional, variable-density, numerical model (SEAWAT and SEAWAT 2000) that incorporates vertical variation of hydraulic conductivities, measured foot by foot, from a continuous core collected from the upper Floridan aquifer of a location in southwest Florida (Budd, 2002; Budd and Vacher, 2004; Vacher et al., in press) to evaluate the effects of heterogeneities on a hypothetical ASR system. In order to compare these effects to the more general case in which average hydraulic parameters are used to characterize flow zones, a model is constructed with average parameters to approximate the heterogeneous case. This study will attempt to determine whether aquifer heterogeneities influence the performance of ASR systems by comparing the results of heterogeneous and homogeneous cases in terms of quantified differences in recovery efficiency, horizontal and vertical flow due to advection and dispersion, plume dimensions, and storage periods. The study will also attempt to determine whether the factors that determine the success of an ASR system including groundwater geochemistry (Price and Pichler, in press), variations in hydraulic conductivity, variations in groundwater velocity, and mixing are affected by small-scale heterogeneities.
Geology and Hydrogeology of Model Setting

The Southwest Florida Water Management District (SWFWMD) Regional Observation Monitoring Program (ROMP) observation well (ROMP 20; DeWitt and Thompson, 1997) used for this study is located in Sarasota County, Florida (Fig. 1). This observation well, installed in 1991, is used to provide general hydrologic data and to monitor saltwater intrusion. The well penetrates the upper part of the Suwannee Formation at the top of the Upper Floridan aquifer. The most suitable zone for ASR in the confined Upper Floridan aquifer is typically at the top of the aquifer (Reese, 2002) which is represented by the Suwannee Formation in the general area of this study. This part of the aquifer exhibits low TDS concentrations and has a competent confining unit, both of which promote the development of a freshwater storage zone about an ASR well.

The lithologic parameters used for this study were obtained from measurements and analysis of a core (W-17087 at the Florida Geologic Survey) that were part of a regional study (Budd, 2001; Budd and Vacher, 2004) that characterized depositional facies and matrix permeability of the Upper Floridan aquifer (Fig. 2).

Grainstones and poorly washed grainstones dominate the Suwannee in ROMP 20. Measured matrix permeabilities of these facies range from $10^{-13.5}$ to $10^{-11.3}$ m$^2$, with median values of $10^{-12.5}$ and $10^{-12.9}$ m$^2$, respectively. The grainstones form relatively thick stratigraphic units that exhibit significant internal permeability variations. A dolostone with very low permeability (mostly <$10^{-13.8}$ m$^2$) occurs at the bottom of the formation. At the top is a number of well-cemented grainstones, pedogenetic limestones (i.e., paleosols), and matrix-supported paleokarst breccias that have similarly low permeabilities. Collectively, grainstones and poorly washed grainstones, which compose 66% of the entire interval, contain 91% of the matrix transmissivity (Budd and Vacher, 2004).
Figure 2. Lithologic cross-section and graphic illustration of matrix permeability variations
SWFWMD conducted an aquifer pumping test (APT) of the Suwannee in ROMP 20 in July, 1992. The tested zone was the 104-m (340-ft) interval from the top of the uppermost grainstone to the bottom of the lowermost grainstone. The results indicated a transmissivity of 1900 m²/day (20,500 ft²/day), for an average hydraulic conductivity of 18 m/day (60 ft/day) for the interval (DeWitt and Thompson, 1997).

In contrast to the result of the APT, the cumulated matrix permeabilities of the interval indicate a matrix transmissivity of 30 m²/day (419 ft²/day), for an average matrix hydraulic conductivity of the tested interval of 0.37 m/day (1.2 ft/day). The disparity between the APT transmissivity and the matrix transmissivity suggests the presence of permeability due to secondary porosity (Vacher et al., in press). The flow log (DeWitt and Thompson, 1997) clearly indicates enhanced flow in the upper part of the tested interval (spanned by the upper three grainstones). Although the curve of cumulated matrix permeability indicates that these upper Suwannee grainstones are more permeable than the grainstones lower in the formation (as indicated by the slope of the line), it is likely that the suggested secondary porosity is in this upper interval (Vacher et al., in press).

The occurrence of secondary porosity in the upper interval is indicated also by gaps in the core recovery of 17087. The core was described in 30-cm sections (footages). Out of the 340 such footages across the tested interval, 23 of them had less than 90% recovery. Although these 23 footages had less than complete core recoveries, there were enough pieces in the gaps for Budd (2001) to describe facies and obtain matrix permeabilities (Budd 2001). The upper cluster (six footages at 10-14 m depth) is mud-supported breccia indicative of paleokarst. Ten of the others are tightly cemented grainstones with anomalously low (for grainstone) permeabilities of $10^{-14}$ to $10^{-13.5}$ m², suggesting brittle layers (Vacher et al., in press). Seven of these footages occur successively in a 2-m interval right at the break in slope of the flow log. All the other footages with missing core were isolated. Thus, overall, paleokarst and brittle, cemented grainstones (i.e., fracture zones) can be plausibly hypothesized as the reasons for the missing core intervals and, by implication, the cause of the secondary porosity and enhanced flow (Vacher et al., in press).
Assuming that all the disparity between the APT transmissivity and the matrix transmissivity is due to secondary permeability and that the quantitative difference between the two can be attributed to the 23 footages (7 m), then the hydraulic conductivity of the thin zones of secondary porosity works out to be 290 m/day (960 ft/day) (Vacher et al., in press).
Previous Work

Fundamental work on ASR wells in Florida was conducted by R.D.G. Pyne and discussed in several publications (Pyne, 1995; Pyne et al., 1996; Pyne, 2003). These publications discuss the development and practical applications of ASR wells in terms such as efficiency, water-quality problems, and well characteristics from several sites located in Florida and from various locations in Virginia, New Jersey, Texas, Colorado, Nevada, and California (Pyne, 1995). A detailed summary of the history and implementation of ASR systems in Southern Florida is also provided in Inventory and Review of Aquifer Storage and Recovery in Southern Florida by Reese (2002).

Modeling studies of ASR wells in the Floridan aquifer of Florida under variable-density conditions have been conducted of ASR wells in order to gain an understanding of the various factors that affect the injection-storage-recovery process and the water quality of the injected plume (Merritt, 1997; Missimer et al., 2002). A detailed study of the effects of aquifer heterogeneity on ASR systems was previously conducted in the San Diego Formation that included flow-velocity measurements and groundwater modeling with MODFLOW and MT3D (Huntley and Bottcher, 1997). Although the use of MODFLOW and MT3D to model the effects of groundwater flow, mixing, and solute transport during injection, storage, and recovery has been successfully conducted and described (Vacher et al., in press) in aquifers of low total dissolved solids (TDS), evaluating most ASR wells that are open or screened in aquifers with background TDS concentrations between slightly brackish (Peace River, Florida) and saline (Marathon Key, Florida), requires the use of a variable-density groundwater flow and transport model.

Examples of variable-density flow and transport models that have been used to evaluate ASR wells have included the U.S.G.S. models SUTRA (Voss, 1986; 2003); HST3D (Kipp, 1987), SEAWAT (Guo et al., 1998; Langevin and Guo, 1999), and SEAWAT 2000 (Langevin et al., 2003), among others. SUTRA was used to evaluate the
potential for the implementation of ASR wells in the partly-confined aquifer underlying a barrier island of Cape Hatteras as part of a study of to evaluate injection and storage of groundwater in the shallow surficial aquifer (Tarbox and Hutchings, 2003). A model was constructed with HST3D (Yobbi, 1997) to evaluate the effects of operational factors on the recovery efficiency of a well in Pinellas County, Florida. The studies described above by Missimer et. al. were conducted using SEAWAT.

The hydraulic characteristics of the sediments used in this study were obtained from a previous study of the matrix permeability of the Floridan aquifer (Budd and Vacher, 2004) and from the results of hydraulic testing conducted by the Southwest Florida Water Management District (SWFWMD) (Dewitt and Thompson, 1997). Most recently, these data were used in a model that was used to evaluate the effects of heterogeneity on the geometry of the ASR “bubble” (Vacher, et al., in press). The model used for the latter study was constructed with Visual MODFLOW Version 3.0 by Waterloo Hydrogeologic, Inc. (WHI). This model was constructed with MODFLOW 2000 and also included 200 layers, which required a customized version of Visual MODFLOW 3.0 available through WHI; however, MODFLOW 2000 is a constant-density model and the effects of buoyancy on the plume geometry could not be evaluated. In order to create the injectate plume, a tracer with a concentration of 1,000 mg/L was injected into an aquifer with a background concentration of 0.0 mg/L. The model results should closely resemble the simulation results using a variable-density model at low-TDS background concentrations and, therefore, the effects of heterogeneity and bubble or plume geometry were very well represented.
Methods

Description of ASR Technology

ASR is defined as the storage of water in a suitable aquifer through a well during times when water is available, and recovery of the water from the same well during times when it is needed (Pyne 1995). The injection phase usually takes place during the part of the year when water supplies are high and a surplus exists. During the injection phase, the injectate invades the aquifer and displaces native formation water. Due to advection and dispersion, mixing takes place during injection along the leading edge of the front forming the transition zone. The injected water that occurs between the well and the transition zone is referred to as the flushed or storage zone. Beyond the transition zone occurs native groundwater, otherwise known as the uninvaded zone. These characteristic zones associated with an ASR well are shown on Figure 3.

The storage period, which can either be omitted or range from days to months, depends on the available water needs and aquifer characteristics. In order for an ASR system to exhibit maximum recovery of injected water, repetitive cycles of injection, storage and recovery need to be implemented. With increasing injection and recovery cycles, the mixing of injected water with native groundwater is reduced and mixing of injected water occurs primarily within the existing transition zone. With each cycle, the volume of the storage zone increases, thereby generally increasing the volume of recoverable water. The entire volume of injected water is generally not recoverable after a single injection and it is only, after repetitive cycles, that the recovery of injected water may approach 100% (Pyne, 1995).
Model Description

The models used for this study are constructed with the three-dimensional, finite-difference, variable-density, numerical model SEAWAT 2000. SEAWAT (Guo and Bennet, 1998), the predecessor to SEAWAT 2000, is a code that coupled MODLFOW-88

![Diagram of typical ASR well zones](image)

*Figure 3. Typical ASR well zones*
and MT3D96 (Zheng, 1996) that was subsequently revised to include MT3DMS (Zheng and Wang, 1998) and modifications to the flow equation and boundary fluxes (Langevin and Guo, 1999). SEAWAT 2000 specifically couples MODFLOW 2000 (Harbaugh et al., 2000) and MT3DMS (Zheng and Wang, 1999).

MODFLOW 2000 generates the velocity field based on the equivalent hydraulic head distribution, and MT3DMS is used to simulate solute transport, which includes multiple species including sodium chloride as salinity or TDS in addition to tracers, and contaminants. The velocity field is continuously updated as the concentration and density distributions change. The head output from SEAWAT is a set of equivalent freshwater heads, while the output from SEAWAT 2000 is a set of actual field heads. Although the actual field heads are the output for SEAWAT 2000, the velocity vectors and groundwater flow mass balance enable determination of groundwater flow direction and flow through model cells.

Most of the simulations used for this study are conducted with SEAWAT 2000. Simulations with SEAWAT were also run in order to evaluate the distribution of equivalent hydraulic heads.

The equivalent freshwater heads used in SEAWAT and SEAWAT 2000 represent the heads measured in the field under constant density conditions. The actual field heads (h) and equivalent freshwater heads (h_f) are calculated as follows:

\[
\begin{align*}
    h &= \rho_f / \rho * h_f + \rho - \rho_f / \rho \ h_f / Z \quad \text{and} \quad h_f = \rho / \rho_f * h - \rho - \rho_f / \rho_f \ h_f / Z
\end{align*}
\]

where: \( \rho \) = density of formation water (ML\(^{-3}\)); 
\( \rho_f \) = density of freshwater (ML\(^{-3}\)); and 
\( Z \) = elevation of measuring point (L)

The governing equation, written in terms of equivalent freshwater heads, for variable-density groundwater flow is:

\[
\frac{d}{d \alpha} [\rho K_{\alpha \alpha} (dh_f / d \alpha + \rho - \rho_f / \rho f * dZ / d \alpha)] + \frac{d}{d \beta} [\rho K_{\beta \beta} (dh_f / d \beta + \rho - \rho_f / \rho f * dZ / d \beta)]
\]
\[
+ \frac{d}{d\gamma} \left[ \rho K_f (dh_f / d\gamma + \rho - \rho_f / \rho_f * dZ/d\gamma) \right] = \rho S_f \frac{dh_f}{dt} + \theta dp/dC \frac{dC}{dt} - \rho_s q_s
\]

where: $\alpha$, $\beta$, and $\gamma$ are orthogonal coordinate axes, aligned with the principal directions of permeability;

$K_f$ = equivalent freshwater hydraulic conductivity (LT\(^{-1}\));

$S_f$ = is equivalent freshwater specific storage (L\(^{-1}\));

$t$ = time (T);

$\theta$ = effective porosity (dimensionless);

$C$ = solute concentration (ML\(^{-3}\));

$\rho_s$ = fluid density source or sink water (ML\(^{-3}\));

$q_s$ = volumetric flow rate of sources and sinks per unit volume of aquifer (T\(^{-1}\)).

In SEAWAT 2000, fluid density is a linear function of solute concentration and does not take into consideration the effects of temperature and pressure. The relationship between solute concentration and density is:

\[
\rho = \rho_f + \frac{d\rho}{dC} C
\]

The governing equation for coupled variable-density flow is solved using the following finite-difference approximation (Guo and Langevin, 2002). The following equation is written in terms of one-dimension or columns of a three-dimension model; however, similar equations would exist for the rows and layers:

\[
\rho i + \frac{1}{2}, j, k^{CC} (hf^m, i+1, j, k- hf^m, i, j, k) + \rho i - \frac{1}{2}, j, k^{CC} (hf^m, i-1, j, k- hf^m, i, j, k) + P i, j, k hf^m, i, j, k - \rho_i, j, k S_f, i, j, k V i, j, k hf^m, i, j, k / t^m - t^{m-1} = \rho_i, j, k S_f, i, j, k V i, j, k + -hf^m, i, j, k + + Qi, j, k - Di, j, k + Vi, j, k R i, j, k^g
\]

where: $i, j, k =$ cell indices

$hf^m$ = equivalent freshwater head at cell $i, j, k$ at time step $m$ (L);

$\rho$ = fluid density used to convert volumetric to mass flux (ML\(^{-3}\));

$CC$ = hydraulic conductivity in the column (L\(^2\)T\(^{-1}\));
Pi, j, k = the sum of head coefficients from source and sink terms (ML^{-1}T^{-1});
Vi, j, k = cell volume (L^3);
Qi, j, k = sum of constants from source and sink term (MT^{-1});
Di, j, k = sum of relative density difference terms (MT^{-1}); and
Ri, j, k = change in fluid mass resulting from concentration change (ML^{-3}T^{-1})

SEAWAT 2000 was run with the proprietary [Environmental Simulations, Inc. (ESI)] graphical user interface (GUI) Groundwater Vistas (GV) Version 4.0 (Rumbaugh, 2004). Construction of this model required that the standard version of GV be revised to accommodate the 200-layer model design. The revision was performed by ESI.

General Model Construction

The model has dimensions of 7,638 by 7,638 m and the cell grids used for the models are similar with 38 rows and 40 columns (Fig. 4). The grid cell dimensions in the center of the model are 85 by 85 m and are kept constant in the vicinity of the well to minimize numerical dispersion associated with the solute-transport solution. These cells expand in both the X and Y directions. The row spacing was expanded to 1045 m and the columns were expanded to 960 m. The first and last columns of the model were assigned a spacing of 85 m, to accommodate specified-head boundaries, as discussed in the following paragraph. The model was constructed with 200 layers representing a total thickness of 61 m (200 ft). Each layer was assigned a thickness of 0.305 meters. The injection-recovery well was assigned to a central cell with dimensions of 85 by 85 m. The cell dimensions for the well were not further reduced in size, in order to minimize convergence problems that could result from the large number of layers. Although the head in the well cannot be accurately simulated with these cell dimensions, the head distribution in the vicinity of the well should be accurate.

The model is intended to simulate a confined aquifer, so the top and bottom of the model were assigned “no flow” boundaries. In order to simulate a flow system with a negligible gradient that would not influence the groundwater flow system, the west side
Figure 4. Finite difference model grid and boundaries

Note: Top and Bottom = No Flow Boundaries
Top Elevation = 0.0 m
Bottom Elevation = -61 m
200 Layers; delta z = 0.305 m
delta x and y = 85 m in vicinity of well
CHD = Constant Head Boundary
of the model was assigned a specified head of 202.1 m, and the east side was assigned a
specified head of 202.2 m.

These cells were assigned varying TDS concentrations from 1.0 kg/m$^3$ to 35
kg/m$^3$, in order to evaluate the effects of buoyancy created by increases in background
concentrations. These boundaries resulted in a horizontal hydraulic gradient of 0.000013
and westward flow. The injection-recovery well was simulated as a fully-penetrating
well. The model design parameters are provided in Table 1. The construction of this
model is consistent with standard groundwater flow and solute-transport design as

The hydraulic conductivities used for the model represent measurements
performed with a mini-permeameter. The measurements were performed every foot over
the 200-foot section modeled and only represent a portion of the measurements
conducted for a previous study (Budd and Vacher, 2004) to evaluate depositional and
hydraulic characteristics of the upper Floridan aquifer. The distribution of hydraulic
conductivity used for the models is provided in Table 2. For the heterogeneous cases,
the hydraulic conductivities in the x, y, and z directions were constant (isotropic);
however, for the homogeneous case the harmonic mean of the horizontal hydraulic
conductivity was used for the vertical hydraulic conductivity. The longitudinal ($\alpha_L$),
transverse ($\alpha_T$), and vertical ($\alpha_V$) dispersivities ranged from $\alpha_L = 21$ to 5.25 m, $\alpha_T = 2.1$
to 0.525 m, and $\alpha_V = 0.21$ m to 0.0525 m. The longitudinal dispersivity is at the upper
end of representative field-scale values for limestone aquifers (Fetter, 1999). This value
produces a Peclet number ($\text{Pe} = dx/\alpha_L$) of 4.3 in the vicinity of the well, conforming
broadly to the guidelines of Anderson and Woessner (1991) and Zheng and Bennett
(2002). Diffusion was not simulated in these models. The model was assigned a specific
storage of $2.12e^{-7}$, a specific yield of 0.15, and an effective porosity of 20%.
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<td>$K_x = K_y = K_z = \text{variable }^*$</td>
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<td>Maximum Fluid Density</td>
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Note $^*$ = see Table 2

$K_x$ = horizontal hydraulic conductivity in m/day
$K_y$ = transverse hydraulic conductivity in m/day
$K_z$ = vertical hydraulic conductivity in m/day
$\alpha_l$ = longitudinal dispersivity in meters
$\alpha_t$ = transverse dispersivity in meters
$\alpha_z$ = vertical dispersivity in meters
$n$ = total porosity
$ne$ = effective porosity
mg/L = milligrams per Liter
NS = Not Simulated
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Table 2. Continued

Note:
- ft = foot
- m = meter
- ft bls = feet below land surface
- m² = meter squared
- k = permeability
- K = hydraulic conductivity
- ft/day = feet per day
- m/day = meter per day
Modeled Simulations

A variety of simulations were run to compare the injection plume configurations or “bubbles” simulated in homogeneous and heterogeneous conditions. The plume configuration is described by the distribution of TDS concentrations. The simulations that were run to compare homogeneous and heterogeneous aquifer conditions included a background concentration of 1000 mg/L TDS and an injectate concentration of 0.0 mg/L. Although in reality the injectate could typically have a greater TDS concentration, e.g., 200 mg/L, the injectate concentration used in these simulations should highlight the potential differences between the two hydrogeologic conditions. All simulations were run as transient simulations for 150 days to allow the hydraulic heads to achieve a steady-state condition. After steady-state initial conditions (hydraulic heads) were achieved, the simulations included a 250-day injection period, a 250-day storage period, and a 250-day recovery period. The injection and extraction rates were constant at 1514 m$^3$/day.

The Pre-Conditioned Gradient (PCG2) solver was used to solve the flow equation and the Implicit Finite Difference solver with upstream weighting was used to solve the transport equation. An initial time step of 0.01 days was used for the simulations. The single ASR cycle simulations consisted of 18 stress periods, each of which consisted of 50 days. The extended storage and multiple cycle simulations included additional stress periods; however, the duration of each stress period was held constant at 50 days.

Due to the potential buoyancy of freshwater injected into a brackish aquifer, simulations were run to determine the TDS concentration at which buoyancy effects become apparent and tend to affect the plume distribution and recovery efficiency. Simulations with background concentrations of 2,500 mg/L, 5,000 mg/L, 10,000 mg/L, 15,000 mg/L, and 35,000 mg/L were run for heterogeneous conditions. Although all of these simulations were run with injection and withdrawal rates of 1514 m$^3$/day, additional simulations with background concentrations of 2,500 and 15,000 mg/L were run with injection and withdrawal rates of 9462.5 m$^3$/day (2,500,000 gallons per day). The increased rates were used to ensure the development of storage zones with TDS concentrations less than 500 mg/L, which would enable the comparison of recovery efficiencies.
During the operation of an ASR system, groundwater can potentially be stored in the aquifer for extended periods of time, without undergoing significant mixing with brackish, background formation water. This is a major advantage of the ASR technology that allows the aquifer to act as a natural reservoir for long-term storage without affecting groundwater quality. In order to evaluate the potential for extended storage under heterogeneous conditions, a simulation was run that included a 250-day injection period (with a background concentration of 1,000 mg/L), a 1175-day storage period, and a 100-day recovery period.

Hydrodynamic dispersion, which consists of mechanical dispersion and molecular diffusion, is a non-steady, irreversible process that decreases the recovery of a tracer because the portion of the flow domain occupied by the tracer as a result of hydrodynamic dispersion and the flow field is always greater than that predicted by the flow field alone (Bear, 1988). Dispersion of injected water in a brackish aquifer is a significant factor that increases mixing and, therefore tends to decrease water quality of the plume and the percent recovery of the ASR system. In order to evaluate the effects of dispersion under heterogeneous conditions, simulations with $\alpha_L = 0.0 \text{ m}, 0.5 \text{ m}, 5.25 \text{ m}, 10.5 \text{ m}, \text{ and } 21 \text{ m}; \alpha_T = 0.0 \text{ m}, 0.05 \text{ m}, 0.525, 1.05, \text{ and } 2.1; \text{ and } \alpha_V = 0.0 \text{ m}, 0.005 \text{ m}, 0.0525 \text{ m}, 0.105 \text{ m}, \text{ and } 0.21 \text{ m}$ were run. These simulations were run to evaluate the hysteresis exhibited between the TDS distribution following injection and the distribution following recovery, i.e., to determine if dispersion is solely responsible for the inability of a pumping well to recover 100% of the injectate, following an equal period of injection.

In addition, the percent recovery of injected water is an indication of the suitability of the aquifer conditions to the operation of an ASR system. The percent recovery tends to increase as the volume of injected water is increased. Typically, water is injected and recovered in cycles to improve the percent recovery. In order to determine the percent recovery associated with the operation of an ASR system under the heterogeneous conditions, a cycled simulation was run to represent potential conditions under which an ASR system may be operated. A single cycle simulation consisted of a 250-day injection, 250-day storage, and 150-day recovery. The following cycles omitted the storage periods and were represented by 250-day periods of injection followed by
100-day periods of recovery. An additional recovery period of 250 days was included following the third cycle. This condition may be implemented in reality where the storage period is technically feasible to be short or omitted. Under optimum conditions, the plume typically does not undergo significant changes (unless the hydraulic gradient is large) during the storage period. This cycled simulation was conducted to determine the potential changes that occur to plume dimensions and groundwater quality through time, as a result of multiple injection, storage, and recovery cycles under a minimal hydraulic gradient.
Model Simulation Results

Homogeneous Simulation

The results of the simulation of the homogeneous case (Table 3) revealed a distribution of sub-vertical, parallel, contours of hydraulic head during the injection (Fig. 5), storage (Fig. 6), and recovery periods (Fig. 7) and vertical, parallel contours of TDS concentrations throughout the injection (Fig. 8), storage (Fig. 9), and recovery periods (Fig. 10). The 500-mg/L TDS contour represents the extent of drinking water in the plume and the 900-mg/L contour represents the practical maximum extent of the plume, i.e., maximum value able to be contoured by the software, at the end of the injection, storage, and recovery periods: approximately 78 m and 180 m; 78 m and 180 m; and 0 m and 161 m, respectively. The TDS distribution at the end of the 250-day storage period exhibits a distribution generally similar to the distribution at the end of the injection period. This minimal perturbation to the injectate plume is due to the minimal regional gradient imposed across the model domain. The TDS distribution following the recovery period exhibits an increase in TDS concentrations; however, TDS concentrations throughout the former plume area remain below background, even though the recovery period is similar to the injection period. This phenomenon indicates that the concentration distributions during injection and recovery exhibit hysteresis, i.e., although the injectate is introduced at the same rate at which it is recovered, all of the injectate is not recovered. Since the horizontal hydraulic gradient is minimal and does not induce migration during storage, the loss of injectate is generally attributed to dispersion (Bear, 1988).

The concentration at the well is approximately 140 mg/L after 250 days of injection and 720 mg/L after 250 days of recovery. After 100 days of recovery (Fig. 11), the 900-mg/L contour occurs at 171 m and the concentration at the well is 540 mg/L.
Figure 6. Distribution of hydraulic heads after 200 days of injection into homogeneous aquifer with background concentration of 1,000 mEq/l.

Figure 6. Distribution of hydraulic heads after 200 days of storage in homogeneous aquifer with background concentration of 1,000 mEq/l.

Figure 7. Distribution of hydraulic heads after 250 days of recovery in homogeneous aquifer with background concentration of 1,000 mEq/l.
Figure 6. Distribution of TDS concentrations in 100 days of increase in homogeneous aquifer with background concentration of 1000 mg/L.

Figure 7. Distribution of TDS concentrations in 100 days of increase in homogeneous aquifer with background concentration of 100 mg/L.

Figure 8. Distribution of TDS concentrations in 100 days of increase in homogeneous aquifer with background concentration of 10 mg/L.

Figure 9. Distribution of TDS concentrations in 100 days of increase in homogeneous aquifer with background concentration of 1 mg/L.
Figure 11. Distribution of TDS concentrations after 100 days of recovery in a homogeneous aquifer with background concentration of 1,000 mg/L.

Note:
- Total simulation time = 600 days
- Contour interval = 100 mg/L
- cL - Longitudinal dispersivity = 21m
- Q = 400,000 gpd
- Vertical exaggeration = 5x
The recovery efficiency of an ASR well is defined as “the volume of water recovered after attaining a designated concentration, which in this case is the drinking water standard for chlorides of 250 mg/L that is approximately 500 mg/L TDS or salinity divided by the volume of water injected” (Pyne, 1995). Since 540 mg/L is practically similar to the drinking water standard for TDS, the percent recovery is calculated from the volume of water recovered (151,400 m$^3$) divided by the injected volume (378,500 m$^3$), which results in a percent efficiency of approximately 40%. This percent recovery is generally similar to the results obtained from simulations performed in the study by Vacher et al., (in press) using a constant density model. The model output for the homogeneous simulation is provided in Appendix A.

In order to evaluate and compare the recovery efficiencies between the homogeneous and heterogeneous cases with higher background concentrations, simulations were conducted with TDS concentrations of 2,500 and 15,000 mg/L with injection and recovery rates of 9462.5 m$^3$/day. The simulation with a background TDS concentration of 2,500 mg/L exhibited the following distances of the 500-mg/L and 2,450-mg/L isochlors (respectively) from the ASR well: 168 m and 489 m, respectively, following 250 days of injection and storage; and 0.0 m and 485 m, respectively following 47.8 days of recovery. The recovery efficiency calculated for this scenario is 19.2%.

The simulation with a background TDS concentration of 15,000 mg/L exhibited the following distances of the 500 and 14,500 mg/L isochlors (respectively) from the ASR well: 44 m and 473 m, respectively, following the initial 250 days of injection and storage; 0.0 m and 485 m, respectively following the first recovery period of 4.4 days; and 118 m and 591 m, respectively, following the second (246-day) injection period. The second recovery period was terminated after 23 days after which the 14,500 mg/L isochlor was located at a distance of 590 m from the well and the recovery efficiency calculated for this scenario is 9.3%.
Heterogeneous Simulation

The results of the simulation of the heterogeneous case revealed a distribution of hydraulic heads throughout the injection (Fig. 12) storage (Fig. 13), and recovery periods (Fig. 14) that varied with depth. In addition, TDS concentrations also varied with depth throughout the injection (Fig. 15), storage (Fig. 16), and recovery periods (Fig. 17). The distribution of TDS at the well after 250 days of recovery is presented in Fig. 18. Since hydraulic head depends on the density of the fluid, and TDS concentrations vary in the horizontal and vertical dimensions, the hydraulic heads are consistent with variations in TDS concentrations. Inspection of the cross-section of hydraulic heads indicates that the hydraulic gradients are greater in the intervals of lower hydraulic conductivity compared to those of the high-conductivity intervals. Simulations conducted with the constant-density model MODFLOW would exhibit vertical, parallel contours throughout an ASR cycle.

The cross sections of TDS concentrations reveal variations in the horizontal extent of penetration of the injectate with depth. These horizontal variations are due predominantly to the heterogeneous distribution of hydraulic conductivities. The layers representing intervals of highest conductivities exhibit the highest accumulations of the injectate and are associated with the greatest extents of penetration. In contrast, the layers of low hydraulic conductivity are not significantly penetrated by the injectate, therefore, concentrations in these areas near the well remain closer to the background concentration. Using the 500-mg/L contour, the maximum extent of penetration of potable groundwater after 250 days of injection occurs at the approximate depths of 15 and 37 m where the approximate horizontal extents are 122 m and 130 m, respectively. Using the 900-mg/L contour, the maximum horizontal extents of the plume at the depths of 15 and 37 m are approximately 253 and 289 m, respectively. Near the base of the model, the horizontal extent of the 500-mg/L contour occurs at approximately 25 m and the maximum extent occurs at 82 m.
Figure 12. Distribution of hydraulic heads after 200 days of injection into heterogeneous aquifer with background concentration of 1,000 mg/l.

Figure 13. Distribution of hydraulic heads after 200 days of storage in heterogeneous aquifer with background concentration of 3,000 mg/l.

Figure 14. Distribution of hydraulic heads after 200 days of recovery in heterogeneous aquifer with background concentration of 1,000 mg/l.
Figure 14: Distribution of TDS concentrations after 290 days of injection into heterogeneous aquifer with background concentration of 1,000 mg/L.

Figure 15: Distribution of TDS concentrations after 290 days of injection into heterogeneous aquifer with background concentration of 1,000 mg/L.

Figure 16: Distribution of TDS concentrations after 290 days of injection into heterogeneous aquifer with background concentration of 1,000 mg/L.

Figure 17: Distribution of TDS concentrations after 290 days of injection into heterogeneous aquifer with background concentration of 1,000 mg/L.
After 250 days of storage, the 500-mg/L contour at the approximate depths of 15 and 37 m occurs at the 113 m and 102 m, respectively. The maximum extent has decreased to approximately 251 and 282 m in these zones of high hydraulic conductivity. The horizontal extent of the injectate near the bottom of the model did not exhibit a significant decrease. The maximum extent of the plume after 250 days of storage appears to remain generally similar to the extent following injection. Using the 500-mg/L TDS contour to compare the plume dimensions after the injection and storage periods, it is apparent that subtle horizontal and vertical variations in the plume occur due to mixing that results from migration induced by variations in TDS and, consequently, density. Although the dynamic hydraulic gradient dissipated soon after the injection period, continued mixing appears to have occurred due to density variations and dispersion.

After 250 days of recovery, the 900-mg/L contour, at depths of 15 m and 37 m, occurs at approximately 216 m and 191 m, respectively from the well and the average concentration at the well is approximately 701 mg/L (Fig. 18). The graph of TDS vs depth (Fig. 18) indicates that the highest concentrations are exhibited by the high conductivity intervals at depths of approximately 15 and 37 m. Due to the higher velocity associated with these intervals, the low-TDS water arrives sooner at the well and is consequently replaced with higher-TDS water sooner than in the low conductivity intervals.

After 100 days of recovery, the 900-mg/L contour occurs at approximately 250 m at the depths of 15 and 37 m (Fig. 19) and the concentration distribution in the vicinity of the well ranges between 500 and 600 mg/L (Fig. 20). Because the model is heterogeneous, the concentration at the well was calculated by weighting the discharge from each layer to the well by its transmissivity. After 100 days of recovery, the concentration at the well under dynamic conditions is 550 mg/L, and the percent recovery is, therefore, approximately 40%. Comparing the plume dimensions, following injection and recovery, indicates that horizontal extent of the plume has decreased to approximately 250 m, at the 15-m and 37-m depths, from 253 and 289 m. This minor difference indicates that the recovery of the injected water is less than 100% and that the injection and recovery periods exhibit hysteresis. The model output for the heterogeneous simulation is provided in Appendix B.
Note: HC = Heterogeneous Case

Figure 18. Graph of TDS vs depth HC with background concentration of 1,000 mg/L after 250 Days of recovery (average TDS = 701 mg/L)
Figure 19. Distribution of TDS concentrations after 100 days of recovery in
heterogeneous aquifer with background concentration of 1,000 mg/L.

Note:
- Total simulation time = 750 days
- Contour interval = 100 mg/L
- dl = Longitudinal dispersivity = 21 m
- Q = 400,000 gpd
- Vertical exaggeration = 5x
Note: HC = Heterogeneous Case

Figure 20. Graph of TDS vs depth HC with background concentration of 1,000 mg/L after 100 days of recovery (average TDS = 530 mg/L)
Simulations with Varying Background TDS

The results of the simulations of the heterogeneous case with varying background TDS concentrations reveal distributions of TDS concentrations that significantly vary following the injection and recovery periods. The simulation with a background concentration of 1,000 mg/L exhibits a plume whose 500-mg/L contour occurs at a maximum distance of approximately 125 m from the well following 250 days of injection (Fig. 15) and storage (Fig. 16). Following the 250-day recovery period, the lowest-concentration contour in the vicinity of the well is 700 mg/L and, with the exception of a small accumulation in the center of the model, the 700-mg/L contour is positioned near the top of the model (Fig. 17).

In contrast, the simulation with a 2,500-mg/L-background concentration exhibited the 500-mg/L contour at a distance of approximately 31 m after 250 days of injection (Fig. 21) and storage (Fig. 22). Following the recovery period, the TDS concentrations near the center of the top of the model are approximately 1,700 mg/L and increase toward the base of the model where the concentrations are approximately 2,000 mg/L (Fig. 23). The TDS distributions after 250 days of recovery increase from the top to the bottom of the well, suggesting that significant density contrasts occur within the injectate plume. The density contrast is especially evident when the TDS distributions following the injection and storage periods are compared to the TDS distribution following recovery.

The simulation with a background concentration of 2,500 mg/L and injection and recovery rates of 9462.5 m$^3$/day exhibits TDS concentration distributions as follows. After 250 days of injection (Fig. 24), the 500-mg/L isochlor at depths of approximately 13.5 m and 37 m is located at 206 m and 197 m, respectively, from the ASR well; after 250 days of storage (Fig. 25), the isochlor occurs at 203 m and 162 m at depths of 13.5 and 37 m, respectively; and after 47 days of recovery (Fig. 26), most of the groundwater with a TDS less than 500 mg/L occurs near the top of the modeled section. The recovery efficiency for this scenario is 19%.

39
Figure 21: Distribution of TDS concentrations after 360 days of injection into heterogeneous aquifer with background concentration of 2,500 mg/L.

Figure 22: Distribution of TDS concentrations after 360 days of storage in heterogeneous aquifer with background concentration of 2,500 mg/L.

Figure 23: Distribution of TDS concentrations after 250 days of recovery in heterogeneous aquifer with background concentration of 2,500 mg/L.
Figure 24. Distribution of TDS concentrations after 250 days of injection into heterogeneous aquifer with background concentration of 2,500 mg/L.

Note:
Total simulation time = 250 days
Contour interval = 200 mg/L
Dl = Longitudinal dispersivity = 2 m
O = 2,500,000 gpd
Vertical exaggeration = 5x
Figure 25. Distribution of TDS concentrations after 250 Days of storage in heterogeneous aquifer with background concentration of 2,500 mg/l.

Note:
Total simulation time = 500 days
Contour interval = 200 mg/l
CL = Longitudinal dispersivity = 2 ft
Q = 2,500,000 gpd
Vertical exaggeration = 5x
Figure 26. Distribution of TDS concentrations after 47 days of recovery in heterogeneous aquifer with background concentration of 2,500 mg/l.

Note:
Total simulation time = 547 days
Contour interval = 200 mg/l
\( c_L \) = Longitudinal dispersivity = 21 m
\( Q \) = 2,500,000 gpd
Vertical exaggeration = 5x
The simulation with a background concentration of 5,000 mg/L exhibits concentrations, following injection (Fig. 27) and storage (Fig. 28), in the vicinity of the well of 750 mg/L and 1,000 mg/L in the highly permeable layers that occur at a depth of approximately 13.5 m and 37.5 m, respectively. After 250 days of recovery (Fig. 29), the lowest-concentration contour of 3250 mg/L is observed near the top of the model and concentrations increase to approximately 3,750 mg/L near the base of the model.

The simulation with a background concentration of 10,000 mg/L exhibits concentrations, following injection (Fig. 30) and storage (Fig. 31), in the vicinity of the well of 1,000 mg/L and 1,500 mg/L in the highly permeable layers that occur at a depth of approximately 13.5 m and 37.5 m, respectively. After 250 days of recovery (Fig. 32), the lowest concentration contour of 5,500 mg/L is observed near the top of the model, and the concentrations increase to approximately 7,500 mg/L near the base of the model.

The simulation with a background concentration of 15,000 mg/L exhibits concentrations, following injection (Fig. 33) and storage (Fig. 34), in the vicinity of the well of 2,500 mg/L and 1,500 mg/L in the highly permeable layers that occur at a depth of approximately 13.5 m and 37.5 m, respectively. After 250 days of recovery (Fig. 35), the lowest-concentration contours of 3,500 and 7,500 mg/L, respectively, are observed near the top of the model and concentrations increase to approximately 11,000 mg/L near the base of the model. Bouyancy stratification, which results in fresher water overlying more saline waters, appears to be evident from these results. The head distributions from this simulation following 250 days of injection (Fig. 36), storage (Fig. 37), and recovery (Fig. 38) were plotted in order to observe the potential effects that velocity variations may have on solute transport. The geometries of the head distributions are generally similar to the geometries of the TDS distributions. The significant variation of hydraulic head distributions among the injection, storage, and recovery periods suggests that velocity variations exist that, in part may be due to density contrasts, which could account for the distribution of mass. The effects of buoyancy are also clearly evident when comparing the injection-storage distributions to the recovery distribution.

The simulation with a background concentration of 15,000 mg/L and injection and recovery rates of 9462.5 m$^3$/day exhibits TDS concentration distributions as follows. After 250 days of injection (Fig. 39), the 500-mg/L isochlor at depths of approximately
Figure 27. Distribution of TDS concentrations after 250 Days of injection into heterogeneous aquifer with background concentration of 5,000 mg/l.

Note:
Total simulation time = 250 days
Contour interval = 250 mg/l
\( e_L = \text{Longitudinal dispersivity} = 21 \text{ m} \)
\( 0 = 400,000 \text{ gpd} \)
Vertical exaggeration = 5x
Figure 28. Distribution of TDS concentrations after 250 days of storage in heterogeneous aquifer with background concentration of 5,000 mg/L.

Note:
- Total simulation time = 500 days
- Contour interval = 250 mg/L
- cL = Longitudinal dispersivity
- Q = 400,000 gpd
- Vertical exaggeration = 5x
Figure 29. Distribution of TDS concentrations after 250 days of recovery in heterogeneous aquifer with background concentration of 5,000 mg/l.

Note:
Total simulation time = 750 days
Contour interval = 250 mg/l
cL = Longitudinal dispersivity = 21 m
Q = 400,000 gpd
Vertical exaggeration = 5x
Figure 30. Distribution of TDS concentrations after 250 days of injection into heterogeneous aquifer with background concentration of 10,000 mg/l.

Figure 31. Distribution of TDS concentrations after 250 days of storage in heterogeneous aquifer with background concentration of 10,000 mg/l.

Figure 32. Distribution of TDS concentrations after 250 days of recovery in heterogeneous aquifer with background concentration of 10,000 mg/l.
Figure 33. Distribution of TDS concentrations after 250 days of injection into heterogeneous aquifer with background concentration of 15,000 mg/L.

Note:
- Total simulation time = 250 days
- Contour interval = 1,000 mg/L
- $dL$ = Longitudinal dispersivity = 21 m
- $Q = 400,000$ gpd
- Vertical exaggeration = 5x
Figure 34. Distribution of TDS concentrations after 250 days of storage in heterogeneous aquifer with background concentration of 15,000 mg/L.

Note:
Total simulation time = 500 days
Contour interval = 1,000 mg/L
CL = Longitudinal dispersivity = 21 m
Q = 400,000 gpd
Vertical exaggeration = 5x
Figure 35. Distribution of TDS concentrations after 250 days of recovery in heterogeneous aquifer with background concentration of 15,000 mg/L.

Note:
Total simulation time = 750 days
Contour interval = 500 mg/L
$L_L$ = Longitudinal dispersivity = 21 m
$Q$ = 400,000 gpd
Vertical exaggeration = 5x
Figure 36. Distribution of hydraulic heads after 250 days of injection into heterogeneous aquifer with background concentration of 15,000 mg/L.

Note:
- Total simulation time = 250 days
- Contour interval = 0.2 m
- dL = Longitudinal dispersivity = 21 m
- Q = 400,000 gpd
- Vertical exaggeration = 5x
Figure 37. Distribution of hydraulic heads after 250 days of storage in heterogeneous aquifer with background concentration of 15,000 mg/l.

Note:
- Total simulation time = 500 days
- Contour interval = 0.2 m
- eL = Longitudinal dispersivity = 21 m
- Q = 400,000 gpd
- Vertical exaggeration = 5x
Figure 38. Distribution of hydraulic heads after 250 Days of recovery in heterogeneous aquifer with background concentration of 15,000 mg/L.

Note:
- Total simulation time = 750 days
- Contour interval = 0.1 m
- CL = Longitudinal dispersivity = 21 m
- Q = 408,000 gpd
- Vertical exaggeration = 5x
Figure 39. Distribution of TDS concentrations after 250 days of injection in heterogeneous aquifer with background concentration of 15,000 mg/l.

Note:
- Total simulation time = 750 days
- Contour interval = 1,000 mg/l
- cL = Longitudinal dispersivity = 21 m
- Q = 2,500,000 gpd
- Vertical exaggeration = 5x
13.5 and 37 m is located at 86 and 45 m, respectively, from the ASR well; after 250 days of storage (Fig. 40), the isochlor occurs at 52 m and 0.0 m (immediate vicinity of well) at depths of 13.5 m and 37 m, respectively, and after 4.4 days of recovery, most of the groundwater with a TDS concentration less than 500 mg/L occurs within 8 m of the top of the modeled section. After the second injection period of 246 days (Fig. 41), the 500-mg/L isochlor at depths of 13.5 m and 37.5 m occurs at distances of 170 m and 103 m, respectively, from the well. After the second recovery period of 15.9 days (Fig. 42), the 500-mg/L isochlor at depths of 13.5 m and 37.5 m occurs at distances of 99 m and 0.0 m, respectively, from the well. At the top of the modeled section, the 500-mg/L storage zone extends to a distance of 101 m from the well. The recovery efficiency for this scenario is 6.5%.

The simulation with a background concentration of 35,000 mg/L exhibits concentrations, following injection (Fig. 43) and storage (Fig. 44), in the vicinity of the well of approximately 5,000 mg/L in the highly permeable layers that occur at a depth of approximately 13.5 m and 37.5 m, respectively, and approximately 30,000 mg/L near the base of the modeled section. Unlike the simulations with lower background concentrations that tend to exhibit similar plume geometries after the injection period, these results exhibit less penetration into the high conductivity interval at a depth of approximately 37 m. In addition, the lowest TDS water (approximately 5,000 mg/L) occurs in the vicinity of the high-conductivity interval at approximately 13.5 m, suggesting that buoyancy and upward flow of the injected water has occurred. After 250 days of storage (Fig. 45) and recovery, the lowest-concentration contours of 10,000 and 17,000 mg/L are observed near the top of the model and concentrations increase to greater than 30,000 mg/L near the base of the model. These distributions also indicate the strong effects of buoyancy resulting in buoyancy stratification. The model output for the varying TDS background simulations is provided in Appendix C.
Figure 40. Distribution of TDS concentrations after 250 days of storage in heterogeneous aquifer with background concentration of 15,000 mg/L.

Note:
- Total simulation time = 750 days
- Contour interval = 500 mg/L
- $d_L = $Longitudinal dispersivity = 21 m
- $Q = 2,500,000$ gpd
- Vertical exaggeration = 5x
Figure 41. Distribution of TDS concentrations after 2nd injection period (346 days) in heterogeneous aquifer with background concentration of 15,000 mg/l.

Note:
Total simulation time = 750 days
Contour interval = 1000 mg/l.
\( \phi_L = \text{Longitudinal dispersivity} = 21 \text{ m} \)
\( Q = 2,500,000 \text{ gpd} \)
Vertical exaggeration = 5x
Figure 42. Distribution of TDS concentrations after 2^{nd} recovery period (15.9 days) in heterogeneous aquifer with background concentration of 15,000 mg/l.

Note:
Total simulation time = 750 days
Contour interval = 1000 mg/l
dl. = Longitudinal dispersivity = 21 m
Q = 2,500,000 gpd
Vertical exaggeration = 5x
Figure 43. Distribution of TDS concentrations after 250 days of injection into heterogeneous aquifer with background concentration of 35,000 mg/L.

Note:
Total simulation time = 250 days
Contour interval = 1,000 mg/L
dl = Longitudinal dispersivity = 21 m
Q = 400,000 gpd
Vertical exaggeration = 5x
Figure 44: Distribution of TDS concentrations after 250 days of storage in heterogeneous aquifer with background concentration of 35,000 mg/L.

Note:
Total simulation time = 500 days
Contour interval = 1,000 mg/L
\( cL \) = Longitudinal dispersivity = 21 m
Q = 400,000 gpd
Vertical exaggeration = 5x
Figure 45. Distribution of TDS concentrations after 250 days of recovery in heterogeneous aquifer with background concentration of 35,000 mg/L.

Note:
Total simulation time = 750 days
Contour interval = 1,000 mg/L
\( dL = \) Longitudinal dispersivity = 21 m
\( D = \) 400,000 gpd
Vertical exaggeration = 5x
Extended Storage Simulation

After 1175 days of storage (Fig. 46), the 900-mg/L contour at depths of 13.5 and 37 m is present at horizontal distances of 251 and 282 m, respectively, from the well. At the base of the model, the 900-mg/L contour is present at a distance of 83 m from the well. The 500-mg/L contour, at a depth of 13.5 m, occurred at 117 m, and at a depth of 37 m, the 500-mg/L contour occurs at a distance of 102 m from the well. At the base of the model, the 500-mg/L contour occurs at 23 m.

Following 100 days of recovery (Fig. 47), the horizontal extent of the 900-mg/L contour at the approximate depths of 13.5 and 37 m are 232 and 220 m, respectively. Near the base of the model, the 900-mg/L contour is present at approximately 110 m from the center of the well. The TDS concentrations in the vicinity of the well range between 500 and 600 mg/L. The average concentration in the well (Fig. 48) exceeds the TDS MCL; therefore, the recovery period is reduced to 78 days after which concentrations in the well were approximately 500 mg/L. The horizontal extent of the TDS plume after 100 days of recovery is slightly reduced compared to the distribution after 78 days of recovery. The percent recovery after 100 days of recovery is approximately 40%.

Following 78 days of recovery (Fig. 49), the horizontal extent of the 900-mg/L contour at the approximate depths of 13.5 and 37 m were 235 and 228 m, respectively. Near the base of the model, the 900-mg/L contour is present at approximately 105 m from the center of the well. The TDS concentration in the vicinity of the well is also approximately 500 mg/L. The model output for the extended storage simulation is provided in Appendix D.

Simulation with Varying Dispersivities

The simulation results using $\alpha_L$, $\alpha_T$, and $\alpha_V = 0.0$ m (Fig. 50) indicates that after 250 days of injection, the maximum horizontal extents of the 500-mg/L and 900-mg/L contours at depths of 13.5 m and 37.5 m, are approximately 231 m and 381 m, and 316 m and 461 m, respectively from the well. At the base of the model, the 900-mg/L contour
Figure 4a. Distribution of TDS concentrations after 1,175 days of storage in a heterogeneous aquifer with background concentration of 1,000 mg/l.

Note:
- Total simulation time = 1125 days
- Contour interval = 100 mg/l
- DL = Longitudinal dispersivity = 21 m
- Q = 400,000 gpd
- Vertical exaggeration = 8x

Figure 4b. Distribution of TDS concentrations after 1,175 days of storage in a heterogeneous aquifer with background concentration of 1,000 mg/l.

Note:
- Total simulation time = 1225 days
- Contour interval = 100 mg/l
- DL = Longitudinal dispersivity = 210 m
- Q = 400,000 gpd
- Vertical exaggeration = 8x
Note: HC - Heterogeneous Case

Figure 48. Graph of TDS vs depth HC with background concentration of 1,000 mg/l after 1175 days of storage-100 days recovery (average TDS = 550 mg/l)
Figure 49. Distribution of TDS concentrations after 1,175 days storage / 78 days recovery in heterogeneous aquifer with background concentration of 1,000 mg/L.

Note:
Total simulation time = 1503 days
Contour interval = 100 mg/L
εL = Longitudinal dispersivity = 21 m
Q = 400,000 gpd
Vertical exaggeration = 5x
occurs at a distance of 78 m. After 250 days of storage (Fig. 51), the horizontal extents of the 500 and 900 mg/L contours at the above depths are 203 m and 368 m, and 266 m and 441 m, respectively. At the base of the model, the 900-mg/L contour occurs at a distance of approximately 75 m. After 250 days of recovery (Fig. 52), the maximum extent of the 900 mg/L contour at depths of 13.5 m and 37.5 m occurs at approximately 350 m and 400 m, respectively, from the well and groundwater with TDS less than or equal to 500 mg/L is not present, due to excessive pumping.

The simulation results using \( \alpha_L, \alpha_T, \) and \( \alpha_V = 0.5 \) m (Fig. 53) indicate that after 250 days of injection, the maximum horizontal extents of the 500-mg/L contour at depths of 13.5 m and 37.5 m, are approximately 214 m and 290 m, respectively, from the well. After 250 days of storage (Fig. 54), the horizontal extents of the 500-mg/L contour at the above depths are 217 m and 290 m, respectively. After 110.5 days of recovery (Fig 55), the 500-mg/L contour occurs at approximately 175 m from the well at a depth of 13.5 m and approximately 195 m from the well at the depth of 37.5 m. Using a logarithmic regression equation between the average TDS concentrations in the well after 100 and 110.5 days of recovery, it is calculated that the concentration in the well would be 500 mg/L after 160 days of recovery; therefore, the recovery efficiency is estimated at 64%.

The simulation results using \( \alpha_L = 5.25 \) m, \( \alpha_T = 0.525 \), and \( \alpha_V = 0.0525 \) m indicates that after 250 days of injection (Fig. 56), the maximum horizontal extents of the 500-mg/L and 900-mg/L contours at depths of 13.5 m and 37 m, are approximately 163 m and 207 m, and 296 m and 368 m, respectively. After 250 days of storage (Fig. 57), the horizontal extents of the 500-mg/L and 900-mg/L contours at the same depths are 162 m and 197 m, and 298 m and 360 m, respectively. At the base of the model, the 900-mg/L contour occurs at a distance of 68 m. After 250 days of recovery (Fig. 58), the maximum extent of the 900-mg/L contour occurs at approximately 298 m from the well and groundwater with TDS less than or equal to 500 mg/L is not present, due to excessive pumping.

The simulation results using \( \alpha_L = 10.5 \) m, \( \alpha_T = 1.05 \), and \( \alpha_V = 0.105 \) m indicates that after 250 days of injection (Fig. 59), the maximum horizontal extent of the 500-mg/L and 900-mg/L contours at depths of 13.5 m and 37 m, are approximately 141 m and 168 m, and 275 m and 321 m, respectively. The 900-mg/L contour at the base of the model
Figure 5a: Distribution of TDS concentrations after 140 days of injection in heterogeneous aquifer (o = 0.0 m) with background concentration of 1,000 mg/l.

Figure 5b: Distribution of TDS concentrations after 210 days of injection in heterogeneous aquifer (o = 0.0 m) with background concentration of 1,000 mg/l.

Figure 5c: Distribution of TDS concentrations after 280 days of injection in heterogeneous aquifer (o = 0.0 m) with background concentration of 1,000 mg/l.

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Figure 53. Distribution of TDS concentrations after 250 days of injection in heterogeneous aquifer (eL = 0.5 m) with background concentration of 1,000 mg/l.

Note:
Total simulation time = 250 days
Contour interval = 100 mg/l
eL = Longitudinal dispersivity = 0.5 m
Q = 400,000 gpd
Vertical exaggeration = 5x
Figure 54. Distribution of TDS concentrations after 250 days of storage in heterogeneous aquifer (dL = 0.5 m) with background concentration of 1,000 mg/L.

Note:
Total simulation time = 500 days
Contour interval = 100 mg/L
dL = Longitudinal dispersivity = 0.5 m
Q = 400,000 gpd
Vertical exaggeration = 5x
Figure 55. Distribution of TDS concentrations after 110.5 days of recovery in heterogeneous aquifer (cL = 0.5 m) with background concentration of 1,000 mg/L.

Note:
Total simulation time = 610.5 days
Contour interval = 100 mg/L
cL = Longitudinal dispersivity = 0.5 m
Q = 400,000 gpd
Vertical exaggeration = 5x
Figure 56: Distribution of TDS concentrations after 250 days of injection into heterogeneous aquifer ($\text{cl} = 5.25 \, \text{m}$) with background concentration of 1,000 mg/l.

Note:
- Total simulation time = 250 days
- Contour interval = 100 mg/l
- $\text{cl}$ = Longitudinal dispersivity = 5.25 m
- $Q$ = 400,000 gpd
- Vertical exaggeration
Figure 57. Distribution of TDS concentrations after 250 days of storage in heterogeneous aquifer (cL = 5.25 m) with background concentration of 1,000 mg/l.

Note:
Total simulation time = 500 days
Contour interval = 100 mg/l
cL = Longitudinal dispersivity = 5.25 m
Q = 400,000 gpd
Vertical exaggeration = 5x
Figure 58. Distribution of TDS concentrations after 250 days of recovery in heterogeneous aquifer (cl = 5.25 m) with background concentration of 1,000 mg/l.

Note:
Total simulation time = 750 days
Contour interval = 100 mg/l
cl = Longitudinal dispersivity = 5.25 m
Q = 400,000 gpd
Vertical exaggeration = 5x
occurs at 74 m from the well. After 250 days of storage (Fig. 60), the horizontal extents of the 500-mg/L and 900 mg/L contours at the same depths were 139 m and 152 m, and 277 m and 320 m, respectively. At the base of the model, the 900-mg/L contour occurs at a distance of 75 m. After 250 days of recovery (Fig. 61), the maximum extent of the 900-mg/L contour occurs at approximately 277 m from the well at both the 13.5 and 37 m depths and groundwater with TDS less than 500 mg/L is not present, due to excessive pumping.

The simulation using $\alpha_L = 21$ m, $\alpha_T = 2.1$, and $\alpha_V = 0.21$ m indicates that after 250 days of injection (Fig. 62), the maximum horizontal extents of the 500-mg/L and 900-mg/L contours at depths of 13.5 m and 37 m, are approximately 122 m and 130 m, and 253 m and 289 m, respectively. The 500-mg/L and 900 mg/L contours at the base of the model occur at 25 m and 82 m from the well. At the top of the model, the 500-mg/L and 900-mg/L contours occur at 47 m and 139 m, respectively from the well. After 250 days of storage (Fig. 63), the horizontal extents of the 500-mg/L and 900 mg/L contours at 13.5 m and 37 m were 119 m and 113 m, and 251 m and 283 m, respectively. At the base of the model, the 900-mg/L contour occurs at a distance of 82 m. After 250 days of recovery (Fig. 64), the maximum extent of the 900-mg/L contour occurs at approximately 250 m from the well at both the 13.5-m and 37-m depths and groundwater with TDS less than 500 mg/L is not present, due to excessive pumping. In the immediate vicinity of the well, the concentrations are approximately 700 mg/L. The model output for the simulations with varying dispersivities is provided in Appendix E.

The recovery efficiencies for the simulations with longitudinal dispersivities of 0.5 m and 21 m are 64% and 40%, respectively. The recovery efficiencies for the simulations with longitudinal dispersivities of 5.25 (56%) and 10.5 m (52%) are interpolated between the recovery efficiencies calculated for simulations with dispersivities of 0.5 and 21 m.

Simulation of Multiple Injection-Storage-Recovery Cycles

The multiple injection-storage-recovery simulation using the heterogeneous case revealed that after the first recovery period consisting of 150 days (Fig. 65), the plume
Figure 68. Distribution of TDS concentrations after 360 days of injection into heterogeneous aquifer (aL = 10.0 m) with background concentration of 1,000 mg/l.

Figure 69. Distribution of TDS concentrations after 200 days of injection into heterogeneous aquifer (aL = 10.0 m) with background concentration of 1,000 mg/l.

Figure 70. Distribution of TDS concentrations after 200 days of injection into heterogeneous aquifer (aL = 10.0 m) with background concentration of 1,000 mg/l.
Figure 6.2. Distribution of TDS concentrations after 250 days of injection into heterogeneous aquifer (cL = 21.0 m) with background concentration of 1,000 mg/l.

Note:
Total simulation time = 250 days
Contour interval = 100 mg/l
cL = Longitudinal dispersivity = 21 m
O = 400,000 gpd
Vertical exaggeration = 5x
Figure 63. Distribution of TDS concentrations after 250 days of storage in heterogeneous aquifer (CL = 21.0 m) with background concentration of 1,000 mg/l.

Note:
Total simulation time = 500 days
Contour interval = 100 mg/l
CL = Longitudinal dispersivity = 21 m
Q = 400,000 gpd
Vertical exaggeration = 5x
Figure 64. Distribution of TDS concentrations after 250 days of recovery in heterogeneous aquifer with background concentration of 1,000 mg/L.

Note:
Total simulation time = 750 days
Contour interval = 100 mg/L
cL = Longitudinal dispersivity = 21 m
Q = -400,000 gpd
Vertical exaggeration = 5x
Figure 05. Distribution of TDS concentrations after 150 days of recovery (1st cycle) in heterogeneous aquifer with background concentration of 1,000 mg/L.

Note:
- Total simulation time ~ 1150 days
- Contour interval = 100 mg/L
- cL = Longitudinal dispersivity = 24.0 m
- Q = 400,000 gpd
- Vertical exaggeration = 5x
consisted of a TDS distribution generally exceeding 600 mg/L. From inspection of the results, the recovery period should have terminated at approximately 100 days. After the second injection period (Fig. 66), the horizontal extent of the 500-mg/L contour at a depth of 13.5 m is 154 m and at 37 m the extent is approximately 159 m. Near the base of the model, the horizontal extent occurs at approximately 42 m. The second recovery period (Fig. 67) indicates that the horizontal extent of the 500-mg/L contour, at the depth of 13.5 m, occurs at 95 m and near the base of the model the contour occurs at a horizontal distance of approximately 25 m from the well.

Following the third injection period (Fig. 68), the 500-mg/L and 900-mg/L contours at depths of 13.5 m and 37.5 m occur at distances of 196 m and 193 m, and 381 m and 398 m, respectively. At the base of the model these contours occur at distances of 70 m and 166 m, respectively. The results following the third recovery period are presented in Figure 69. The third recovery period was terminated at 250 days, at which the concentration in the well was approximately 500 mg/L. The model output for the multiple injection-storage-recovery cycles is provided in Appendix F.
Figure 65. Distribution of TDS concentrations after 250 days of injection (2nd cycle) into heterogeneous aquifer with background concentration of 1,000 mg/l.

Note:
- Total simulation time = 1050 days
- Contour interval = 100 mg/l
- CL = Longitudinal dispersivity = 21.0 m
- Q = 400,000 gpd
- Vertical exaggeration = 5x
Figure 67. Distribution of TDS concentrations after 100 days of recovery (2nd cycle) in heterogeneous aquifer with background concentration of 1,000 mg/L.

Note:
- Total simulation time = 1150 days
- Contour interval = 100 mg/L
- cl = Longitudinal dispersivity = 21.0 m
- Q = 400,000 gpd
- Vertical exaggeration = 5x
Figure 68. Distribution of TDS concentrations after 250 days of injection (3° cycle) into heterogeneous aquifer with background concentration of 1,000 mg/L.

Note:
Total simulation time = 1250 days
Contour interval = 100 mg/L
cL = Longitudinal dispersivity = 21.0 m
Q = 400,000 gpd
Vertical exaggeration = 5x
Figure 69: Distribution of TDS concentrations after 250 days of recovery (3rd cycle) in heterogeneous aquifer with background concentration of 1,000 mg/L.

Note:
Total simulation time = 1500 days
Contour interval = 100 mg/L
CL = Longitudinal dispersivity = 21.0 m
Q = 400,000 gpd
Vertical exaggeration = 5x
Discussion

Effects of Small-Scale Heterogeneities

Comparing the geometry and dimensions of the plume for the homogeneous and heterogeneous simulations after 250 days of injection provides an indication of the variations in TDS concentrations that result from heterogeneity. The 500-mg/L and 900-mg/L contours occur at 78 and 180 m, respectively, in the homogeneous case. In the homogeneous case with low background concentrations, the injected water generally migrates horizontally by advection with horizontal and vertical components due to dispersion. Inspection of the results of simulations with SEAWAT and SEAWAT 2000 indicates that minimal vertical flow is present with a background concentration of 1,000 mg/L. With increasing background concentrations (to 35,000 mg/L) in the homogeneous models, horizontal flow remains predominant, vertical flow remains minimal, and variations in the horizontal travel paths do not develop because vertical density contrasts that result in buoyancy effects do not develop. The concentration contours for simulations with background TDS concentrations of 1,000 mg/L and 35,000 mg/L generally remain vertical throughout the injection, storage, and recovery periods. Following recovery, all of the injectate is not recovered and is because of mixing in the transition zone, especially near the outer edge of the plume where dispersion increases the distribution of solute.

The recovery efficiencies for the homogeneous simulations (see Table 3) with background concentrations and injection/recovery rates of 1,000 mg/L and 1,514 m$^3$/day; 2,500 mg/L and 9,462.5 m$^3$/day; and 15,000 mg/L and 9,462.5 m$^3$/day after 250 days of injection and storage were 40% (100-day recovery), 19% (48-day recovery), and 2% (4-day recovery), respectively. The recovery efficiency for the model with the background TDS concentration of 15,000 mg/L and injection rate of 9,462.5 m$^3$/day increased to 9.3% when a second injection period of 250 days was included in the simulation.
<table>
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<th>Model Description</th>
<th>Dispersion (cm)</th>
<th>Depth of Storage Zone (500 mg/L Contam)</th>
<th>Background TDS (mg/L)</th>
<th>Inj/Rec Rate (m³/day)</th>
<th>AFR Period (days)</th>
<th>Average TDS in Well (mg/L)</th>
<th>Recovery Efficiency (%)</th>
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Note: NA = Not Analyzed
mg/L = milligrams per liter
TDS = Total Dissolved Solids
Inj = Injection
Rec = Recovery
m = meter
In the heterogeneous case, the plume exhibits variations in the horizontal extent depending on the hydraulic conductivity. At the approximate depths of 15 and 37 m, which represent intervals of high conductivity associated with fractures, the 500-mg/l and 900-mg/L contours occur at 122 m and 130 m, and 253 m and 289 m, respectively. The increased horizontal extents of the plume in the heterogeneous case following the injection period and the minor decrease in the maximum plume dimensions following recovery indicate that the high-hydraulic conductivity layers associated with fractures may result in a greater loss of injectate compared to the homogeneous case. The concentrations in the well for the homogeneous and heterogeneous cases after 250 and 100 days are generally similar, and so it appears that the percent recoveries are also similar, at approximately 40%. The recovery efficiencies for the heterogeneous simulations with background concentrations and injection/recovery rates of 1,000 mg/L and 1,514 m³/day; 2,500 mg/L and 9,462.5 m³/day; and 15,000 mg/L and 9,462.5 m³/day after 250 days of injection and storage were 40%, 19%, and <2%, respectively. The recovery efficiency for the simulation with a background concentration of 15,000 mg/L is considered to be significantly less than 2% because the average TDS concentration of the groundwater after 4.4 days was 980 mg/L. In contrast, the average TDS concentration of groundwater from the homogeneous simulation following 4.4 days of recovery is 470 mg/L. The recovery efficiency for the heterogeneous model with the background TDS concentration of 15,000 mg/L and injection rate of 9,462.5 m³/day increases to 6.5% when a second injection period of 246 days is included in the simulation.

A rapid decrease in the quality of the injected source water and volume of the storage zone with increasing background concentrations is exhibited by these simulations and is likely due to rapid mixing with high-TDS brackish water. With increasing background concentrations the accumulation of lower-TDS water in the storage zone becomes restricted to the high-conductivity intervals. The plumes for all simulations exhibit lowest concentrations in the layers of highest hydraulic conductivity suggesting that increased volumes of injectate are able to penetrate deeper into the aquifer (during the injection period), thereby decreasing mixing with the background formation water as additional water is injected. An accumulation of potable water represented by a maximum TDS concentration of 500 mg/L develops over one cycle when the background
concentration does not exceed 2,500 mg/L. The accumulation of the lowest TDS concentrations in the top of the model is a result of the combined effect of the high-conductivity layers there and buoyancy. The relatively low TDS water that is distributed in the layers of high hydraulic conductivity following the injection period is recovered before water in less-conductive layers; however, the TDS of the groundwater in these high-conductivity layers still remains lower than that in the lower part of the ASR interval, resulting in strong density contrasts and buoyancy stratification. As a result, the lower-TDS and lower-density water in the vicinity of the high-conductivity intervals near the well migrates vertically upwards in response to the large density contrast that it experiences compared to the higher TDS water in the low conductive layers in the lower part of the modeled section.

These relationships indicate that, over one cycle, a storage zone can be developed in an aquifer with a background TDS concentration as high as approximately 2,500 mg/L. With increasing background concentrations, the percent recovery can be expected to decrease rapidly over one cycle. However, a significant storage zone in higher TDS backgrounds can be expected to develop after multiple cycles of injection, storage, and recovery.

These simulations indicate that, in general, the horizontal extent of penetration and the storage zone decrease with increasing dispersivities; however, with increasing dispersivities vertical mixing is increased. It should be noted that although simulation of the effects of advection with the use of a numerical solute transport model can be estimated by setting dispersivities to very small values (Zheng and Bennett, 2002), the simulation in this study that included dispersivities set to 0.0 meters likely exhibits the effects of numerical dispersion associated with the solution of the solute-transport equation by the implicit finite-difference method with upstream weighting (Zheng and Bennett, 2002). Nonetheless, the relationship exhibited by this simulation is similar to those that included larger dispersivities. The results also indicate that with minimal dispersion, significant mixing between formation and injected water occurs in response to advection. During an ASR cycle, advective solute transport (i.e., with minimal dispersion) will also result in a loss of solute, i.e., less than 100% recovery, suggesting that velocity variations between the injection and recovery periods may account, in part,
for this loss. Typically, dispersion has been determined to be responsible for the inability
to recover injected tracers (Bear, 1988), and the injected water in these models is
analogous to a tracer.

These simulations also indicate that the volume of stored freshwater increases
with increasing cycles, and so the recovery efficiencies also increase with time.
Therefore it is possible to achieve 100% recovery, following the implementation of
multiple ASR cycles.

Analysis of Mass Balance

Following the injection, storage, and recovery of water during the first cycle it is
evident that complete recovery is not possible. It is generally assumed that this
phenomenon is due to dispersive mixing in the transition zone; as a result, groundwater
near the leading edge of the plume is assumed to not be recoverable during recovery.
The mass balance results at various cells within the model (Table 4) were inspected to
determine the potential effect that variations in flow velocities and travel paths during
injection and recovery may have on the recovery of the injected volume of water.
Specifically, the intention was to determine if the flow paths of injected and recovered
water were simply reversed and if the total flows through the cells were similar following
Table 4. Mass Balance Time-Flow Results

Inflows to Cell: Column 18, Row 19, Layer 44

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<th>Y min</th>
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Outflows to Cell: Column 18, Row 19, Layer 44

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### Table 4. Continued

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<th>Total</th>
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Inflows to Cell: Column 20, Row 19, Layer 91

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<th>X max</th>
<th>Y min</th>
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Outflows to Cell: Column 20, Row 19, Layer 91

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<th>X max</th>
<th>Y min</th>
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<th>Top</th>
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<td>17.14</td>
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the same period of injection and recovery. The cell mass balances were obtained from columns 18, 19, and 20 in the model across the plume within layer 44, providing a cross-section of mass flow. Additional cells included columns 18, 19, and 20 from layers 43 and 91. Two of the cells that were evaluated including column 19, row 19, and layer 44 (inflow-Fig. 70 and outflow-Fig. 71) and layer 91 (inflow-Fig. 72 and outflow-Fig. 73) represent hydraulic conductivities associated with fracture flow ($K = 291.68 \text{ m/day}$) and intergranular flow ($K = 0.2 \text{ m/day}$), respectively. Layer 44 is bound by low permeability layers including layer 43 with $K = 1.61 \text{ m/day}$ and layer 45 with $K = 0.2 \text{ m/day}$. Layer 91 is bound by low permeability layers including layer 90 with $K = 0.27 \text{ m/day}$ and layer 92 with $K = 0.43 \text{ m/day}$. The variations in inflow and outflow at each cell face and the total inflow and outflow at the cell were plotted at 150 day increments beginning with the initiation of the injection cycle, following the steady-state starting conditions.

Inspection of the inflow through the cell at column 19, row 19, and layer 44 (Fig. 74) after the injection period, it is apparent that the flow enters the cell from x-direction at $8.71 \text{ m}^3/\text{day}$ and flows out in various directions but predominantly in the x-direction at $5.13 \text{ m}^3/\text{day}$ and through the top of the cell at $3.06 \text{ m}^3/\text{day}$. Flow through the top of the cell is into a lower-conductivity interval. Following the recovery period, inflow to the cell is from the x-direction at $4.71 \text{ m}^3/\text{day}$, both y-directions at $0.18 \text{ m}^3/\text{day}$, the top at $1.05 \text{ m}^3/\text{day}$ and from the bottom at $1.99 \text{ m}^3/\text{day}$. Outflow from this cell is in the x-direction at $8.11 \text{ m}^3/\text{day}$. Comparing the flow through this cell, it is evident that the flow through the cell is slightly diminished following the recovery period. In addition, input to the cell is from the top and bottom following the recovery period; however, outflow from this cell following the injection period is primarily through the top. Thus it appears that varying travel paths occur in response to heterogeneity and density contrasts (associated with variations in TDS concentrations).

Inspection of the cell flow at column 18, row 19, and layer 44 (Fig. 74), which is located within the transition zone, indicates that, during injection, inflow to the cell is primarily from the x-direction at $5.13 \text{ m}^3/\text{day}$ and outflow is in the x-direction at $3.55 \text{ m}^3/\text{day}$, the y-directions at $0.08 \text{ m}^3/\text{day}$, the top at $0.87 \text{ m}^3/\text{day}$, and the bottom at $0.53 \text{ m}^3/\text{day}$.
Figure 70. Flow mass balance (inflows) for cell column 19, row 19, and layer 44.
Figure 71. Flow mass balance (outflows) for cell column 19, row 19, and layer 44
Figure 72. Flow mass balance (inflows) for cell column 19, row 19, and layer 91
Figure 73. Flow Mass Balance (Outflows) for Cell Column 19, Row 19, and Layer 91
Note: Flow rates in cubic meters/day
   = Flow vectors following injection cycle
   = Flow vectors following recovery cycle

Figure 74. Mass balance analysis for cells at C18-C20, R19, and layer 44
m$^3$/day. Following the recovery period, the distribution of inflow is very similar to the outflow following injection. Thus it appears that although primary flow was in the x-direction, secondary contributions to this high-conductivity interval were from the top and bottom, at this location within the plume.

The cell located adjacent to the cell containing the well at column 20, Row 19, and layer 44 (Fig. 74) exhibited inflow in the x-direction at 18.61 m$^3$/day and through the bottom at 1.43 m$^3$/day and outflow via the x-direction at 8.7 m$^3$/day, the top at 10.18 m$^3$/day, and in both y-directions at 0.58 m$^3$/day following the injection period. This strong vertical flow may be in response to the density contrast that exists immediately after water of low TDS concentration is injected into the formation of contrasting TDS concentration and the strong effects of injection near the well (i.e., hydraulic head). At the end of the recovery period, inflow to this cell is primarily in the x-direction at 8.11 m$^3$/day, from the bottom at 4.8 m$^3$/day, from the top at 4.12 m$^3$/day, and from both y-directions at 0.53 m$^3$/day. Outflow from this cell is entirely in the x-direction.

The cell adjacent to the well and immediately overlying the high-conductivity layer at column 20, row 19, and layer 43 (Fig. 75) exhibited inflow primarily from the bottom at 10.18 m$^3$/day following the injection period, and outflow was primarily out the top at 9.08 m$^3$/day and in the y-directions at 0.58 m$^3$/day. Following the recovery period, the inflow to the cell was from the top at 3.12 m$^3$/day and from the y-directions at 0.53 m$^3$/day. Outflow from the cell was almost entirely out the bottom at 4.12 m$^3$/day. In addition, total flow into this cell is greater during injection compared to the flow following recovery. Thus it appears that the strong injection pressures and buoyancy result in upward flow into adjacent intervals and during extraction groundwater from the low-conductivity intervals is induced to flow into the high-conductivity intervals. The flow path during recovery is consistent with the refraction of groundwater at the boundary of units of highly contrasting hydraulic conductivities (Freeze and Cherry, 1979).

Inflow to the cell at column 19, row 19, and layer 91 (Fig. 76), a low conductivity interval, 150 days after the start of the injection period is mostly from the top of the cell at 5.18 m$^3$/day and outflow is primarily out the bottom at 4.82 m$^3$/day and in the y-
Note: Flow rates in cubic meters/day

- Flow vectors following injection cycle

= Flow vectors following recovery cycle

Figure 76. Mass balance analysis for cells at C19, R19, and layer 91
directions at 0.18 m$^3$/day. After 150 days of recovery, inflow to the cell was primarily from the bottom at 5.97 m$^3$/day and in the y-directions at 0.18 m$^3$/day and outflow was primarily out the top at 6.33 m$^3$/day. In this cell, the flow through the cell 150 days following injection and recovery appears to have simply reversed directions.

In summary, analysis of flow through various cells throughout the model indicates that significant vertical flow occurs in the heterogeneous case. Inspection of cells of a high conductivity layer and overlying low conductivity layer, from the transition zone to the edge of the well, indicates that both horizontal and vertical flow exist. During the injection period, flow adjacent to the well and in the center of the model is in the x-direction and into the overlying low-conductivity layer. At the end of the recovery period, flow into the high-conductivity layer is from the x-direction, followed by significant flow from the bottom and the top, signifying flow from adjacent low-conductivity layers into the high conductivity layer. In contrast flow into a low conductivity layer that is not bound by high-conductivity layers, following injection and recovery appears to follow similar vertical paths. In addition, in most layers inspected, flow into the aquifer model cells following injection is greater than the flow through the same cells following the recovery period. These variations in flow suggest that variations in solute transport paths may result in the inability of all injected mass to be recovered during a single ASR cycle.
Conclusions

This modeling study of the effects of small-scale heterogeneities of hydraulic conductivity on the performance of a hypothetical ASR well enables the following conclusions:

1) Homogeneous and heterogeneous models exhibit significantly different ASR plume geometries and TDS distributions. The “bubble” simplification can lead to misinterpretations of flow and solute transport characteristics as the aquifer becomes increasingly heterogeneous.

2) The efficiency of an ASR well, measured in terms of percent recovery, does not differ between the homogeneous and heterogeneous models with background concentrations less than 2,500 mg/L and the model parameters used in this study. Previous modeling of the same homogeneous and heterogeneous scenarios with MODFLOW 2000 (Vacher et al., in press) confirms that the recovery efficiencies are essentially identical. Since the homogeneous case represents an average of the hydraulic conductivity distribution of the heterogeneous case, the recovery efficiencies would be expected to be similar with low-TDS background concentrations. However, the recovery efficiency is greater in the homogeneous model (9.3%) compared to the heterogeneous aquifer model (6.5%) when the background concentration is 15,000 mg/L. Inspection of the graphs of recovery efficiencies and background concentrations of the homogeneous and heterogeneous models indicates that the recovery efficiencies differ when the background TDS concentrations are greater than 2,500 mg/L.

3) These results indicate that when the effects of buoyancy and significant density contrasts exist, the recovery efficiencies of homogeneous and heterogeneous aquifer models will differ with the homogeneous aquifer model exhibiting greater recovery efficiencies. In essence, the homogeneous aquifer model does not exhibit the effects of buoyancy with any combination of injectate and background
TDS concentrations. A background TDS concentration of the aquifer equal to or greater 2,500 mg/L appears to affect percent recovery for one cycle when the injection rate is 1514 m$^3$/day. The homogeneous and heterogeneous models with background TDS concentrations of 2,500 mg/L and injection rate of 9462.5 m$^3$/day exhibited a recovery efficiency of approximately 19% compared to the efficiency of 40% for an injection rate of 1514 m$^3$/day and a background TDS concentration of 1,000 mg/L. At 15,000 mg/L, a storage zone is not developed during one ASR injection period. A storage zone is developed in the homogeneous and heterogeneous aquifer models when the injection rate is 9462.5 m$^3$/day; however, two ASR cycles are required to yield recovery efficiencies of 9.3% for the homogeneous and 6.5% for the heterogeneous models.

4) Operation of an ASR well in an aquifer of low-TDS background concentration (1,000 mg/L) and minimal regional hydraulic gradient will enable a prolonged storage period without a significant reduction in the storage volume. With increasing background TDS concentrations, these results indicate that buoyancy effects are evident during the 250-day storage period. Significant density contrasts, as a result of large variations in TDS concentrations, are also capable of generating notable flow during the 250-day storage periods simulated by these models.

5) The horizontal extent of the TDS distribution, following the injection period, in the transition zone (e.g. identified by the 900-mg/L contour where the background TDS concentration is 1,000 mg/L) and the storage zone, identified by the 500-mg/L contour, increase with decreasing dispersivities. The vertical distribution of the TDS concentrations in the transition zone and the storage zone increase with increasing dispersivities. This response is likely due to the increased sensitivity of variable-density models to transverse dispersivity (horizontal and vertical), compared to longitudinal dispersivity, where concentration contours generally parallel the groundwater flow direction (Souza and Voss (1987, 1989; Voss and Souza, 1998, Langevin 2001; and Shoemaker, 2004). Results of modeling the effects of advection in these variable-density flow fields indicate that dispersion alone may not account for all of the mixing that occurs.
6) The efficiency of an ASR well typically increases with increasing number of ASR cycles and may approach 100% recovery after three ASR cycles consisting of three injections at 1514 m$^3$/day for 250 days, two recovery periods of 100 and 150 days, followed by a 250 day recovery period.

7) Mass-balance analysis of the heterogeneous simulation with a background concentration of 1,000 mg/L indicates that groundwater migrates along varying paths between injection and recovery cycles, which may partly explain the loss of mass during an ASR cycle.
List of References


Appendix A:  Model Output for Homogeneous Simulations
Appendix A
MODFLOW-2000
U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL
VERSION 3.10 02/13/2004

This model run produced both GLOBAL and LIST files. This is the LIST file.

-----
| M T | Conversion from Groundwater Vistas
| 3 D | MT3D Model
-----
THE TRANSPORT MODEL CONSISTS OF  200 LAYER(S)  38 ROW(S)  40 COLUMN(S)
NUMBER OF STRESS PERIOD(S) FOR TRANSPORT SIMULATION =  18
NUMBER OF ALL COMPONENTS INCLUDED IN SIMULATION =  1
NUMBER OF MOBILE COMPONENTS INCLUDED IN SIMULATION =  1
UNIT FOR TIME IS D ; UNIT FOR LENGTH IS M ; UNIT FOR MASS IS KG
PACKAGES INCLUDED IN CURRENT SIMULATION:
1 2 3 4 5 6 7 8 9 10
T T T T F F F F F

COUPLING BETWEEN FLOW AND TRANSPORT IS IMPLICIT
100 COUPLING ITERATIONS
0.1000 IS THE DENSITY CONVERGENCE CRITERIA
MT3DMS SPECIES USED IN EQUATION OF STATE FOR FLUID DENSITY:  1
AN UPSTREAM-WEIGHTED ALGORITHM IS USED TO CALCULATE FLUID DENSITY TERMS THAT CONSERVE
MASS
FIRSTDT SPECIFIED BY USER IN THE VDF FILE IS:  0.1000000E-01
1000. REFERENCE DENSITY
0.7143 DENSITY SLOPE FOR EQUATION OF STATE
VARIABLE-DENSITY WATER-TABLE CORRECTIONS NOT ADDED
BTN4 -- BASIC TRANSPORT PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 81
4561676 ELEMENTS OF THE X ARRAY USED BY THE BTN PACKAGE
304200 ELEMENTS OF THE IX ARRAY USED BY THE BTN PACKAGE

FMI4 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95
FLOW MODEL IS TRANSIENT

ADV4 -- ADVECTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 82
ADVECTION IS SOLVED WITH THE UPSTREAM FINITE DIFFERENCE SCHEME
COURANT NUMBER ALLOWED IN SOLVING THE ADVECTION TERM = 0.750
0 ELEMENTS OF THE X ARRAY USED BY THE ADV PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE ADV PACKAGE

DSP4 -- DISPERSION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 83
3040600 ELEMENTS OF THE X ARRAY USED BY THE DSP PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE DSP PACKAGE

113
SSM4 -- SINK & SOURCE MIXING PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 84

HEADER LINE OF THE SSM PACKAGE INPUT FILE:
T F F F F F
MAJOR STRESS COMPONENTS PRESENT IN THE FLOW MODEL:
0 WELL
MAXIMUM NUMBER OF POINT SINKS/SOURCES = 30800
215600 ELEMENTS OF THE X ARRAY USED BY THE SSM PACKAGE
0 ELEMENTS OF THE IX ARAY USED BY THE SSM PACKAGE

RCT4 -- CHEMICAL REACTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 85
NO SORPTION [OR DUAL-DOMAIN MODEL] IS SIMULATED
NO FIRST-ORDER RATE REACTION IS SIMULATED
REACTION COEFFICIENTS ASSIGNED CELL-BY-CELL
INITIAL SORBED/IMMOBILE PHASE CONCENTRATION ASSIGNED BY DEFAULT
0 ELEMENTS OF THE X ARRAY USED BY THE RCT PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE RCT PACKAGE

GCG4 -- GENERALIZED CONJUGATE GRADIENT SOLVER PACKAGE, VERSION 4.5, MAY 2003 INPUT READ FROM UNIT 86
MAXIMUM OF 1 OUTER ITERATIONS
AND 50 INNER ITERATIONS ALLOWED FOR CLOSURE
THE PRECONDITIONING TYPE SELECTED IS MODIFIED INCOMPLETE CHOLESKY (MIC).
DISPERSION CROSS TERMS LUMPED INTO RIGHT-HAND-SIDE
6688050 ELEMENTS OF THE X ARRAY USED BY THE GCG PACKAGE
150 ELEMENTS OF THE IX ARRAY USED BY THE GCG PACKAGE

# MODFLOW2000 Basic Package
#MODFLOW Data Set Created by Groundwater Vistas
#
200 LAYERS 38 ROWS 40 COLUMNS
18 STRESS PERIOD(S) IN SIMULATION

BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 1
1000 ELEMENTS IN IR ARRAY ARE USED BY BAS

WEL6 -- WELL PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 12
# MODFLOW2000 Well Package
0 Named Parameters 0 List entries
MAXIMUM OF 400 ACTIVE WELLS AT ONE TIME
CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 54
1600 ELEMENTS IN RX ARRAY ARE USED BY WEL

CHD6 -- TIME-VARIANT SPECIFIED-HEAD PACKAGE, VERSION 6, 1/11/2000
INPUT READ FROM UNIT 40
# MODFLOW2000 Constant-Head Boundary Package (CHD)
Appendix A (Continued)

No named parameters
MAXIMUM OF 15200 TIME-VARIANT SPECIFIED-HEAD CELLS AT ONE TIME
76000 ELEMENTS IN RX ARRAY ARE USED BY CHD

77600 ELEMENTS OF RX ARRAY USED OUT OF 77600
1000 ELEMENTS OF IR ARRAY USED OUT OF 1000
2736001 ELEMENTS OF THE VDF ARRAY USED BY VDF PROCESS

1

# MODFLOW2000 Basic Package
#MODFLOW Data Set Created by Groundwater Vistas

-------------------------------------------------------------
TRANSPORT STEP NO. 20
-------------------------------------------------------------

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 400.0000 D

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 20, TIME STEP 20, STRESS PERIOD 8

-------------------------------------------------------------------------
IN                           OUT
----------------             ----------------
CONSTANT CONCENTRATION:    177936.5                   -407087.5
CONSTANT HEAD:    0.000000                    0.000000
WELLS:    0.000000                    0.000000
DECAY OR BIODEGRADATION:    0.000000                    0.000000
MASS STORAGE (SOLUTE):    341416.9                   -21.86395
-------------------------------------------------------------------------
[TOTAL]:    519354.4     KG            -556406.1     KG

NET (IN - OUT):   -37051.71
DISCREPANCY (PERCENT):   -6.888467

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 8

DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 8

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 8

-------------------------------------------------------------------------
Appendix A (Continued)

IN:

---

STORAGE = 1009.6500
CONSTANT HEAD = 178063614.0626
WELLS = 378500000.0000
DCDT = 236274.4159
TOTAL IN = 556800898.1286

OUT:

----

STORAGE = 149403436.5906
CONSTANT HEAD = 407378256.9908
WELLS = 0.0000
DCDT = 16.6733
TOTAL OUT = 556781710.2546

IN - OUT = 19187.8739
PERCENT DISCREPANCY = 0.00

TIME SUMMARY AT END OF TRANSPORT STEP 20 IN TIME STEP 20 IN STRESS PERIOD 8

SECONDS MINUTES HOURS DAYS YEARS
-----------------------------------------------------------
TRANS STEP LENGTH 2508.9 41.816 0.69693 2.90387E-02 7.95038E-05
TIME STEP LENGTH 7.39284E+05 12321. 205.36 8.5565 2.34265E-02
STRESS PERIOD TIME 4.32000E+06 72000. 1200.0 50.000 0.13689
TOTAL TIME 3.45600E+07 5.76000E+05 9600.0 400.00 1.0951

TRANSPORT STEP NO. 20

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 400.0000 D

116
Appendix A (Continued)

CUMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 20, TIME STEP 20, STRESS PERIOD 8

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<td>-21.86395</td>
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[TOTAL]: 519354.4 KG -556406.1 KG

NET (IN - OUT): -37051.71
DISCREPANCY (PERCENT): -6.888467

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 8

DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 8

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 8

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T

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IN - OUT = 19187.8739
IN - OUT = 1.5641
Appendix A (Continued)

PERCENT DISCREPANCY = 0.00  PERCENT DISCREPANCY = 0.00

TIME SUMMARY AT END OF TRANSPORT STEP 20 IN TIME STEP 20 IN STRESS PERIOD 8
SECONDS MINUTES HOURS DAYS YEARS
-----------------------------------------------------------------------------------------------
TRANS STEP LENGTH 2508.9 41.816 0.69693 2.90387E-02 7.95038E-05
TIME STEP LENGTH 7.39284E+05 12321. 205.36 8.5565 2.34265E-02
STRESS PERIOD TIME 4.32000E+06 72000. 1200.0 50.000 0.13689
TOTAL TIME 3.45600E+07 5.76000E+05 9600.0 400.00 1.0951
-----------------------------------------------------------------------------------------------

TRANSPORT STEP NO. 20

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 400.0000 D
..................................................................
CUMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 20, TIME STEP 20, STRESS PERIOD 8
------------------------------------------------------------------------------------------
IN                           OUT
----------------             ----------------
CONSTANT CONCENTRATION: 177936.5                   -407087.5
CONSTANT HEAD: 0.000000                    0.000000
WELLS: 0.000000                    0.000000
DECAY OR BIODEGRADATION: 0.000000                    0.000000
MASS STORAGE (SOLUTE): 341416.9                   -21.86395
---------------------------------------------------------------------------
[TOTAL]: 519354.4 KG            -556406.1 KG

NET (IN - OUT): -37051.71
DISCREPANCY (PERCENT): -6.888467

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 8
DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 8
MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 8
Appendix A (Continued)

CUMULATIVE MASS RATES FOR THIS TIME STEP M/T
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IN:                                      IN:
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STORAGE =        1009.6500               STORAGE =           5.9267
CONSTANT HEAD =   178063614.0626         CONSTANT HEAD =           0.0000
WELLS =   378500000.0000                 WELLS =     1514000.0000
DCDT =      236274.4159                  DCDT =        1081.4865
TOTAL IN =   556800898.1286              TOTAL IN =     1515087.4132

OUT:                                     OUT:
----                                     ----
STORAGE =  149403436.5906                STORAGE =           0.9713
CONSTANT HEAD =  407378256.9908         CONSTANT HEAD =     1515084.8436
WELLS =           0.0000                 WELLS =           0.0000
DCDT =          16.6733                  DCDT =       3.4180E-02
TOTAL OUT =  556781710.2546              TOTAL OUT =     1515085.8491

IN - OUT =       19187.8739              IN - OUT =           1.5641

PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00

TIME SUMMARY AT END OF TRANSPORT STEP
20 IN TIME STEP 20 IN STRESS PERIOD 8
SECONDS MINUTES HOURS DAYS YEARS
-----------------------------------------------------------
TRANS STEP LENGTH 2508.9 41.816 0.69693 2.90387E-02 7.95038E-05
TIME STEP LENGTH 7.39284E+05 12321. 205.36 8.5565 2.34265E-02
STRESS PERIOD TIME 4.32000E+06 72000. 1200.0 50.000 0.13689
TOTAL TIME 3.45600E+07 5.76000E+05 9600.0 400.0 1.0951

TRANSPORT STEP NO. 20

119
Appendix A (Continued)

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 900.0000 D
------------------------------------------------------------------

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 20,
TIME STEP 20, STRESS PERIOD 18

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TOTAL: 949816.9 KG, -956965.2 KG

NET (IN - OUT): -7148.272
DISCREPANCY (PERCENT): -0.7497733

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 18
DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 18

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 18
------------------------------------------------------------------

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T

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<tr>
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120
Appendix A (Continued)

IN - OUT = 20527.3304 IN - OUT = 0.1079

PERCENT DISCREPANCY = 0.00 PERCENT DISCREPANCY = 0.00

TIME SUMMARY AT END OF TRANSPORT STEP 20 IN TIME STEP 20 IN STRESS PERIOD 18
SECONDS MINUTES HOURS DAYS YEARS

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Appendix B: Model Output for Heterogeneous Simulations
Appendix B

MODFLOW-2000
U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL
VERSION 3.10 02/13/2004

This model run produced both GLOBAL and LIST files. This is the LIST file.

-----
| M T | Conversion from Groundwater Vistas
| 13 D | MT3D Model
-----

THE TRANSPORT MODEL CONSISTS OF 200 LAYER(S) 38 ROW(S) 40 COLUMN(S)
NUMBER OF STRESS PERIOD(S) FOR TRANSPORT SIMULATION = 18
NUMBER OF ALL COMPONENTS INCLUDED IN SIMULATION = 1
NUMBER OF MOBILE COMPONENTS INCLUDED IN SIMULATION = 1
UNIT FOR TIME IS D ; UNIT FOR LENGTH IS M ; UNIT FOR MASS IS KG
PACKAGES INCLUDED IN CURRENT SIMULATION:
  1 2 3 4 5 6 7 8 9 10
  T T T T F F F F

COUPLING BETWEEN FLOW AND TRANSPORT IS IMPLICIT
100 COUPLING ITERATIONS
0.1000 IS THE DENSITY CONVERGENCE CRITERIA
MT3DMS SPECIES USED IN EQUATION OF STATE FOR FLUID DENSITY: 1
AN UPSTREAM-WEIGHTED ALGORITHM IS USED TO CALCULATE FLUID DENSITY TERMS THAT CONSERVE MASS
FIRSTDT SPECIFIED BY USER IN THE VDF FILE IS: 0.1000000E-01
1000. REFERENCE DENSITY
0.7143 DENSITY SLOPE FOR EQUATION OF STATE
VARIABLE-DENSITY WATER-TABLE CORRECTIONS NOT ADDED
BTN4 -- BASIC TRANSPORT PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 81
  4561676 ELEMENTS OF THE X ARRAY USED BY THE BTN PACKAGE
  304200 ELEMENTS OF THE IX ARRAY USED BY THE BTN PACKAGE

FMI4 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95
FLOW MODEL IS TRANSIENT

ADV4 -- ADVECTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 82
ADVECTION IS SOLVED WITH THE UPSTREAM FINITE DIFFERENCE SCHEME
COURANT NUMBER ALLOWED IN SOLVING THE ADVECTION TERM = 0.750
  0 ELEMENTS OF THE X ARRAY USED BY THE ADV PACKAGE
  0 ELEMENTS OF THE IX ARRAY USED BY THE ADV PACKAGE

DSP4 -- DISPERSION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 83
3040600 ELEMENTS OF THE X ARRAY USED BY THE DSP PACKAGE
  0 ELEMENTS OF THE IX ARRAY USED BY THE DSP PACKAGE
Appendix B (Continued)

SSM4 -- SINK & SOURCE MIXING PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 84

HEADER LINE OF THE SSM PACKAGE INPUT FILE:
  T F F F F F
MAJOR STRESS COMPONENTS PRESENT IN THE FLOW MODEL:
  o WELL
MAXIMUM NUMBER OF POINT SINKS/SOURCES = 30800
  215600 ELEMENTS OF THE X ARRAY USED BY THE SSM PACKAGE
  0 ELEMENTS OF THE IX ARRAY USED BY THE SSM PACKAGE

RCT4 -- CHEMICAL REACTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 85

NO SORPTION [OR DUAL-DOMAIN MODEL] IS SIMULATED
NO FIRST-ORDER RATE REACTION IS SIMULATED
REACTION COEFFICIENTS ASSIGNED CELL-BY-CELL
INITIAL SORBED/IMMOBILE PHASE CONCENTRATION ASSIGNED BY DEFAULT
  0 ELEMENTS OF THE X ARRAY USED BY THE RCT PACKAGE
  0 ELEMENTS OF THE IX ARRAY USED BY THE RCT PACKAGE

GCG4 -- GENERALIZED CONJUGATE GRADIENT SOLVER PACKAGE, VERSION 4.5, MAY 2003 INPUT READ FROM UNIT 86

MAXIMUM OF 1 OUTER ITERATIONS
  AND 50 INNER ITERATIONS ALLOWED FOR CLOSURE
THE PRECONDITIONING TYPE SELECTED IS MODIFIED INCOMPLETE CHOLESKY (MIC).
DISPERSION CROSS TERMS LUMPED INTO RIGHT-HAND-SIDE
  6688050 ELEMENTS OF THE X ARRAY USED BY THE GCG PACKAGE
  150 ELEMENTS OF THE IX ARRAY USED BY THE GCG PACKAGE

# MODFLOW2000 Basic Package
# MODFLOW Data Set Created by Groundwater Vistas
#
200 LAYERS  38 ROWS  40 COLUMNS
18 STRESS PERIOD(S) IN SIMULATION

BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 1
  1000 ELEMENTS IN IR ARRAY ARE USED BY BAS

WEL6 -- WELL PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 12
# MODFLOW2000 Well Package
  0 Named Parameters  0 List entries
MAXIMUM OF 400 ACTIVE WELLS AT ONE TIME
CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 54
  1600 ELEMENTS IN RX ARRAY ARE USED BY WEL

CHD6 -- TIME-VARIANT SPECIFIED-HEAD PACKAGE, VERSION 6, 1/11/2000
INPUT READ FROM UNIT 40
# MODFLOW2000 Constant-Head Boundary Package (CHD)
Appendix B (Continued)

No named parameters
MAXIMUM OF 15,200 TIME-VARIANT SPECIFIED-HEAD CELLS AT ONE TIME
76,000 ELEMENTS IN RX ARRAY ARE USED BY CHD

77,600 ELEMENTS OF RX ARRAY USED OUT OF 77,600
10,000 ELEMENTS OF IR ARRAY USED OUT OF 10,000
273,601 ELEMENTS OF THE VDF ARRAY USED BY VDF PROCESS

1

# MODFLOW2000 Basic Package
# MODFLOW Data Set Created by Groundwater Vistas

FMI4 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95
FLOW MODEL IS TRANSIENT
FLOW MODEL CONTAINS CONSTANT-HEAD CELLS

"THKSAT" FLOW TERMS FOR TIME STEP 20, STRESS PERIOD 8 READ UNFORMATTED ON UNIT 95

"QXX" FLOW TERMS FOR TIME STEP 20, STRESS PERIOD 8 READ UNFORMATTED ON UNIT 95

"QYY" FLOW TERMS FOR TIME STEP 20, STRESS PERIOD 8 READ UNFORMATTED ON UNIT 95

"QZZ" FLOW TERMS FOR TIME STEP 20, STRESS PERIOD 8 READ UNFORMATTED ON UNIT 95

"STO" FLOW TERMS FOR TIME STEP 20, STRESS PERIOD 8 READ UNFORMATTED ON UNIT 95

MAXIMUM STEPSIZE DURING WHICH ANY PARTICLE CANNOT MOVE MORE THAN ONE CELL
= 2.124 (WHEN MIN. R.F.=1) AT K= 129, I= 19, J= 21

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE ADVECTION TERM
(FOR PURE FINITE-DIFFERENCE OPTION, MIXELM=0)
= 1.926 (WHEN MIN. R.F.=1) AT K= 128, I= 19, J= 21

"CNH" FLOW TERMS FOR TIME STEP 20, STRESS PERIOD 8 READ UNFORMATTED ON UNIT 95

"WEL" FLOW TERMS FOR TIME STEP 20, STRESS PERIOD 8 READ UNFORMATTED ON UNIT 95
Appendix B (Continued)

TOTAL NUMBER OF POINT SOURCES/SINKS PRESENT IN THE FLOW MODEL = 30600

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE SINK & SOURCE TERM
= 6.212 (WHEN MIN. R.F.=1) AT K= 34, I= 19, J= 21

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE DISPERSION TERM
= 0.1532E-01 (WHEN MIN. R.F.=1) AT K= 128, I= 19, J= 21

1 CALLS TO GCG PACKAGE FOR TRANSPORT TIME STEP 19 IN FLOW TIME STEP 20 STRESS PERIOD 8
4 TOTAL ITERATIONS

0 COMPLETED COUPLING ITERATION 1
MAXIMUM DENSITY DIFFERENCE = -0.10003E-01
AT CELL (I,J,K) = ( 19, 20, 118)

SOLVING FOR HEAD
6 CALLS TO PCG ROUTINE FOR TIME STEP 20 IN STRESS PERIOD 8
126 TOTAL ITERATIONS

MAXIMUM HEAD CHANGE FOR EACH ITERATION (1 INDICATES THE FIRST INNER ITERATION):

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126
### Appendix B (Continued)

MAXIMUM RESIDUAL FOR EACH ITERATION (1 INDICATES THE FIRST INNER ITERATION):

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<td>2.604</td>
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<td>2.307</td>
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<td>1.901</td>
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<td>1.760</td>
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<td>1.552</td>
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<td>1.316</td>
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<td>1.289</td>
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<td>1.261</td>
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<td>1.234</td>
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<td>1.207</td>
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<tr>
<td></td>
<td>0</td>
<td>1.127</td>
<td>0</td>
<td>1.100</td>
<td>0</td>
<td>1.067</td>
<td>0</td>
<td>1.031</td>
<td>0</td>
<td>0.9942</td>
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<tr>
<td></td>
<td>1</td>
<td>0.9932</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix B (Continued)

FM4 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95

FLOW MODEL IS TRANSIENT

FLOW MODEL CONTAINS CONSTANT-HEAD CELLS

"THKSAT  " FLOW TERMS FOR TIME STEP 20, STRESS PERIOD 8 READ UNFORMATTED ON UNIT 95
--------------------------------------------------------------------------------------------
"QXX     " FLOW TERMS FOR TIME STEP 20, STRESS PERIOD 8 READ UNFORMATTED ON UNIT 95
--------------------------------------------------------------------------------------------
"QYY     " FLOW TERMS FOR TIME STEP 20, STRESS PERIOD 8 READ UNFORMATTED ON UNIT 95
--------------------------------------------------------------------------------------------
"QZZ     " FLOW TERMS FOR TIME STEP 20, STRESS PERIOD 8 READ UNFORMATTED ON UNIT 95
--------------------------------------------------------------------------------------------
"STO     " FLOW TERMS FOR TIME STEP 20, STRESS PERIOD 8 READ UNFORMATTED ON UNIT 95

MAXIMUM STEPSIZE DURING WHICH ANY PARTICLE CANNOT MOVE MORE THAN ONE CELL

= 2.124 (WHEN MIN. R.F.=1) AT K= 129, I= 19, J= 21

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE ADVECTION TERM

(FOR PURE FINITE-DIFFERENCE OPTION, MIXELM=0)

= 1.926 (WHEN MIN. R.F.=1) AT K= 128, I= 19, J= 21

"CNH     " FLOW TERMS FOR TIME STEP 20, STRESS PERIOD 8 READ UNFORMATTED ON UNIT 95
--------------------------------------------------------------------------------------------
"WEL     " FLOW TERMS FOR TIME STEP 20, STRESS PERIOD 8 READ UNFORMATTED ON UNIT 95

TOTAL NUMBER OF POINT SOURCES/SINKS PRESENT IN THE FLOW MODEL = 30600

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE SINK & SOURCE TERM

= 6.212 (WHEN MIN. R.F.=1) AT K= 34, I= 19, J= 21

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE DISPERSION TERM

= 0.1532E-01 (WHEN MIN. R.F.=1) AT K= 128, I= 19, J= 21

1 CALLS TO GCG PACKAGE FOR TRANSPORT TIME STEP 20 IN FLOW TIME STEP 20 STRESS PERIOD 8

1 TOTAL ITERATIONS

MAXIMUM CONCENTRATION CHANGES FOR EACH ITERATION:

MAX. CHANGE LAYER,ROW,COL MAX. CHANGE LAYER,ROW,COL MAX. CHANGE LAYER,ROW,COL MAX. CHANGE LAYER,ROW,COL
Appendix B (Continued)

0.000 (1, 1, 1)

0 COMPLETED COUPLING ITERATION 1
MAXIMUM DENSITY DIFFERENCE = 0.0000
AT CELL (I,J,K) = (19, 20, 118)

UBUDSV SAVING "STORAGE" ON UNIT 50 AT TIME STEP 20, STRESS PERIOD 8
UBUDSV SAVING "CONSTANT HEAD" ON UNIT 50 AT TIME STEP 20, STRESS PERIOD 8
UBUDSV SAVING "FLOW RIGHT FACE" ON UNIT 50 AT TIME STEP 20, STRESS PERIOD 8
UBUDSV SAVING "FLOW FRONT FACE" ON UNIT 50 AT TIME STEP 20, STRESS PERIOD 8
UBUDSV SAVING "FLOW LOWER FACE" ON UNIT 50 AT TIME STEP 20, STRESS PERIOD 8
UBUDSV SAVING "WELLS" ON UNIT 54 AT TIME STEP 20, STRESS PERIOD 8
UBUDSV SAVING "DCDT" ON UNIT 50 AT TIME STEP 20, STRESS PERIOD 8

FOR COMPONENT NO. 01

TRANSPORT STEP NO. 20

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 400.0000 D

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 20, TIME STEP 20, STRESS PERIOD 8

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION: 177939.5</td>
<td>-407123.7</td>
</tr>
<tr>
<td>CONSTANT HEAD: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE): 341927.8</td>
<td>-91.08384</td>
</tr>
</tbody>
</table>

[TOTAL]: 519868.6 KG -556511.9 KG

NET (IN - OUT): -36643.27
DISCREPANCY (PERCENT): -6.808609

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 8

130
Appendix B (Continued)

DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 8

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 8

<table>
<thead>
<tr>
<th>CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>IN:</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>STORAGE = 1359.9221</td>
</tr>
<tr>
<td>CONSTANT HEAD = 178066607.3073</td>
</tr>
<tr>
<td>WELLS = 378500000.7500</td>
</tr>
<tr>
<td>DCDT = 236748.2968</td>
</tr>
<tr>
<td>TOTAL IN = 556804716.2762</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OUT:</th>
<th>OUT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>STORAGE = 149403757.0672</td>
<td>STORAGE = 1.0631</td>
</tr>
<tr>
<td>CONSTANT HEAD = 407414498.6510</td>
<td>CONSTANT HEAD = 1515081.8366</td>
</tr>
<tr>
<td>WELLS = 0.0000</td>
<td>WELLS = 0.0000</td>
</tr>
<tr>
<td>DCDT = 65.8461</td>
<td>DCDT = 0.3803</td>
</tr>
<tr>
<td>TOTAL OUT = 556818321.5644</td>
<td>TOTAL OUT = 1515083.2800</td>
</tr>
<tr>
<td>IN - OUT = -13605.2882</td>
<td>IN - OUT = -0.2794</td>
</tr>
<tr>
<td>PERCENT DISCREPANCY = 0.00</td>
<td>PERCENT DISCREPANCY = 0.00</td>
</tr>
</tbody>
</table>

TIME SUMMARY AT END OF TRANSPORT STEP 20 IN TIME STEP 20 IN STRESS PERIOD 8

<table>
<thead>
<tr>
<th>SECONDS</th>
<th>MINUTES</th>
<th>HOURS</th>
<th>DAYS</th>
<th>YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANS STEP LENGTH 2508.9</td>
<td>41.816</td>
<td>0.69693</td>
<td>2.90387E-02</td>
<td>7.95038E-05</td>
</tr>
<tr>
<td>TIME STEP LENGTH 7.39284E+05</td>
<td>12321.</td>
<td>205.36</td>
<td>8.5565</td>
<td>2.34265E-02</td>
</tr>
<tr>
<td>STRESS PERIOD TIME 4.32000E+06</td>
<td>72000.</td>
<td>1200.0</td>
<td>50.000</td>
<td>0.13689</td>
</tr>
<tr>
<td>TOTAL TIME 3.45600E+07</td>
<td>5.76000E+05</td>
<td>9600.0</td>
<td>400.0</td>
<td>1.0951</td>
</tr>
</tbody>
</table>

TRANSPORT STEP NO. 20
Appendix B (Continued)

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 650.0000 D

---------------------------------------------------------------

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 20, TIME STEP 20, STRESS PERIOD 13

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION:</td>
<td></td>
</tr>
<tr>
<td>225948.3</td>
<td>-455206.0</td>
</tr>
<tr>
<td>CONSTANT HEAD:</td>
<td></td>
</tr>
<tr>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS:</td>
<td></td>
</tr>
<tr>
<td>0.000000</td>
<td>0.000000</td>
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<tr>
<td>DECAY OR BIODEGRADATION:</td>
<td></td>
</tr>
<tr>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE):</td>
<td></td>
</tr>
<tr>
<td>349450.1</td>
<td>-7613.408</td>
</tr>
</tbody>
</table>

[TOTAL]: 575473.1 KG -612116.6 KG

NET (IN - OUT): -36643.45
DISCREPANCY (PERCENT): -6.171062

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 13

DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 13

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 13

---------------------------------------------------------------

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T

<table>
<thead>
<tr>
<th>IN:</th>
<th>OUT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>STORAGE = 74951.8752</td>
<td>STORAGE = 0.9910</td>
</tr>
<tr>
<td>CONSTANT HEAD = 226109705.2689</td>
<td>CONSTANT HEAD = 192261.0728</td>
</tr>
<tr>
<td>WELLS = 378500000.7500</td>
<td>WELLS = 0.0000</td>
</tr>
<tr>
<td>DCDT = 241154.6112</td>
<td>DCDT = 35.8868</td>
</tr>
<tr>
<td>TOTAL IN = 604925812.5053</td>
<td>TOTAL IN = 192297.9506</td>
</tr>
</tbody>
</table>

OUT:                                      OUT:

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</thead>
<tbody>
<tr>
<td>STORAGE = 149403764.9717</td>
<td>STORAGE = 0.9929</td>
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<tr>
<td>CONSTANT HEAD = 455531186.7247</td>
<td>CONSTANT HEAD = 192261.0769</td>
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<tr>
<td>WELLS = 0.0000</td>
<td>WELLS = 0.0000</td>
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<tr>
<td>DCDT = 4472.1295</td>
<td>DCDT = 35.8868</td>
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</tbody>
</table>
Appendix B (Continued)

TOTAL OUT = 604372.6
IN - OUT = -455207.6
PERCENT DISCREPANCY = -0.6880330
HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 18
Appendix B (Continued)

DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 18

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 18

<table>
<thead>
<tr>
<th>IN:</th>
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<tbody>
<tr>
<td>--- STORAGE = 149081.6520</td>
<td>-- STORAGE = 0.4848</td>
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<tr>
<td>--- CONSTANT HEAD = 604804329.2189</td>
<td>-- CONSTANT HEAD = 1515080.8872</td>
</tr>
<tr>
<td>--- WELLS = 378500000.7500</td>
<td>-- WELLS = 0.0000</td>
</tr>
<tr>
<td>--- DCDT = 247827.6525</td>
<td>-- DCDT = 12.2876</td>
</tr>
<tr>
<td>TOTAL IN = 983701239.2734</td>
<td>TOTAL OUT = 983691960.3080</td>
</tr>
<tr>
<td>IN - OUT = 9278.9654</td>
<td>IN - OUT = -0.6850</td>
</tr>
<tr>
<td>PERCENT DISCREPANCY = 0.00</td>
<td>PERCENT DISCREPANCY = 0.00</td>
</tr>
</tbody>
</table>

TIME SUMMARY AT END OF TRANSPORT STEP 20 IN TIME STEP 20 IN STRESS PERIOD 18

<table>
<thead>
<tr>
<th>TRANS STEP LENGTH</th>
<th>TIME STEP LENGTH</th>
<th>STRESS PERIOD TIME</th>
<th>TOTAL TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>2508.9</td>
<td>7.39284E+05</td>
<td>4.32000E+06</td>
<td>7.77600E+06</td>
</tr>
<tr>
<td>41.816</td>
<td>12321.</td>
<td>72000.</td>
<td>21600.</td>
</tr>
<tr>
<td>0.69693</td>
<td>8.5565</td>
<td>50.000</td>
<td>900.00</td>
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<tr>
<td>2.90387E-02</td>
<td>2.34265E-02</td>
<td>0.13689</td>
<td>2.4641</td>
</tr>
</tbody>
</table>
Appendix C: Model Output for Varying TDS Background Simulations
Appendix C

Suwan 2.5

MODFLOW-2000

U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL

VERSION 3.10 02/13/2004

This model run produced both GLOBAL and LIST files. This is the LIST file.

-----
| M T | Conversion from Groundwater Vistas |
|-----|
| 1 3 D | MT3D Model |

THE TRANSPORT MODEL CONSISTS OF 200 LAYER(S) 38 ROW(S) 40 COLUMN(S)
NUMBER OF STRESS PERIOD(S) FOR TRANSPORT SIMULATION = 18
NUMBER OF ALL COMPONENTS INCLUDED IN SIMULATION = 1
NUMBER OF MOBILE COMPONENTS INCLUDED IN SIMULATION = 1
UNIT FOR TIME IS D; UNIT FOR LENGTH IS M; UNIT FOR MASS IS KG
PACKAGES INCLUDED IN CURRENT SIMULATION:
1 2 3 4 5 6 7 8 9 10
T T T T F F F F

COUPLING BETWEEN FLOW AND TRANSPORT IS IMPLICIT
100 COUPLING ITERATIONS
0.1000 IS THE DENSITY CONVERGENCE CRITERIA
MT3DMS SPECIES USED IN EQUATION OF STATE FOR FLUID DENSITY: 1
AN UPSTREAM-WEIGHTED ALGORITHM IS USED TO CALCULATE FLUID
DENSITY TERMS THAT CONSERVE MASS
FIRSTDT SPECIFIED BY USER IN THE VDF FILE IS: 0.1000000E-01
1000. REFERENCE DENSITY
0.7143 DENSITY SLOPE FOR EQUATION OF STATE
VARIABLE-DENSITY WATER-TABLE CORRECTIONS NOT ADDED
BTN4 -- BASIC TRANSPORT PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 81
4561676 ELEMENTS OF THE X ARRAY USED BY THE BTN PACKAGE
304200 ELEMENTS OF THE IX ARRAY USED BY THE BTN PACKAGE

FMI4 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95
FLOW MODEL IS TRANSIENT
ADV4 -- ADVECTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 82
ADVECTION IS SOLVED WITH THE UPSTREAM FINITE DIFFERENCE SCHEME
COURANT NUMBER ALLOWED IN SOLVING THE ADVECTION TERM = 0.750
0 ELEMENTS OF THE X ARRAY USED BY THE ADV PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE ADV PACKAGE
Appendix C (Continued)

DSP4 -- DISPERSION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 83

3040600 ELEMENTS OF THE X ARRAY USED BY THE DSP PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE DSP PACKAGE

SSM4 -- SINK & SOURCE MIXING PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 84

HEADER LINE OF THE SSM PACKAGE INPUT FILE:
T F F F F F
MAJOR STRESS COMPONENTS PRESENT IN THE FLOW MODEL:
o WELL
MAXIMUM NUMBER OF POINT SINKS/SOURCES = 30600
214200 ELEMENTS OF THE X ARRAY USED BY THE SSM PACKAGE
0 ELEMENTS OF THE IX ARRAY BY THE SSM PACKAGE

RCT4 -- CHEMICAL REACTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 85
NO SORPTION [OR DUAL-DOMAIN MODEL] IS SIMULATED
NO FIRST-ORDER RATE REACTION IS SIMULATED
REACTION COEFFICIENTS ASSIGNED CELL-BY-CELL
INITIAL SORBED/IMMOBILE PHASE CONCENTRATION ASSIGNED BY DEFAULT
0 ELEMENTS OF THE X ARRAY USED BY THE RCT PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE RCT PACKAGE

GCG4 -- GENERALIZED CONJUGATE GRADIENT SOLVER PACKAGE, VERSION 4.5, MAY 2003
INPUT READ FROM UNIT 86
MAXIMUM OF 1 OUTER ITERATIONS
AND 50 INNER ITERATIONS ALLOWED FOR CLOSURE
THE PRECONDITIONING TYPE SELECTED IS MODIFIED INCOMPLETE CHOLESKY (MIC).
DISPERSION CROSS TERMS LUMPED INTO RIGHT-HAND-SIDE
6688050 ELEMENTS OF THE X ARRAY USED BY THE GCG PACKAGE
150 ELEMENTS OF THE IX ARRAY USED BY THE GCG PACKAGE

# MODFLOW2000 Basic Package
#MODFLOW Data Set Created by Groundwater Vistas
#
200 LAYERS 38 ROWS 40 COLUMNS
18 STRESS PERIOD(S) IN SIMULATION

BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 1
1000 ELEMENTS IN IR ARRAY ARE USED BY BAS

WEL6 -- WELL PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 12
# MODFLOW2000 Well Package
0 Named Parameters 0 List entries
MAXIMUM OF 200 ACTIVE WELLS AT ONE TIME
CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 54
Appendix C (Continued)

800 ELEMENTS IN RX ARRAY ARE USED BY WEL

CHD6 -- TIME-VARIANT SPECIFIED-HEAD PACKAGE, VERSION 6, 1/11/2000
INPUT READ FROM UNIT 40
# MODFLOW2000 Constant-Head Boundary Package (CHD)
No named parameters
MAXIMUM OF 15200 TIME-VARIANT SPECIFIED-HEAD CELLS AT ONE TIME
76000 ELEMENTS IN RX ARRAY ARE USED BY CHD

76800 ELEMENTS OF RX ARRAY USED OUT OF 76800
1000 ELEMENTS OF IR ARRAY USED OUT OF 1000
2736001 ELEMENTS OF THE VDF ARRAY USED BY VDF PROCESS

# MODFLOW2000 Basic Package
# MODFLOW Data Set Created by Groundwater Vistas

TRANSPORT STEP NO. 25

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 400.0000 D

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 25, TIME STEP 20, STRESS PERIOD 8

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION: 628434.2</td>
<td>-1016867.</td>
</tr>
<tr>
<td>CONSTANT HEAD: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE): 829121.6</td>
<td>-431.3344</td>
</tr>
</tbody>
</table>

[TOTAL]: 1457566. KG -1575018. KG

NET (IN - OUT): -117452.4
DISCREPANCY (PERCENT): -7.746026

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 8
DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 8

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 8
Appendix C (Continued)  

CUMULATIVE MASS RATES FOR THIS TIME STEP M/T

--- ---
IN: IN:
STORAGE = 4104.5930  STORAGE = 0.8276
CONSTANT HEAD = 251822579.0953  CONSTANT HEAD = 0.0000
WELLS = 378500000.7500  WELLS = 1514000.0030
DCDT = 575576.9073  DCDT = 2704.0046
TOTAL IN = 630902261.3456  TOTAL IN = 1516704.8353

OUT: OUT:
---- ----
STORAGE = 223486425.6884  STORAGE = 0.6511
CONSTANT HEAD = 407473173.3178  CONSTANT HEAD = 1516703.6216
WELLS = 0.0000  WELLS = 0.0000
DCDT = 317.7517  DCDT = 0.3792
TOTAL OUT = 630959916.7579  TOTAL OUT = 1516704.6519

IN - OUT = -57655.4123  IN - OUT = 0.1833
PERCENT DISCREPANCY = -0.01  PERCENT DISCREPANCY = 0.00

0

TIME SUMMARY AT END OF TRANSPORT STEP 25 IN TIME STEP 20 IN STRESS PERIOD 8
SECONDS MINUTES HOURS DAYS YEARS
-------------------------------------------------------------
TRANS STEP LENGTH 10903.  181.72  3.0286  0.12619  3.45497E-04
TIME STEP LENGTH 7.39284E+05  12321.  205.36  8.5565  2.34265E-02
STRESS PERIOD TIME 4.32000E+06  72000.  1200.0  50.000  0.13689
TOTAL TIME 3.45600E+07  5.76000E+05  960.0  400.0  1.0951

-----------------------------
TRANSPORT STEP NO. 25
-----------------------------

139
Appendix C (Continued)

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 650.0000 D

CUMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP  25, TIME STEP  20, STRESS PERIOD  13

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION: 747220.7</td>
<td>-1135931.</td>
</tr>
<tr>
<td>CONSTANT HEAD: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE): 862095.7</td>
<td>-33405.14</td>
</tr>
</tbody>
</table>

[TOTAL]: 1609603. KG -1727057. KG

NET (IN – OUT): -117453.2
DISCREPANCY (PERCENT): -7.040165

HEAD WILL BE SAVED ON UNIT  30 AT END OF TIME STEP  20, STRESS PERIOD  13

DRAWDOWN WILL BE SAVED ON UNIT  31 AT END OF TIME STEP  20, STRESS PERIOD  13

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD  13

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T

<table>
<thead>
<tr>
<th>IN:</th>
<th>OUT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>STORAGE = 115302.2191</td>
<td>STORAGE = 0.1071</td>
</tr>
<tr>
<td>CONSTANT HEAD = 299422032.3147</td>
<td>CONSTANT HEAD = 190528.7348</td>
</tr>
<tr>
<td>WELLS = 378500000.7500</td>
<td>WELLS = 0.0000</td>
</tr>
<tr>
<td>DCDT = 596340.9994</td>
<td>DCDT = 146.5656</td>
</tr>
<tr>
<td>TOTAL IN = 678633676.2833</td>
<td>TOTAL OUT = 190675.4075</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>OUT:</td>
<td>TOTAL OUT = 190675.5294</td>
</tr>
<tr>
<td>---</td>
<td>----</td>
</tr>
<tr>
<td>STORAGE = 223486434.7459</td>
<td>STORAGE = 0.1352</td>
</tr>
<tr>
<td>CONSTANT HEAD = 455183951.7071</td>
<td>CONSTANT HEAD = 190528.8286</td>
</tr>
<tr>
<td>WELLS = 0.0000</td>
<td>WELLS = 0.0000</td>
</tr>
<tr>
<td>DCDT = 21054.5595</td>
<td>DCDT = 146.5656</td>
</tr>
<tr>
<td>TOTAL IN = 190675.4075</td>
<td>TOTAL OUT = 190675.5294</td>
</tr>
</tbody>
</table>
Appendix C (Continued)

IN - OUT = -57764.7292  IN - OUT = -0.1220

PERCENT DISCREPANCY = -0.01  PERCENT DISCREPANCY = 0.00

TIME SUMMARY AT END OF TRANSPORT STEP 25 IN TIME STEP 20 IN STRESS PERIOD 13
SECONDS MINUTES HOURS DAYS YEARS
-----------------------------------------------------------
TRANS STEP LENGTH 10903. 181.72 3.0286 0.12619 3.45497E-04
TIME STEP LENGTH 7.39284E+05 12321. 205.36 8.5565 2.34265E-02
STRESS PERIOD TIME 4.32000E+06 7200. 1200.0 50.000 0.13689
TOTAL TIME 5.61600E+07 9.36000E+05 15600. 650.00 1.7796

----------------------------------------
TRANSPORT STEP NO. 25

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 900.0000 D

--------------------------------------------------------------
CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 25, TIME STEP 20, STRESS PERIOD 18

IN             OUT
----------------             ----------------
CONSTANT CONCENTRATION: 1693180.                   -1135938.
CONSTANT HEAD: 0.000000                    0.000000
WELLS: 0.000000                   -522328.6
DECAY OR BIODEGRADATION: 0.000000                    0.000000
MASS STORAGE (SOLUTE): 882625.1                   -383149.5
---------------------------------------------------------------------------
[TOTAL]: 2576373. KG            -2599140. KG

NET (IN - OUT): -22767.62
DISCREPANCY (PERCENT): -0.8798209

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 18
DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 18
Appendix C (Continued)

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 18

<table>
<thead>
<tr>
<th>CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>IN:</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>STORAGE = 227974.5083</td>
</tr>
<tr>
<td>CONSTANT HEAD = 678481543.6106</td>
</tr>
<tr>
<td>WELLS = 378500000.7500</td>
</tr>
<tr>
<td>DCDT = 610441.6046</td>
</tr>
<tr>
<td>TOTAL IN = 1057819960.4735</td>
</tr>
<tr>
<td>OUT:</td>
</tr>
<tr>
<td>----</td>
</tr>
<tr>
<td>STORAGE = 223487920.0036</td>
</tr>
<tr>
<td>CONSTANT HEAD = 455186797.5931</td>
</tr>
<tr>
<td>WELLS = 378872292.6718</td>
</tr>
<tr>
<td>DCDT = 259985.3114</td>
</tr>
<tr>
<td>TOTAL OUT = 1057806995.5799</td>
</tr>
<tr>
<td>IN - OUT = 12964.8937</td>
</tr>
<tr>
<td>PERCENT DISCREPANCY = 0.00</td>
</tr>
</tbody>
</table>

TIME SUMMARY AT END OF TRANSPORT STEP 25 IN TIME STEP 20 IN STRESS PERIOD 18

<table>
<thead>
<tr>
<th>SECONDS</th>
<th>MINUTES</th>
<th>HOURS</th>
<th>DAYS</th>
<th>YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANS STEP LENGTH</td>
<td>10903</td>
<td>181.72</td>
<td>3.0286</td>
<td>0.12619</td>
</tr>
<tr>
<td>TIME STEP LENGTH</td>
<td>7.39284E+05</td>
<td>12321</td>
<td>205.36</td>
<td>8.5565</td>
</tr>
<tr>
<td>STRESS PERIOD TIME</td>
<td>4.32000E+06</td>
<td>72000</td>
<td>1200.0</td>
<td>50.000</td>
</tr>
<tr>
<td>TOTAL TIME</td>
<td>7.77600E+07</td>
<td>129600</td>
<td>21600.0</td>
<td>900.00</td>
</tr>
</tbody>
</table>

0
This model run produced both GLOBAL and LIST files. This is the LIST file.

-----
1 M T | Conversion from Groundwater Vistas
13 D | MT3D Model
-----
THE TRANSPORT MODEL CONSISTS OF 200 LAYER(S) 39 ROW(S) 40 COLUMN(S)
NUMBER OF STRESS PERIOD(S) FOR TRANSPORT SIMULATION = 18
NUMBER OF ALL COMPONENTS INCLUDED IN SIMULATION = 1
NUMBER OF MOBILE COMPONENTS INCLUDED IN SIMULATION = 1
UNIT FOR TIME IS D ; UNIT FOR LENGTH IS M ; UNIT FOR MASS IS KG
PACKAGES INCLUDED IN CURRENT SIMULATION:
   1 2 3 4 5 6 7 8 9 10
   T T T T F F F F F

COUPLING BETWEEN FLOW AND TRANSPORT IS IMPLICIT
100 COUPLING ITERATIONS
0.1000 IS THE DENSITY CONVERGENCE CRITERIA
MT3DMS SPECIES USED IN EQUATION OF STATE FOR FLUID DENSITY: 1
AN UPSTREAM-WEIGHTED ALGORITHM IS USED TO CALCULATE FLUID DENSITY TERMS THAT CONSERVE MASS
FIRSTDT SPECIFIED BY USER IN THE VDF FILE IS: 0.1000000E-01
1000. REFERENCE DENSITY
0.7143 DENSITY SLOPE FOR EQUATION OF STATE
VARIABLE-DENSITY WATER-TABLE CORRECTIONS NOT ADDED
BTN4 -- BASIC TRANSPORT PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 81
   4681718 ELEMENTS OF THE X ARRAY USED BY THE BTN PACKAGE
   312200 ELEMENTS OF THE IX ARRAY USED BY THE BTN PACKAGE

FMI4 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95
FLOW MODEL IS TRANSIENT
ADV4 -- ADVECTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 82
ADVECTION IS SOLVED WITH THE UPSTREAM FINITE DIFFERENCE SCHEME
COURANT NUMBER ALLOWED IN SOLVING THE ADVECTION TERM = 0.750
   0 ELEMENTS OF THE X ARRAY USED BY THE ADV PACKAGE
   0 ELEMENTS OF THE IX ARRAY USED BY THE ADV PACKAGE

DSP4 -- DISPERSION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 83
Appendix C (Continued)

SSM4 -- SINK & SOURCE MIXING PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 84

HEADER LINE OF THE SSM PACKAGE INPUT FILE:

T F F F F F

MAJOR STRESS COMPONENTS PRESENT IN THE FLOW MODEL:

- WELL

MAXIMUM NUMBER OF POINT SINKS/SOURCES = 31400

219800 ELEMENTS OF THE X ARRAY USED BY THE SSM PACKAGE

0 ELEMENTS OF THE IX ARRAY USED BY THE SSM PACKAGE

RCT4 -- CHEMICAL REACTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 85

TYPE OF SORPTION SELECTED IS [LINEAR]

NO FIRST-ORDER RATE REACTION IS SIMULATED

REACTION COEFFICIENTS ASSIGNED CELL-BY-CELL

INITIAL SORBED/IMMOBILE PHASE CONCENTRATION ASSIGNED BY DEFAULT

936000 ELEMENTS OF THE X ARRAY USED BY THE RCT PACKAGE

0 ELEMENTS OF THE IX ARRAY USED BY THE RCT PACKAGE

GCG4 -- GENERALIZED CONJUGATE GRADIENT SOLVER PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 86

MAXIMUM OF 1 OUTER ITERATIONS

AND 50 INNER ITERATIONS ALLOWED FOR CLOSURE

THE PRECONDITIONING TYPE SELECTED IS MODIFIED INCOMPLETE CHOLESKY (MIC).

DISPERSION CROSS TERMS LUMPED INTO RIGHT-HAND-SIDE

6864050 ELEMENTS OF THE X ARRAY USED BY THE GCG PACKAGE

150 ELEMENTS OF THE IX ARRAY USED BY THE GCG PACKAGE

# MODFLOW2000 Basic Package

#MODFLOW Data Set Created by Groundwater Vistas

# MODFLOW2000 Well Package

200 LAYERS  39 ROWS  40 COLUMNS
18 STRESS PERIOD(S) IN SIMULATION

BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 1
1000 ELEMENTS IN IR ARRAY ARE USED BY BAS

WEL6 -- WELL PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 12

# MODFLOW2000 Well Package

0 Named Parameters  0 List entries
MAXIMUM OF 200 ACTIVE WELLS AT ONE TIME
CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 54
800 ELEMENTS IN RX ARRAY ARE USED BY WEL
Appendix C (Continued)

CHD6 -- TIME-VARIANT SPECIFIED-HEAD PACKAGE, VERSION 6, 1/11/2000
INPUT READ FROM UNIT 40

# MODFLOW2000 Constant-Head Boundary Package (CHD)
No named parameters
MAXIMUM OF 15600 TIME-VARIANT SPECIFIED-HEAD CELLS AT ONE TIME
78000 ELEMENTS IN RX ARRAY ARE USED BY CHD

78800 ELEMENTS OF RX ARRAY USED OUT OF 78800
1000 ELEMENTS OF IR ARRAY USED OUT OF 1000
2808001 ELEMENTS OF THE VDF ARRAY USED BY VDF PROCESS

# MODFLOW2000 Basic Package
#MODFLOW Data Set Created by Groundwater Vistas

---------------------------------
TRANSPORT STEP NO. 25
---------------------------------
TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 400.0000 D

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 25, TIME STEP 20, STRESS PERIOD 8

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION: 0.3542142E+08</td>
<td>-2000782.</td>
</tr>
<tr>
<td>CONSTANT HEAD: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE): 1627906.</td>
<td>-1403.853</td>
</tr>
<tr>
<td>MASS STORAGE (SORBED): 0.000000</td>
<td>0.000000</td>
</tr>
</tbody>
</table>

[TOTAL]: 0.3704983E+08 KG   -0.3731443E+08 KG

NET (IN - OUT): -264602.0
DISCREPANCY (PERCENT): -0.7116375

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 8
DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 8

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 8

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Appendix C (Continued)

CUMULATIVE MASS RATES FOR THIS TIME STEP M/T
------------------                 ------------------------
IN:                                      IN:
---                                      ---
STORAGE = 100123.1373  STORAGE = 28.0689
CONSTANT HEAD = 710958635.3564  CONSTANT HEAD = 0.0000
WELLS = 378500000.7500  WELLS = 1514000.0030
DCDT = 1127296.1428  DCDT = 5414.2223
TOTAL IN = 7489313755.3864  TOTAL IN = 1519442.2942

OUT:                                     OUT:
----                                     ----
STORAGE = 7087672548.2672  STORAGE = 76.9186
CONSTANT HEAD = 401585650.2738  CONSTANT HEAD = 1519358.4740
WELLS = 0.0000  WELLS = 0.0000
DCDT = 1032.4589  DCDT = 6.9730
TOTAL OUT = 7489259231.0000  TOTAL OUT = 1519442.3656
IN - OUT = 54524.3865  IN - OUT = -7.1478E-02
PERCENT DISCREPANCY = 0.00  PERCENT DISCREPANCY = 0.00

TIME SUMMARY AT END OF TRANSPORT STEP 25 IN TIME STEP 20 IN STRESS PERIOD 8 SECONDS MINUTES HOURS DAYS YEARS
-----------------------------------------------------------
TRANS STEP LENGTH 10903.  181.72  3.0286  0.12619  3.45497E-04
TIME STEP LENGTH 7.39284E+05  12321.  205.36  8.5565  2.34265E-02
STRESS PERIOD TIME 4.32000E+06  72000.  1200.0  50.000  0.13689
TOTAL TIME 3.45600E+07  5.76000E+05  9600.0  400.00  1.0951

TRANSPORT STEP NO. 25

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 650.0000 D
Appendix C (Continued)........................................................................................................

CUMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP  25, TIME STEP  20, STRESS PERIOD  13
------------------------------------------------------------------------------------------

IN                           OUT
----------------             ----------------
CONSTANT CONCENTRATION:   0.3565753E+08               -2254294.
CONSTANT HEAD:    0.000000                    0.000000
WELLS:    0.000000                    0.000000
DECAY OR BIODEGRADATION:    0.000000                    0.000000
MASS STORAGE (SOLUTE):    1723890.                   -97359.57
MASS STORAGE (SORBED):    0.000000                    0.000000
---------------------------------------------------------------------------
[TOTAL]:   0.3739922E+08 KG           -0.3766390E+08 KG

NET (IN - OUT):   -264674.0
DISCREPANCY (PERCENT):  -0.7052038

HEAD WILL BE SAVED ON UNIT   30 AT END OF TIME STEP  20, STRESS PERIOD   13

DRAWDOWN WILL BE SAVED ON UNIT   31 AT END OF TIME STEP  20, STRESS PERIOD   13

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD  13
------------------------------------------------------------------------------

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T
------------------                 ------------------------
IN:                                      IN:
---                                      ---
STORAGE =     3580970.3319               STORAGE =           4.9366
CONSTANT HEAD =  715967646.1911         CONSTANT HEAD =      193360.0206
WELLS =   378500000.7500                 WELLS =           0.0000
DCDT =     1187465.5622                  DCDT =         397.8884
TOTAL IN =  7540245082.8352              TOTAL IN =      193762.8456

OUT:                                     OUT:
----                                     ----
STORAGE =  7087672666.0197               STORAGE =           4.5041
CONSTANT HEAD =   452469136.8926         CONSTANT HEAD =      193360.5616
WELLS =           0.0000                 WELLS =           0.0000
DCDT =       61179.7995                  DCDT =         397.8851
TOTAL OUT =  7540202982.7118             TOTAL OUT =      193762.9507

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Appendix C (Continued)

IN - OUT = 42100.1235  IN - OUT = -0.1051

PERCENT DISCREPANCY = 0.00  PERCENT DISCREPANCY = 0.00

0

TIME SUMMARY AT END OF TRANSPORT STEP 25 IN TIME STEP 20 IN STRESS PERIOD 13

<table>
<thead>
<tr>
<th>SECONDS</th>
<th>MINUTES</th>
<th>HOURS</th>
<th>DAYS</th>
<th>YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>----------</td>
<td>---------</td>
<td>-------</td>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>TRANS STEP LENGTH</td>
<td>10903.181.72 0.12619 3.45497E-04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIME STEP LENGTH</td>
<td>7.39284E+05 12321.205.36 8.5565 2.34265E-02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STRESS PERIOD TIME</td>
<td>4.32000E+06 72000.1200.0 50.000 0.13689</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL TIME</td>
<td>5.61600E+07 9.36000E+05 15600.650.00 1.7796</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 900.0000 D

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 25, TIME STEP 20, STRESS PERIOD 18

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION</td>
<td>0.3753320E+08</td>
</tr>
<tr>
<td>CONSTANT HEAD</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE)</td>
<td>1762011.</td>
</tr>
<tr>
<td>MASS STORAGE (SORBED)</td>
<td>0.000000</td>
</tr>
</tbody>
</table>

[TOTAL]: 0.3933039E+08 KG -0.3939136E+08 KG

NET (IN - OUT): -60974.69
DISCREPANCY (PERCENT): -0.1549119

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 18
Appendix C (Continued)

DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 18

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 18

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T

<table>
<thead>
<tr>
<th>IN:</th>
<th></th>
<th>IN:</th>
</tr>
</thead>
<tbody>
<tr>
<td>STORAGE = 7077218.6793</td>
<td>STORAGE = 13.5084</td>
<td></td>
</tr>
<tr>
<td>CONSTANT HEAD = 753349193.4805</td>
<td>CONSTANT HEAD = 1519402.4529</td>
<td></td>
</tr>
<tr>
<td>WELLS = 378500000.7500</td>
<td>WELLS = 0.0000</td>
<td></td>
</tr>
<tr>
<td>DCDT = 1213370.4976</td>
<td>DCDT = 64.0688</td>
<td></td>
</tr>
<tr>
<td>TOTAL IN = 7920239783.4074</td>
<td>TOTAL IN = 1519480.0301</td>
<td></td>
</tr>
</tbody>
</table>

OUT: | OUT: |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>STORAGE = 7087688166.4147</td>
<td>STORAGE = 8.6878</td>
</tr>
<tr>
<td>CONSTANT HEAD = 452603976.3183</td>
<td>CONSTANT HEAD = 0.0000</td>
</tr>
<tr>
<td>WELLS = 379279526.3864</td>
<td>WELLS = 1517930.2585</td>
</tr>
<tr>
<td>DCDT = 490399.8512</td>
<td>DCDT = 1541.0616</td>
</tr>
<tr>
<td>TOTAL OUT = 7920062068.9706</td>
<td>TOTAL OUT = 1519480.0078</td>
</tr>
<tr>
<td>IN - OUT = 177714.4367</td>
<td>IN - OUT = 2.2244E-02</td>
</tr>
<tr>
<td>PERCENT DISCREPANCY = 0.00</td>
<td>PERCENT DISCREPANCY = 0.00</td>
</tr>
</tbody>
</table>

0

TIME SUMMARY AT END OF TRANSPORT STEP 25 IN TIME STEP 20 IN STRESS PERIOD 18

<table>
<thead>
<tr>
<th>SECONDS</th>
<th>MINUTES</th>
<th>HOURS</th>
<th>DAYS</th>
<th>YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANS STEP LENGTH 10903.</td>
<td>181.72</td>
<td>3.0286</td>
<td>0.12619</td>
<td>3.45497E-04</td>
</tr>
<tr>
<td>TIME STEP LENGTH 7.39284E+05</td>
<td>12321</td>
<td>205.36</td>
<td>8.5565</td>
<td>2.54265E-02</td>
</tr>
<tr>
<td>STRESS PERIOD TIME 4.32E+06</td>
<td>72000</td>
<td>1200.0</td>
<td>50.000</td>
<td>0.13689</td>
</tr>
<tr>
<td>TOTAL TIME 7.776E+07</td>
<td>1.296E+06</td>
<td>21600</td>
<td>900.00</td>
<td>2.4641</td>
</tr>
</tbody>
</table>
Appendix C (Continued)

Suwan 10

MODFLOW-2000
U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL
VERSION 3.10 02/13/2004

This model run produced both GLOBAL and LIST files. This is the LIST file.

-----
1 M T 1 Conversion from Groundwater Vistas
13 D 1 MT3D Model
-----
THE TRANSPORT MODEL CONSISTS OF 200 LAYER(S) 38 ROW(S) 40 COLUMN(S)
NUMBER OF STRESS PERIOD(S) FOR TRANSPORT SIMULATION = 18
NUMBER OF ALL COMPONENTS INCLUDED IN SIMULATION = 1
NUMBER OF MOBILE COMPONENTS INCLUDED IN SIMULATION = 1
UNIT FOR TIME IS D ; UNIT FOR LENGTH IS M ; UNIT FOR MASS IS KG
PACKAGES INCLUDED IN CURRENT SIMULATION:
1 2 3 4 5 6 7 8 9 10
T T T T F F F F F

COUPLING BETWEEN FLOW AND TRANSPORT IS IMPLICIT
100 COUPLING ITERATIONS
0.1000 IS THE DENSITY CONVERGENCE CRITERIA
MT3DMS SPECIES USED IN EQUATION OF STATE FOR FLUID DENSITY: 1
AN UPSTREAM-WEIGHTED ALGORITHM IS USED TO CALCULATE FLUID DENSITY TERMS THAT CONSERVE MASS
FIRSTDT SPECIFIED BY USER IN THE VDF FILE IS: 0.1000000E-01
1000. REFERENCE DENSITY
0.7143 DENSITY SLOPE FOR EQUATION OF STATE
VARIABLE-DENSITY WATER-TABLE CORRECTIONS NOT ADDED
BTN4 -- BASIC TRANSPORT PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 81
4561676 ELEMENTS OF THE X ARRAY USED BY THE BTN PACKAGE
304200 ELEMENTS OF THE IX ARRAY USED BY THE BTN PACKAGE

FM4 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95
FLOW MODEL IS TRANSIENT

ADV4 -- ADVECTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 82
ADVECTION IS SOLVED WITH THE UPSTREAM FINITE DIFFERENCE SCHEME
COURANT NUMBER ALLOWED IN SOLVING THE ADVECTION TERM = 0.750
0 ELEMENTS OF THE X ARRAY USED BY THE ADV PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE ADV PACKAGE

DSP4 -- DISPERSION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 83
Appendix C (Continued)

3040600 ELEMENTS OF THE X ARRAY USED BY THE DSP PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE DSP PACKAGE

SSM4 -- SINK & SOURCE MIXING PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 84

HEADER LINE OF THE SSM PACKAGE INPUT FILE:
T F F F F F
MAJOR STRESS COMPONENTS PRESENT IN THE FLOW MODEL:
  o WELL
MAXIMUM NUMBER OF POINT SINKS/SOURCES = 30800
  215600 ELEMENTS OF THE X ARRAY USED BY THE SSM PACKAGE
  0 ELEMENTS OF THE IX ARRAY USED BY THE SSM PACKAGE

RCT4 -- CHEMICAL REACTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 85
NO SORPTION [OR DUAL-DOMAIN MODEL] IS SIMULATED
NO FIRST-ORDER RATE REACTION IS SIMULATED
REACTION COEFFICIENTS ASSIGNED CELL-BY-CELL
INITIAL SORBED/IMMOBILE PHASE CONCENTRATION ASSIGNED BY DEFAULT
  0 ELEMENTS OF THE X ARRAY USED BY THE RCT PACKAGE
  0 ELEMENTS OF THE IX ARRAY USED BY THE RCT PACKAGE

GCG4 -- GENERALIZED CONJUGATE GRADIENT SOLVER PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 86
MAXIMUM OF 1 OUTER ITERATIONS
  AND 50 INNER ITERATIONS ALLOWED FOR CLOSURE
THE PRECONDITIONING TYPE SELECTED IS MODIFIED INCOMPLETE CHOLESKY (MIC).
DISPERSION CROSS TERMS LUMPED INTO RIGHT-HAND-SIDE
  6688050 ELEMENTS OF THE X ARRAY USED BY THE GCG PACKAGE
  150 ELEMENTS OF THE IX ARRAY USED BY THE GCG PACKAGE

# MODFLOW2000 Basic Package
#MODFLOW Data Set Created by Groundwater Vistas
#
200 LAYERS 38 ROWS 40 COLUMNS
18 STRESS PERIOD(S) IN SIMULATION

BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 1
1000 ELEMENTS IN IR ARRAY ARE USED BY BAS

WEL6 -- WELL PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 12
# MODFLOW2000 Well Package
  0 Named Parameters 0 List entries
MAXIMUM OF 400 ACTIVE WELLS AT ONE TIME
CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 54
  1600 ELEMENTS IN RX ARRAY ARE USED BY WEL

151
Appendix C (Continued)

CHD6 -- TIME-VARIANT SPECIFIED-HEAD PACKAGE, VERSION 6, 1/11/2000

INPUT READ FROM UNIT  40

# MODFLOW2000 Constant-Head Boundary Package (CHD)

No named parameters

MAXIMUM OF  15200 TIME-VARIANT SPECIFIED-HEAD CELLS AT ONE TIME
76000 ELEMENTS IN RX ARRAY ARE USED BY CHD

77600  ELEMENTS OF RX ARRAY USED OUT OF  77600
1000  ELEMENTS OF IR ARRAY USED OUT OF  1000
2736001 ELEMENTS OF THE VDF ARRAY USED BY VDF PROCESS

1

# MODFLOW2000 Basic Package

#MODFLOW Data Set Created by Groundwater Vistas

---------------------------------------------------------------
TRANSPORT STEP NO.  20
---------------------------------------------------------------

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION =  400.0000  D

---------------------------------------------------------------
CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP  20, TIME STEP  20, STRESS PERIOD  8
---------------------------------------------------------------

IN       OUT
-----------  -----------
CONSTANT CONCENTRATION:  1790834.    -4070059.
CONSTANT HEAD:  0.000000         0.000000
WELLS:  0.000000         0.000000
DECAY OR BIODEGRADATION:  0.000000     0.000000
MASS STORAGE (SOLUTE):  3443842.    -10181.74

[TOTAL]:  5235096.  KG     -5583204.  KG

NET (IN - OUT):  -348108.4
DISCREPANCY (PERCENT):  -6.435547

HEAD WILL BE SAVED ON UNIT  30 AT END OF TIME STEP  20, STRESS PERIOD  8

DRAWDOWN WILL BE SAVED ON UNIT  31 AT END OF TIME STEP  20, STRESS PERIOD  8

1

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD  8

---------------------------------------------------------------
### Appendix C (Continued)

<table>
<thead>
<tr>
<th>CUMULATIVE MASS</th>
<th>M RATES FOR THIS TIME STEP</th>
<th>M/T</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IN:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STORAGE =</td>
<td>42329.8144</td>
<td></td>
</tr>
<tr>
<td>CONSTANT HEAD =</td>
<td>180362628.4679</td>
<td></td>
</tr>
<tr>
<td>WELLS =</td>
<td>378500000.7500</td>
<td></td>
</tr>
<tr>
<td>DCDT =</td>
<td>2386903.1805</td>
<td></td>
</tr>
<tr>
<td>TOTAL IN =</td>
<td>561291862.2127</td>
<td></td>
</tr>
<tr>
<td><strong>OUT:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STORAGE =</td>
<td>151369963.0741</td>
<td></td>
</tr>
<tr>
<td>CONSTANT HEAD =</td>
<td>40991360.8099</td>
<td></td>
</tr>
<tr>
<td>WELLS =</td>
<td>0.0000</td>
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</tr>
<tr>
<td>DCDT =</td>
<td>7043.5362</td>
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</tr>
<tr>
<td>TOTAL OUT =</td>
<td>561290167.4201</td>
<td></td>
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<tr>
<td>IN - OUT =</td>
<td>1694.7926</td>
<td></td>
</tr>
</tbody>
</table>

**PERCENT DISCREPANCY** = 0.00

#### TIME SUMMARY AT END OF TRANSPORT STEP

<table>
<thead>
<tr>
<th>SECONDS</th>
<th>MINUTES</th>
<th>HOURS</th>
<th>DAYS</th>
<th>YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2508.9</td>
<td>41.816</td>
<td>0.69693</td>
<td>2.90387E-02</td>
<td>7.95038E-05</td>
</tr>
<tr>
<td>7.39284E+05</td>
<td>12321.</td>
<td>205.36</td>
<td>8.5565</td>
<td>2.34265E-02</td>
</tr>
<tr>
<td>4.32000E+06</td>
<td>72000.</td>
<td>1200.0</td>
<td>50.000</td>
<td>0.13689</td>
</tr>
<tr>
<td>3.45600E+07</td>
<td>5.76000E+05</td>
<td>9600.0</td>
<td>400.00</td>
<td>1.0951</td>
</tr>
</tbody>
</table>

**TRANSPORT STEP NO.** 20

**TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION** = 650.0000 D
Appendix C (Continued) .................................................................

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 20, TIME STEP 20, STRESS PERIOD 13

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION:</td>
<td>-4553967.</td>
</tr>
<tr>
<td>CONSTANT HEAD:</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS:</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION:</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE):</td>
<td>-404743.7</td>
</tr>
</tbody>
</table>

[TOTAL]: 6113566. KG -6461674. KG

NET (IN - OUT): -348108.2
DISCREPANCY (PERCENT): -5.536406

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 13

DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 13

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 13

<table>
<thead>
<tr>
<th>IN:</th>
<th>OUT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>STORAGE = 116398.6747</td>
<td>STORAGE = 2.0145</td>
</tr>
<tr>
<td>CONSTANT HEAD = 229025000.9366</td>
<td>CONSTANT HEAD = 194740.1217</td>
</tr>
<tr>
<td>WELLS = 378500000.7500</td>
<td>WELLS = 0.0000</td>
</tr>
<tr>
<td>DCDT = 2644345.6029</td>
<td>DCDT = 1153.3277</td>
</tr>
<tr>
<td>TOTAL IN = 610285745.9642</td>
<td>TOTAL OUT = 610284046.5078</td>
</tr>
</tbody>
</table>

IN - OUT = 1699.4564 IN - OUT = 0.9316

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Appendix C (Continued)

PERCENT DISCREPANCY = 0.00

PERCENT DISCREPANCY = 0.00

TIME SUMMARY AT END OF TRANSPORT STEP 20 IN TIME STEP 20 IN STRESS PERIOD 13
SECONDS MINUTES HOURS DAYS YEARS
-----------------------------------------------------------
TRANS STEP LENGTH 2508.9 41.816 0.69693 2.90387E-02 7.95038E-05
TIME STEP LENGTH 7.39284E+05 12321. 205.36 8.5565 2.34265E-02
STRESS PERIOD TIME 4.32000E+06 72000. 1200.0 50.000 0.13689
TOTAL TIME 5.61600E+07 9.36000E+05 15600. 650.00 1.7796

TRANSPORT STEP NO. 20

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 900.0000 D

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 20, TIME STEP 20, STRESS PERIOD 18
------------------------------------------------------------------------------------------
IN                           OUT
----------------             ----------------
CONSTANT CONCENTRATION:    6056856.                   -4553983.
CONSTANT HEAD:    0.000000                    0.000000
WELLS:    0.000000                   -2282179.
DECAY OR BIODEGRADATION:    0.000000                    0.000000
MASS STORAGE (SOLUTE):    3888554.                   -1638769.

[TOTAL]:    9947402.     KG            -9978000.     KG

NET (IN - OUT):   -30598.18
DISCREPANCY (PERCENT): -0.3071274

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 18

DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 18
### Appendix C (Continued)

**MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 18**

----------------------------------------------------------------------------------------------------------------------

<table>
<thead>
<tr>
<th>CUMULATIVE MASS</th>
<th>RATES FOR THIS TIME STEP</th>
<th>M/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN:</td>
<td>IN:</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>STORAGE =</td>
<td>201122.4758</td>
<td>2.5144</td>
</tr>
<tr>
<td>CONSTANT HEAD =</td>
<td>610012019.7324</td>
<td>1524814.2852</td>
</tr>
<tr>
<td>WELLS =</td>
<td>37850000.7500</td>
<td>0.0000</td>
</tr>
<tr>
<td>DCDT =</td>
<td>2678435.7280</td>
<td>81.5698</td>
</tr>
<tr>
<td>TOTAL IN =</td>
<td>991391578.6862</td>
<td>1524898.3693</td>
</tr>
</tbody>
</table>

| OUT:            | OUT:                     |     |
| ----            | ----                     |     |
| STORAGE =       | 151380650.7675           | 2.9600 |
| CONSTANT HEAD = | 458651231.0381           | 0.0000 |
| WELLS =         | 380126774.6360           | 1521923.6838 |
| DCDT =          | 1095705.0039             | 2972.3906 |
| TOTAL OUT =     | 991254361.4455           | 1524899.0345 |

| IN - OUT =      | -0.6651                  |     |
| PERCENT DISCREPANCY = | 0.01  | 0.00 |

0

**TIME SUMMARY AT END OF TRANSPORT STEP 20 IN TIME STEP 20 IN STRESS PERIOD 18**

<table>
<thead>
<tr>
<th>SECONDS</th>
<th>MINUTES</th>
<th>HOURS</th>
<th>DAYS</th>
<th>YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANS STEP LENGTH</td>
<td>2508.9</td>
<td>41.816</td>
<td>0.69693</td>
<td>2.90387E-02</td>
</tr>
<tr>
<td>TIME STEP LENGTH</td>
<td>7.39284E+05</td>
<td>12321.</td>
<td>205.36</td>
<td>8.5565</td>
</tr>
<tr>
<td>STRESS PERIOD TIME</td>
<td>4.32000E+06</td>
<td>72000.</td>
<td>1200.0</td>
<td>50.000</td>
</tr>
<tr>
<td>TOTAL TIME</td>
<td>7.77600E+07</td>
<td>129600.</td>
<td>21600.</td>
<td>900.00</td>
</tr>
</tbody>
</table>

1

156
This model run produced both GLOBAL and LIST files. This is the LIST file.

-----

M T 1 Conversion from Groundwater Vistas
D 1 MT3D Model

-----

THE TRANSPORT MODEL CONSISTS OF 200 LAYER(S) 38 ROW(S) 40 COLUMN(S)
NUMBER OF STRESS PERIOD(S) FOR TRANSPORT SIMULATION = 18
NUMBER OF ALL COMPONENTS INCLUDED IN SIMULATION = 1
NUMBER OF MOBILE COMPONENTS INCLUDED IN SIMULATION = 1
UNIT FOR TIME IS D ; UNIT FOR LENGTH IS M ; UNIT FOR MASS IS KG
PACKAGES INCLUDED IN CURRENT SIMULATION:
1 2 3 4 5 6 7 8 9 10
T T T T F F F F F

COUPLING BETWEEN FLOW AND TRANSPORT IS IMPlicit
100 COUPLING ITERATIONS
0.1000 IS THE DENSITY CONVERGENCE CRITERIA
MT3DMS SPECIES USED IN EQUATION OF STATE FOR FLUID DENSITY: 1
AN UPSTREAM-WEIGHTED ALGORITHM IS USED TO CALCULATE FLUID DENSITY TERMS THAT CONSERVE MASS
FIRSTDT SPECIFIED BY USER IN THE VDF FILE IS: 0.1000000E-01
1000. REFERENCE DENSITY
0.7143 DENSITY SLOPE FOR EQUATION OF STATE
VARIABLE-DENSITY WATER-TABLE CORRECTIONS NOT ADDED
BTN4 -- BASIC TRANSPORT PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 81
4561676 ELEMENTS OF THE X ARRAY USED BY THE BTN PACKAGE
304200 ELEMENTS OF THE IX ARRAY USED BY THE BTN PACKAGE

FMI4 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95
FLOW MODEL IS TRANSIENT

ADV4 -- ADVECTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 82
ADVECTION IS SOLVED WITH THE UPSTREAM FINITE DIFFERENCE SCHEME
COURANT NUMBER ALLOWED IN SOLVING THE ADVECTION TERM = 0.750
0 ELEMENTS OF THE X ARRAY USED BY THE ADV PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE ADV PACKAGE

DSP4 -- DISPERSION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 83
3040600 ELEMENTS OF THE X ARRAY USED BY THE DSP PACKAGE
Appendix C (Continued)

0 ELEMENTS OF THE IX ARRAY USED BY THE DSP PACKAGE

SSM4 -- SINK & SOURCE MIXING PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 84

HEADER LINE OF THE SSM PACKAGE INPUT FILE:
T F F F F
MAJOR STRESS COMPONENTS PRESENT IN THE FLOW MODEL:
0 WELL
MAXIMUM NUMBER OF POINT SINKS/SOURCES =  30800
215600 ELEMENTS OF THE X ARRAY USED BY THE SSM PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE SSM PACKAGE

RCT4 -- CHEMICAL REACTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 85
NO SORPTION [OR DUAL-DOMAIN MODEL] IS SIMULATED
NO FIRST-ORDER RATE REACTION IS SIMULATED
REACTION COEFFICIENTS ASSIGNED CELL-BY-CELL
INITIAL SORBED/IMMOBILE PHASE CONCENTRATION Assigned BY DEFAULT
0 ELEMENTS OF THE X ARRAY USED BY THE RCT PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE RCT PACKAGE

GCG4 -- GENERALIZED CONJUGATE GRADIENT SOLVER PACKAGE, VERSION 4.5, MAY 2003 INPUT READ FROM UNIT 86
MAXIMUM OF 1 OUTER ITERATIONS
AND 50 INNER ITERATIONS ALLOWED FOR CLOSURE
THE PRECONDITIONING TYPE SELECTED IS MODIFIED INCOMPLETE CHOLESKY (MIC).
DISPERSION CROSS TERMS LUMPED INTO RIGHT-HAND-SIDE
6688050 ELEMENTS OF THE X ARRAY USED BY THE GCG PACKAGE
150 ELEMENTS OF THE IX ARRAY USED BY THE GCG PACKAGE

# MODFLOW2000 Basic Package

#MODFLOW Data Set Created by Groundwater Vistas
#
200 LAYERS  38 ROWS  40 COLUMNS
18 STRESS PERIOD(S) IN SIMULATION

BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 1
1000 ELEMENTS IN IR ARRAY ARE USED BY BAS

WEL6 -- WELL PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 12
# MODFLOW2000 Well Package
0 Named Parameters 0 List entries
MAXIMUM OF 400 ACTIVE WELLS AT ONE TIME
CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 54
1600 ELEMENTS IN RX ARRAY ARE USED BY WEL

CHD6 -- TIME-VARIANT SPECIFIED-HEAD PACKAGE, VERSION 6, 1/11/2000
Appendix C (Continued)

INPUT READ FROM UNIT 40
# MODFLOW2000 Constant-Head Boundary Package (CHD)
No named parameters
MAXIMUM OF 15200 TIME-VARIANT SPECIFIED-HEAD CELLS AT ONE TIME
76000 ELEMENTS IN RX ARRAY ARE USED BY CHD

77600 ELEMENTS OF RX ARRAY USED OUT OF 77600
1000 ELEMENTS OF IR ARRAY USED OUT OF 1000
2736001 ELEMENTS OF THE VDF ARRAY USED BY VDF PROCESS

# MODFLOW2000 Basic Package
#MODFLOW Data Set Created by Groundwater Vistas

<table>
<thead>
<tr>
<th></th>
<th>IN</th>
<th>OUT</th>
</tr>
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<tbody>
<tr>
<td>CONSTANT CONCENTRATION:</td>
<td>6379060.</td>
<td>-0.1423474E+08</td>
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<tr>
<td>CONSTANT HEAD:</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS:</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION:</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE):</td>
<td>0.1201403E+08</td>
<td>-16160.81</td>
</tr>
</tbody>
</table>

[TOTAL]: 0.1839832E+08 KG -0.1960822E+08 KG

NET (IN - OUT): -1209905.
DISCREPANCY (PERCENT): -6.366828

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 8

DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 8

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 8
Appendix C (Continued)

CUMULATIVE MASS   M   RATES FOR THIS TIME STEP   M/T
------------------                 ------------------------
IN:                                      IN:
---                                      ---
STORAGE =  153208.1157               STORAGE =       9.5228E-03
CONSTANT HEAD =   186815332.5952         CONSTANT HEAD =           0.0000
WELLS =   378500000.7500                 WELLS =     1514000.0030
DCDT =     8317594.9997                  DCDT =       37885.3715
TOTAL IN =   573786136.4607              TOTAL IN =     1551885.3840

OUT:                                     OUT:
----                                     ----
STORAGE =   156893252.8332               STORAGE =       8.8225E-03
CONSTANT HEAD =   416874463.9887         CONSTANT HEAD =     1551843.7786
WELLS =           0.0000                 WELLS =           0.0000
DCDT =        9749.3595                  DCDT =          41.8058
TOTAL OUT =   573777466.1814             TOTAL OUT =     1551885.5932

IN - OUT =        8670.2793              IN - OUT =          -0.2092
PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00

TIME SUMMARY AT END OF TRANSPORT STEP   20 IN TIME STEP   20 IN STRESS PERIOD   8
SECONDS     MINUTES      HOURS       DAYS        YEARS
-----------------------------------------------------------
TRANS STEP LENGTH  2508.9      41.816     0.69693     2.90387E-02 7.95038E-05
TIME STEP LENGTH 7.39284E+05  12321.      205.36      8.5565     2.34265E-02
STRESS PERIOD TIME 4.32000E+06    72000.      1200.0      50.000     0.13689
TOTAL TIME 3.45600E+07 5.76000E+05  9600.0      400.00      1.0951

1
Appendix C (Continued)

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 200.0000 D

CUMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 20, TIME STEP 20, STRESS PERIOD 4

<table>
<thead>
<tr>
<th>IN</th>
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</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION:</td>
<td>1377525.</td>
</tr>
<tr>
<td></td>
<td>-1377510.</td>
</tr>
<tr>
<td>CONSTANT HEAD:</td>
<td>0.000000</td>
</tr>
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<td></td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS:</td>
<td>0.000000</td>
</tr>
<tr>
<td></td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION:</td>
<td>0.000000</td>
</tr>
<tr>
<td></td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE):</td>
<td>1564434.</td>
</tr>
<tr>
<td></td>
<td>-1564439.</td>
</tr>
</tbody>
</table>

[TOTAL]: 2941999. KG -2941990. KG

NET (IN - OUT): 8.599161
DISCREPANCY (PERCENT): 0.2922902E-03

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 4

DRAWDOWNS WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 4

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 4

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T

<table>
<thead>
<tr>
<th>IN:</th>
<th>OUT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>STORAGE = 1178.9776</td>
<td>STORAGE = 7.6660</td>
</tr>
<tr>
<td>CONSTANT HEAD = 40341808.0643</td>
<td>CONSTANT HEAD = 201706.5759</td>
</tr>
<tr>
<td>WELLS = 0.0000</td>
<td>WELLS = 0.0000</td>
</tr>
<tr>
<td>DCDT = 1025752.2116</td>
<td>DCDT = 5740.8940</td>
</tr>
<tr>
<td>TOTAL IN = 41368739.2536</td>
<td>TOTAL IN = 207455.1359</td>
</tr>
</tbody>
</table>

TOTAL OUT = 41368424.8689     TOTAL OUT = 207455.2901
Appendix C (Continued)

\[
\begin{array}{c}
\text{IN - OUT} = 314.3847 & \text{IN - OUT} = -0.1542 \\
\text{PERCENT DISCREPANCY} = 0.00 & \text{PERCENT DISCREPANCY} = 0.00
\end{array}
\]

TIME SUMMARY AT END OF TRANSPORT STEP 20 IN TIME STEP 20 IN STRESS PERIOD 4

\[
\begin{array}{cccccc}
\text{SECONDS} & \text{MINUTES} & \text{HOURS} & \text{DAYS} & \text{YEARS} \\
\hline
\text{TRANS STEP LENGTH} & 2508.9 & 41.816 & 0.69693 & 2.90387E-02 & 7.95038E-05 \\
\text{TIME STEP LENGTH} & 7.39284E+05 & 12321. & 205.36 & 8.5565 & 2.34265E-02 \\
\text{STRESS PERIOD TIME} & 4.32000E+06 & 72000. & 1200.0 & 50.000 & 0.13689 \\
\text{TOTAL TIME} & 1.72800E+07 & 2.88000E+05 & 4800.0 & 200.00 & 0.54757
\end{array}
\]

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 20, TIME STEP 20, STRESS PERIOD 9

\[
\begin{array}{ccc}
\text{IN} & \text{OUT} \\
\hline
\text{CONSTANT CONCENTRATION:} & 0.1459242E+08 & -1377570. \\
\text{CONSTANT HEAD:} & 0.000000 & 0.000000 \\
\text{WELLS:} & 0.000000 & -9634902. \\
\text{DECAY OR BIODEGRADATION:} & 0.000000 & 0.000000 \\
\text{MASS STORAGE (SOLUTE):} & 1863818. & -4366460. \\
\hline
\text{[TOTAL]} & 0.1645986E+08 KG & -0.1537999E+08 KG
\end{array}
\]

\[
\begin{array}{c}
\text{NET (IN - OUT):} & 1079871. \\
\text{DISCREPANCY (PERCENT):} & 6.783145
\end{array}
\]

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 9

DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 9
Appendix C (Continued)

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 9

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T

IN:             IN:
---              ---
STORAGE = 106269.2162  STORAGE = 6.6630
CONSTANT HEAD = 427349422.4009  CONSTANT HEAD = 1551852.3405
WELLS = 0.0000  WELLS = 0.0000
DCDT = 1219900.1048  DCDT = 611.7234
TOTAL IN = 428675591.7220  TOTAL IN = 1552470.7268

OUT:            OUT:
----            ----
STORAGE = 30930.4572  STORAGE = 7.2079
CONSTANT HEAD = 40343110.9155  CONSTANT HEAD = 0.0000
WELLS = 385377369.4603  WELLS = 1543929.9341
DCDT = 2855253.4367  DCDT = 8534.5511
TOTAL OUT = 428606664.2697  TOTAL OUT = 1552471.6930

IN - OUT = 68927.4523  IN - OUT = -0.9662

PERCENT DISCREPANCY = 0.02  PERCENT DISCREPANCY = 0.00

0

TIME SUMMARY AT END OF TRANSPORT STEP 20 IN TIME STEP 20 IN STRESS PERIOD 9

SECONDS MINUTES HOURS DAYS YEARS

---------------------------------------------
TRANS STEP LENGTH 2508.9 41.816 0.69693 2.90387E-02 7.95038E-05
TIME STEP LENGTH 7.39284E+05 12321. 205.36 8.5565 2.34265E-02
STRESS PERIOD TIME 4.32000E+06 72000. 1200.0 50.000 0.13689
TOTAL TIME 3.88800E+07 6.48000E+05 10800. 450.00 1.2320

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Appendix D: Model Output for Extended Storage Simulation
This model run produced both GLOBAL and LIST files. This is the LIST file.

<table>
<thead>
<tr>
<th>M</th>
<th>T</th>
<th>Conversion from Groundwater Vistas</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>D</td>
<td>MT3D Model</td>
</tr>
</tbody>
</table>

The transport model consists of 200 layer(s) 38 row(s) 40 column(s)
Number of stress period(s) for transport simulation = 35
Number of all components included in simulation = 1
Number of mobile components included in simulation = 1
Unit for time is D ; Unit for length is M ; Unit for mass is KG
Packages included in current simulation:
1 2 3 4 5 6 7 8 9 10
T T T T F F F F

Coupling between flow and transport is implicit
100 coupling iterations
0.1000 is the density convergence criteria
MT3DMS species used in equation of state for fluid density: 1
An upstream-weighted algorithm is used to calculate fluid density terms that conserve mass
FirstDdt specified by user in the VDF file is: 0.1000000E-01
1000. reference density
0.7143 density slope for equation of state
Variable-density water-table corrections not added
BTN4 -- Basic Transport Package, Version 4.5, May 2003, input read from unit 81
4561676 elements of the X array used by the BTN package
304200 elements of the IX array used by the BTN package

FM4 -- Flow Model Interface Package, Version 4.5, May 2003, input read from unit 95
Flow model is transient

ADV4 -- Advection Package, Version 4.5, May 2003, input read from unit 82
Advection is solved with the upstream finite difference scheme
Courant number allowed in solving the advection term = 0.750
0 elements of the X array used by the ADV package
0 elements of the IX array used by the ADV package

DSP4 -- Dispersion Package, Version 4.5, May 2003, input read from unit 83
3040600 elements of the X array used by the DSP package
0 elements of the IX array used by the DSP package
Appendix D (Continued)

SSM4 -- SINK & SOURCE MIXING PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 84

HEADER LINE OF THE SSM PACKAGE INPUT FILE:
T F F F F F

MAJOR STRESS COMPONENTS PRESENT IN THE FLOW MODEL:
0 WELL

MAXIMUM NUMBER OF POINT SINKS/SOURCES = 30800
215600 ELEMENTS OF THE \textit{X} ARRAY USED BY THE SSM PACKAGE
0 ELEMENTS OF THE IX ARRAY BY THE SSM PACKAGE

RCT4 -- CHEMICAL REACTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 85

NO SORPTION [OR DUAL-DOMAIN MODEL] IS SIMULATED
NO FIRST-ORDER RATE REACTION IS SIMULATED
REACTION COEFFICIENTS ASSIGNED CELL-BY-CELL
INITIAL SORBED/IMMOBILE PHASE CONCENTRATION ASSIGNED BY DEFAULT
0 ELEMENTS OF THE \textit{X} ARRAY USED BY THE RCT PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE RCT PACKAGE

GCG4 -- GENERALIZED CONJUGATE GRADIENT SOLVER PACKAGE, VERSION 4.5, MAY 2003 INPUT READ FROM UNIT 86

MAXIMUM OF 1 OUTER ITERATIONS
AND 50 INNER ITERATIONS ALLOWED FOR CLOSURE
THE PRECONDITIONING TYPE SELECTED IS MODIFIED INCOMPLETE CHOLESKY (MIC).
DISPERSION CROSS TERMS LUMPED INTO RIGHT-HAND-SIDE
6688050 ELEMENTS OF THE \textit{X} ARRAY USED BY THE GCG PACKAGE
150 ELEMENTS OF THE IX ARRAY USED BY THE GCG PACKAGE

# MODFLOW2000 Basic Package
#MODFLOW Data Set Created by Groundwater Vistas
#
200 LAYERS 38 ROWS 40 COLUMNS
35 STRESS PERIOD(S) IN SIMULATION

BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 1
1000 ELEMENTS IN IR ARRAY ARE USED BY BAS

WEL6 -- WELL PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 12
# MODFLOW2000 Well Package
0 Named Parameters 0 List entries
MAXIMUM OF 400 ACTIVE WELLS AT ONE TIME
CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 54
1600 ELEMENTS IN RX ARRAY ARE USED BY WEL

CHD6 -- TIME-VARIANT SPECIFIED-HEAD PACKAGE, VERSION 6, 1/11/2000
INPUT READ FROM UNIT 40
# MODFLOW2000 Constant-Head Boundary Package (CHD)
Appendix D (Continued)
No named parameters
MAXIMUM OF 15200 TIME-VARIANT SPECIFIED-HEAD CELLS AT ONE TIME
76000 ELEMENTS IN RX ARRAY ARE USED BY CHD

77600 ELEMENTS OF RX ARRAY USED OUT OF 77600
1000 ELEMENTS OF IR ARRAY USED OUT OF 1000
2736001 ELEMENTS OF THE VDF ARRAY USED BY VDF PROCESS

---------------------------------------------------------------
TRANSPORT STEP NO. 10
---------------------------------------------------------------

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 1385.727 D

---------------------------------------------------------------
CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 10, TIME STEP 18, STRESS PERIOD 28
---------------------------------------------------------------

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION:</td>
<td>367289.9</td>
</tr>
<tr>
<td>CONSTANT HEAD:</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS:</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION:</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE):</td>
<td>334901.9</td>
</tr>
<tr>
<td>[TOTAL]:</td>
<td>702266.5</td>
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<tr>
<td>NET (IN - OUT):</td>
<td>-49669.38</td>
</tr>
<tr>
<td>DISCREPANCY (PERCENT):</td>
<td>-6.831150</td>
</tr>
</tbody>
</table>

SOLVING FOR HEAD
1 CALLS TO PCG ROUTINE FOR TIME STEP 18 IN STRESS PERIOD 28
1 TOTAL ITERATIONS
FM4 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95
FLOW MODEL IS TRANSIENT
FLOW MODEL CONTAINS CONSTANT-HEAD CELLS

"THKSAT " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95
---------------------------------------------------------------
"QXX " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95
---------------------------------------------------------------
Appendix D (Continued)

"QYY " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

"QZZ " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

"STO " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

MAXIMUM STEPSIZE DURING WHICH ANY PARTICLE CANNOT MOVE MORE THAN ONE CELL
= 36.23  (WHEN MIN. R.F.=1)  AT K=  94, I=  19, J=  21

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE ADVECTION TERM
(FOR PURE FINITE-DIFFERENCE OPTION, MIXELM=0)
= 35.84  (WHEN MIN. R.F.=1)  AT K= 103, I=  19, J=  21

"CNH " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

"WEL " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

TOTAL NUMBER OF POINT SOURCES/SINKS PRESENT IN THE FLOW MODEL = 30400

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE SINK & SOURCE TERM
= 4399.  (WHEN MIN. R.F.=1)  AT K= 127, I=  38, J=  40

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE DISPERSION TERM
= 0.2632  (WHEN MIN. R.F.=1)  AT K=  93, I=  19, J=  21

1 CALLS TO GCG PACKAGE FOR TRANSPORT TIME STEP  11 IN FLOW TIME STEP  18 STRESS PERIOD  28
1 TOTAL ITERATIONS

COMPLETED COUPLING ITERATION  1
MAXIMUM DENSITY DIFFERENCE = 0.0000
AT CELL (I,J,K) = (  19, 22, 125)

SOLVING FOR HEAD
1 CALLS TO PCG ROUTINE FOR TIME STEP  18 IN STRESS PERIOD  28
1 TOTAL ITERATIONS

FMI4 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95
FLOW MODEL IS TRANSIENT
FLOW MODEL CONTAINS CONSTANT-HEAD CELLS

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Appendix D (Continued)

"THKSAT" FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

"QXX" FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

"QYY" FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

"QZZ" FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

"STO" FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

MAXIMUM STEPSIZE DURING WHICH ANY PARTICLE CANNOT MOVE MORE THAN ONE CELL

= 36.23 (WHEN MIN. R.F.=1) AT K= 94, I= 19, J= 21

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE ADVECTION TERM
(FOR PURE FINITE-DIFFERENCE OPTION, MIXELM=0)

= 35.84 (WHEN MIN. R.F.=1) AT K= 103, I= 19, J= 21

"CNH" FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

"WEL" FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

TOTAL NUMBER OF POINT SOURCES/SINKS PRESENT IN THE FLOW MODEL = 30400

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE SINK & SOURCE TERM

= 4399. (WHEN MIN. R.F.=1) AT K= 127, I= 38, J= 40

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE DISPERSION TERM

= 0.2632 (WHEN MIN. R.F.=1) AT K= 93, I= 19, J= 21

1 CALLS TO GCG PACKAGE FOR TRANSPORT TIME STEP 12 IN FLOW TIME STEP 18 STRESS PERIOD 28

1 TOTAL ITERATIONS

0 COMPLETED COUPLING ITERATION 1

MAXIMUM DENSITY DIFFERENCE = 0.0000

AT CELL (I,J,K) = ( 19, 22, 125)
Appendix D (Continued)

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 1385.937 D

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 12, TIME STEP 18, STRESS PERIOD 28

<table>
<thead>
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<th>IN</th>
<th>OUT</th>
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<tbody>
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<td>CONSTANT CONCENTRATION:</td>
<td>-596577.5</td>
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<tr>
<td>CONSTANT HEAD:</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS:</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION:</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE):</td>
<td>-6101.472</td>
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</tbody>
</table>

TOTAL: 702306.8 KG -751976.2 KG

NET (IN - OUT): -49669.38
DISCREPANCY (PERCENT): -6.830772

SOLVING FOR HEAD
1 CALLS TO PCG ROUTINE FOR TIME STEP 18 IN STRESS PERIOD 28
1 TOTAL ITERATIONS

FLOW MODEL CONTAINS CONSTANT-HEAD CELLS

"THKSAT " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95
"QXX " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95
"QYY " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95
"QZZ " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95
Appendix D (Continued)

"STO " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

MAXIMUM STEPSIZE DURING WHICH ANY PARTICLE CANNOT MOVE MORE THAN ONE CELL
= 36.23  (WHEN MIN. R.F.=1)  AT K= 94, I= 19, J= 21

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE ADVECTION TERM
(FOR PURE FINITE-DIFFERENCE OPTION, MIXELM=0)
= 35.84  (WHEN MIN. R.F.=1)  AT K= 103, I= 19, J= 21

"CNH " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

"WEL " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

TOTAL NUMBER OF POINT SOURCES/SINKS PRESENT IN THE FLOW MODEL = 30400

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE SINK & SOURCE TERM
= 4399.  (WHEN MIN. R.F.=1)  AT K= 127, I= 38, J= 40

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE DISPERSION TERM
= 0.2632  (WHEN MIN. R.F.=1)  AT K= 93, I= 19, J= 21

1 CALLS TO GCG PACKAGE FOR TRANSPORT TIME STEP 13 IN FLOW TIME STEP 18 STRESS PERIOD 28
1 TOTAL ITERATIONS

0COMPLETED COUPLING ITERATION 1
MAXIMUM DENSITY DIFFERENCE = 0.0000
AT CELL (I,J,K) = (19, 22, 125)

SOLVING FOR HEAD
1 CALLS TO PCG ROUTINE FOR TIME STEP 18 IN STRESS PERIOD 28
1 TOTAL ITERATIONS

FM4 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95
FLOW MODEL IS TRANSIENT
FLOW MODEL CONTAINS CONSTANT-HEAD CELLS

"THKSAT " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95
Appendix D (Continued)

"QXX             " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

"QYY             " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

"QZZ             " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

"STO             " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

MAXIMUM STEPSIZE DURING WHICH ANY PARTICLE CANNOT MOVE MORE THAN ONE CELL
= 36.23  (WHEN MIN. R.F.=1)  AT K=  94, I=  19, J=  21

MAXIMUM STEPSIZE WHICH MEETS STABILITY CRITERION OF THE ADVECTION TERM
(FOR PURE FINITE-DIFFERENCE OPTION, MIXELM=0)
= 35.84  (WHEN MIN. R.F.=1)  AT K= 103, I=  19, J=  21

"CNH             " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95

"WEL             " FLOW TERMS FOR TIME STEP 18, STRESS PERIOD 28 READ UNFORMATTED ON UNIT 95
Appendix E: Model Output for Simulations with Varying Dispersivities
This model run produced both GLOBAL and LIST files. This is the LIST file.

-----
1 M T 1 Conversion from Groundwater Vistas
13 D 1 MT3D Model
-----
THE TRANSPORT MODEL CONSISTS OF 200 LAYER(S) 38 ROW(S) 40 COLUMN(S)
NUMBER OF STRESS PERIOD(S) FOR TRANSPORT SIMULATION = 18
NUMBER OF ALL COMPONENTS INCLUDED IN SIMULATION = 1
NUMBER OF MOBILE COMPONENTS INCLUDED IN SIMULATION = 1
UNIT FOR TIME IS D ; UNIT FOR LENGTH IS M ; UNIT FOR MASS IS KG
PACKAGES INCLUDED IN CURRENT SIMULATION:
1 2 3 4 5 6 7 8 9 10
T T T T F F F F F

COUPLING BETWEEN FLOW AND TRANSPORT IS IMPLICIT
100 COUPLING ITERATIONS
0.1000 IS THE DENSITY CONVERGENCE CRITERIA
MT3DMS SPECIES USED IN EQUATION OF STATE FOR FLUID DENSITY: 1
AN UPSTREAM-WEIGHTED ALGORITHM IS USED TO CALCULATE FLUID DENSITY TERMS THAT CONSERVE MASS
FIRSTDT SPECIFIED BY USER IN THE VDF FILE IS: 0.1000000E-01
1000. REFERENCE DENSITY
0.7143 DENSITY SLOPE FOR EQUATION OF STATE
VARIABLE-DENSITY WATER-TABLE CORRECTIONS NOT ADDED
BTN4 -- BASIC TRANSPORT PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 81
4561676 ELEMENTS OF THE X ARRAY USED BY THE BTN PACKAGE
304200 ELEMENTS OF THE IX ARRAY USED BY THE BTN PACKAGE

FMI4 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95
FLOW MODEL IS TRANSIENT

ADV4 -- ADVECTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 82
ADVECTION IS SOLVED WITH THE UPSTREAM FINITE DIFFERENCE SCHEME
COURANT NUMBER ALLOWED IN SOLVING THE ADVECTION TERM = 0.750
0 ELEMENTS OF THE X ARRAY USED BY THE ADV PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE ADV PACKAGE

DSP4 -- DISPERSION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 83
3040600 ELEMENTS OF THE X ARRAY USED BY THE DSP PACKAGE
Appendix E (Continued)

0 ELEMENTS OF THE IX ARRAY USED BY THE DSP PACKAGE

SSM4 -- SINK & SOURCE MIXING PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 84

HEADER LINE OF THE SSM PACKAGE INPUT FILE:
T F F F F F
MAJOR STRESS COMPONENTS PRESENT IN THE FLOW MODEL:
0 WELL
MAXIMUM NUMBER OF POINT SINKS/SOURCES = 30800
215600 ELEMENTS OF THE X ARRAY USED BY THE SSM PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE SSM PACKAGE

RCT4 -- CHEMICAL REACTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 85
NO SORPTION [OR DUAL-DOMAIN MODEL] IS SIMULATED
NO FIRST-ORDER RATE REACTION IS SIMULATED
REACTION COEFFICIENTS ASSIGNED CELL-BY-CELL
INITIAL SORBED/IMMOBILE PHASE CONCENTRATION ASSIGNED BY DEFAULT
0 ELEMENTS OF THE X ARRAY USED BY THE RCT PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE RCT PACKAGE

GCG4 -- GENERALIZED CONJUGATE GRADIENT SOLVER PACKAGE, VERSION 4.5, MAY 2003 INPUT READ FROM UNIT 86
MAXIMUM OF 1 OUTER ITERATIONS
AND 50 INNER ITERATIONS ALLOWED FOR CLOSURE
THE PRECONDITIONING TYPE SELECTED IS MODIFIED INCOMPLETE CHOLESKY (MIC).
DISPERSION CROSS TERMS LUMPED INTO RIGHT-HAND-SIDE
6688050 ELEMENTS OF THE X ARRAY USED BY THE GCG PACKAGE
150 ELEMENTS OF THE IX ARRAY USED BY THE GCG PACKAGE

# MODFLOW2000 Basic Package
#MODFLOW Data Set Created by Groundwater Vistas
#
200 LAYERS 38 ROWS 40 COLUMNS
18 STRESS PERIOD(S) IN SIMULATION

BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 1
1000 ELEMENTS IN IR ARRAY ARE USED BY BAS

WEL6 -- WELL PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 12
# MODFLOW2000 Well Package
0 Named Parameters 0 List entries
MAXIMUM OF 400 ACTIVE WELLS AT ONE TIME
CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 54
1600 ELEMENTS IN RX ARRAY ARE USED BY WEL

CHD6 -- TIME-VARIANT SPECIFIED-HEAD PACKAGE, VERSION 6, 1/11/2000

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Appendix E (Continued)

INPUT READ FROM UNIT  40
# MODFLOW2000 Constant-Head Boundary Package (CHD)
No named parameters
MAXIMUM OF  15200 TIME-VARIANT SPECIFIED-HEAD CELLS AT ONE TIME
  76000 ELEMENTS IN RX ARRAY ARE USED BY CHD

  77600 ELEMENTS OF RX ARRAY USED OUT OF  77600
  1000 ELEMENTS OF IR ARRAY USED OUT OF  1000
  2736001 ELEMENTS OF THE VDF ARRAY USED BY VDF PROCESS

# MODFLOW2000 Basic Package
#MODFLOW Data Set Created by Groundwater Vistas

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION: 177939.5</td>
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</tr>
<tr>
<td>CONSTANT HEAD: 0.000000 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS: 0.000000 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION: 0.000000 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE): 354068.3</td>
<td>-48.88584</td>
</tr>
<tr>
<td>[TOTAL]: 532009.3 KG</td>
<td>-556471.3 KG</td>
</tr>
</tbody>
</table>

NET (IN - OUT): -24462.06

DISCREPANCY (PERCENT): -4.494716

HEAD WILL BE SAVED ON UNIT  30 AT END OF TIME STEP  20, STRESS PERIOD  8

DRAWDOWN WILL BE SAVED ON UNIT  31 AT END OF TIME STEP  20, STRESS PERIOD  8

1
Appendix E (Continued)
MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 8

------------------------------------------------------------------------------
CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T
------------------                 ------------------------
IN:                                      IN:
---                                      ---
STORAGE =        1510.1370               STORAGE =           1.5311
CONSTANT HEAD =   178066607.3073         CONSTANT HEAD =           0.0000
WELLS =   378500000.7500                 WELLS =     1514000.0030
DCDT =      247697.3025                  DCDT =        1081.5768
TOTAL IN =   556815815.4969              TOTAL IN =     1515083.1109

OUT:                                     OUT:
----                                     ----
STORAGE =   149403907.0651               STORAGE =           1.0202
CONSTANT HEAD =   407415999.1286         CONSTANT HEAD =     1515081.6480
WELLS =           0.0000                 WELLS =           0.0000
DCDT =          36.9202                  DCDT =           0.1264
TOTAL OUT =   556819943.1139             TOTAL OUT =     1515082.7946

IN - OUT =       -4127.6170              IN - OUT =           0.3164
PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00

TIME SUMMARY AT END OF TRANSPORT STEP 20 IN TIME STEP 20 IN STRESS PERIOD 8
SECONDS     MINUTES      HOURS       DAYS        YEARS
-----------------------------------------------------------
TRANS STEP LENGTH  2508.9      41.816     0.69693     2.90387E-02 7.95038E-05
TIME STEP LENGTH 7.39284E+05  12321.      205.36      8.5565     2.34265E-02
STRESS PERIOD TIME 4.32000E+06  72000.      1200.0      50.000     0.13689
TOTAL TIME 3.45600E+07 5.76000E+05 9600.0        400.00     1.0951
Appendix E (Continued)

TRANSPORT STEP NO. 20

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 650.0000 D

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 20, TIME STEP 20, STRESS PERIOD 13

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION: 225947.9</td>
<td>-455208.2</td>
</tr>
<tr>
<td>CONSTANT HEAD: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE): 383164.9</td>
<td>-29145.45</td>
</tr>
</tbody>
</table>

[TOTAL]: 609187.7 KG -633650.9 KG

NET (IN - OUT): -24463.28
DISCREPANCY (PERCENT): -3.936678

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 13
DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 13

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T

<table>
<thead>
<tr>
<th>IN:</th>
<th>OUT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>STORAGE = 75111.1211</td>
<td>STORAGE = 3.5190</td>
</tr>
<tr>
<td>CONSTANT HEAD = 226109263.1669</td>
<td>CONSTANT HEAD = 192258.7720</td>
</tr>
<tr>
<td>WELLS = 37850000.7500</td>
<td>WELLS = 0.0000</td>
</tr>
<tr>
<td>DCDT = 266805.9199</td>
<td>DCDT = 95.2858</td>
</tr>
<tr>
<td>TOTAL IN = 604951180.9579</td>
<td>TOTAL IN = 192357.5768</td>
</tr>
</tbody>
</table>

178
Appendix E (Continued)

<table>
<thead>
<tr>
<th>WELLS = 0.0000</th>
<th>WELLS = 0.0000</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCDT = 19145.5170</td>
<td>DCDT = 95.2872</td>
</tr>
</tbody>
</table>

TOTAL OUT = 604956435.1870  TOTAL OUT = 192360.8730

IN - OUT = -5254.2291  IN - OUT = -3.2961

PERCENT DISCREPANCY = 0.00  PERCENT DISCREPANCY = 0.00


<table>
<thead>
<tr>
<th>TIME SUMMARY AT END OF TRANSPORT STEP</th>
<th>20</th>
<th>IN TIME STEP</th>
<th>20</th>
<th>IN STRESS PERIOD</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>SECONDS</td>
<td>MINUTES</td>
<td>HOURS</td>
<td>DAYS</td>
<td>YEARS</td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-----------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRANS STEP LENGTH</td>
<td>2508.9</td>
<td>41.816</td>
<td>0.69693</td>
<td>2.90387E-02</td>
<td>7.95038E-05</td>
</tr>
<tr>
<td>TIME STEP LENGTH</td>
<td>7.39284E+05</td>
<td>12321.</td>
<td>205.36</td>
<td>8.5565</td>
<td>2.34265E-02</td>
</tr>
<tr>
<td>STRESS PERIOD TIME</td>
<td>4.32000E+06</td>
<td>72000.</td>
<td>1200.0</td>
<td>50.000</td>
<td>0.13689</td>
</tr>
<tr>
<td>TOTAL TIME</td>
<td>5.61600E+07</td>
<td>9.36000E+05</td>
<td>15600.</td>
<td>650.00</td>
<td>1.7796</td>
</tr>
</tbody>
</table>

TRANSPORT STEP NO. 20

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 900.0000 D

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 20, TIME STEP 20, STRESS PERIOD 18

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION:</td>
<td>604371.6</td>
</tr>
<tr>
<td>CONSTANT HEAD:</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS:</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION:</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE):</td>
<td>397545.1</td>
</tr>
<tr>
<td>[TOTAL]:</td>
<td>1002066. KG</td>
</tr>
</tbody>
</table>
Appendix E (Continued)

NET (IN - OUT):    2111.463
DISCREPANCY (PERCENT): 0.2109333

HEAD WILL BE SAVED ON UNIT  30 AT END OF TIME STEP  20, STRESS PERIOD   18

DRAWDOWN WILL BE SAVED ON UNIT  31 AT END OF TIME STEP  20, STRESS PERIOD   18

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD  18

-----------------------------------------------

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T
-----------------------------------------------

IN:                                      IN:
---                                      ---
STORAGE =      149482.6893               STORAGE =           1.1028
CONSTANT HEAD =   604803331.4612         CONSTANT HEAD =     1515082.3793
WELLS =   378500000.7500                 WELLS =           0.0000
DCDT =      276746.6171                  DCDT =          25.3615
TOTAL IN =   983729561.5176              TOTAL IN =     1515108.8436

OUT:                                     OUT:
----                                     ----
STORAGE =   149404712.4673               STORAGE =           1.0659
CONSTANT HEAD =   455534974.7023         CONSTANT HEAD =           0.0000
WELLS =   378613403.4220                 WELLS =     1514745.1551
DCDT =      161912.5129                  DCDT =         361.6596
TOTAL OUT =   983715003.1046             TOTAL OUT =     1515107.8807

IN - OUT =       14558.4130              IN - OUT =           0.9630

PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00

TIME SUMMARY AT END OF TRANSPORT STEP   20 IN TIME STEP   20 IN STRESS PERIOD  18
SECONDS       MINUTES      HOURS       DAYS        YEARS
-----------------------------------------------------------
TRANS STEP LENGTH  2508.9      41.816     0.69693     2.90387E-02 7.95038E-05
TIME STEP LENGTH 7.39284E+05  12321.      205.36      8.5565     2.34265E-02
STRESS PERIOD TIME 4.32000E+06  72000.      1200.0      50.000     0.13689
TOTAL TIME 7.77600E+07 1.29600E+06  21600.     900.00     2.4641

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Appendix E (Continued)

Suwan Hetero D 5.25

MODFLOW-2000
U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL
VERSION 3.10 02/13/2004

This model run produced both GLOBAL and LIST files. This is the LIST file.

-----
M T | Conversion from Groundwater Vistas
D | MT3D Model
-----
THE TRANSPORT MODEL CONSISTS OF 200 LAYER(S) 38 ROW(S) 40 COLUMN(S)
NUMBER OF STRESS PERIOD(S) FOR TRANSPORT SIMULATION = 18
NUMBER OF ALL COMPONENTS INCLUDED IN SIMULATION = 1
NUMBER OF MOBILE COMPONENTS INCLUDED IN SIMULATION = 1
UNIT FOR TIME IS D ; UNIT FOR LENGTH IS M ; UNIT FOR MASS IS KG
PACKAGES INCLUDED IN CURRENT SIMULATION:
1 2 3 4 5 6 7 8 9 10
T T T T F F F

COUPLING BETWEEN FLOW AND TRANSPORT IS IMPLICIT
100 COUPLING ITERATIONS
0.1000 IS THE DENSITY CONVERGENCE CRITERIA
MT3DMS SPECIES USED IN EQUATION OF STATE FOR FLUID DENSITY: 1
AN UPSTREAM-WEIGHTED ALGORITHM IS USED TO CALCULATE FLUID DENSITY TERMS THAT CONSERVE MASS
FIRSTDT SPECIFIED BY USER IN THE VDF FILE IS: 0.1000000E-01
1000. REFERENCE DENSITY
0.7143 DENSITY SLOPE FOR EQUATION OF STATE
VARIABLE-DENSITY WATER-TABLE CORRECTIONS NOT ADDED
BTN4 -- BASIC TRANSPORT PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 81
4561676 ELEMENTS OF THE X ARRAY USED BY THE BTN PACKAGE
304200 ELEMENTS OF THE IX ARRAY USED BY THE BTN PACKAGE

FM4 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95
FLOW MODEL IS TRANSIENT

ADV4 -- ADVECTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 82
ADVECTION IS SOLVED WITH THE UPSTREAM FINITE DIFFERENCE SCHEME
COURANT NUMBER ALLOWED IN SOLVING THE ADVECTION TERM = 0.750
0 ELEMENTS OF THE X ARRAY USED BY THE ADV PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE ADV PACKAGE

DSP4 -- DISPERSION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 83
3040600 ELEMENTS OF THE X ARRAY USED BY THE DSP PACKAGE
Appendix E (Continued)

0 ELEMENTS OF THE IX ARRAY USED BY THE DSP PACKAGE

SSM4 -- SINK & SOURCE MIXING PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 84

HEADER LINE OF THE SSM PACKAGE INPUT FILE:
T F F F F F
MAJOR STRESS COMPONENTS PRESENT IN THE FLOW MODEL:
- WELL
MAXIMUM NUMBER OF POINT SINKS/SOURCES = 30800
215600 ELEMENTS OF THE X ARRAY USED BY THE SSM PACKAGE
0 ELEMENTS OF THE IX ARRAY BY THE SSM PACKAGE

RCT4 -- CHEMICAL REACTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 85
NO SORPTION [OR DUAL-DOMAIN MODEL] IS SIMULATED
NO FIRST-ORDER RATE REACTION IS SIMULATED
REACTION COEFFICIENTS ASSIGNED CELL-BY-CELL
INITIAL SORBED/IMMOBILE PHASE CONCENTRATION ASSIGNED BY DEFAULT
0 ELEMENTS OF THE X ARRAY USED BY THE RCT PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE RCT PACKAGE

GCG4 -- GENERALIZED CONJUGATE GRADIENT SOLVER PACKAGE, VERSION 4.5, MAY 2003 INPUT READ FROM UNIT 86
MAXIMUM OF 1 OUTER ITERATIONS
AND 50 INNER ITERATIONS ALLOWED FOR CLOSURE
THE PRECONDITIONING TYPE SELECTED IS MODIFIED INCOMPLETE CHOLESKY (MIC).
DISPERSION CROSS TERMS LUMPED INTO RIGHT-HAND-SIDE
6688050 ELEMENTS OF THE X ARRAY USED BY THE GCG PACKAGE
150 ELEMENTS OF THE IX ARRAY USED BY THE GCG PACKAGE

# MODFLOW2000 Basic Package
#MODFLOW Data Set Created by Groundwater Vistas
#
200 LAYERS 38 ROWS 40 COLUMNS
18 STRESS PERIOD(S) IN SIMULATION

BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 1
1000 ELEMENTS IN IR ARRAY ARE USED BY BAS

WEL6 -- WELL PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 12
# MODFLOW2000 Well Package
0 Named Parameters 0 List entries
MAXIMUM OF 400 ACTIVE WELLS AT ONE TIME
CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 54
1600 ELEMENTS IN RX ARRAY ARE USED BY WEL
CHD6 -- TIME-VARIANT SPECIFIED-HEAD PACKAGE, VERSION 6, 1/11/2000
Appendix E (Continued)

INPUT READ FROM UNIT  40
# MODFLOW2000 Constant-Head Boundary Package (CHD)
No named parameters
MAXIMUM OF  15200 TIME-VARIANT SPECIFIED-HEAD CELLS AT ONE TIME
  76000 ELEMENTS IN RX ARRAY ARE USED BY CHD

  77600  ELEMENTS OF RX ARRAY USED OUT OF   77600
  1000  ELEMENTS OF IR ARRAY USED OUT OF    1000
  2736001 ELEMENTS OF THE VDF ARRAY USED BY VDF PROCESS

# MODFLOW2000 Basic Package
#MODFLOW Data Set Created by Groundwater Vistas

---------------------------------------------------------------
TRANSPORT STEP NO.  25
---------------------------------------------------------------
TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION =   400.0000   D

---------------------------------------------------------------
CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP   25, TIME STEP   20, STRESS PERIOD    8

---------------------------------------------------------------
IN                           OUT
----------------             ----------------
CONSTANT CONCENTRATION: 177953.3                   -407100.7
CONSTANT HEAD: 0.000000                    0.000000
WELLS: 0.000000                    0.000000
DECAY OR BIODEGRADATION: 0.000000                    0.000000
MASS STORAGE (SOLUTE): 335133.2                   -121.3936

[TOTAL]: 513087.7 KG            -556519.1 KG

NET (IN - OUT): -43431.39
DISCREPANCY (PERCENT): -8.121000

HEAD WILL BE SAVED ON UNIT   30 AT END OF TIME STEP  20, STRESS PERIOD    8

DRAWDOWN WILL BE SAVED ON UNIT   31 AT END OF TIME STEP  20, STRESS PERIOD    8

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD   8

---------------------------------------------------------------
Appendix E (Continued)

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T
------------------                 ------------------------
IN:                                      IN:
---                                      ---
STORAGE =        1238.7598               STORAGE =           0.2245
CONSTANT HEAD =   178080366.5120         CONSTANT HEAD =           0.0000
WELLS =   378499999.7500                 WELLS =     1513999.9990
DCDT =      233066.7606                  DCDT =        1081.7044
TOTAL IN =   556814671.7824              TOTAL IN =     1515081.9280
OUT:                                      OUT:
----                                     ----
STORAGE =   149403653.2148               STORAGE =           0.1614
CONSTANT HEAD =   407391509.6637         CONSTANT HEAD =     1515081.3874
WELLS =           0.0000                 WELLS =           0.0000
DCDT =          85.0837                  DCDT =           0.2543
TOTAL OUT =   556795247.9623             TOTAL OUT =     1515081.8031
IN - OUT =       19423.8201              IN - OUT =           0.1249
PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00

0

TIME SUMMARY AT END OF TRANSPORT STEP 25 IN TIME STEP 20 IN STRESS PERIOD 8
SECONDS MINUTES HOURS DAYS YEARS
-----------------------------------------------------------
TRANS STEP LENGTH 10903. 181.72 3.0286 0.12619 3.45497E-04
TIME STEP LENGTH 7.39284E+05 12321. 205.36 8.5565 2.34265E-02
STRESS PERIOD TIME 4.32000E+06 72000. 1200.0 50.000 0.13689
TOTAL TIME 3.45600E+07 5.76000E+05 9600.0 400.00 1.0951

-----------------------------------------------------------
TRANSPORT STEP NO. 25
CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 25, TIME STEP 20, STRESS PERIOD 13

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION:</td>
<td>225951.0</td>
</tr>
<tr>
<td>CONSTANT HEAD:</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS:</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION:</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE):</td>
<td>345504.1</td>
</tr>
</tbody>
</table>

[TOTAL]: 571529.6 KG -614961.3 KG

NET (IN - OUT): -43431.62
DISCREPANCY (PERCENT): -7.321020

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 13
DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 13

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T

<table>
<thead>
<tr>
<th>IN:</th>
<th>OUT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>STORAGE = 74846.1726</td>
<td>STORAGE = 0.3116</td>
</tr>
<tr>
<td>CONSTANT HEAD = 226112347.4801</td>
<td>CONSTANT HEAD = 192218.1648</td>
</tr>
<tr>
<td>WELLS = 378499999.7500</td>
<td>WELLS = 0.0000</td>
</tr>
<tr>
<td>DCDT = 239621.4713</td>
<td>DCDT = 45.6247</td>
</tr>
<tr>
<td>TOTAL IN = 604926814.8741</td>
<td>TOTAL IN = 192264.1011</td>
</tr>
</tbody>
</table>

OUT:                                      OUT:

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>STORAGE = 149403659.3921</td>
<td>STORAGE = 0.2950</td>
</tr>
<tr>
<td>CONSTANT HEAD = 455497162.0779</td>
<td>CONSTANT HEAD = 192216.0151</td>
</tr>
<tr>
<td>WELLS = 0.0000</td>
<td>WELLS = 0.0000</td>
</tr>
<tr>
<td>DCDT = 6628.9457</td>
<td>DCDT = 45.6246</td>
</tr>
<tr>
<td>TOTAL OUT = 604907450.4157</td>
<td>TOTAL OUT = 192261.9347</td>
</tr>
</tbody>
</table>
Appendix E (Continued)

\[
\begin{array}{ccc}
\text{IN - OUT} &=& 19364.4584 \\
\text{IN - OUT} &=& 2.1663 \\
\text{PERCENT DISCREPANCY} &=& 0.00 \\
\text{PERCENT DISCREPANCY} &=& 0.00
\end{array}
\]


TIME SUMMARY AT END OF TRANSPORT STEP 25 IN TIME STEP 20 IN STRESS PERIOD 13

<table>
<thead>
<tr>
<th>SECONDS</th>
<th>MINUTES</th>
<th>HOURS</th>
<th>DAYS</th>
<th>YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>10903.00</td>
<td>181.72</td>
<td>3.0286</td>
<td>0.1262</td>
<td>3.45497E-04</td>
</tr>
<tr>
<td>7.39284E+05</td>
<td>12321.00</td>
<td>205.36</td>
<td>8.5565</td>
<td>2.34265E-02</td>
</tr>
<tr>
<td>4.32000E+06</td>
<td>72000.00</td>
<td>1200.00</td>
<td>50.0000</td>
<td>0.13689</td>
</tr>
<tr>
<td>5.61600E+07</td>
<td>9.36000E+05</td>
<td>15600.00</td>
<td>650.0000</td>
<td>1.7796</td>
</tr>
</tbody>
</table>

TRANSPORT STEP NO. 25

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 900.000 D

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 25, TIME STEP 20, STRESS PERIOD 18

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION:</td>
<td>604375.3</td>
</tr>
<tr>
<td>CONSTANT HEAD:</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS:</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION:</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE):</td>
<td>350967.3</td>
</tr>
</tbody>
</table>

[TOTAL]: 955491.0 KG -960025.0 KG

NET (IN - OUT): -4533.990
DISCREPANCY (PERCENT): -0.4733962

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 18
DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 18

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 18

<table>
<thead>
<tr>
<th>CUMULATIVE MASS</th>
<th>M RATES FOR THIS TIME STEP</th>
<th>M/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN:</td>
<td>IN:</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>STORAGE</td>
<td>148987.4264</td>
<td>0.1111</td>
</tr>
<tr>
<td>CONSTANT HEAD</td>
<td>604807007.5191</td>
<td>1515081.8573</td>
</tr>
<tr>
<td>WELLS</td>
<td>378499999.7500</td>
<td>0.0000</td>
</tr>
<tr>
<td>DCDT</td>
<td>243400.2564</td>
<td>4.8148</td>
</tr>
<tr>
<td>TOTAL IN</td>
<td>983699394.9519</td>
<td>1515086.7831</td>
</tr>
</tbody>
</table>

| OUT:            | OUT:                        |     |
| ---             | ---                         |     |
| STORAGE         | 149404199.9950              | 0.1076|
| CONSTANT HEAD   | 455498798.7021              | 0.0000|
| WELLS           | 378631172.7932              | 1514743.5077|
| DCDT            | 117254.8932                 | 342.7563|
| TOTAL OUT       | 983651426.3834              | 1515086.3716|

IN - OUT = 47968.5685 IN - OUT = 0.4115
PERCENT DISCREPANCY = 0.00 PERCENT DISCREPANCY = 0.00

TIME SUMMARY AT END OF TRANSPORT STEP 25 IN TIME STEP 20 IN STRESS PERIOD 18

<table>
<thead>
<tr>
<th>SECONDS</th>
<th>MINUTES</th>
<th>HOURS</th>
<th>DAYS</th>
<th>YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRANS STEP LENGTH</td>
<td>10903.</td>
<td>181.72</td>
<td>3.0286</td>
<td>0.12619</td>
</tr>
<tr>
<td>TIME STEP LENGTH</td>
<td>7.39284E+05</td>
<td>12321.</td>
<td>205.36</td>
<td>8.5565</td>
</tr>
<tr>
<td>STRESS PERIOD TIME</td>
<td>4.32000E+06</td>
<td>72000.</td>
<td>1200.0</td>
<td>50.000</td>
</tr>
<tr>
<td>TOTAL TIME</td>
<td>7.77600E+07</td>
<td>1.29600E+06</td>
<td>21600.</td>
<td>900.00</td>
</tr>
</tbody>
</table>

1
This model run produced both GLOBAL and LIST files. This is the LIST file.

-----
1 M T | Conversion from Groundwater Vistas
13 D | MT3D Model
-----

THE TRANSPORT MODEL CONSISTS OF 200 LAYER(S) 38 ROW(S) 40 COLUMN(S)
NUMBER OF STRESS PERIOD(S) FOR TRANSPORT SIMULATION = 18
NUMBER OF ALL COMPONENTS INCLUDED IN SIMULATION = 1
NUMBER OF MOBILE COMPONENTS INCLUDED IN SIMULATION = 1
UNIT FOR TIME IS D ; UNIT FOR LENGTH IS M ; UNIT FOR MASS IS KG
PACKAGES INCLUDED IN CURRENT SIMULATION:
  1  2  3  4  5  6  7  8  9 10
T T T T F F F F F

COUPLING BETWEEN FLOW AND TRANSPORT IS IMPLICIT

100 COUPLING ITERATIONS
0.1000 IS THE DENSITY CONVERGENCE CRITERIA
MT3DMS SPECIES USED IN EQUATION OF STATE FOR FLUID DENSITY: 1
AN UPSTREAM-WEIGHTED ALGORITHM IS USED TO CALCULATE FLUID DENSITY TERMS THAT CONSERVE MASS
FIRSTDT SPECIFIED BY USER IN THE VDF FILE IS: 0.1000000E-01
1000. REFERENCE DENSITY
0.7143 DENSITY SLOPE FOR EQUATION OF STATE
VARIABLE-DENSITY WATER-TABLE CORRECTIONS NOT ADDED
BTN4 -- BASIC TRANSPORT PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 81
  4561676 ELEMENTS OF THE X ARRAY USED BY THE BTN PACKAGE
  304200 ELEMENTS OF THE IX ARRAY USED BY THE BTN PACKAGE

FM34 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95
FLOW MODEL IS TRANSIENT

ADV4 -- ADVECTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 82
ADVECTION IS SOLVED WITH THE UPSTREAM FINITE DIFFERENCE SCHEME
COURANT NUMBER ALLOWED IN SOLVING THE ADVECTION TERM = 0.750
  0 ELEMENTS OF THE X ARRAY USED BY THE ADV PACKAGE
  0 ELEMENTS OF THE IX ARRAY USED BY THE ADV PACKAGE

DSP4 -- DISPERSION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 83
  3040600 ELEMENTS OF THE X ARRAY USED BY THE DSP PACKAGE
Appendix E (Continued)

0 ELEMENTS OF THE IX ARRAY USED BY THE DSP PACKAGE

SSM4 -- SINK & SOURCE MIXING PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 84

HEADER LINE OF THE SSM PACKAGE INPUT FILE:
T F F F F F
MAJOR STRESS COMPONENTS PRESENT IN THE FLOW MODEL:
ω WELL
MAXIMUM NUMBER OF POINT SINKS/SOURCES = 30800
215600 ELEMENTS OF THE X ARRAY USED BY THE SSM PACKAGE
0 ELEMENTS OF THE IX ARRAY BY THE SSM PACKAGE

RCT4 -- CHEMICAL REACTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 85
NO SORPTION [OR DUAL-DOMAIN MODEL] IS SIMULATED
NO FIRST-ORDER RATE REACTION IS SIMULATED
REACTION COEFFICIENTS ASSIGNED CELL-BY-CELL
INITIAL SORBED/IMMOBILE PHASE CONCENTRATION ASSIGNED BY DEFAULT
0 ELEMENTS OF THE X ARRAY USED BY THE RCT PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE RCT PACKAGE

GCG4 -- GENERALIZED CONJUGATE GRADIENT SOLVER PACKAGE, VERSION 4.5, MAY 2003 INPUT READ FROM UNIT 86
MAXIMUM OF 1 OUTER ITERATIONS
AND 50 INNER ITERATIONS ALLOWED FOR CLOSURE
THE PRECONDITIONING TYPE SELECTED IS MODIFIED INCOMPLETE CHOLESKY (MIC).
DISPERSION CROSS TERMS LUMPED INTO RIGHT-HAND-SIDE
6688050 ELEMENTS OF THE X ARRAY USED BY THE GCG PACKAGE
150 ELEMENTS OF THE IX ARRAY USED BY THE GCG PACKAGE

# MODFLOW2000 Basic Package
#MODFLOW Data Set Created by Groundwater Vistas
#
200 LAYERS 38 ROWS 40 COLUMNS
18 STRESS PERIOD(S) IN SIMULATION

BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 1
1000 ELEMENTS IN IR ARRAY ARE USED BY BAS

WEL6 -- WELL PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 12
# MODFLOW2000 Well Package
0 Named Parameters 0 List entries
MAXIMUM OF 400 ACTIVE WELLS AT ONE TIME
CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 54
1600 ELEMENTS IN RX ARRAY ARE USED BY WEL

CHD6 -- TIME-VARIANT SPECIFIED-HEAD PACKAGE, VERSION 6, 1/11/2000
Appendix E (Continued)

INPUT READ FROM UNIT  40

# MODFLOW2000 Constant-Head Boundary Package (CHD)
No named parameters

MAXIMUM OF 15200 TIME-VARIANT SPECIFIED-HEAD CELLS AT ONE TIME
76000 ELEMENTS IN RX ARRAY ARE USED BY CHD

77600 ELEMENTS OF RX ARRAY USED OUT OF 77600
1000 ELEMENTS OF IR ARRAY USED OUT OF 1000
2736001 ELEMENTS OF THE VDF ARRAY USED BY VDF PROCESS

# MODFLOW2000 Basic Package
#MODFLOW Data Set Created by Groundwater Vistas

TRANSPORT STEP NO.  25

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION =  400.0000  D

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP  25, TIME STEP  20, STRESS PERIOD  8

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION: 177953.3</td>
<td>-407100.7</td>
</tr>
<tr>
<td>CONSTANT HEAD: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE): 335133.2</td>
<td>-121.3936</td>
</tr>
</tbody>
</table>

[TOTAL]: 513087.7 KG -556519.1 KG

NET (IN - OUT): -43431.39
DISCREPANCY (PERCENT): -8.121000

HEAD WILL BE SAVED ON UNIT  30 AT END OF TIME STEP  20, STRESS PERIOD  8

DRAWDOWN WILL BE SAVED ON UNIT  31 AT END OF TIME STEP  20, STRESS PERIOD  8

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD  8
Appendix E (Continued) .................................................................................................

CUMULATIVE MASS RATES FOR THIS TIME STEP M/T
------------------ ------------------------
IN: IN:
--- ---
STORAGE = 1238.7598 STORAGE = 0.2245
CONSTANT HEAD = 178080366.5120 CONSTANT HEAD = 0.0000
WELLS = 378499999.7500 WELLS = 1513999.9990
DCDT = 233066.7606 DCDT = 1081.7044
TOTAL IN = 556814671.7824 TOTAL IN = 1515081.9280

OUT: OUT:
---- ----
STORAGE = 149403653.2148 STORAGE = 0.1614
CONSTANT HEAD = 407391509.6637 CONSTANT HEAD = 1515081.3874
WELLS = 0.0000 WELLS = 0.0000
DCDT = 85.0837 DCDT = 0.2543
TOTAL OUT = 556795247.9623 TOTAL OUT = 1515081.8031

IN - OUT = 19423.8201 IN - OUT = 0.1249
PERCENT DISCREPANCY = 0.00 PERCENT DISCREPANCY = 0.00

TIME SUMMARY AT END OF TRANSPORT STEP 25 IN TIME STEP 20 IN STRESS PERIOD 8
SECONDS MINUTES HOURS DAYS YEARS
-----------------------------------------------------------
TRANS STEP LENGTH 10903. 181.72 3.0286 0.12619 3.45497E-04
TIME STEP LENGTH 7.39284E+05 12321. 205.36 8.5565 2.34265E-02
STRESS PERIOD TIME 4.320000E+06 72000. 1200.0 50.000 0.13689
TOTAL TIME 3.456000E+07 5.760000E+05 9600.0 400.00 1.0951

0
Appendix E (Continued)

TRANSPORT STEP NO. 25

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 650.0000 D

CUMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP  25, TIME STEP  20, STRESS PERIOD  13

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION:</td>
<td>225951.0                   -455172.0</td>
</tr>
<tr>
<td>CONSTANT HEAD:</td>
<td>0.000000                    0.000000</td>
</tr>
<tr>
<td>WELLS:</td>
<td>0.000000                    0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION:</td>
<td>0.000000                    0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE):</td>
<td>345504.1                   -10492.22</td>
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</tbody>
</table>

[TOTAL]: 571529.6 KG -614961.3 KG

NET (IN - OUT): -43431.62
DISCREPANCY (PERCENT): -7.321020

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 13

DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 13

CUMULATIVE MASS RATES FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 13

<table>
<thead>
<tr>
<th>IN:</th>
<th>IN:</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>STORAGE = 74846.1726</td>
<td>STORAGE = 0.3116</td>
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<tr>
<td>CONSTANT HEAD = 226112347.4801</td>
<td>CONSTANT HEAD = 192218.1648</td>
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<tr>
<td>WELLS = 378499999.7500</td>
<td>WELLS = 0.0000</td>
</tr>
<tr>
<td>DCDT = 239621.4713</td>
<td>DCDT = 45.6247</td>
</tr>
<tr>
<td>TOTAL IN = 604926814.8741</td>
<td>TOTAL IN = 192264.1011</td>
</tr>
</tbody>
</table>

OUT:                                      OUT:                                      |
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>STORAGE = 149403659.3921</td>
<td>STORAGE = 0.2950</td>
</tr>
<tr>
<td>CONSTANT HEAD = 455497162.0779</td>
<td>CONSTANT HEAD = 192216.0151</td>
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</table>
Appendix E (Continued)

<table>
<thead>
<tr>
<th></th>
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<th>WELLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC DT</td>
<td>6628.9457</td>
<td>45.6246</td>
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<tr>
<td>TOTAL OUT</td>
<td>604907450.4157</td>
<td>192261.9347</td>
</tr>
<tr>
<td>IN - OUT</td>
<td>19364.4584</td>
<td>2.1663</td>
</tr>
<tr>
<td>PERCENT DISCREPANCY</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

0

TIME SUMMARY AT END OF TRANSPORT STEP  25 IN TIME STEP  20 IN STRESS PERIOD  13
SECONDS   MINUTES   HOURS   DAYS   YEARS
-------------------------
TRANS STEP LENGTH 10903. 181.72 3.0286 0.12619 3.45497E-04
TIME STEP LENGTH 7.39284E+05 12321. 205.36 8.5565 2.34265E-02
STRESS PERIOD TIME 4.32000E+06 72000. 1200.0 50.000 0.13689
TOTAL TIME 5.61600E+07 9.36000E+05 15600. 650.00 1.7796

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP  25, TIME STEP  20, STRESS PERIOD  18

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
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</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION: 604375.3</td>
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<tr>
<td>CONSTANT HEAD: 0.000000</td>
<td>0.000000</td>
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<tr>
<td>WELLS: 0.000000</td>
<td>-184159.6</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE): 350967.3</td>
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</tr>
<tr>
<td>[TOTAL]: 955491.0 KG</td>
<td>-960025.0 KG</td>
</tr>
</tbody>
</table>
Appendix E (Continued)

NET (IN - OUT): -4533.990
DISCREPANCY (PERCENT): -0.4733962

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 18

DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 18

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 18

<p>| CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T |
|------------------|------------------------|</p>
<table>
<thead>
<tr>
<th>IN:</th>
<th>IN:</th>
</tr>
</thead>
<tbody>
<tr>
<td>STORAGE =</td>
<td>STORAGE =</td>
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<tr>
<td>148987.4264</td>
<td>0.1111</td>
</tr>
<tr>
<td>CONSTANT HEAD =</td>
<td>CONSTANT HEAD =</td>
</tr>
<tr>
<td>604807007.5191</td>
<td>1515081.8573</td>
</tr>
<tr>
<td>WELLS =</td>
<td>WELLS =</td>
</tr>
<tr>
<td>378499999.7500</td>
<td>0.0000</td>
</tr>
<tr>
<td>DCDT =</td>
<td>DCDT =</td>
</tr>
<tr>
<td>243400.2564</td>
<td>4.8148</td>
</tr>
<tr>
<td>TOTAL IN =</td>
<td>TOTAL IN =</td>
</tr>
<tr>
<td>983699394.9519</td>
<td>1515086.7831</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OUT:</th>
<th>OUT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>STORAGE =</td>
<td>STORAGE =</td>
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<tr>
<td>149404199.9950</td>
<td>0.1076</td>
</tr>
<tr>
<td>CONSTANT HEAD =</td>
<td>CONSTANT HEAD =</td>
</tr>
<tr>
<td>455498798.7021</td>
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<tr>
<td>WELLS =</td>
<td>WELLS =</td>
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<tr>
<td>378631172.7932</td>
<td>1514743.5077</td>
</tr>
<tr>
<td>DCDT =</td>
<td>DCDT =</td>
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<tr>
<td>117254.8932</td>
<td>342.7563</td>
</tr>
<tr>
<td>TOTAL OUT =</td>
<td>TOTAL OUT =</td>
</tr>
<tr>
<td>983651426.3834</td>
<td>1515086.3716</td>
</tr>
</tbody>
</table>

| IN - OUT =       | IN - OUT =             |
| 47968.5685       | 0.4115                 |

PERCENT DISCREPANCY = 0.00

TIME SUMMARY AT END OF TRANSPORT STEP 25 IN TIME STEP 20 IN STRESS PERIOD 18

<table>
<thead>
<tr>
<th>SECONDS</th>
<th>MINUTES</th>
<th>HOURS</th>
<th>DAYS</th>
<th>YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANS STEP LENGTH</td>
<td>10903.</td>
<td>181.72</td>
<td>3.0286</td>
<td>0.12619</td>
</tr>
<tr>
<td>TIME STEP LENGTH</td>
<td>7.39284E+05</td>
<td>12321.</td>
<td>205.36</td>
<td>8.5565</td>
</tr>
<tr>
<td>STRESS PERIOD TIME</td>
<td>4.32000E+06</td>
<td>72000.</td>
<td>1200.0</td>
<td>50.000</td>
</tr>
<tr>
<td>TOTAL TIME</td>
<td>7.77600E+07</td>
<td>1.29600E+06</td>
<td>21600.</td>
<td>900.00</td>
</tr>
</tbody>
</table>
Appendix F: Model Output for Simulation of Multiple Injection-Storage-Recovery Cycles
Appendix F
Hetero Cycled 3 Yrs.

MODEFLOW-2000
U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL
VERSION 3.10 02/13/2004

This model run produced both GLOBAL and LIST files. This is the LIST file.

-----
1 M T 1 Conversion from Groundwater Vistas
13 D 1 MT3D Model
-----
THE TRANSPORT MODEL CONSISTS OF 200 LAYER(S) 38 ROW(S) 40 COLUMN(S)
NUMBER OF STRESS PERIOD(S) FOR TRANSPORT SIMULATION = 35
NUMBER OF ALL COMPONENTS INCLUDED IN SIMULATION = 1
NUMBER OF MOBILE COMPONENTS INCLUDED IN SIMULATION = 1
UNIT FOR TIME IS D ; UNIT FOR LENGTH IS M ; UNIT FOR MASS IS KG
PACKAGES INCLUDED IN CURRENT SIMULATION:
1 2 3 4 5 6 7 8 9 10
T T T T F F F F F

COUPLING BETWEEN FLOW AND TRANSPORT IS IMPLICIT
100 COUPLING ITERATIONS
0.1000 IS THE DENSITY CONVERGENCE CRITERIA
MT3DMS SPECIES USED IN EQUATION OF STATE FOR FLUID DENSITY: 1
AN UPSTREAM-WEIGHTED ALGORITHM IS USED TO CALCULATE FLUID DENSITY TERMS THAT CONSERVE MASS
FIRSTDT SPECIFIED BY USER IN THE VDF FILE IS: 0.1000000E-01
1000.00 REFERENCE DENSITY
0.7143 DENSITY SLOPE FOR EQUATION OF STATE
VARIABLE-DENSITY WATER-TABLE CORRECTIONS NOT ADDED
BTN4 -- BASIC TRANSPORT PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 81
4561676 ELEMENTS OF THE X ARRAY USED BY THE BTN PACKAGE
304200 ELEMENTS OF THE IX ARRAY USED BY THE BTN PACKAGE

FMI4 -- FLOW MODEL INTERFACE PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 95
FLOW MODEL IS TRANSIENT

ADV4 -- ADVECTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 82
ADVECTION IS SOLVED WITH THE UPSTREAM FINITE DIFFERENCE SCHEME
COURANT NUMBER ALLOWED IN SOLVING THE ADVECTION TERM = 0.750
0 ELEMENTS OF THE X ARRAY USED BY THE ADV PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE ADV PACKAGE

DSP4 -- DISPERSION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 83
3040600 ELEMENTS OF THE X ARRAY USED BY THE DSP PACKAGE
Appendix F (Continued)

0 ELEMENTS OF THE IX ARRAY USED BY THE DSP PACKAGE

SSM4 -- SINK & SOURCE MIXING PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 84

HEADER LINE OF THE SSM PACKAGE INPUT FILE:
T F F F F F
MAJOR STRESS COMPONENTS PRESENT IN THE FLOW MODEL:
0 WELL
MAXIMUM NUMBER OF POINT SINKS/SOURCES = 30800
215600 ELEMENTS OF THE X ARRAY USED BY THE SSM PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE SSM PACKAGE

RCT4 -- CHEMICAL REACTION PACKAGE, VERSION 4.5, MAY 2003, INPUT READ FROM UNIT 85
NO SORPTION [OR DUAL-DOMAIN MODEL] IS SIMULATED
NO FIRST-ORDER RATE REACTION IS SIMULATED
REACTION COEFFICIENTS ASSIGNED CELL-BY-CELL
INITIAL SORBED/IMMOBILE PHASE CONCENTRATION ASSIGNED BY DEFAULT
0 ELEMENTS OF THE X ARRAY USED BY THE RCT PACKAGE
0 ELEMENTS OF THE IX ARRAY USED BY THE RCT PACKAGE

GCG4 -- GENERALIZED CONJUGATE GRADIENT SOLVER PACKAGE, VERSION 4.5, MAY 2003 INPUT READ FROM UNIT 86
MAXIMUM OF 1 OUTER ITERATIONS
AND 50 INNER ITERATIONS ALLOWED FOR CLOSURE
THE PRECONDITIONING TYPE SELECTED IS MODIFIED INCOMPLETE CHOLESKY (MIC).
DISPERSION CROSS TERMS LUMPED INTO RIGHT-HAND-SIDE
6688050 ELEMENTS OF THE X ARRAY USED BY THE GCG PACKAGE
150 ELEMENTS OF THE IX ARRAY USED BY THE GCG PACKAGE

# MODFLOW2000 Basic Package
# MODFLOW Data Set Created by Groundwater Vistas
#
200 LAYERS  38 ROWS  40 COLUMNS
35 STRESS PERIOD(S) IN SIMULATION

BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 1
1000 ELEMENTS IN IR ARRAY ARE USED BY BAS

WEL6 -- WELL PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 12
# MODFLOW2000 Well Package
0 Named Parameters 0 List entries
MAXIMUM OF 400 ACTIVE WELLS AT ONE TIME
CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT 54
1600 ELEMENTS IN RX ARRAY ARE USED BY WEL

CHD6 -- TIME-VARIANT SPECIFIED-HEAD PACKAGE, VERSION 6, 1/11/2000
Appendix F (Continued)

INPUT READ FROM UNIT  40

# MODFLOW2000 Constant-Head Boundary Package (CHD)
No named parameters
MAXIMUM OF  15200 TIME-VARIANT SPECIFIED-HEAD CELLS AT ONE TIME
76000 ELEMENTS IN RX ARRAY ARE USED BY CHD

77600 ELEMENTS OF RX ARRAY USED OUT OF 77600
1000 ELEMENTS OF IR ARRAY USED OUT OF 1000
2736001 ELEMENTS OF THE VDF ARRAY USED BY VDF PROCESS

# MODFLOW2000 Basic Package
#MODFLOW Data Set Created by Groundwater Vistas

<table>
<thead>
<tr>
<th>TRANSPORT STEP NO.</th>
<th>9</th>
</tr>
</thead>
</table>

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 1050.000 D

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 9, TIME STEP 20, STRESS PERIOD 21

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION:</td>
<td>-833451.4</td>
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<tr>
<td>CONSTANT HEAD:</td>
<td>452882.7</td>
</tr>
<tr>
<td>WELLS:</td>
<td>0.000000</td>
</tr>
<tr>
<td></td>
<td>-104160.4</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION:</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE):</td>
<td>753573.1</td>
</tr>
<tr>
<td></td>
<td>-133887.6</td>
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</tbody>
</table>

[TOTAL]: 1206608. KG -1220948. KG

NET (IN - OUT): -14339.52
DISCREPANCY (PERCENT): -1.181396

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 21

DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 21

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 21
Appendix F (Continued)

CUMULATIVE MASS     M     RATES FOR THIS TIME STEP     M/T
------------------                 ------------------------
IN:                                      IN:
---                                      ---
STORAGE =      152801.0356               STORAGE =       3.8690E-02
CONSTANT HEAD =   453206181.5845         CONSTANT HEAD =           0.0000
WELLS =   757000001.5000                 WELLS =     1514000.0030
DCDT =      530288.1962                  DCDT =        1081.5214
TOTAL IN =  1210889272.3163              TOTAL IN =     1515081.5631

OUT:                                     OUT:
----                                     ----
STORAGE =   149555199.7322               STORAGE =       3.2990E-02
CONSTANT HEAD =   834046723.5887         CONSTANT HEAD =     1515081.4241
WELLS =   227174094.8027                 WELLS =           0.0000
DCDT =       92905.7010                  DCDT =       7.1599E-02
TOTAL OUT =  1210868923.8246             TOTAL OUT =     1515081.5287

IN - OUT =       20348.4917              IN - OUT =       3.4347E-02
PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00

TIME SUMMARY AT END OF TRANSPORT STEP    9 IN TIME STEP   20 IN STRESS PERIOD  21
SECONDS     MINUTES     HOURS     DAYS     YEARS
-----------------------------------------------------------
TRANS STEP LENGTH 1.05311E+05  1755.2      29.253      1.2189     3.3371E-03
TIME STEP LENGTH 4.61296E+05  7688.3      128.140     5.391     1.46176E-02
STRESS PERIOD TIME 4.32000E+06  72000.00     1200.000     50.000     0.13689
TOTAL TIME 9.07200E+07 1.51200E+06  25200.0     1050.0     2.8747

TRANSPORT STEP NO.    9

-----------------------------------
Appendix F (Continued)

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 1150.000 D

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP  9, TIME STEP  20, STRESS PERIOD  23

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION:</td>
<td>604134.3</td>
</tr>
<tr>
<td>CONSTANT HEAD:</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS:</td>
<td>0.000000</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION:</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE):</td>
<td>761778.8</td>
</tr>
</tbody>
</table>

[TOTAL]: 1366212. KG -1377732. KG

NET (IN - OUT): -11519.51
DISCREPANCY (PERCENT): -0.8396314

HEAD WILL BE SAVED ON UNIT  30 AT END OF TIME STEP  20, STRESS PERIOD  23

DRAWDOWN WILL BE SAVED ON UNIT  31 AT END OF TIME STEP  20, STRESS PERIOD  23

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD  23

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T

<table>
<thead>
<tr>
<th>IN:</th>
<th>OUT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>STORAGE = 300615.8627</td>
<td>STORAGE = 9.8475E-03</td>
</tr>
<tr>
<td>CONSTANT HEAD = 604565805.7632</td>
<td>CONSTANT HEAD = 1515081.4426</td>
</tr>
<tr>
<td>WELLS = 757000001.5000</td>
<td>WELLS = 0.0000</td>
</tr>
<tr>
<td>DCDT = 536308.7756</td>
<td>DCDT = 24.4864</td>
</tr>
<tr>
<td>TOTAL IN = 1362402731.9015</td>
<td>TOTAL OUT = 1362382162.2078</td>
</tr>
</tbody>
</table>

TOTAL IN = 1515105.9388

TOTAL OUT = 1515105.9532

200
Appendix F (Continued)

IN - OUT = 20569.6938 \quad \text{IN - OUT} = -1.4366 \times 10^{-02}

PERCENT DISCREPANCY = 0.00 \quad \text{PERCENT DISCREPANCY} = 0.00

TIME SUMMARY AT END OF TRANSPORT STEP 9 IN TIME STEP 20 IN STRESS PERIOD 23

SECONDS \quad \text{MINUTES} \quad \text{HOURS} \quad \text{DAYS} \quad \text{YEARS}

\begin{align*}
\text{TRANS STEP LENGTH} & \quad 1.05311 \times 10^5 \quad 1755.2 \quad 29.253 \quad 1.2189 \quad 3.33711 \times 10^{-03} \\
\text{TIME STEP LENGTH} & \quad 4.61296 \times 10^5 \quad 7688.3 \quad 128.14 \quad 5.3391 \quad 1.46176 \times 10^{-02} \\
\text{STRESS PERIOD TIME} & \quad 4.32000 \times 10^6 \quad 72000. \quad 1200.0 \quad 50.000 \quad 0.13689 \\
\text{TOTAL TIME} & \quad 9.93600 \times 10^7 \quad 1.65600 \times 10^6 \quad 27600. \quad 1150.0 \quad 3.1485
\end{align*}

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

STRESS PERIOD NO. 024

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

LENGTH OF CURRENT STRESS PERIOD = 50.0000
NUMBER OF TIME STEPS FOR CURRENT STRESS PERIOD = 20
TIME STEP MULTIPLIER USED IN FLOW SOLUTION = 1.100000
USER-SPECIFIED TRANSPORT STEPSIZE = 0.1000000 \text{D}
MAXIMUM NUMBER OF TRANSPORT STEPS ALLOWED IN ONE FLOW TIME STEP = 500
MULTIPLIER FOR SUCCESSIVE TRANSPORT STEPS [USED IN IMPLICIT SCHEMES] = 1.450
MAXIMUM TRANSPORT STEP SIZE [USED IN IMPLICIT SCHEMES] = 100.0000 \text{D}

-------------------------------------------

TRANSPORT STEP NO. 9

-------------------------------------------

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 1250.000 \text{ D}

-----------------------------------------------------------------------------------------------------

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 9, TIME STEP 20, STRESS PERIOD 25
Appendix F (Continued)

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION:</td>
<td></td>
</tr>
<tr>
<td>604135.6</td>
<td>-984702.3</td>
</tr>
<tr>
<td>CONSTANT HEAD:</td>
<td></td>
</tr>
<tr>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS:</td>
<td></td>
</tr>
<tr>
<td>0.000000</td>
<td>-148551.8</td>
</tr>
<tr>
<td>DECAY OR BIODEGRADATION:</td>
<td></td>
</tr>
<tr>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE):</td>
<td></td>
</tr>
<tr>
<td>908789.7</td>
<td>-246792.2</td>
</tr>
</tbody>
</table>

[TOTAL]: 1513226. KG -1529643. KG

NET (IN - OUT): -16417.02
DISCREPANCY (PERCENT): -1.079049

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 25
DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 25
1

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 25

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T

<table>
<thead>
<tr>
<th>IN:</th>
<th>OUT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>STORAGE = 301746.8412</td>
<td>STORAGE = 4.8798E-02</td>
</tr>
<tr>
<td>CONSTANT HEAD = 604567161.2748</td>
<td>CONSTANT HEAD = 0.0000</td>
</tr>
<tr>
<td>WELLS = 908400001.8000</td>
<td>WELLS = 1514000.0030</td>
</tr>
<tr>
<td>DCDT = 639609.0465</td>
<td>DCDT = 1081.5887</td>
</tr>
<tr>
<td>TOTAL IN = 1513908518.9625</td>
<td>TOTAL IN = 1515081.6405</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OUT:</th>
<th>IN - OUT = 20229.8451</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>STORAGE = 149704145.7410</td>
<td>STORAGE = 4.0135E-02</td>
</tr>
<tr>
<td>CONSTANT HEAD = 985405704.9542</td>
<td>CONSTANT HEAD = 1515081.4805</td>
</tr>
<tr>
<td>WELLS = 378605595.0578</td>
<td>WELLS = 0.0000</td>
</tr>
<tr>
<td>DCDT = 172843.3644</td>
<td>DCDT = 0.1389</td>
</tr>
<tr>
<td>TOTAL OUT = 1513888289.1174</td>
<td>TOTAL OUT = 1515081.6595</td>
</tr>
</tbody>
</table>

IN - OUT = 20229.8451

PERCENT DISCREPANCY = 0.00

202
Appendix F (Continued)

TIME SUMMARY AT END OF TRANSPORT STEP 9 IN TIME STEP 20 IN STRESS PERIOD 25 SECONDS MINUTES HOURS DAYS YEARS

-------------------------------------------
TRANS STEP LENGTH 1.05311E+05 1755.2 29.253 1.2189 3.3371E-03
TIME STEP LENGTH 4.61296E+05 7688.3 128.14 5.3391 1.46176E-02
STRESS PERIOD TIME 4.32000E+06 72000. 1200.0 50.000 0.13689
TOTAL TIME 1.08000E+08 1.80000E+06 30000. 1250.0 3.4223

-------------------------------------------
TRANSPORT STEP NO. 9
-------------------------------------------

TOTAL ELAPSED TIME SINCE BEGINNING OF SIMULATION = 50.00000 D

CUMMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP 9, TIME STEP 20, STRESS PERIOD 1

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT CONCENTRATION: 75696.33</td>
<td>-0.8192252E-05</td>
</tr>
<tr>
<td>CONSTANT HEAD: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>WELLS: 0.000000</td>
<td>-25483.75</td>
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<tr>
<td>DECAY OR BIODEGRADATION: 0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>MASS STORAGE (SOLUTE): 1597.896</td>
<td>-47480.61</td>
</tr>
</tbody>
</table>

[TOTAL]: 77295.60 KG -72965.91 KG

NET (IN - OUT): 4329.697
DISCREPANCY (PERCENT): 5.762883

HEAD WILL BE SAVED ON UNIT 30 AT END OF TIME STEP 20, STRESS PERIOD 1

DRAWDOWN WILL BE SAVED ON UNIT 31 AT END OF TIME STEP 20, STRESS PERIOD 1

MASS BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 20 IN STRESS PERIOD 1

CUMULATIVE MASS M RATES FOR THIS TIME STEP M/T
Appendix F (Continued)

IN:
---
STORAGE = 1382.2210
CONSTANT HEAD = 75750400.9792
WELLS = 0.0000
DCDT = 1095.4641
TOTAL IN = 75752878.6643

OUT:
----
STORAGE = 1547.0163
CONSTANT HEAD = 0.0000
WELLS = 75718150.6769
DCDT = 32463.7894
TOTAL OUT = 75752161.4827

IN - OUT = 717.1816
PERCENT DISCREPANCY = 0.00

TIME SUMMARY AT END OF TRANSPORT STEP 9 IN TIME STEP 20 IN STRESS PERIOD 1
SECONDS MINUTES HOURS DAYS YEARS
---------------------------------------------
TRANS STEP LENGTH 1.05311E+05 1755.2 29.253 1.2189 3.33711E-03
TIME STEP LENGTH 4.61296E+05 7688.3 128.14 5.3391 1.46176E-02
STRESS PERIOD TIME 4.32000E+06 72000. 1200.0 50.000 0.13689
TOTAL TIME 4.32000E+06 72000. 1200.0 50.000 0.13689