ORNL/TM-9467

ornl

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Application of the Finite Element Groundwater Model FEWA to the Engineered Test Facility

P. M. Craig
E. C. Davis

ENVIRONMENTAL SCIENCES DIVISION
Publication No. 2581

ORNL/TM--9467

DE86 001424

ENVIRONMENTAL SCIENCES DIVISION

APPLICATION OF THE FINITE ELEMENT GROUNDWATER MODEL FEWA TO THE ENGINEERED TEST FACILITY

P. M. Craig[1] and E. C. Davis

Environmental Sciences Division
Publication No. 2581

---

[1]University of Tennessee, Knoxville, TN 37916

NUCLEAR AND CHEMICAL WASTE PROGRAMS
(Activity No. AR 05 15 15 0; ONL-WL14)

Date Published - September 1985

Prepared for the
Office of Defense Waste and Byproducts Management

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

CRAIG, P. M., and E. C. DAVIS. 1985. Application of the finite element groundwater model FEWA to the Engineered Test Facility. ORNL/TM-9467. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 104 pp.

A finite element model for water transport through porous media (FEWA) has been applied to the unconfined aquifer at the Oak Ridge National Laboratory Solid Waste Storage Area 6 Engineered Test Facility (ETF). The model was developed in 1983 as part of the Shallow Land Burial Technology - Humid Task (ONL-WL14) and was previously verified using several general hydrologic problems for which an analytic solution exists. Model application and calibration, as described in this report, consisted of modeling the ETF water table for three specialized cases: a one-dimensional steady-state simulation, a one-dimensional transient simulation, and a two-dimensional transient simulation. In the one-dimensional steady-state simulation, the FEWA output accurately predicted the water table during a long period in which there were no man-induced or natural perturbations to the system. The input parameters of most importance for this case were hydraulic conductivity and aquifer bottom elevation. In the two transient cases, the FEWA output has matched observed water table responses to a single rainfall event occurring in February 1983, yielding a calibrated finite element model that is useful for further study of additional precipitation events as well as contaminant transport at the experimental site.

1. INTRODUCTION

Disposal of most low-level radioactive solid waste (LLW) generated in this country has been by shallow land burial (SLB), a methodology subject to a variety of water-related environmental problems (Carter, Moghissi, and Kahn 1979). In an effort to better define these potential problems, and to develop improved waste disposal scenarios, Oak Ridge National Laboratory (ORNL) designed a demonstration facility for testing and evaluating alternative disposal techniques including grouting and lining of waste trenches. The experimental site, known as the Engineered Test Facility or ETF, is located in ORNL's Solid Waste Storage Area 6 (SWSA 6) (Fig. 1) and has previously been the subject of extensive disposal site characterization studies (Davis et al. 1984, Newbold and Bogle 1984).

To facilitate water and contaminant transport modeling at the site, background information relative to soils, geologic characteristics, and hydrologic parameters were collected beginning in August 1980 and continuing through December 1983. A data summary including much of the information collected during this 41-month study period was recently completed by ORNL for the National Low-Level Waste Management Program (Davis and Craig 1984). Further information concerning the ETF, including the experimental design, can be found in a report by Boegly and Davis (1983).

1.1 BACKGROUND

The main objective of the ETF study was to test two alternative disposal methods (trench lining using an impermeable Hypalon fabric and trench grouting using a cement-bentonite slurry) against standard disposal practices in a humid environment. A humid climate was defined as a climate that has more precipitation than evaporation during the course of a year. In such a climate, the potential for the migration of leachable constituents from a waste disposed of by standard SLB practices is considerably greater than in a dry climate. The problem is twofold as both the infiltration of precipitation and the

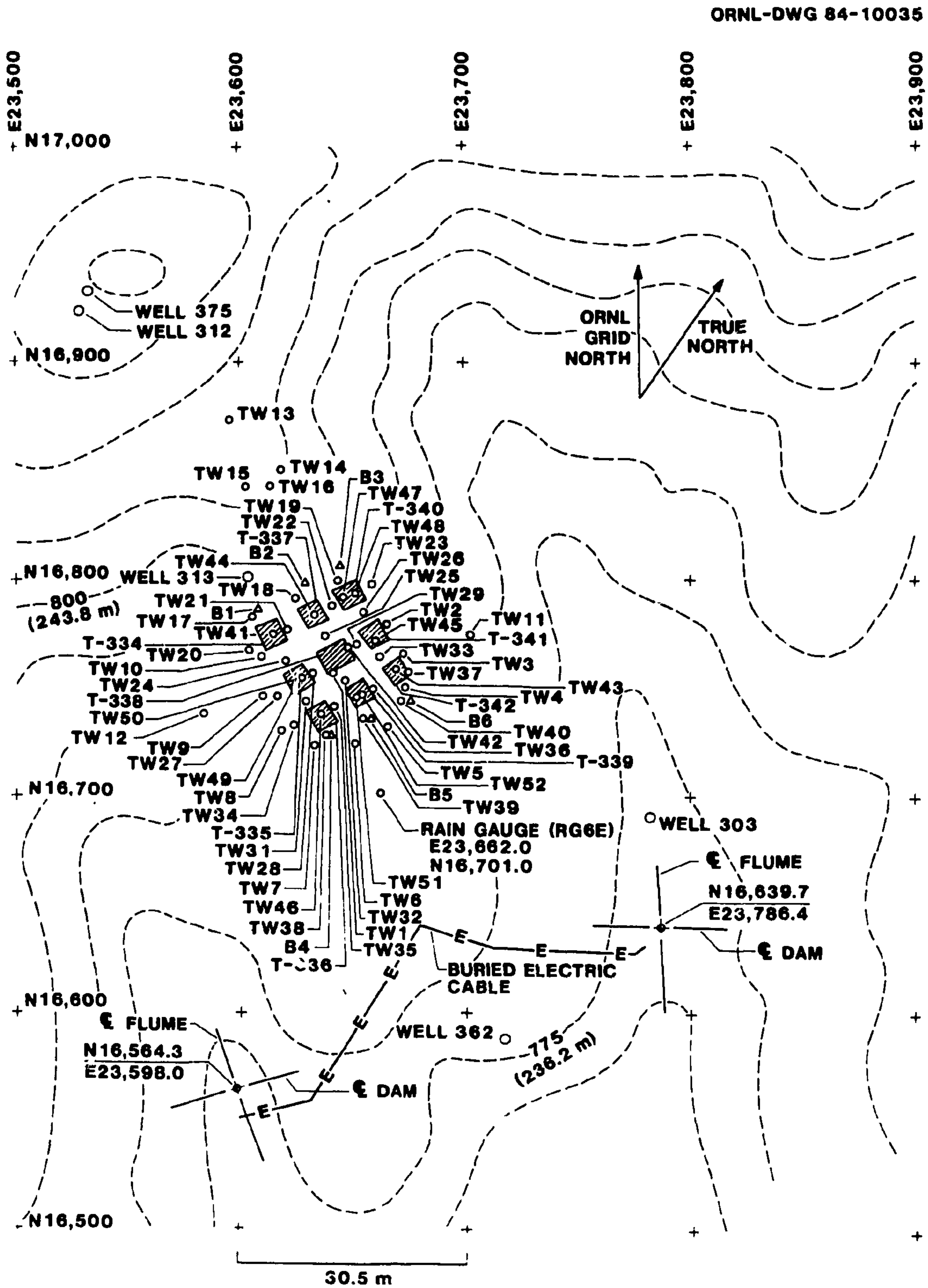


Fig. 1. Plan view of the ETF site in ORNL SWSA 6.

intersection of the groundwater table with the trench bottom can both cause significant water-waste contact and radionuclide leaching. Thus, the primary purpose of the ETF study has been to evaluate the two improved trench treatments relative to preventing this waste leaching, with secondary emphasis on site characterization methods and groundwater modeling.

As a component of the overall ETF research plan, a groundwater flow model was developed for use as a predictive tool for evaluating proposed waste disposal sites, trench closure scenarios, and as a general groundwater flow model for complex geologic systems. The code [Finite Element Model of Water Transport Through Aquifers (FEWA)] was developed by Yeh and Huff (1983) and uses a finite element method for solving the saturated groundwater flow equations. The code was previously verified using several example problems for which there exists an analytic solution; this study, however, represents the first attempt at calibrating the model and demonstrating its usefulness at a field waste disposal site.

The purpose of this report is to address the groundwater flow modeling portion of the ETF research objectives by documenting the application of FEWA to the ETF experimental site. In preparing for the modeling analysis the hydrologic data collected for the period including January 1, 1980, through December 31, 1983, were processed and analyzed for use in the modeling study (Davis and Craig 1984). These hydrologic data were needed for two purposes -- the most obvious being input data to FEWA while the other was for verification of the modeled results. The following section of this report discusses the capabilities of the FEWA code in greater detail.

1.2 THE FINITE ELEMENT MODEL FEWA

The FEWA code used in this study was developed to handle complex and/or transient conditions that were found to be inadequately handled by many available groundwater flow models. Its purpose is to model the effects of natural and artificial disturbances on the piezometric head distribution and groundwater flow in a system of aquifers. The program computes and predicts the temporal-spatial distributions of piezometric head and water flow velocity on a two-dimensional plane. The system may consist of as many types of aquifers as desired, and each aquifer may be completely confined, completely unconfined, or partially confined and partially unconfined. Each aquifer may be inhomogeneous and anisotropic in material properties. Important processes included in the model are sources/sinks, pressure and gravity forces, aquifer leakage, consolidation, and compressibility of water.

The vertically integrated groundwater flow equation in this code is solved with the Galerkin finite element method subject to appropriate initial and boundary conditions. Twelve numerical schemes were included to ensure convergent solutions for as wide a range of inputs as possible. Both quadrilateral and triangular elements are used to facilitate the discretization of the region of interest.

The input to the code can be divided into the following eight categories: (1) geometry in terms of nodes and elements, and boundaries in terms of nodes and segments; (2) number and types of aquifers; (3) spatially varying thickness (in the confined portion) or bottom elevation (in the unconfined portion) of all aquifers considered; (4) hydraulic conductivities or transmissivities, compressibilities of water and media, effective porosity, specific yield, and viscosity of water for each aquifer type; (5) spatially dependent initial conditions of piezometric heads either from field measurements or from model simulations; (6) spatially distributed or point sources/sinks to represent natural infiltration/evaporation or artificial recharging/pumping; (7) piezometric head on Dirichlet boundaries normally adjacent to surface water bodies such as streams, rivers, lakes, impoundments, and coastal waters, and prescribed fluxes through open boundaries normally with adjacent aquifers; and (8) leaky characteristics of the confining aquitards (beds) represented by leakage coefficients and transient heads above or below the beds. The input in items 6 through 8 can be time-dependent or constant with time.

The output from the code is in the following form: (1) piezometric head distribution over a two-dimensional grid at any desired time; (2) rate and amount of water through all types of boundaries at any desired time; and (3) rate and amount of water accumulated in the aquifer system and transported through confining beds at any desired time. As the title implies, the code uses the finite element method for solving the partial differential equations governing the flow of water through a saturated porous media. It is essentially a horizontal two-dimensional model, though it can be made to model a one-dimensional case as considered in Sect. 2 of this report.

1.3 ETF HYDROGEOLOGIC CHARACTERISTICS

The ETF, which was selected as the site for applying the FEWA code, is located in Melton Valley, ~2 km south of ORNL. Geologically, it is within the Copper Creek thrust block and is underlain by strata of the Middle to Late Cambrian Conasauga Group. The specific formation is the Maryville Limestone, which consists of silty limestone interbedded with mudstones and shales. The structure of the formation is highly deformed with small-scale folding, several examples of which were exposed during trench excavation at the ETF. The formation is also heavily fractured, and flow through these fractures is believed to be quite significant during periods of heavy precipitation.

The ETF's groundwater is a shallow unconfined aquifer that rapidly responds to precipitation. The aquifer is very heterogeneous lithologically and structurally with many dips and folds (Davis et al. 1984). Water table fluctuations have been measured for a period of three years and indicate that the yearly cycle is ~1 m, exhibiting a maximum in the winter and a minimum in the late summer. Response of water levels to rainfall is rapid, usually on the order of 5-10 h, and water levels require several days to return to prestorm conditions. Deeper wells (30-70 m) located onsite respond much less dramatically than the shallower wells (10 m deep) and appear to exhibit a <1-m annual fluctuation. Aquifer characteristics have been determined through a combination of tracer tests (Cooper 1981), pump tests (Vaughan et al. 1982), and in-situ measurements of hydraulic conductivity (Davis et al. 1984). Table 1 summarizes the ETF aquifer characteristics that have been determined in these previous studies.

Table 1. Summary of Engineered Test Facility aquifer characteristics

Method	Parameter	Value
Tracer test	Average linear velocity	0.17 m/d
Pump test	Transmissivity (T)	1.25×10^{-3} to 4.36×10^{-3} m^2/min
	Storage coefficient (S)	5×10^{-4} to 0.01
Well slug test	Hydraulic conductivity (K)	6.31×10^{-5} cm/s
Darcy eq.	Effective porosity (Θ)	0.03
	Effective aquifer thickness	67 m

Of all the data needed as input to FEWA (Appendix A), infiltration or aquifer recharge was the only major item not obtained directly from previously published site characterization data. The infiltration was obtained using the physically based Green and Ampt model (Green and Ampt 1911), which requires a knowledge of the soils physical parameters and site precipitation records. A computer program was developed to compute recharge to the unconfined aquifer that could be directly input to the FEWA model (Appendix B).

2. MODEL APPLICATION IN ONE DIMENSION

Initial application of the FEWA code to the ETF focused on a one-dimensional case using a cross section of the experimental site, which extends ~120 m between wells 375 and 362 (Fig. 2). The upslope well (well 375) is located at a surface elevation of 247.9 m whereas the downslope well (well 362) is at elevation 236.3 m, yielding a topographic relief of 11.6 m across the section. The section includes a total of 10 wells (wells 312, 375, 15, 313, 17, 24, 31, 38, 6 and 362) and traverses the tops of experimental trenches 334 (lined trench), 335 (grouted trench), and 336 (control trench). To apply the FEWA code, the cross section was divided into a single row of elements of known dimensions that spanned the distance between wells 375 and 362 when joined side by side. The element layout, numbering, and nodal designations are summarized in Fig. 2.

A total of 40 elements were used with each element being 3.05 m on a side. The length of the row of elements is therefore 122 m (3.05 m x 40), which easily spans the 120-m distance between wells 375 and 362. No attempt was made to adjust the element size to facilitate locating the 10 observation wells on nodes; instead, the wells were merely assigned to their nearest node. In this manner, well 312 was assigned to node 3, well 375 to node 2, well 15 to node 24, well 313 to node 32, well 17 to node 35, well 24 to node 39, well 31 to node 43, well 38 to node 47, well 6 to node 50, and well 362 to node 82.

Two situations were modeled at the ETF using the above-mentioned cross section. The first was the steady-state case representing the water table configuration during a long period in which there were no man-induced or natural perturbations to the system. The second case involved transient water table conditions that occurred following a storm event. The following sections of this report deal with each of the two cases in greater detail.

2.1 ONE-DIMENSIONAL STEADY STATE

The steady-state solution in the one-dimensional case involves specifying the head at the two boundaries (in the case of the ETF

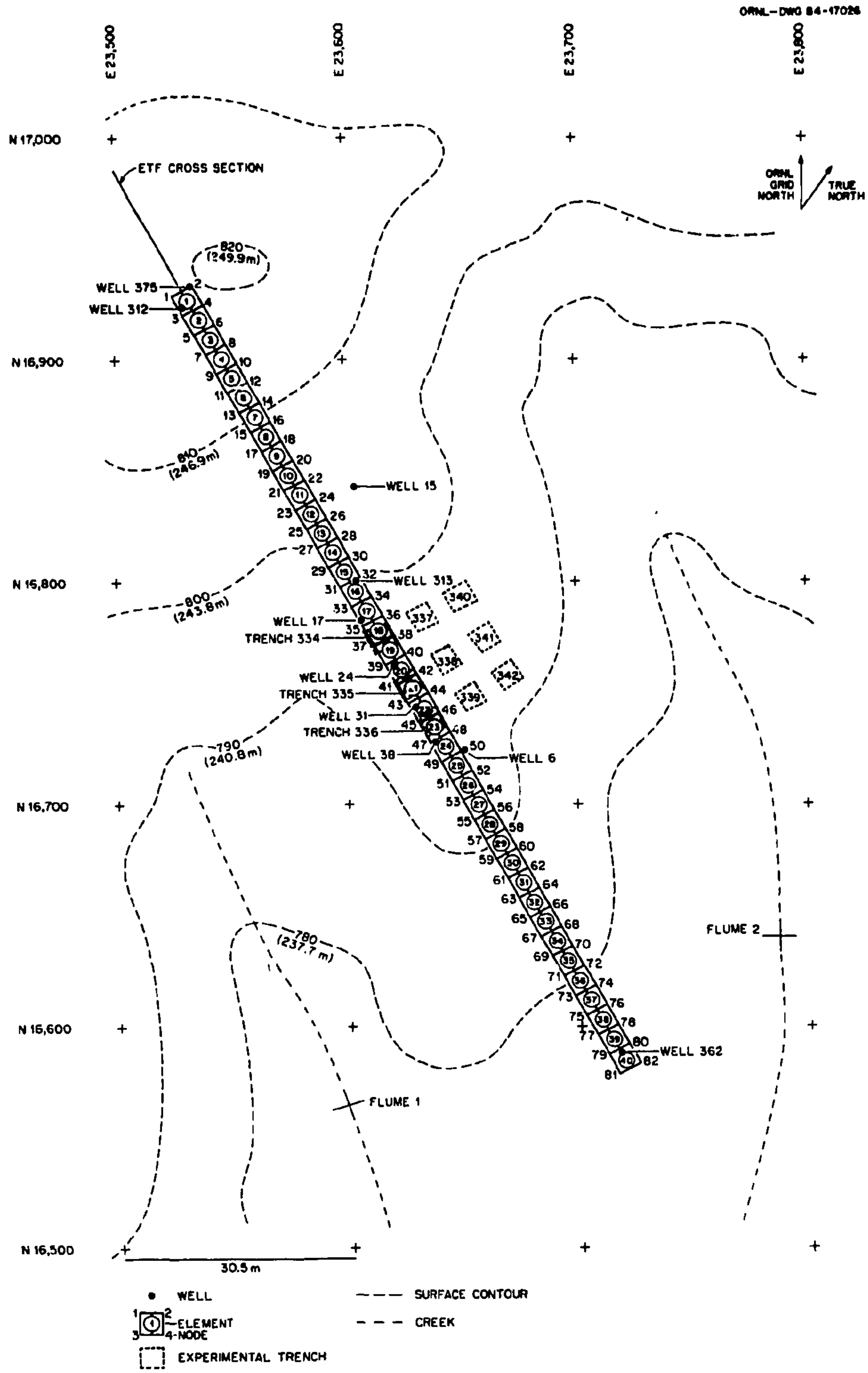


Fig. 2. ETF cross section used for modeling the one-dimensional case.

cross section in Fig. 2, the head at wells 375 and 362) and allowing the model to predict the steady-state head at each of the 78 remaining nodes along the cross section. The most important input data, aside from the geometry of the problem, include the boundary conditions, the hydraulic conductivity of each of the 40 elements, and the depth of the water table aquifer.

The Dirichlet (constant head) boundaries applied to this one-dimensional steady-state case specified a water elevation (head) of 242.0 m at upslope well 375, and a head of 234.5 m at downslope well 362. These initial condition elevations were assigned based on the observed water table at these two wells at near steady-state conditions. The bottom of the unconfined aquifer was then set at elevation 200 m for each of the 40 elements and represents an input parameter with which considerable uncertainty is associated. For example, using Darcy's equation to back-calculate aquifer thickness results in a value of 67 m (Table 1), putting the bottom of the aquifer at elevation 170 m (surface elevation minus depth to water minus aquifer thickness = aquifer bottom elevation). However, experience with site drilling indicates that the depth of the aquifer bottom or depth to unweathered rock may be considerably less than 67 m. In any case, there does not appear to be a well defined aquitard in the Conasauga Formation underlying the ETF.

The hydraulic conductivity (K) of the aquifer was determined using a series of slug tests conducted in 36 of the ETF wells. The method of analysis was based on Hvorslev (1951) and results in a measurement of hydraulic conductivity for a zone immediately surrounding the screened portion of the test wells. Based on these slug tests, an average value of 6.31×10^{-7} m/s was estimated as the aquifer hydraulic conductivity.

The 40-element cross section spanning the distance between wells 375 and 362 was then divided into three groups of elements based on slopes of the observed water table. Each group of elements was assigned a different material type and unique K value. The value of K was assigned to each of the three material types based on the ratio of the slopes of the observed water table in the region associated with each material type. For example, if the water table was steeply sloped in a particular region along the cross section, the value of K was decreased below 6.3×10^{-7} m/s to accommodate less water movement. If the water table was flatter, the K value was increased proportionally to allow for more rapid water movement in the region. In this manner elements 1 through 11 and 16 through 21 were assigned a K value of 1.5×10^{-6} m/s, elements 12 through 15 a K value of 2.2×10^{-7} m/s, and elements 22 through 40 a K value of 6.3×10^{-7} m/s. Appendix C contains a complete listing of the input data used in this one-dimensional steady-state simulation. For a detailed description of each input parameter within the respective data sets shown in Appendix C, refer to the FEWA input guide of Appendix A.

The modeled solution (head distribution along the ETF cross section) to the steady-state problem can be compared with actual water table measurements taken from the ten monitoring wells lying along the cross section. Such a comparison is made in Fig. 3 using data from September 1983 and April 1984 which represent the lower and upper bound of the water table during periods of low to moderate rainfall.

A comparison of the observed water table for these two dates and the predicted steady-state water table (dashed line in Fig. 3) are in excellent agreement indicating that the aquifer bottom elevation and values of hydraulic conductivity were adequately estimated from field data. This steady-state one-dimensional problem can now be expanded to the more complicated one-dimensional transient case considered in the next section.

2.2 ONE-DIMENSIONAL TRANSIENT

Transient modeling involves the computation of the water table elevations as they vary with time due to some perturbation in the system, for example, a heavy rainfall event. The initial conditions of the aquifer are the measured conditions just prior to the start of the perturbation of interest. The aquifer is modeled, beginning at the initial conditions, and then forward in time at discrete intervals.

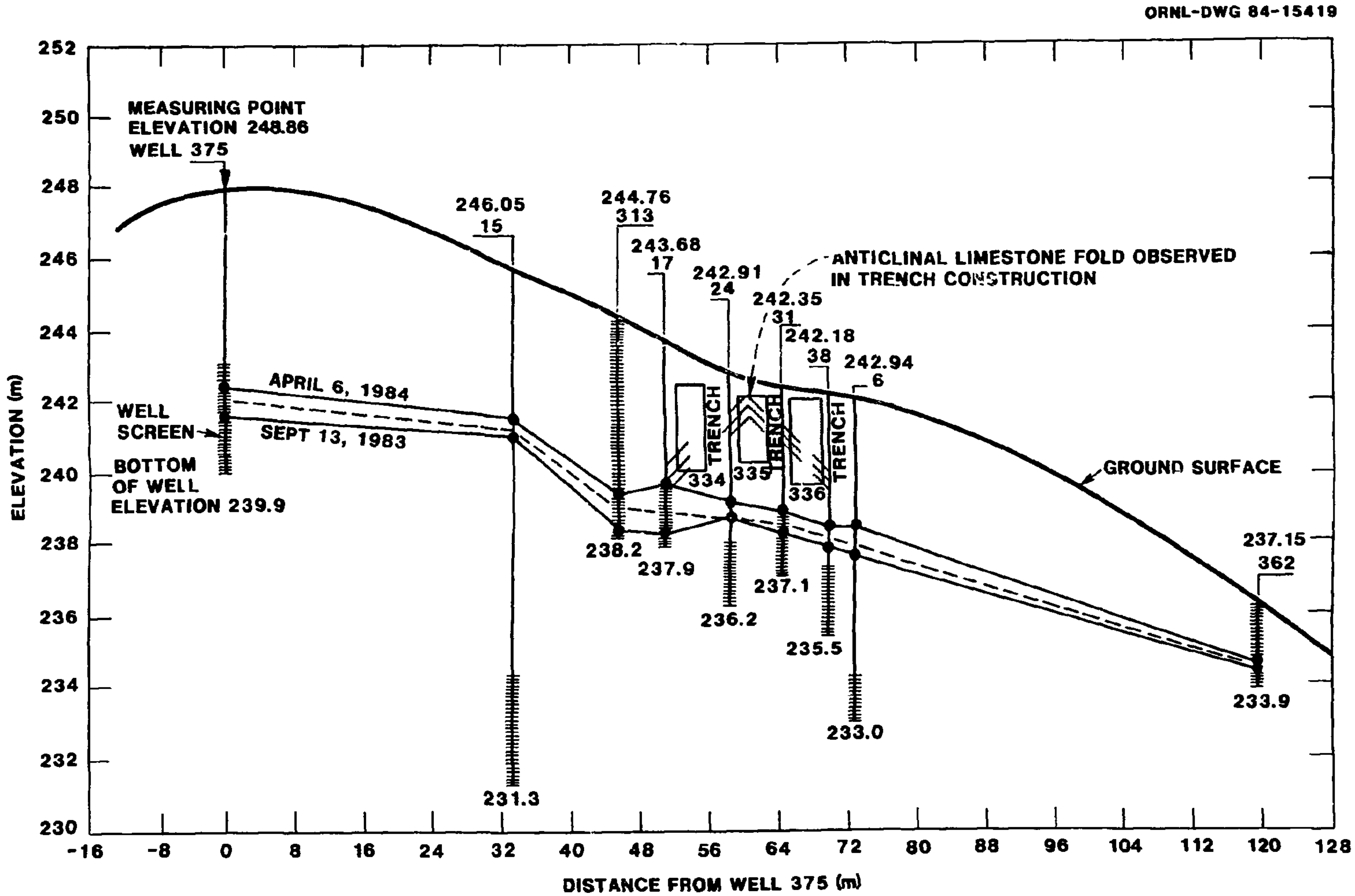


Fig. 3. Observed vs predicted water table for the one-dimensional steady-state simulation.

The size of the time intervals depends on the expected aquifer response; the slower the response the larger the allowable time step, the faster the response the smaller the time step. In this way the response of an aquifer to a particular rainfall event can be predicted.

The application of FEWA to the ETF site during transient conditions was conducted using a rainfall event that occurred in February 1984. Important parameters needed in the modeling process were saturated hydraulic conductivity (previously estimated and unchanged from the steady-state conditions), effective porosity (interconnected pore space), specific yield, and the boundary conditions at the site of interest. Time-varying Dirichlet (known head) boundary conditions were used for this case as with the steady-state case, while effective porosity and specific yield were modified for the transient runs. A more detailed discussion of calibration runs for these two parameters is discussed in Sect. 2.2.4.

2.2.1 Measured Response of the Aquifer

To calibrate the model, water level data were collected from 7 of the 10 observation wells for a 2-week period beginning on February 2, 1984, and continuing through February 16, 1984. Each of the 7 wells (wells 375, 313, 24, 31, 38, 6, and 362) was equipped with a Belfort Instrument Company portable liquid level recorder (Cat. No. 5-FW series) capable of continuously recording water table elevations on an 8-d strip chart. During this 2-week monitoring period, precipitation at the site totaled 46.3 mm with daily summaries contained in Table 2. Of the seven wells equipped with recorders, only four were used extensively for model calibration (wells 313, 24, 31, and 6). Wells 375 and 362 are located at the boundaries of the cross section; the water table response at those nodes was used to set the Dirichlet boundary conditions. In addition, data from well 38 were discarded because of problems with the float and water level recorder. Thus, data from four points along the cross section shown in Fig. 2 were available for transient modeling.

Table 2. Daily Summaries of Precipitation from February 2 through February 16, 1984

Day of month	Precipitation (cm)
2	0.000
3	0.193
4	0.000
5	0.000
6	0.413
7	0.186
8	0.000
9	0.000
10	0.521
11	0.244
12	0.000
13	2.830
14	0.000
15	0.000
16	0.000

2.2.2 Aquifer Recharge

The perturbation modeled for the transient case was a precipitation event that lasted ~24 h and occurred on February 13, 1984. Table 3 contains an hourly listing of the precipitation modeled. During this time there were two distinct periods of rainfall separated by 12 h of little or no rain. The total precipitation for the period of interest was 28.3 mm.

These rainfall data had to be converted to aquifer recharge estimates for input to FEWA. This was accomplished by estimating the infiltration and then lagging it by an applicable time period. Estimates of infiltration were obtained using the Green and Ampt infiltration model (Green and Ampt 1911) along with the time compression method for low rainfall periods (Reeves and Miller 1975). This is a physically based analytical model that solved the Richards Equation of infiltration for a uniform soil with a sharp wetting front. The model works well for determining infiltration, but performs poorly in determining soil moisture content. Since soil moisture

Table 3. Precipitation at the ETF for February 13, 1984

Hour of day	Precipitation (cm)
1	0.038
2	0.321
3	0.321
4	0.235
5	0.000
6	0.000
7	0.000
8	0.000
9	0.000
10	0.000
11	0.000
12	0.000
13	0.000
14	0.000
15	0.000
16	0.000
17	0.070
18	0.204
19	0.204
20	0.872
21	0.275
22	0.189
23	0.058
24	0.000

content variation with time is not needed for FEWA, this method of computing infiltration fills all the necessary requirements. Appendix B contains a listing of this infiltration model.

All of the infiltrating water was assumed to reach the aquifer. This is believed to be a reasonable assumption for two reasons; first, the rainfall event occurred during the winter on a grassy area where evaporation could be assumed to be near zero in the upper soil layers, secondly, the fractured nature of the unsaturated zone at the experimental site is conducive to the rapid transport of water. This zone is characteristically weathered rock that is densely fractured facilitating the rapid transport of infiltration to the water table. From observed data taken at the ETF, this was found to be the case as the aquifer begins to respond 3 to 5 h after the start of a rainfall event (Davis et al. 1984). Based on these observations, the infiltration was lagged 4 h before it recharged the aquifer.

Two different infiltration conditions were used: one for the disturbed areas around the experimental trenches, and one for the relatively undisturbed areas everywhere else. The predicted infiltration over the disturbed area is listed in Table 4, which contains output from the infiltration model of Appendix B without the time lagging. The necessary soil parameters for determining the infiltration are also listed in Table 4. The infiltration parameters for the undisturbed area are similar to those used for determining infiltration for the disturbed soil and are therefore not listed. The actual aquifer recharge values can be found in Appendix C in the one-dimensional transient data set.

2.2.3 Initial and Boundary Conditions

Boundary conditions for the transient modeling were obtained by using the wells located at the upslope and downslope ends of the cross section shown in Fig. 2. Water elevations at well 375 were used for nodes 1 and 2, and water elevations at well 362 were used for nodes 81 and 82. The initial conditions along the cross section were determined by the water level recorders located on wells 313, 31, 24, and 6, and were set to the respective water elevation at the beginning of the rainfall event. This corresponds to hour 0100 on February 13, 1984. The initial water elevations at the remaining 70 nodes were determined by linear interpolation.

2.2.4 Model Calibration

Once the input data were determined, the calibration of the transient portion of the model began. It was decided not to adjust the hydraulic conductivity values determined in the steady-state case. On the other hand, effective porosity, aquifer bottom elevation, and specific yield are terms that do not greatly effect a steady-state condition (with no source terms) but, for the transient case, needed adjustment to make the predicted results reflect the measured data.

Table 4. Infiltration run for the undisturbed elements

Time (h)	Precipitation (cm)	Infiltration (cm/h)	Excess (cm/h)	Total (cm)	Compressed time (h)
1	0.038	0.038	0.000	0.038	0.00
2	0.321	0.250	0.071	0.288	1.00
3	0.321	0.199	0.122	0.487	2.00
4	0.235	0.118	0.117	0.605	3.00
5	0.000	0.000	0.000	0.609	2.50
6	0.000	0.000	0.000	0.613	2.00
7	0.000	0.000	0.000	0.617	1.50
8	0.000	0.000	0.000	0.621	1.00
9	0.000	0.000	0.000	0.625	0.50
10	0.000	0.000	0.000	0.629	0.00
11	0.000	0.000	0.000	0.633	0.00
12	0.000	0.000	0.000	0.637	0.00
13	0.000	0.000	0.000	0.641	0.00
14	0.000	0.000	0.000	0.645	0.00
15	0.000	0.000	0.000	0.649	0.00
16	0.000	0.000	0.000	0.653	0.00
17	0.070	0.070	0.000	0.723	0.08
18	0.204	0.204	0.000	0.927	0.92
19	0.204	0.153	0.051	1.080	1.92
20	0.872	0.130	0.742	1.180	2.92
21	0.275	0.119	0.156	1.329	3.92
22	0.189	0.108	0.081	1.437	4.92
23	0.058	0.058	0.000	1.495	5.58
24	0.000	0.000	0.000	1.495	5.08

Assumptions for infiltration run:
Effective porosity = 0.03.
Capillary pressure head = 20. cm.
Hydraulic conductivity = 0.15 cm/h.
Antecedent moisture = 0.010.
Total precipitation = 2.84 cm.

There was considerable difference in the way the individual wells responded to the storm being modeled. As a result, model predictions were not intended to exactly match the measured data, but rather to match the trends and try to achieve approximately the same rise in the aquifer. There was no attempt to achieve exact matches at each of the four wells because of the nature of the hydraulic data taken. The hydraulic conductivities, specific yields, and effective porosities were average values for the site determined by field studies that included an aquifer pump test and individual well slug tests. The nature of the pump test was such that it gave average computed specific yields and transmissivities, not microscale (element by element) values. The individual well slug tests do reflect more microscale data, but may be heavily influenced by the well screen and the backfill material around the screen. Thus, all data used in this study have come from averaging processes and may actually exhibit a high degree of variability when considering individual elements. As a result, the site was only divided into three distinct material types. This segmentation resulted in predicting the general trends in the data, but not the exact response at an individual well.

The final values of the parameters determined from the calibration study are listed in Table 5. The main adjustments to the steady-state parameters are the increased effective porosity and the decreased specific yield. The specific yield was essentially set equal to the effective porosity, which indicates little or no water retained in the soil pores. This would not be a valid assumption if the ETF were

Table 5. Calibrated hydraulic parameters for the ETF

Material type	Hydraulic conductivities (m/s)	Specific yield	Effective porosity	Aquifer bottom (m)
1	0.63×10^{-6}	0.04	0.04	220
2	0.15×10^{-5}	0.04	0.04	220
3	0.22×10^{-6}	0.04	0.04	220

dominated by standard porous media flow. Rather, the ETF groundwater flow is dominated by microfractures of the weathered shale and limestone. By addressing these microfractures in an average sense, the porous flow models are still applicable. These microfractures can drain more readily as they have larger spaces and less capillary retention, thus, facilitating more complete drainage.

2.2.5 Results

The results of the modeling will be presented by comparing a specific well to the predicted water level response of the closest node, thus allowing examination of the transient water table response at specific points along the cross section. Figure 4 contains the comparison of well 313 and node 32, Fig. 5 the comparison of well 24 and node 39, Fig. 6 the comparison of well 31 and node 43, and Fig. 7 the comparison of well 6 and node 50. From the nature of the site (the geologic strike or preferred flow direction is normal to the modeled cross-section), it was anticipated that the model could predict the rising limb and peak elevation at each of the wells, but the falling limb, which represents the drainage from the site, would be more difficult. Since the strike and, therefore, high conductivities, are perpendicular to the cross section, and the one-dimensional case allows no water to flow in this direction, the recovery limb was expected to show less rapid drainage using the model.

The node that responded as anticipated was node 43 (Fig. 6). In this figure the actual recession limb of the curve is seen to fall considerably faster than the modeled curve. Similarily, wells 24 and 6 were accurately modeled (Figs. 5 and 7) with an even better match of the recession portion of the curves. Well 313 (Fig. 4) had an entirely different response with the modeled results overestimating the actual response to the storm. This well is much older than the other three and is made of a larger diameter casing perforated from top to bottom. The other wells have smaller casings and are screened only from the well bottom to near the phreatic surface. These construction differences, or perhaps different soil characteristics, may have caused

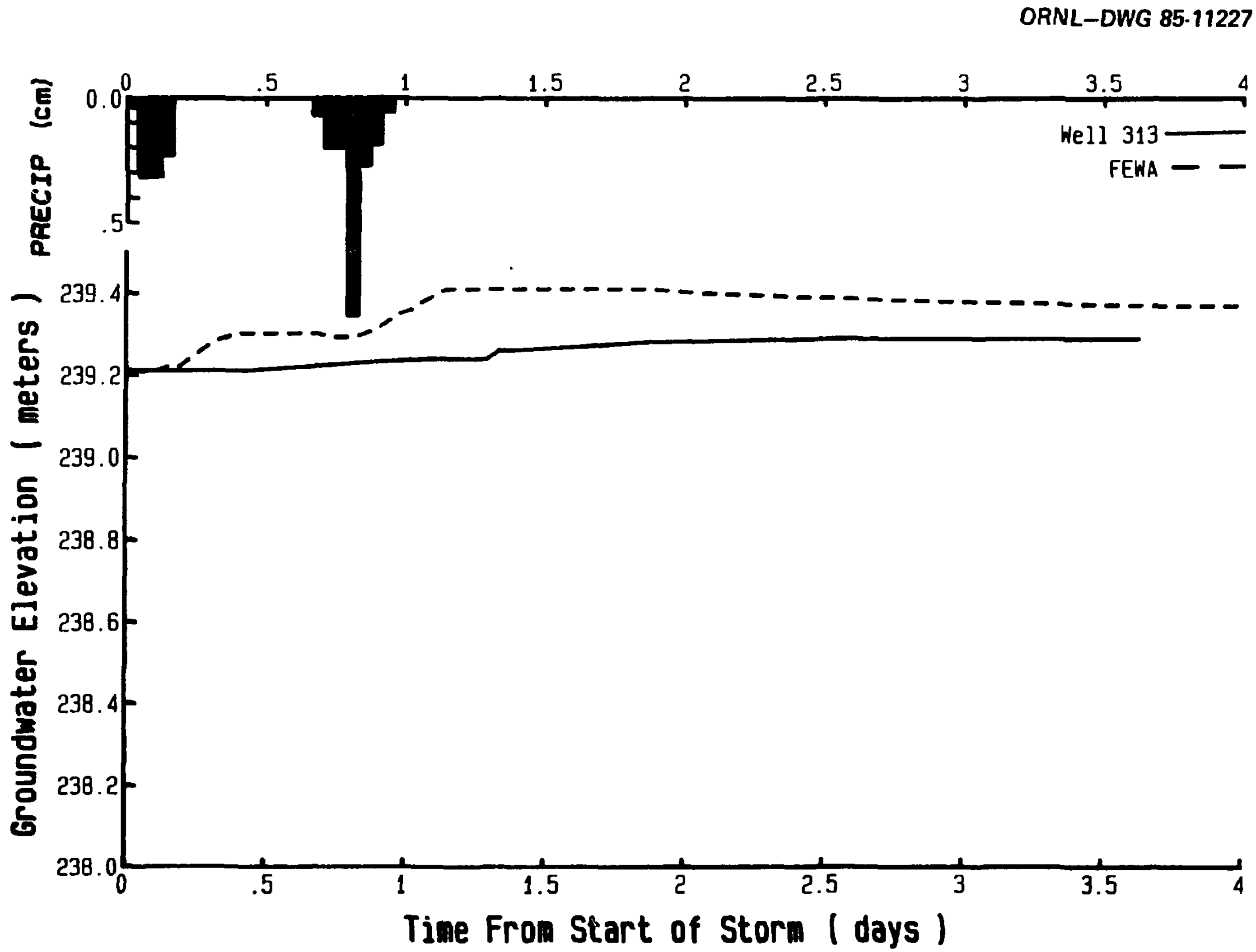


Fig. 4. Observed vs predicted water table response for the one-dimensional transient simulation at well 313 node 32.

ORNL–DWG 85-11226

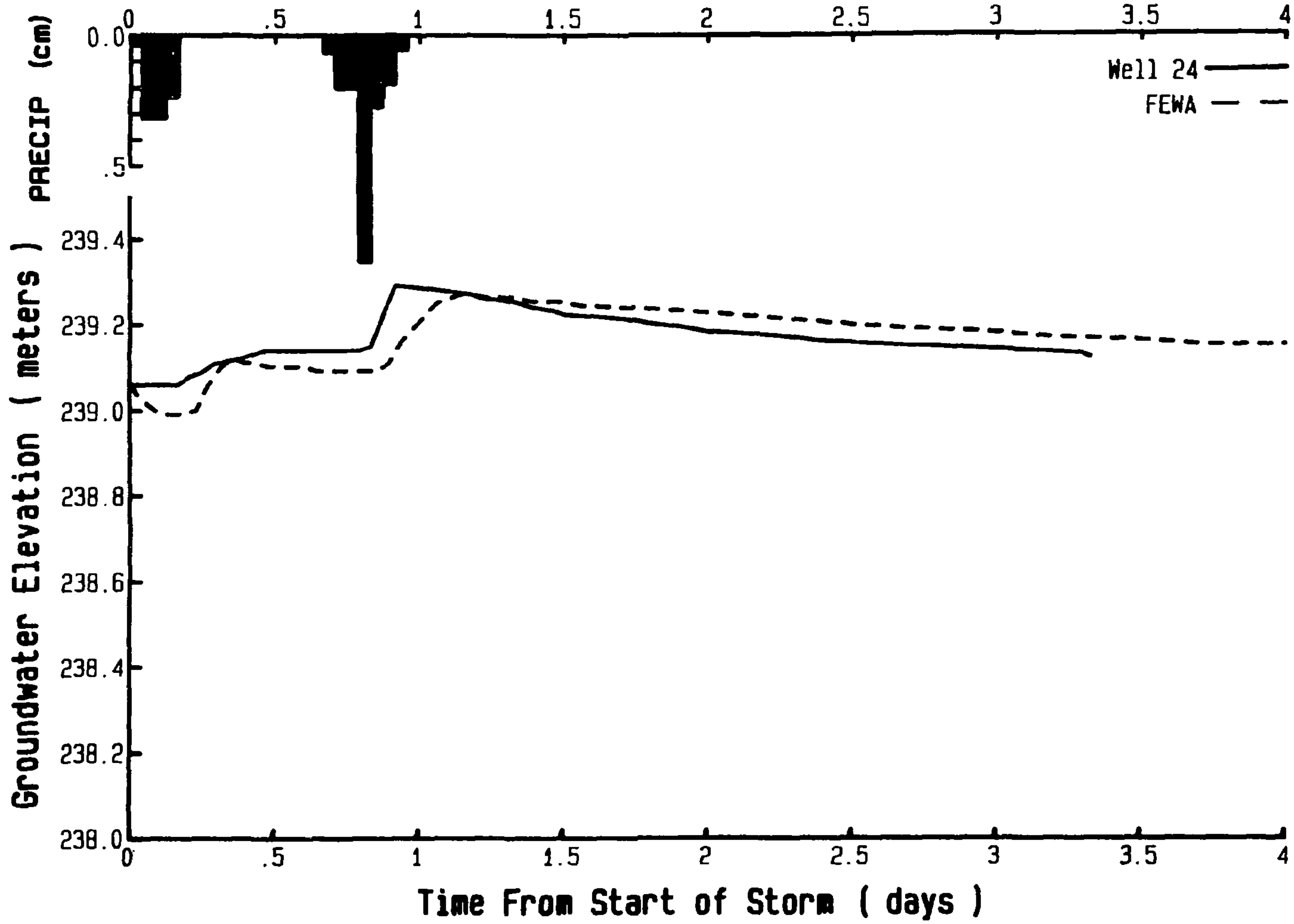


Fig. 5. Observed vs predicted water table response for the one-dimensional transient simulation at well 24 node 39.

ORNL–DWG 85-11225

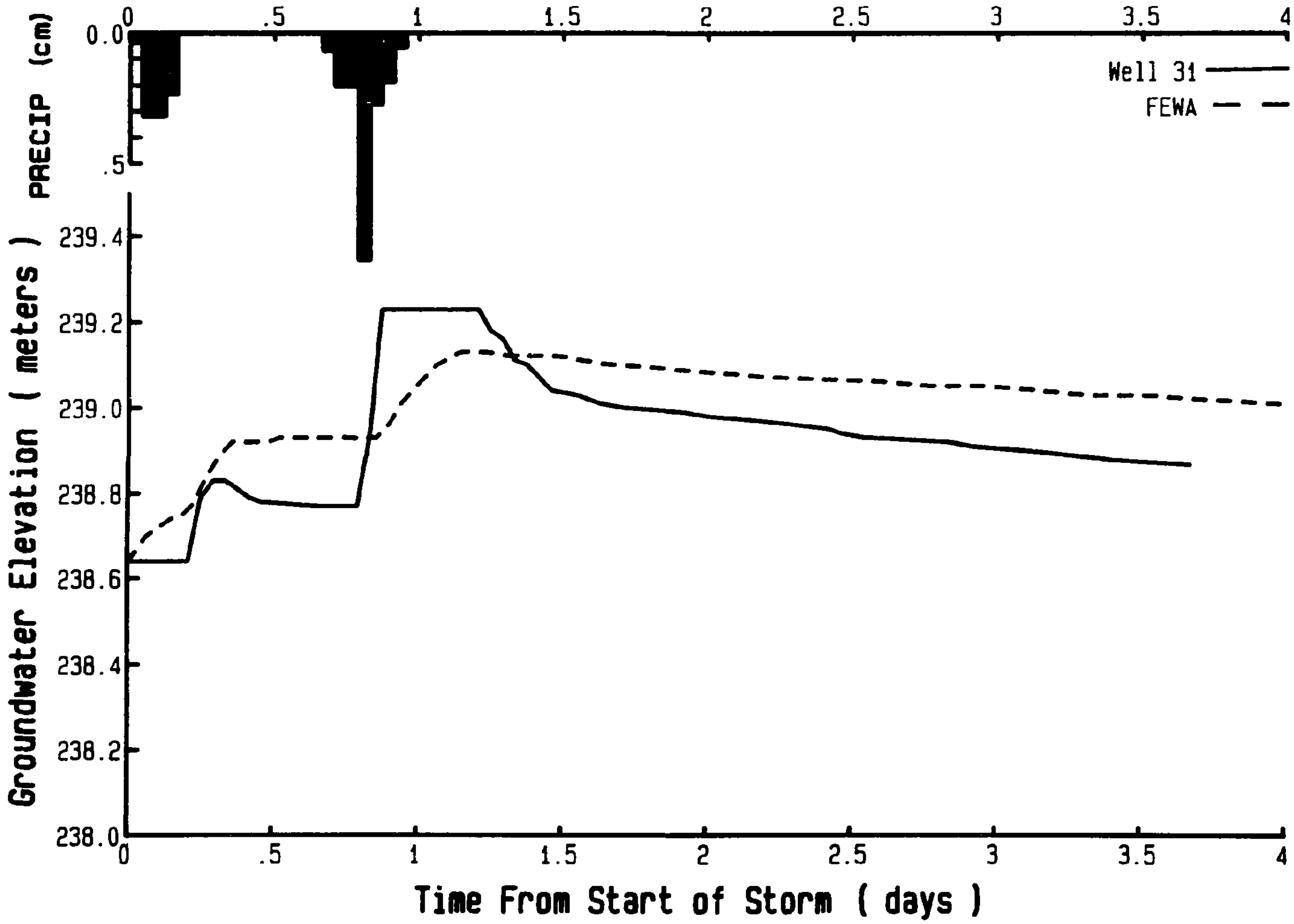


Fig. 6. Observed vs predicted water table response for the one-dimensional transient simulation at well 31 node 43.

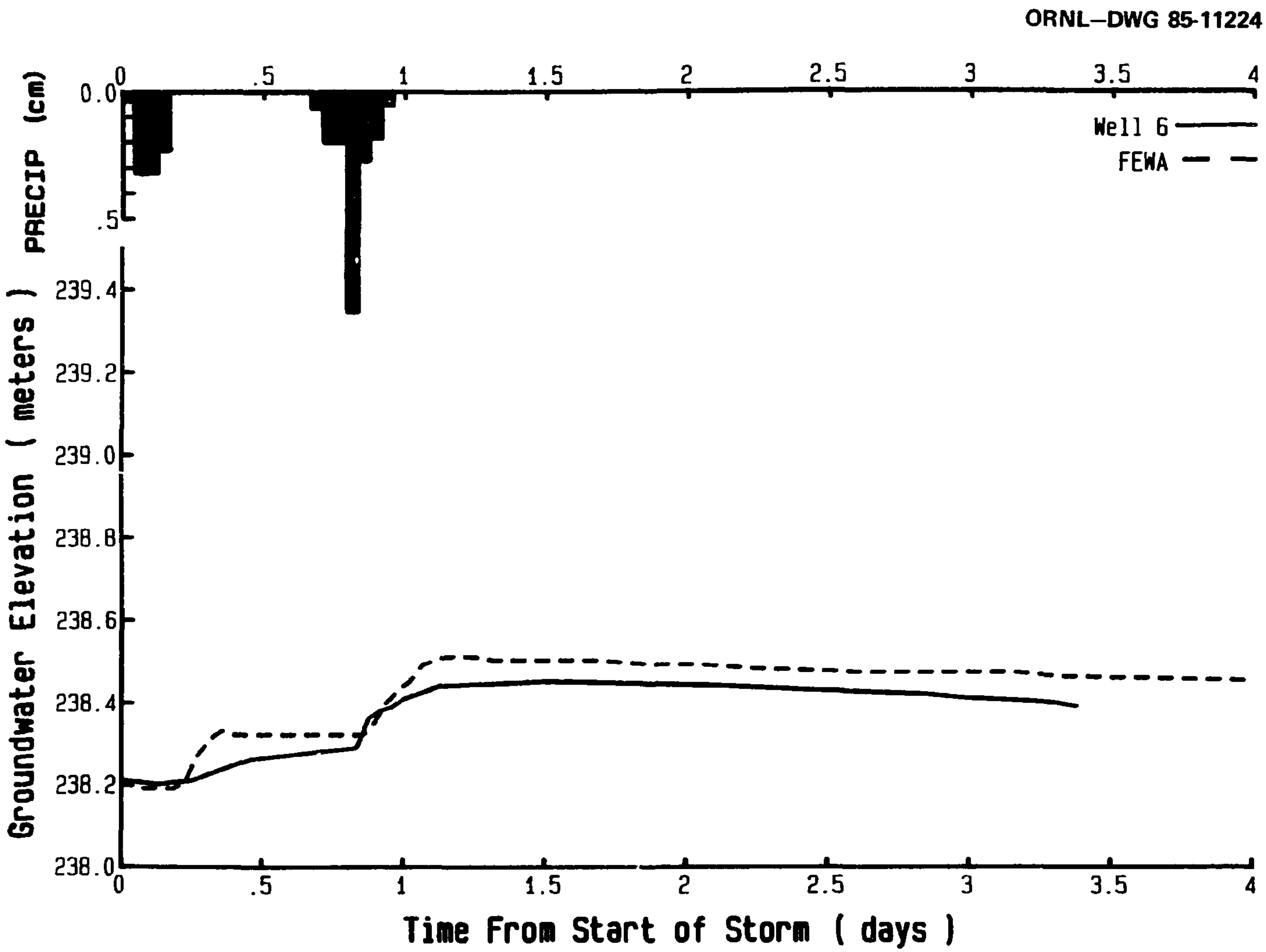


Fig. 7. Observed vs predicted water table response for the one-dimensional transient simulation at well 6 node 50.

the slow water table rise and small measured response observed at well 313. There is not enough small-scale data to support modifying the soil properties in the area around well 313, and since there is only a 20 cm difference in heights between the modeled and observed results for this well, no further changes to the one-dimensional data set were made.

In summary, Figs. 5, 6, and 7 show that the predicted water table trends are generally in good agreement with the measured data. The period of little or no rainfall between storms resulted in a flat or falling water table in both the computed and measured heads at this time. Better predictions could be made if there had been more detailed hydraulic and soils data at the site, particularly on a smaller scale more accurately reflecting the size of the site being modeled. However, FEWA did a good job in simulating the aquifer response to this precipitation event and was next applied to the site in a two-dimensional case.

3. MODEL APPLICATION IN TWO DIMENSIONS

The second phase of applying FEWA to the ETF site involved modeling the site in two dimensions. A horizontal discretization of the site was first made and nodes were preferentially located at coordinates containing wells equipped with water level recorders. In this manner nodes were located at wells 1 through 12, 375, 362, 15, and 363. Well 363 is the southernmost well and corresponds to node 1 of the discretization. A total of 158 elements and 169 nodes were used with the layout summarized in Fig. 8. In this figure, the wells of interest are identified as small open circles located at a node; the nine experimental trenches are located near the center of the site and are shaded. Both quadrilateral and triangular elements were used to facilitate a meaningful breakdown of the site, with the elements surrounding the trench area being chosen to give the most flexibility in assigning material types while incorporating the wells in the area.

The area of discretization in Fig. 8 is 0.97 ha with an average element size of 61.7 m^2. The smaller elements are located in the areas of suspected rapid spatial variability whereas the larger elements are in the areas surrounding the experimental trenches where little spatial variability is expected. The elements to the south of well 362 are not part of the area of interest but were included simply to make better use of the existing boundary conditions (two small creeks draining the ETF).

3.1 TWO-DIMENSIONAL TRANSIENT

Much of the discussion of the one-dimensional transient case is applicable to the two-dimensional case as well; therefore, only those portions that are unique to the two-dimensional case will be addressed. A general discussion of the transient application can be found in Sect. 2.2 of the one-dimensional analysis. As with the one-dimensional case, hydraulic conductivities, effective porosity, specific yield, and boundary conditions are the important input data to FEWA. A major difference in the hydraulic parameters from the

ORNL/TM-9467

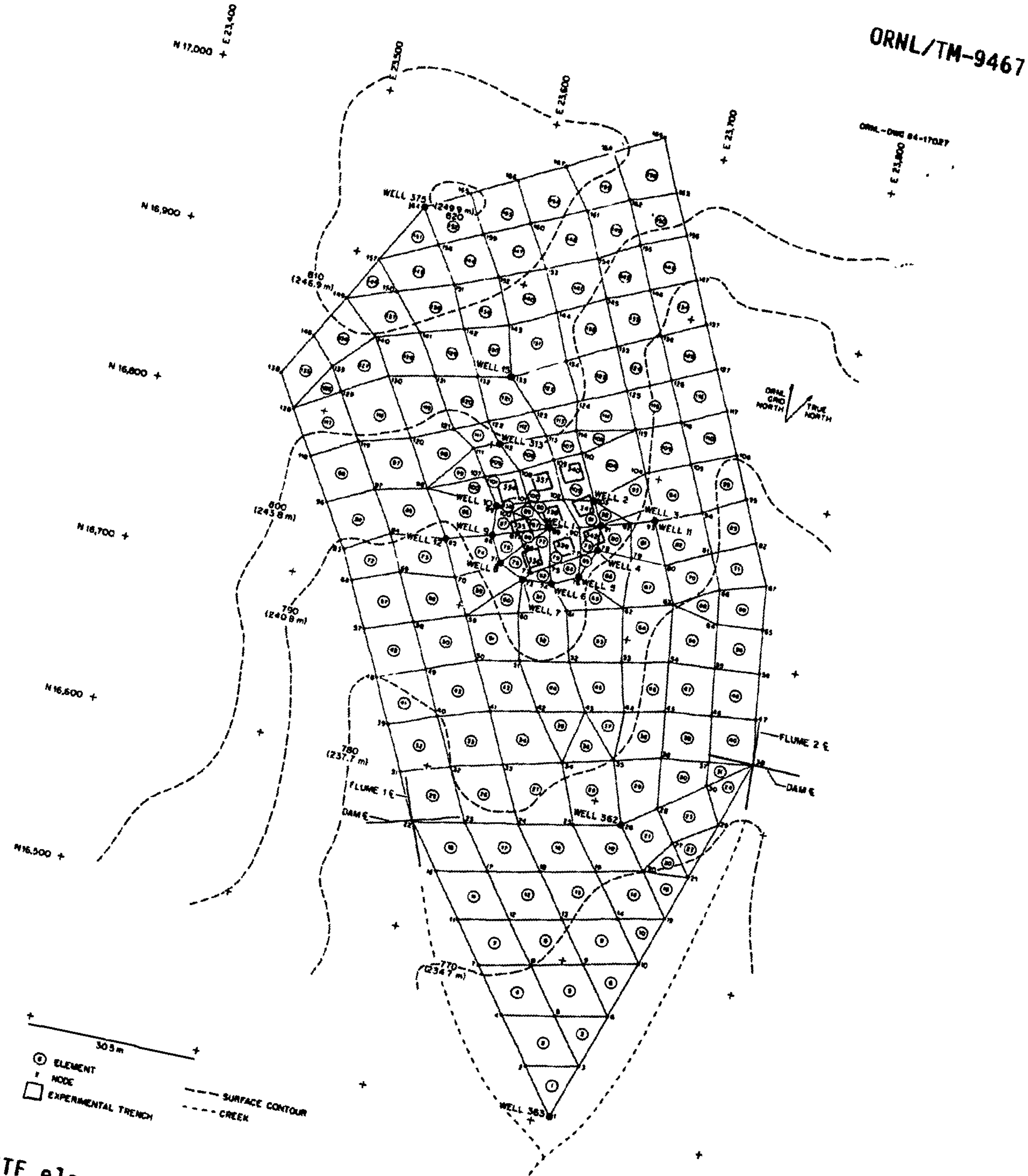


Fig. 8. ETF element and nodal layout for modeling the two-dimensional case.

one-dimensional case is that the site is not isotropic; therefore, the east-west and north-south hydraulic conductivities are different. These anisotropic conditions, along with the different boundary conditions, are the two most important differences in the two-dimensional case.

3.1.1 Measured Response of the Aquifer

The period modeled was February 13 through February 17, 1984, which was the same period considered in the one-dimensional case. Again, the group of water level recorders placed along the cross section shown in Fig. 2 were used to collect storm response data. With this configuration of water level recorders, no data are available for comparing the predicted results to those areas off the cross section yet within the discretized area. This places a slight limitation on the calibration capability. The boundary conditions ensured the behavior of the near boundary nodes while the nodes farthest from the boundaries (those along the cross section) had water level data to be compared with.

3.1.2 Aquifer Recharge

The same aquifer recharge values used in the one-dimensional case were used here. The areal distribution of this recharge for the two-dimensional case needed to be established. To accomplish this, two recharge areas were defined -- one of higher infiltration capacity, and one of lower capacity. The elements over, and immediately surrounding, the experimental trenches were assigned the higher recharge rates, and the remainder of the site was assigned the lower rates. This was done in part to simulate the higher infiltration taking place over the trenches where considerable excavation and backfilling had taken place. The exact elements receiving this higher infiltration can be obtained from the input data listed in Appendix C and Fig. 8.

3.1.3 Initial and Boundary Conditions

Completely different initial and boundary conditions were used than those specified in the one-dimensional case. For example, to determine the initial conditions of the water table, the steady-state solution for the two-dimensional case was used instead of the measured and interpoluted heads used in the one-dimensional scenario. This was necessary since water level data were available only on the cross-section during this event, and little information was available at the boundaries of the site. Therefore, the solution taken was to use the steady-state heads as the initial conditions. This choice resulted in the initial computed heads being slightly different than the actual measured values along the cross section prior to the modeled period. As a result, the only way to compare heads at a particular time was to add the difference in the heads at time zero to the predicted head at the time slice of interest. For example, if there was a +10-cm difference between observed and computed head at time zero (observed head minus computed head = 10 cm), and the computed head at 3 h was 241.39 m, the value to be compared with the measured head was 241.49 m (241.39 m + 0.10 m).

With the site layout shown in Fig. 8, there were 46 boundary nodes requiring piezometric head values before the site could be modeled. Two different types of boundary conditions were used to satisfy this requirement, Dirichlet (known heads) and Neumann (known fluxes). The nodes to the south of, and including, the two flumes, were assigned as Dirichlet nodes. The piezometric head used was the ground level elevation at each node. This assumption is reasonable because this is a relatively low-lying area where the water table is often at or near the ground level elevation. There were two more Dirichlet nodes assigned, nodes 164 and 165. They were located at the northern edge of the site to provide the sloping water table that is known to exist. Their elevation was determined by the water level data from well 375.

The remainder of the nodes along the boundary, which are all those north of the two flumes (except 164 and 165), were assigned as Neumann nodes. The segments between the Neumann nodes were assigned a zero flux (no water flows between them). It was assumed that the Neumann boundary nodes lie on groundwater divides or on flowpaths parallel to the boundary side. For example, the boundary nodes to the north are located along the groundwater divide of the ridge the ETF is located on. The boundary nodes to the east and the west follow dry creek beds that drain the site. It was further assumed that the groundwater flows parallel to the creeks at these east and west edges.

Application of these two types of boundary conditions (Dirichlet and Neumann) allows a complete description of the necessary boundaries required for modeling the site. In addition to being used in the transient modeling, they were also used in obtaining the steady-state solution of the groundwater head distribution, which was an important part of estimating the site initial conditions.

3.1.4 Model Calibration

Unlike the one-dimensional case, no calibration was performed on the two-dimensional case. Instead, adjustments were made to the assignment of the material types and recharge rates to the various elements. The east-west hydraulic conductivity could have been adjusted, but the initial computed results did not indicate that any changes needed to be made to improve the predicted responses.

3.1.5 Results

As in the one-dimensional transient case, results of the FEWA computations are compared to the available water level data at the wells along the cross section shown in Fig. 2. Figure 9 compares node 112 and well 313, Fig. 10 compares node 100 and well 24, Fig. 11 compares node 88 and well 31, and Fig. 12 compares node 74 and well 6. The predicted water level response was the poorest with well 313 (Fig. 9). This is the same result found in the one-dimensional case and again may be due to differences in well construction or undefined differences in the material in the vicinity of this particular well.

ORNL–DWG 85-11223

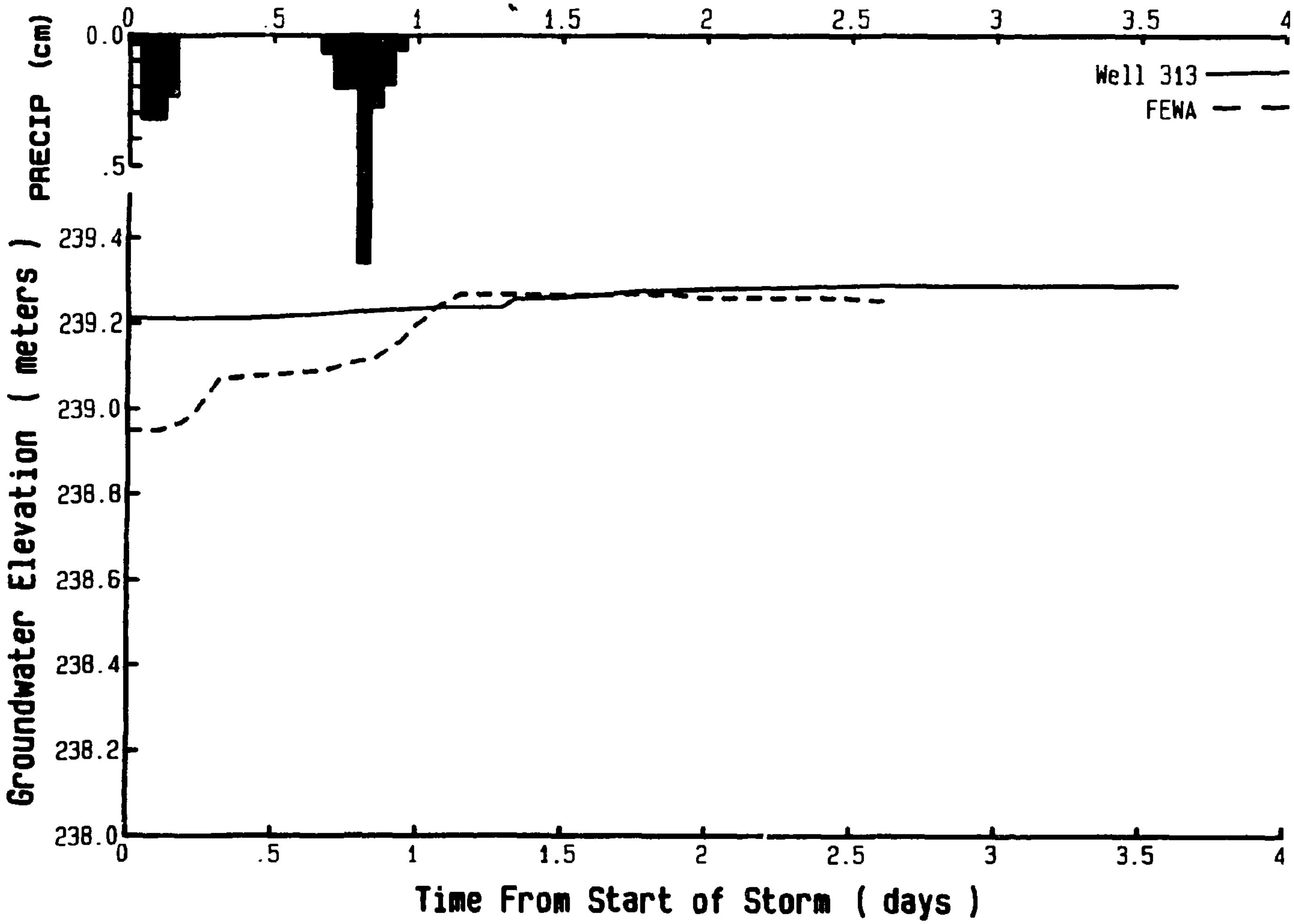


Fig. 9. Observed vs predicted water table response for the two-dimensional transient simulation at well 313 node 32.

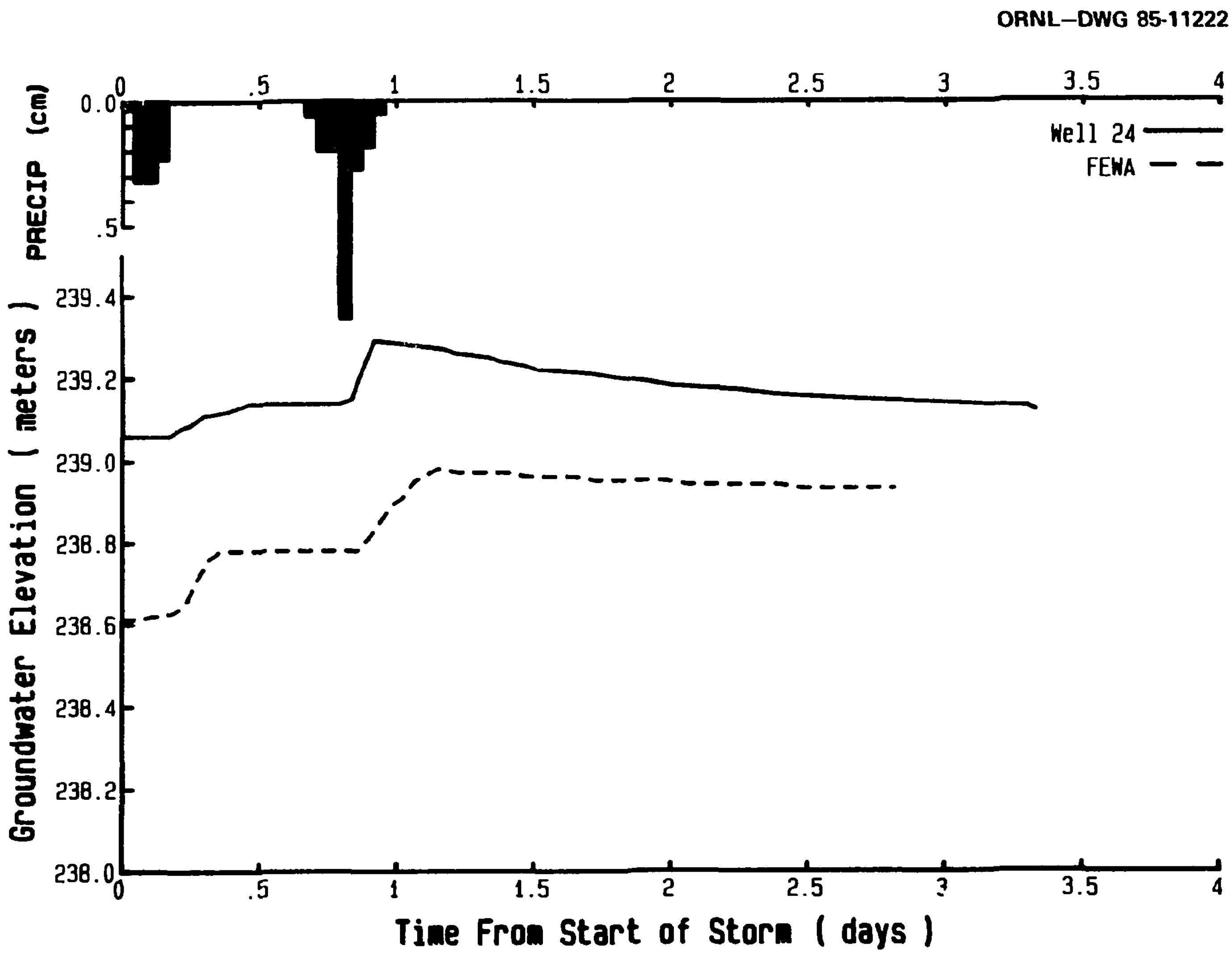


Fig. 10. Observed vs predicted water table response for the two-dimensional transient simulation at well 24 node 39.

ORNL–DWG 85-11221

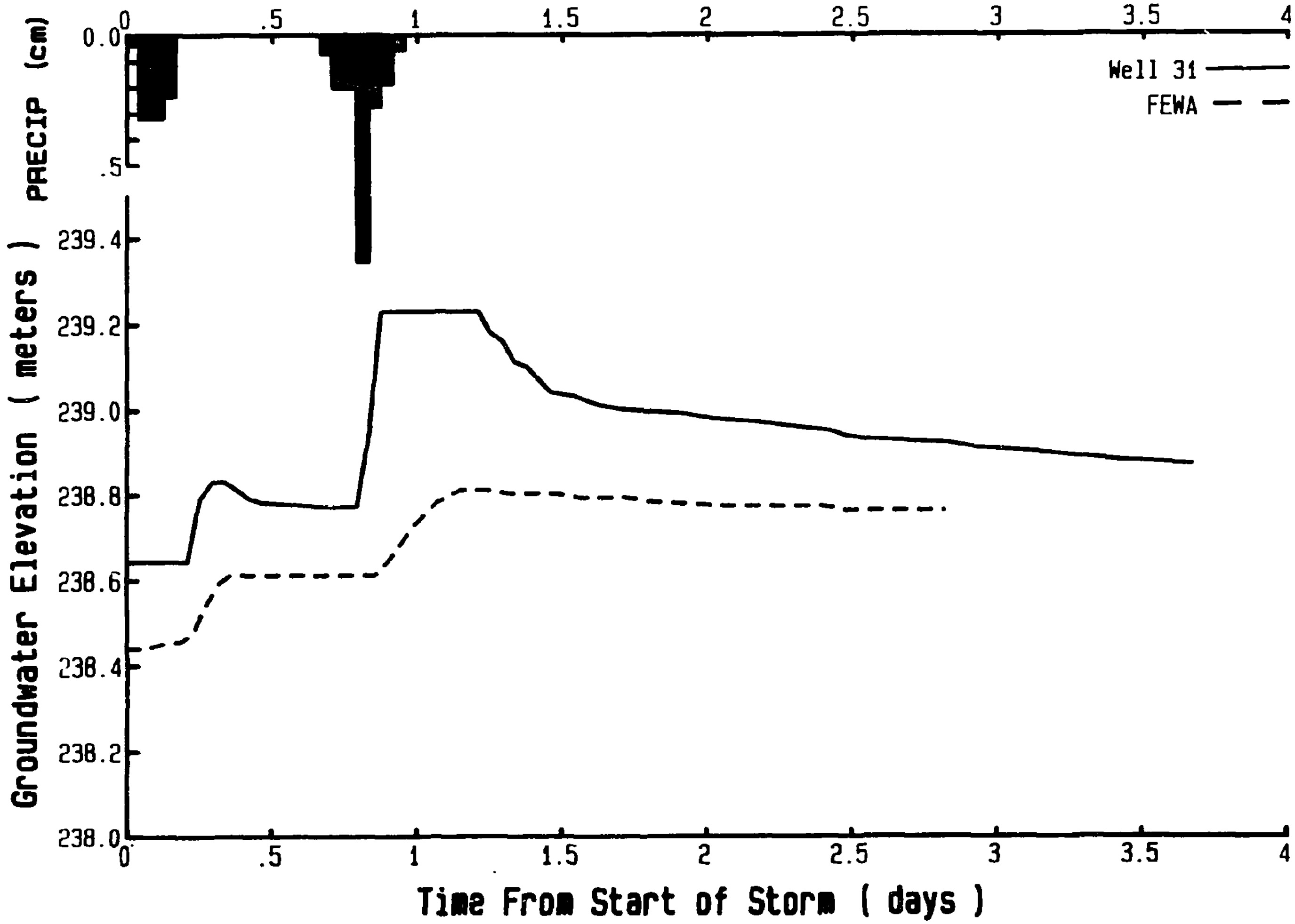


Fig. 11. Observed vs predicted water table response for the two-dimensional transient simulation at well 31 node 43.

ORNL–DWG 85-11220

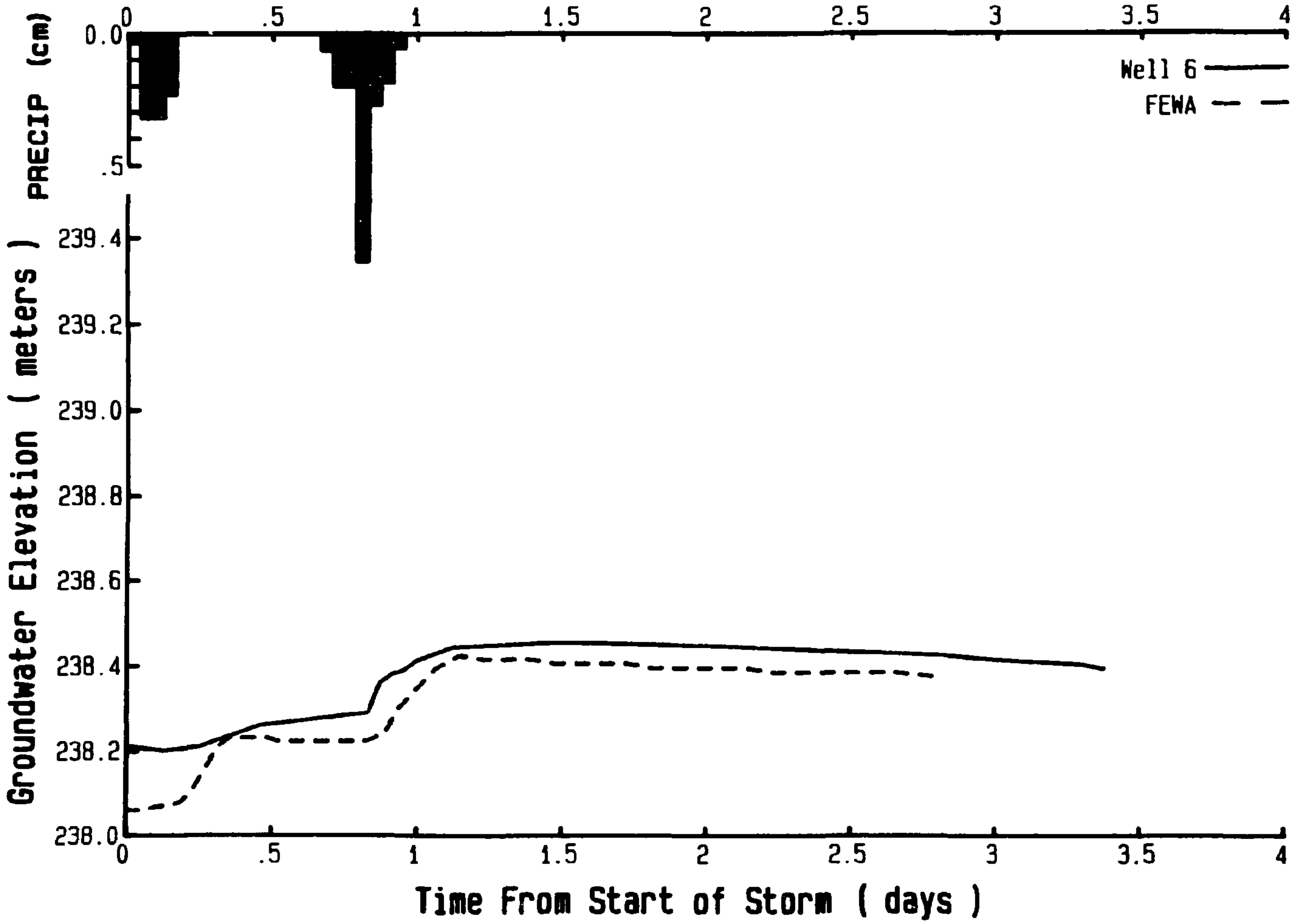


Fig. 12. Observed vs predicted water table response for the two-dimensional transient simulation at well 6 node 50.

The predicted response at wells 24, 31, and 6 (Figs. 10-12, respectively) was in very good agreement with the measured water levels at these wells. As indicated in Sect. 3.1.3, there is an offset associated with each well and node that must be taken into consideration when making the comparisons. The elevations presented here for both the computed and measured data were not adjusted by this offset. However, one can readily make the adjustments and see that the computed response is very close to the measured water table. The largest discrepancy for the peak elevations occurred for well 31 and node 88 (Fig. 11). The response of well 31 was more abrupt than could be justified using the available data, so nothing was done to try and bring the computed head more in line with the measured values.

4. SUMMARY AND CONCLUSIONS

The horizontal two-dimensional finite element groundwater flow model (FEWA), developed for the National Low-Level Waste Program, was applied to the unconfined aquifer at the ORNL ETF as a first step in reviewing its usefulness and applicability. The model was used to compute steady-state and time-dependent solutions to the groundwater flow equations for both one- and two-dimensional cases. The modeling effort described in this report progressed from one-dimensional steady-state solutions to a full two-dimensional transient application.

The one-dimensional case consisted of two separate tasks: one to apply FEWA to the steady-state case and the other to a transient case. The hydraulic input parameters for the steady-state case were determined from measured data and observed water surface slopes. The predicted heads from the model compared well with measured water level data taken from long dry periods used to estimate steady-state conditions at the site. The transient case was performed using a rainfall event that occurred on February 13, 1984. The best estimate of aquifer recharge was determined from this rainfall and was input to the FEWA model. The input parameters that effect the transient modeling results were calibrated to give the best justifiable fit to the measured response at wells located on a site cross section. The results from the transient case compare rather well with the measured data with the exception of well 313. The discrepancy at this well was not great in the sense that the difference in the computed and measured water levels were great, but rather the comparison of the shape of the response curves was not good. In general, the predicted results at the remaining wells were in good agreement with the measured responses for this one-dimensional case.

The horizontal two-dimensional case involved the modeling of the transient case only. The steady-state solution was not considered to be of any great importance in its own right, considering the information previously obtained in the one-dimensional steady-state case. The two-dimensional steady-state computations were conducted only for the purpose of establishing initial water table conditions. The hydraulic conductivities perpendicular to strike were assigned the same values as in the one-dimensional case, while the conductivities parallel to strike were set equal to twice the perpendicular values. The results of the two-dimensional case closely followed the one-dimensional results. The computed water levels and measured responses were again in good agreement (Figs. 9-12) with the possible exception of well 313. This was an expected result since the data used were essentially the same for the two cases.

In conclusion, the performance of the FEWA code was quite good given the limitations of the input data. Computationally, the solutions readily converged with the exception of the two-dimensional steady-state case. Even there the solution was converging, but needed more iterations (which were added later). The two biggest problems in using FEWA for this application were the lack of the correct input data and the FEWA documentation. The documentation problem is actually a matter of inconvenience. It is felt that in order for the model to be widely used the documentation needs to contain more general discussions of the input data, specifically the numeric options. The lack of spatially varied input data is a result of the original ETF experimental design. The ETF was not initially designed for testing a groundwater model, but rather for monitoring leachate from experimental trenches. Given more detailed data, FEWA would have been even more accurate in its predicted water level elevations.

This study was the first step in checking the applicability and usefulness of FEWA as a tool for low-level waste disposal site hydrologic analysis. FEWA will be applied to the ETF for several other precipitation events for which additional response data exists for wells 1 through 15. This will allow for better calibration and validation of the model and input parameters. The ultimate purpose of the ETF groundwater flow modeling subtask is to obtain a calibrated model that can predict groundwater velocities for future radionuclide transport studies. Finally, if FEWA continues to perform well, it will demonstrate that the model is useful for analyses of groundwater flow regimes and related waste disposal site studies.

REFERENCES

Boegly, W. J., Jr., and E. C. Davis. 1983. Design and construction of a low-level waste shallow land burial experimental facility. ORNL/TM-8847. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Carter, M. W., A. A. Moghissi, and B. Kahn. 1979. Management of Low-Level Radioactive Waste, vol. 1. Pergamon Press, New York.

Cooper, W. T. 1981. Interactions between organic solutes and mineral surfaces and their significance in hydrogeology. Ph.D. thesis. Indiana University, Bloomington.

Davis, E. C., and P. M. Craig. 1984. Summary of rainfall, runoff, water table, and water quality data from ORNL's solid waste storage area six engineered test facility: 1980-1984 data base. ORNL/NFW-84/41. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Davis, E. C., W. J. Boegly, Jr., E. R. Rothschild, B. P. Spalding, N. D. Vaughan, C. S. Haase, D. D. Huff, S. Y. Lee, E. C. Walls, J. D. Newbold, and E. D. Smith. 1984. Site characterization techniques used at a low-level waste shallow land burial field demonstration facility. ORNL/TM-9146. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Green, W. H., and G. A. Ampt. 1911. Studies on soil physics part 1, the flow of air and water through soils. J. Agr. Sci. 4:1-24.

Hvorslev, M. L. 1951. Time lag and soil permeability in groundwater observations. Bull. No. 36. Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi.

Newbold, J. D., and M. A. Bogle. 1984. An automated system for monitoring groundwater levels at an experimental low-level waste disposal site. ORNL/TM-9007. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Reeves, M., and E. E. Miller. 1975. Estimating infiltration for erratic rainfall. Water Res. Research 11:1-8.

Vaughan, N. D., C. S. Haase, D. D. Huff, S. Y. Lee, and E. C. Walls. 1982. Field demonstration of improved shallow land burial practices for low-level radioactive solid wastes: Preliminary site characterization and progress report. ORNL/TM-8477. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Yeh, G. T., and D. D. Huff. FEWA: A finite element model of water flow through aquifers. ORNL-5976. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

APPENDIX A

INPUT GUIDE TO FEWA

APPENDIX A: INPUT GUIDE TO FEWA

1. TITLE: FORMAT(I5,9A8,I3) - One card per problem.

NPROB	TITLE		IBUG
5		77	80

NPROB = Problem number.

TITLE = Array for the title of the problem. It may contain up to 72 characters from column 6 to column 77.

IBUG = Integer indicating if the diagnostic output is desired? 0 = No, 1 = Yes.

2. BASIC INTEGER PARAMETERS: Three cards per problem are needed.

Card 1 - FORMAT(20A4)

DATNAM
80

DATNAM = Data name to describe this data set.

Card 2 - FORMAT(16I5)

NNP	NEL	NMAT	NCM	NTI	KSS	KSTR	KCP
5	10	15	20	25	30	35	40

NSTRT	NITER	ILUMP	IMID	ICONFI	NDTCHG	IPNTS	NPITER
45	50	55	60	65	70	75	80

NNP = Number of nodal points.

NEL = Number of elements.

NMAT = Number of material types.

APPENDIX A (continued)

NCM = Number of elements with IE(M,5) correction.

NTI = Number of time steps or time increments.

KSS = Steady-state control,
0 = steady-state solution desired,
1 = transient-state or transient solutions.

KSTR = Auxiliary storage output? 0 = no,
1 = output stored in Logical Unit 1.

KCP = Permeability input control;
-1 = input transmissivity, used only for confined aquifers,
0 = input saturated hydraulic conductivity,
1 = input saturated permeability.

NSTRT = Number of logical records to be read via auxiliary storage device for restarting calculation, 0 = no restart.

NITER = Number of iterations allowed for solving the nonlinear equation.

ILUMP = Mass matrix lumped? 0 = no, 1 = yes.

IMID = Mid-difference integration? 0 = No, 1 = Yes.

ICONFI = Confined aquifer? 0 = No, 1 = Yes.

NDTCHG = No. of times to reset step size to initial time step size.

IPNTS = Is pointwise iterative method used?
0 = No, 1= yes.

NPITER = No. of iterations used to solve the matrix equation pointwise.

*** NOTE: NTI can be computed by NTI = I1 + 1 + I2 + 1,

where I1 = largest integer not exceeding
Log(DELMAX/DELT)/Log(1+CHNG),

I2 = largest integer not exceeding
(RTIME-DELT*((1+CHNG)**(I1+1)-1)/CHNG)/DELMAX,

RTIME = real simulation time,

DELMAX, DELT, and CHNG are defined in Data Set 3.

APPENDIX A (continued)

Card 3 - FORMAT(16I5)

IVML	
5	80

IVML = Is the velocity solving matrix lumped?
0 = no, 1 = yes.

3. BASIC REAL PARAMETERS

Three cards per problem. Use of an E-, D-, or another F-type field specification in the input card overrides any of the D10.3 field.

Card 1 - FORMAT(20A4)

DATNAM
80

DATNAM = Data name to describe this data set.
It may contain up to 80 characters.

Card 2 - FORMAT(8D10.3).

DELT	CHNG	DELMAX	TMAX	TOLA	TOLB	RHO	GRAV
10	20	30	40	50	60	70	80

DELT = Initial time step size (T).

CHNG = Percentage of change in time step size in each of the subsequent time increment, (dimensionless in decimal point).

DELMAX = Maximum value of DELT (T).

TMAX = Maximum simulation time (T).

TOLA = Steady-state convergence criteria (L).

TOLB = Transient-state convergence criteria (L).

RHO = Density of water (M/L**3).

GRAV = Acceleration of gravity (L/T**2).

APPENDIX A (continued)

Card 3 - FORMAT(8D10.3).

VISC	W	OME	OMI	
10	20	30	40	80

VISC = Dynamic viscosity of water (M/LxT).

W = Time derivative weighting factor;
0.5 = Crank-Nicolson central and mid-difference,
1.0 = backward difference.

OME = Iteration parameter;
0.0-1.0 = under-relaxation,
1.0-1.0 = exact relaxation,
1.0-2.0 = over-relaxation.

OMI = Relaxation parameter; 0-1 = under-relaxation,
1 = exact relaxation, 1-2 = over-relaxation.

4. PRINTER AND DISK STORE CONTROL AND TIMES FOR STEP SIZE RESETTING

The number of cards here depends on the number of time increments NTI and the times of resetting step-size NDTCHG. The number of cards is [(NTI/80+1)*2 + (NDTCHG/8+1) + 1]. One card for the data name, (NTI/80+1) cards for printer output control, (NTI/80+1) cards for storage control, and (NDTCHG/8+1) cards for time-step-size resetting.

Card 1 - FORMAT(20A4)

DATNAM
80

DATNAM = Data name to describe this data set. It may contain up to 80 characters.

Card 2 to Card [(NTI/80+1)+1] - FORMAT(80I1)

KPRO	KPR(1)	KPR(2)	--- KPR(I) ---	KPR(NTI)
1	2	3		80

APPENDIX A (continued)

KPRO = Printer control for steady-state and initial conditions;
0 = print nothing,
1 = print FLOW, FRATE, and TFLOW,
2 = print above (1) plus piezometric head h,
3 = print above (2) plus integrated flux.

KPR(I) = Printer control for I-th time step similar to KPRO.

Card [(NTI/80+1)+2] to Card [(NTI/80+1)*2+1] - FORMAT(80I1)

KDSKO	KDSK(1)	KDSK(2)	---	KDSK(I)	---	KDSK(NTI)	
1	2	3					80

KDSKO = Auxiliary storage control for steady-state and initial condition;
0 = no storage,
1 = store on Logical Unit 1.

KDSK(I) = Auxiliary storage control for I-th time step similar to KDSKO.

Card [(NTI/80+1)*2 +2] to card [(NTI/80)*2 + (NDTCHG/8+1) +1]

TDTCH(1)	TDTCH(2)	---	TDTCH(I)	---	TDTCH(NDTCHG)	
10	20					80

TDTCH(I) = Time when I-th step-size resetting is needed.

5. MATERIAL PROPERTIES

A total of (NMAT+1) cards is required for this data set.

Card 1 - FORMAT(20A4)

DATNAM
80

DATNAM = Data name for this data set. It may contain up to 80 characters.

APPENDIX A (continued)

Card 2 to Card [NMAT+1] - FORMAT(8D10.3)

PROP(1,1)	PROP(1,2)	----	PROP(1,7)	
10	20		70	80

.

.

PROP(I,1)	PROP(I,2)	----	PROP(I,7)	
10	20		70	80

.

.

PROP(NMAT,1)	PROP(NMAT,2)	----	PROP(NMAT,7)	
10	20		70	80

PROP(I,1) = Modified coefficient of compressibility of the medium I (1/L).

PROP(I,2) = Modified coefficient of compressibility of water in medium I (1/L).

PROP(I,3) = Effective porosity of medium I, (dimensionless in decimal point).

PROP(I,4) = xx-component of the saturated hydraulic conductivity tensor (L/T) or saturated permeability (L**2).

PROP(I,5) = yy-component of the saturated hydraulic conductivity tensor (L/T) or saturated permeability (L**2).

PROP(I,6) = xy-component of the saturated hydraulic conductivity tensor (L/T) or saturated permeability (L**2).

PROP(I,7) = Specific yield of medium I, (dimensionless in decimal point).

APPENDIX A (continued)

NOTE: DATA SETS 6 THROUGH 10 ARE NOT NEEDED IF NSTRT .GT. 0.

6. BOTTOM ELEVATION AND THICKNESS OF THE AQUIFERS.

A set of cards is needed per problem. The first card is used to describe this data set.

Card 1 - FORMAT(20A4)

DATNAM
80

DATNAM = Data name to describe this data set. It may contain up to 80 characters.

Card 2 on - FORMAT(3I5,5X,4D10.3)

NI	NSEQ	NAD		BNI	BAD	
5	10	15	20	30	40	80

NI = Node number of the first node in the sequence.

NSEQ = NSEQ subsequent node numbers will be automatically generated.

NAD = Node number increment for each of the NSEQ nodes.

BNI = Aquifer bottom elevation (unconfined case) or aquifer thickness (confined case) of node NI (L).

BAD = Increment of aquifer bottom elevation or aquifer thickness for each of the NSEQ subsequent nodes (L).

**** NOTE: A blank card must be used to signal the end of this data set.

**** A group of cards similar to Group Card 2 is needed for inputting aquifer thickness.

APPENDIX A (continued)

7. NODAL POINT COORDINATE

Usually a total of (2*NNP+1) cards is required, one for the description of this data set, NNP cards for x-coordinate, and NNP cards for y-coordinate. However, if a group of subsequent cards appears in regular pattern, automatic generation may be made.

Card 1 - FORMAT(20A4)

DATNAM
80

DATNAM = 80 columns of characters to describe this data set.

Card 2 to Card (NNP+1) - FORMAT(3I5,5X,4D10.3)

NI	NSEQ	NAD		XNI	XAD	XRD	
5	10	15	20	30	40	50	80

NI = Node number of the first node in the sequence.

NSEQ = NSEQ subsequent nodes will be automatically generated.

NAD = Increment of node number for each of the NSEQ subsequent nodes.

XNI = x-coordinate of node NI (L).

XAD = Increment of x-coordinate for each of the NSEQ subsequent nodes (L).

XRD = Percentage of the increase of the increment over its preceding increment (Decimal point);
If XRD .EQ. 0, all increments' XADs are the same.
If XRD .GT. 0, the first increment is XAD*(1+XRD), the second increment is XAD*(1+XRD)**2, the third increment is XAD*(1+XRD)**3, and so on.

**** NOTE: A blank card must be used to signal the end of this data set.

APPENDIX A (continued)

Card (NNP+2) to Card (2*NNP+1) - FORMAT(3I5,5X,4D10.3)

NI	NSEQ	NAD		YNI	YAD	YRD	
5	10	15	20	30	40	50	80

NI = Node number of the first node in the sequence.

NSEQ = NSEQ subsequent nodes will be automatically generated.

NAD = Increment of node number for each of the NSEQ subsequent nodes.

YNI = y-coordinate of node NI (L).

YAD = Increment of y-coordinate for each of the NSEQ subsequent nodes (L).

YRD = Percentage of the increase of the increment over its preceding increment (Decimal point); If YRD .EQ. 0, all increments' YADs are the same. If YRD .GT. 0, the first increment is YAD*(1+YRD), the second increment is YAD*(1+YRD)**2, the third increment is YAD*(1+YRD)**3, and so on.

NOTE: A blank card must be used to signal the end of this subdata set.

8. ELEMENT INCIDENCES

Usually a total of (NEL+1) cards is needed. The first card is used to describe the data set, and the second card contains element incidence and material type for each element. However, if a group of elements appears in regular pattern, automatic generation is made.

Card 1 - FORMAT(20A4)

DATNAM
80

DATNAM = 80 columns of characters are used to describe this data set.

APPENDIX A (continued)

Card 2 on - FORMAT(16I5)

MI	IE(MI,1)	IE(MI,2) ---	IE(MI,5)	MODL	NLAY	
5	10	15	30	35	40	80

MI = Global element number.

IE(MI,1) = Global node number of the first node of element MI.

IE(MI,2) = Global node number of the second node of element MI.

IE(MI,3) = Global node number of the third node of element MI.

IE(MI,4) = Global node number of the fourth node of element MI.

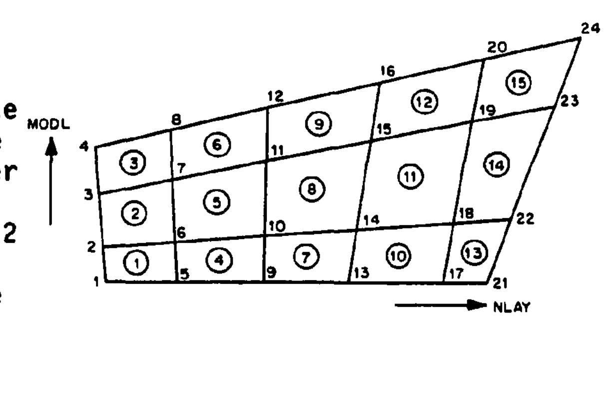
IE(MI,5) = Material type to be applied to element block MODL X NLAY. If the element block is confined, use positive number. If the element block is unconfined, use negative number.

MODL = Number of elements in the direction of most rapidly numbered nodes.

NLAY = Number of elements in the direction of least rapidly numbered nodes.

IE(MI,1) ~ IE(MI,4) are numbered beginning with the lower left corner and progressing around the element in a counterclockwise direction. For a rectangular block of elements, it is only necessary to specify the first element, the width MODL, and the length NLAY, where MODL and NLAY are measured in elements. The following figure provides an example. The object is considered rectangular since it has width MODL = 3 on two opposite sides and length NLAY = 5 on the other two opposite sides. To generate automatically definitions of element 2 through 15, including both the incidence and material type, only one card is necessary.

ORNL-DWG 81-3924 ESD



APPENDIX A (continued)

1	2	5	6	2	1	3	5	
5	10	15	20	25	30	35	40	80

Although all elements of this example will be assumed to contain the same material type, MTYP, this situation can easily be changed by using material-correction facility.

**** NOTE: A blank card must be used to signal the end of this data set.

9. MATERIAL TYPE CORRECTION

This data set is required only if NCM > 0. Normally (NCM+1) cards are required; the first one is for the description of data set and the rest is for the material-type correction, one for each correction.

Card 1 - FORMAT(20A4)

DATNAM	
	80

DATNAM = Date name used to describe this data set. It may contain up to 80 characters.

Card 2 on - FORAMT(5I5)

M	NSEQ	MAD	MTYP	MTYPAD	
5	10	15	20	25	80

M = Global element number of the first element in the sequence.

NSEQ = NSEQ subsequent elements will automatically generate material types.

MAD = Increment of element number for each of the NSEQ subsequent elements.

MTYP = Material type for element M.

MTYPAD = Incrememt of MTYP for each of the NSEQ subsequent elements.

**** NOTE: A blank card must be used to signal the end of this data set.

APPENDIX A (continued)

10. CARD INPUT FOR INITIAL OR PRE-INITIAL CONDITIONS

This data set is read in similarly to that in card data set 6.

Card 1 - FORMAT(20A4)

DATNAM
80

DATNAM = 80 columns of characters are used to describe this data set.

Card 2 on - FORMAT(3I5,5X,4D10.3)

NI	NSEQ	NAD		HNI	HAD	
5	10	15	20	30	40	80

NI = Global node number of the first node in the sequence.

NSEQ = NSEQ subsequent nodes will be generated automatically.

NAD = Increment of node number for each of the NSEQ nodes.

HNI = Initial or pre-initial pieometric head of node NI (L).

HAD = Increment of initial or pre-initial head for each of the NSEQ nodes (L).

**** NOTE: A blank card must be used to signal the end of this data set.

NOTE ON INITIAL CONDITIONS AND RESTARTING: The initial condition for a transient calculation may be obtained in three different ways: from card input, auxiliary storage input, or steady-state calculation using time-invariant boundary conditions that are different from those for transient computation. In the latter case a card input of the pre-initial conditions is required as the zeroth order iterate of the steady-state solution. Auxiliary storage input is necessary whenever the restarting facility is being used. That is, head distributions for

APPENDIX A (continued)

NSTRT different times have been generated and written on disk or magnetic tape. If NSTRT > 0, these distributions will be read from Logical Unit 2, and NSTRT-th distribution will be used as the initial condition for current calculation. If KSTR > 0, the head values will be written on a different device as they are read out so that a complete record of the calculations may be kept on one device, Logical Unit 1. If either the first (card input) or the last (steady-state) option is desired, then NSTRT = 0.

NOTE ON AUXILIARY STORAGE UNITS: Logical Unit 1 is used to store output if KSTR > 0, and Logical Unit 2 is used for input if NSTRT > 0. Proper identification of these two units must be made in the JCL if either of these two options is used.

NOTE ON STEADY-STATE INPUT: Steady-state option may be used to provide either the final state of a system under study or the initial conditions for a transient-state calculation. In the former case KSS = 0 and NTI = 0, and in the latter case KSS = 0 and NTI > 0. If KSS > 0, there will be no steady-state calculation.

11. INTEGER PARAMETERS FOR TRANSIENT SOURCE, BOUNDARY CONDITIONS, AND LEAKING UPPER AND LOWER AQUIFERS.

Two cards per problem are required.

Card 1 - FORMAT(20A4)

DATNAM
80

DATNAM = 80 columns of characters for describing this data set.

Card 2 - FORMAT(16I5)

NNEL	NNNP	NNPR	NNDP	NDNP	NDPR	NDDP	NSPR
5	10	15	20	25	30	35	40

NSDP	NHUPR	NHUDP	NHLPR	NHLDP	NWNP	NWPR	NWDP
45	50	55	60	65	70	75	80

APPENDIX A (continued)

NNEL = No. of Neumann element-sides.

NNNP = No. of Neumann boundary node points.

NNPR = No. of Neumann flux profiles.

NNDP = No. of data points in each of the NNPR profiles.

NDNP = No. of Dirichlet node points, should be .GE. 1.

NDPR = No. of Dirichlet head profiles, should be .GE. 1.

NDDP = No. of data points in each of the NDPR profiles, should be .GE. 2.

NSPR = No. of source/sink profiles, should be .GE. 1.

NSDP = No. of data points in each of the NSPR profiles, should be .GE. 2.

NHUPR = No. of head profiles in upper leaking aquifers, should be .GE. 1.

NHUDP = No. of data points in each of the NHUPR profiles, should be .GE. 2.

NHLPR = No. of head profiles in lower leaking aquifers, should be .GE. 1.

NHLDP = No. of data points in each of the NHLPR profiles, should be .GE. 2.

NWNP = No. of well source/sink nodes.

NWPR = No. of well source/sink profiles.

NWDP = No. of data points in each well source/sink profile.

12. SOURCES/SINKS

(a) Data Set Description: FORMAT(20A4) - One card per problem.

DATNAM
80

APPENDIX A (continued)

(b) Element-wide Source/Sink Profiles: Format(8D10.3)
Number of cards depends on NSPR and NSDP. This subdata set is read in NSPR-wisely. Each card contains four data points.

First profile

TSOS(1,1)	SOS(1,1)	TSOS(1,2)	SOS(1,2)	---
10	20	30	40	80

•

•

---	TSCS(1,NSDP)	SCS(1,NSDP)
		80

Second profile

TSOS(2,1)	SOS(2,1)	TSOS(2,2)	SOS(2,2)	---
10	20	30	40	80

•

•

---	TSOS(2,NSDP)	SCS(2,NSDP)
		80

•

•

•

I-th profile

TSOS(I,1)	SOS(I,1)	TSOS(I,2)	SOS(I,2)	---
10	20	30	40	80

APPENDIX A (continued)

•

•

---	TSCS(I,NSDP)	SCS(I,NSDP)
		80

•

•

•

NSPR-th profile

TSOS(NSPR,1)	SOS(NSPR,1)	TSOS(NSPR,2)	SOS(NSPR,2)	---
10	20	30	40	80

•

•

---	TSOS(NSPR,NSDP)	SCS(NSPR,NSDP)
		80

TSOS(I,J) = Time of J-th data point in I-th profile (T).

SOS(I,J) = Source/sink value of J-th data point in I-th profile (L**3/T/L**2)

(c) Source Type in Each Element: FORMAT(5I5) - Usually one card element. However, automatic generation can be made.

M	NSFC	MAD	MTYP	MTYPAD	
5	10	15	20	25	80

M = Global element number of the first element in the sequence.

APPENDIX A (continued)

NSEQ = NSEQ elements will contain the source type to be generated automatically.

MAD = Increment of element number for each of the NSEQ elements.

MTYP = Source type in element M.

MTYPAD = Increment of MTYP for each of the NSEQ subsequent elements.

**** NOTE: A blank card must be used to signal the end of this data set.

(d) Well Source/Sink Profile: FORMAT(8D10.3). Number of cards depends on NWPR and NWDP. This subdata set is read in similarly to Data Set 12 (b).

First profile

TWSSF(1,1)	WSSF(1,1)	TWSSF(1,2)	WSSF(1,2)	---
10	20	30	40	80

•

•

---	TWSSF(1,NWDP)	WSSF(1,NWDP)
		80

Second profile

TWSSF(2,1)	WSSF(2,1)	TWSSF(2,2)	WSSF(2,2)	---
10	20	30	40	80

•

•

APPENDIX A (continued)

---	TWSSF(2,NWDP)	WSSF(2,NWDP)	
			80

•

•

•

I-th profile

TWSSF(I,1)	WSSF(I,1)	TWSSF(I,2)	WSSF(I,2)	---
10	20	30	40	80

•

•

---	TWSSF(I,NWDP)	WSSF(I,NWDP)	
			80

•

•

•

NWPR-th Profile

TWSSF(NWPR,1)	TWSSF(NWPR,1)	TWSSF(NWPR,2)	WSSF(NWPR,2)	---
10	20	30	40	80

•

•

---	TWSSF(NWPR,NWDP)	WSSF(NWPR,NWDP)	
			80

APPENDIX A (continued)

TWSSF(I,J) = Time of J-th data point in I-th well source/sink profile (T).

WSSF(I,J) = Source/sink value of J-th data point in I-th well source/sink profile (L**3/T).

(e) Global Nodal Number of Compressed Well Source/Sink Nodes. The number of cards required in this subdata set depends on NWNP. Each card contains 16 nodes with FORMAT(16I5).

NPW(1)	NPW(2)	NPW(3)	---	NPW(I)	---	NPW(NWNP)
5	10	15				80

NPW(I) = Global node number of I-th well source/sink node.

(f) Type of Well Source/Sink Nodes: FORMAT(5I5)
Normally one card per well node, i.e., a total of NWNP cards. However, if the well nodes appear in regular pattern, automatic generation may be made.

NI	NSEQ	NIAD	NITYP	NITYPA	
5	10	15	20	25	80

NI = Compressed well node number of the first node in a sequence.

NSEQ = NSEQ subsequent well nodes will be generated automatically.

NIAD = Increment of compressed well node number for each of the NSEQ nodes.

NITYP = Type of well source/sink profile assigned to node NI.

NITYPA = Increment of NITYP for each of the NSEQ subsequent nodes.

**** NOTE: A blank card must be used to signal the end of this subdata set.

APPENDIX A (continued)

13. DIRICHLET BOUNDARY CONDITIONS: This data set is required if NDNP > 0.

(a) Data Description: FORMAT(20A4) - One card per problem.

DATNAM
80

DATNAM = 80 columns of characters for describing the nature of this data set.

(b) Dirichlet-head Profiles: FORMAT(8D10.3) - This subdata set is read in similarly to that in subdata set 12 (b).

First profile

THED(1,1)	HED(1,1)	THED(1,2)	HED(1,2)	---
10	20	30	40	80

•

•

---	THED(1,NDDP)	HED(1,NDDP)
		80

APPENDIX A (continued)

Second profile

THED(2,1)	HED(2,1)	THED(2,2)	HED(2,2)	---
10	20	30	40	80

•

•

---	THED(2,NDDP)	HED(2,NDDP)
		80

•

•

•

I-th profile

THED(I,1)	HED(I,1)	THED(I,2)	HED(I,2)	---
10	20	30	40	80

•

•

---	THED(I,NDDP)	HED(I,NDDP)
		80

•

•

•

APPENDIX A (continued)

NDPR-th profile

THED(NDPR,1)	HED(NDPR,1)	THED(NDPR,2)	HED(NDPR,2)	
10	20	30	40	80

•

•

---	THED(NDPR,NDDP)	HED(NDPR,NDDP)	
			80

THED(I,J) = Time of J-th data point in I-th Dirichlet-head profile (T).

HED(I,J) = Head value of J-th data point in I-th Dirichlet-head profile (L).

(c) Dirichlet Nodes: FORMAT(16I5) - The number of cards in this subdata set depends on NDNP. Each card contains 16 nodes.

NPD(1)	NPD(2)	NPD(3)	--- NPD(I) ---	NPD(NDNP)
5	10	15		80

NPD(I) = Global node number of I-th Dirichlet node.

(d) Type of Dirichlet Node: FORMAT(5I5) - Normally one card per Dirichlet node, i.e., a total of NDNP cards. However, if the Dirichlet nodes appear in a regular pattern, automatic generation may be made.

NI	NSEQ	NIAD	NITYP	NITYPA	
5	10	15	20	25	80

NI = Compressed Dirichlet node number of the first node in the sequence.

APPENDIX A (continued)

NSEQ = NSEQ subsequent Dirichlet nodes will be generated automatically.

NIAD = Increment of compressed Dirichlet node number for each of the NSEQ nodes.

NITYP = Type of Dirichlet-head profile for node NI.

NITYPA = Increment of NITYP for each of the NSEQ subsequent nodes.

**** NOTE: A blank card must be used to signal the end of this subdata set.

14. NEUMANN BOUNDARY CONDITIONS: This data set is required if and only if NNNP > 0.

(a) Data Description: FORMAT(20A4) - One card per problem.

DATNAM
80

DATNAM = 80 columns of characters for describing the nature and purpose of this data set.

(b) Prescribed Neumann Flux Profiles: FORMAT(8D10.3) - This subdata set is read in similar to that in subdata set 12 (b).

First profile

TRNF(1,1)	RNF(1,1)	TRNF(1,2)	RNF(1,2)	---
10	20	30	40	80

•

•

---	TRNF(1,NNDP)	RNF(1,NNDP)
		80

APPENDIX A (continued)

Second profile

TRNF(2,1)	RNF(2,1)	TRNF(2,2)	RNF(2,2)	---
10	20	30	40	80

•

•

---	TRNF(2,NNDP)	RNF(2,NNDP)	
			80

•

•

•

I-th profile

TRNF(I,1)	RNF(I,1)	TRNF(I,2)	RNF(I,2)	---
10	20	30	40	80

•

•

---	TRNF(I,NNDP)	RNF(I,NNDP)	
			80

•

•

•

APPENDIX A (continued)

NNPR-th profile

TRNF(NNPR,1)	RNF(NNPR,1)	TRNF(NNPR,2)	RNF(NNPR,2)	---
10	20	30	40	80

•

•

---	TRNF(NNPR,NNDP)	RNF(NNPR,NNDP)	
			80

TRNF(I,J) = Time of J-th data point in I-th Neumann flux profile (T).

RNF(I,J) = Value of Neumann flux of J-th data point in I-th Neumann flux profile (L**3/T/L).

(c) Neumann Nodes: FORMAT(16I5) - The number of cards required in this subdata set depends on NNNP. Each card contains 16 nodes.

NPN(1)	NPN(2)	NPN(3)	---	NPN(I)	---	NPN(NNNP)	---
5	10	15					80

NPN(I) = global nodal point number of I-th Neumann node.

(d) Type of Neumann Node: FORMAT(5I5)

NI	NSEQ	NIAD	NITYP	NTYPAD	
5	10	15	20	25	80

NI = Compressed Neumann node number of the first node in the sequence.

NSEQ = The type of NSEQ subsequent Neumann flux profiles will be generated automatically.

NIAD = Increment of compressed Neumann node number in each of the NSEQ nodes.

APPENDIX A (continued)

NITYP = Type of Neumann flux profile for node NI.

NTYPAD = Increment of NITYP for each of the NSEQ subsequent nodes.

**** NOTE: A blank card must be used to signal the end of this subdata set.

(e) Neumann Boundary Element-sides: FORMAT(16I5)

MI	NSEQ	IS1	IS2	IS1AD	IS2AD	
5	10	15	20	25	30	80

MI = Compressed element-side number of the first element-side in the sequence.

NSEQ = NSEQ subsequent element-sides will be generated automatically.

IS1 = Compressed Neumann node number of the first node in the element-side MI.

IS2 = Compressed Neumann node number of the second node in the element-side MI.

IS1AD = Increment of the first compressed Neumann node number of element-side MI.

IS2AD = Increment of the second compressed Neumann node number of element-side MI.

**** NOTE: A blank card must be used to signal the end of this subdata set.

15. UPPER LEAKING AQUIFERS

(a) Data Description: FORMAT(20A4)

DATNAM
80

DATNAM = 80 columns of characters for describing the name and purpose of this data set.

APPENDIX A (continued)

(b) Head Profiles in the Upper Leaking Aquifers: FORMAT(8D10.3)
This subdata set is read in similar to that in subdata set 12 (b). The number of cards depends on NHUPR and NHUDP. The data are read in NHUPR-wisely.

First profile

THUTAB(1,1)	HUTAB(1,1)	THUTAB(1,2)	---
10	20	30	80

•

•

---	THUTAB(1,NHUDP)	HUTAB(1,NHUDP)	
			80

Second profile

THUTAB(2,1)	HUTAB(2,1)	THUTAB(2,2)	---
10	20	30	80

•

•

---	THUTAB(2,NHUDP)	HUTAB(2,NHUDP)	
			80

•

•

•

I-th profile

THUTAB(I,1)	HUTAB(I,1)	THUTAB(I,2)	---
10	20	30	80

APPENDIX A (continued)

•

•

---	THUTAB(I,NHUDP)	HUTAB(I,NHUDP)

80

•

•

•

NHUPR-th profile

THUTAB(NHUPR,1)	HUTAB(NHUPR,1)	THUTAB(NHUPR,2)	---
10	20	30	80

•

•

---	THUTAB(NHUPR,NHUDP)	HUTAB(NHUPR,NHPDP)

80

THUTAB(I,J) = Time of J-th data point in I-th upper-aquifer head vs time profile (T).

HUTAB(I,J) = Head in the upper leaking aquifer of J-th data point in I-th profile (L).

(c) Leaking Coefficient in the Upper Aquifer: FORMAT(8D10.3) The number of cards depends on NHUPR. Each card contains 8 points of the NHUPR values.

RKU(1)	RKU(2)	---	RKU(I)	---	RKU(NHUPR)
10	20				80

RKU(I) = Leaking coefficient of I-th upper leaking aquifer type (1/T).

APPENDIX A (continued)

(d) Type of Upper Leaking Aquifers: FORMAT(5I5)

M	NSEQ	MAD	MTYP	MTYPAD	
5	10	15	20	25	80

M = Global element number of the first element in the sequence that will have the upper leaking aquifer type automatically generated.

NSEQ = NSEQ subsequent elements will have their overlying leaky aquifer type generated automatically.

MAD = Increment of element number for each of the NSEQ elements.

MTYP = Upper leaking aquifer type for element M.

MTYPAD = Increment of MTYP for each of the NSEQ subsequent elements.

**** NOTE: A blank must be used to signal the end of this subdata set.

16. LOWER LEAKING AQUIFERS: This data set is read in identical to that in Data Set 15.

(a) Data Description: FORMAT(20A4)

DATNAM
80

DATNAM = 80 columns of characters for describing the data set.

(b) Head Profiles in the Lower Leaking Aquifers: FORMAT(8D10.3)

First profile

THLTAB(1,1)	HLTAB(1,1)	THLTAB(1,2)	---
10	20	30	80

APPENDIX A (continued)

•

•

```
----    THLTAB(1,NHLDP)      HLTAB(1,NHLDP)
                                                        80
```

Second profile

```
THLTAB(2,1)     HLTAB(2,1)     THLTAB(2,2)          ---
          10            20             30            80
```

•

•

```
----    THLTAB(2,NHLDP)      HLTAB(2,NHDP)
                                                        80
```

•

•

•

I-th profile

```
THLTAB(I,1)     HLTAB(I,1)     THLTAB(I,2)          ---
          10            20             30            80
```

•

•

```
--      THLTAB(I,NHLDP)      HLTAB(I,NHLDP)
                                                        80
```

APPENDIX A (continued)

•

•

•

NHLPR-th profile

THLTAB(NHLPR,1)	HLTAB(NHLPR,1)	THLTAB(NHLPR,2)	---
10	20	30	80

•

•

----	THLTAB(NHLPR,NHLDP)	HLTAB(NHLPR,NHLDP)
		80

THLTAB(I,J) = Time of J-th data point in I-th lower-aquifer head vs time profile (T).

HLTAB(I,J) = Head in the lower leaking aquifer of J-th data point in I-th profile.

(c) Leaking Coefficients in the Lower Aquifers: FORMAT(8D10.3)

RKL(1)	RKL(2)	-----	RKL(I)	----	RKL(NHLPR)
10	20				80

RKL(I) = Leaking coefficient of I-th profile (1/T).

(d) Type of Lower Leaking Aquifer: FORMAT(5I5)

M	NSEQ	MAD	MTYP	MTYPAD	
5	10	15	20	25	80

APPENDIX A (continued)

M = Global element number of the first element in the sequence that will have the lower leaking aquifer type generated automatically.

NSEQ = NSEQ subsequent elements will have their underlying leaky aquifer type generated automatically.

MAD = Increment of elements for each of the NSEQ subsequent elements.

MTYP = Lower leaking aquifer type for element M.

MTYPAD = Increment of MTYP for each of the NSEQ subsequent elements.

**** NOTE: A blank card must be used to signal the end of this subdata set.

17. END OF JOB

If another problem is to be run, then input begins again with input data set 1. If termination of the job is desired, a blank card must be inserted at the end of the data set.

APPENDIX B

COMPUTER CODE USED TO PREDICT RECHARGE TO THE ETF UNCONFINED AQUIFER

APPENDIX B
COMPUTER CODE USED TO PREDICT RECHARGE TO THE ETF UNCONFINED AQUIFER

```
C   PROGRAM TO COMPUTE THE INFILTRATION AT THE ETF SITE USING VARIOUS
C   METHODS.  THE METHODS USED ARE THE FOLLOWING:
C
C              1  -  The Green and Ampt (GA) Proceedure
C                      f = K * ( 1 + n * SIF / F )
C                    Where
C                      f - Infiltration (cm/h)
C                      K - Hydraulic conductivity = K(sat)/2 (cm/h)
C                      n - Effective porosity
C                    SIF - GA capillary pressure head (cm)
C                      F - Infiltration amount  (cm)
C
C
      COMMON IHR,GMASS,FOLD,FC,F
      CHARACTER*22 INFILE,OUTFIL,FFEED*1
      DOUBLE PRECISION T1(4),T2(4)
      REAL*4 P(100),GAF(100),GTIME(100),OLDT,HR,GMASS(100)
      INTEGER*4 IP(12)
      LOGICAL FLAG
C
      DATA FLAG /.TRUE./, OLDT/0./
C
C  READING IN THE CONSTANTS AND EQUATION PARAMETERS
C
      FFEED = CHAR(12)
      WRITE(5,1000)
      READ(5,*) EFFP,SATK,PSIF,ASW
      WRITE(5,1005)
      READ (5,*) AVGD
C
      WRITE(5,1020)
  100 READ(5,1030) INFILE
      OPEN(3,FORM='FORMATTED',ACCESS='SEQUENTIAL',STATUS='OLD',
     1       FILE=INFILE,ERR=100,DEVICE='DSK')
      IF (IERR.NE.0) GOTO 100
  110 WRITE(5,1040)
      READ(5,1030) OUTFIL
      OPEN(6,FORM='FORMATTED',ACCESS='SEQUENTIAL',STATUS='UNKNOWN',
     1      FILE=OUTFIL,ERR=110,DEVICE='DSK')
      WRITE(6,1120)
C
C   READ IN THE PRECIPITATION
C
      PSUM = 0
      READ(3,*) NHOURS
      RTI = FLOAT(NHOURS)/12.
```

APPENDIX B (continued)

```
      N = RTI
      IF (FLOAT(N).NE.RTI) N = INT(RTI)+1
      DO 115 IHR = 1,N
      I1 = 12*(IHR-1)+1
      I2 = 12*IHR
      IF (I2.GT.NHOURS) I2 = NHOURS
      READ(3,1050) (IP(KK),KK=1,12)
      II = 1
      DO 115 KK = I1,I2
      P(KK) = FLOAT(IP(II))/1000.
      II = II+1
      PSUM = PSUM+P(KK)
  115 CONTINUE
C
C   BEGIN THE ACTUAL COMPUTATIONS FOR INPUT RAINFALL DATA
C
      IS = 1
      T1(1) = 0.
      T2(1) = 0.
      FC = 0.
      HR = 1.
      FOLD = 0.
      GAK = SATK/2.
      AVAILP = EFFP-ASW
      PSIFN = PSIF*AVAILP
      FMAX = AVAILP*AVGD*100.
      DO 150 IHR = 1,NHOURS
C  CHECK TO SEE IF THE MASS HAS FILLED UP THE AVAILABLE SOIL VOIDS
C  IF SO THEN THE SOIL WONT LET MORE PRECIP INFILTRATE THAN CAN PERC.
      IF (FOLD.LT.FMAX) GOTU 116
      F = GAK
      IF (P(IHR).LT.GAK) F = P(IHR)
      FC = FOLD+F
      GO TO 140
C  LOW RAINFALL PERIODS
  116 IF (P(IHR).GT.0.050) GOTO 117
      GAF(IHR) = P(IHR)
      FOLD = FOLD/2.
      HR = HR-1.5
      IF (FLAG) HR = 0.
      OLDT = HR
      IF (HR.LT.0.) THEN
          HR = 0.
          OLDT = 0.
          FOLD = 0.
      ENDIF
      GTIME(IHR) = HR
      IF (IHR.EQ.1) THEN
          GMASS(1) = P(1)
      ELSE
          GMASS(IHR) = GMASS(IHR-1) + P(IHR)
```

APPENDIX B (continued)

```
      ENDIF
      IS = IS+1
      T1(IS) = IHR*3600.+14400.
      T2(IS) = GAF(IHR)/3.6E5
      IF (IS.EQ.4) THEN
         WRITE(6,1130) (T1(K),T2(K),K=1,4)
         IS = 0
      ENDIF
      TYPE 999,IHR,HR,GMASS(IHR)
      IF (HR.LT.0.2) FOLD = 0.
      IF (HR.GT.0.) FOLD = TMASS(PSIFN,HR,GAK,FOLD)
      HR = HR+1.
      GOTO 150
C
C  GET THE INFILTRATION AND SUMMATION OF MASS FOR
   SIGNIFICANT (>.05MM) PRECIP
C
  117 FC = TMASS(PSIFN,HR,GAK,FOLD)
      FLAG = .FALSE.
C   NOW GET THE INFILTRATION RATE FOR THE END OF TIME INTERVAL
      F = FC - FOLD
      IF (F.LE.P(IHR)) GOTO 140
C   IF THE PRECIP IS LESS THAN THE INFILTRATION THEN GO INTO THE TIME
C   COMPRESSION ROUTINE AND GET NEW TIME = TOTAL ACTUAL MASS
      FC = FOLD
      F = P(IHR)
C   5 MIN = 0.083333 HOURS AND 1 MIN = 0.0166667 HOURS
      TINC = 0.08333333
      IF (OLDT.LT.3.) TINC = 0.01666667
      IF (OLDT.LT.0.5) TINC = 0.00833333
      IF (OLDT.LT.0.1) TINC = 0.00027778
      DO 120 TIME = OLDT+TINC,HR,TINC
      FC = TMASS(PSIFN,TIME,GAK,FC)
      IF (FC-FOLD.GE.P(IHR)) GOTO 130
  120 CONTINUE
  130 HR = TIME
C   EXITING THE TIME COMPRESSION MODE
  140 CONTINUE
      GTIME(IHR) = HR
      GAF(IHR) = F
      IF (IHR.EQ.1) THEN
         GMASS(1) = FC
      ELSE
         GMASS(IHR) = GMASS(IHR-1) + F
      ENDIF
C
C  STORING AND CONVERTING TIME AND INFILTRATION FOR USE IN FEWA
C
      IS = IS+1
      T1(IS) = IHR*3600.+14400.
      T2(IS) = F/3.6E5
```

APPENDIX B (continued)

```
      IF (IS.EQ.4) THEN
          WRITE(6,1130) (T1(K),T2(K),K=1,4)
          IS = 0
      ENDIF
      TYPE 999,IHR,HR,GMASS(IHR)
  999 FORMAT(' INTEGER HOUR =',I3,'     COMPUTATIONAL HOUR =',F5.2,
     1      '      TOTAL MASS =',F8.3)
C       ASW = ASW+(FC-FOLD)/200.
      OLDT = HR
      FOLD = FC
      HR = HR+1.
  150 CONTINUE
C
C  END OF THE GREEN and AMPT PROCEEDURE
C
      IF (IS.EQ.0) GOTO 160
      WRITE(6,1130) (T1(K),T2(K),K=1,IS)
  160 SUM = 0
      WRITE(21,1060) EFFP,SATK,PSIF,ASW
      WRITE(21,1070) PSUM
      WRITE(21,1080)
      DO 200 IHR = 1,NHOURS
      EXCESS = P(IHR) - GAF(IHR)
      WRITE(21,1090) IHR,P(IHR),GAF(IHR),EXCESS,GMASS(IHR),GTIME(IHR)
  200 CONTINUE
      WRITE(21,1110) FFEED
      CLOSE (3)
      CLOSE (6)
      CLOSE (21)
      STOP
 1000 FORMAT(5(/),' [ INTRATE   Ver 1.0 ]',///
     115X,'INPUT PARAMETERS FOR THE GREEN AND AMPT PROCEEDURE.',//,
     15X,'PLEASE ENTER THE EFFECTIVE POROSITY [ n dimensionless ], ',/,
     25X,'THE SATURATED HYDRAULIC CONDUCTIVITY [ K  cm/hr ],',/,
     35X,'GREEN-AMPT CAPILLARY PRESSURE HEAD [ PSIF  cm ], and',/,
     45X,'ANTECEDENT SOIL WATER [ ASW  vol/vol ].',/,
     4' e.g.   0.36,145E-5,999,0.05: ',$)
 1005 FORMAT(//,'ENTER THE AVERAGE DEPTH TO
     THE WATER TABLE ( meters ): 1',$)
 1010 FORMAT(///,15X,'INPUT PARAMETERS FOR HORTON''S METHOD',//,
     15X,'PLEASE ENTER THE INITIAL INFILTRATION CAPACITY [ f0  cm/hr ]'
     2/,5X,'THE STEADY-STATE INFILTRATION CAPACITY [ fc  cm/hr ],',/,
     3' e.g.  3.5,.25: ',$)
 1020 FORMAT(//,'ENTER THE FILE SPECIFICATIONS FOR THE RAINFALL: ',$)
 1030 FORMAT(A22)
 1040 FORMAT(/,'ENTER THE OUTPUT FILE SPECIFICATIONS: ',$)
 1050 FORMAT(20X,12I5)
```

APPENDIX B (continued)

```
 1060 FORMAT(5(/),35X,'INFILTRATION PROGRAM',/,30X,'USING GREEN'
     1,' and AMPT''S PROCEEDURE'///,27X,'INPUT DATA AND OTHER USEFUL'
     2,' INFORMATION',//,8X,
     3'EFFECTIVE POROSITY = ',F5.3,T45,'SATURATED HYDRAULIC COND = '
     4,E8.2,/,8X,
     5'WETTING FRONT PRES. HEAD = ',F6.1,T45,'ANTECEDENT MOISTURE = '
     6,F5.3,//)
 1070 FORMAT(30X,'TOTAL PRECIPITATION = ',F10.2,' (cm)'/)
 1080 FORMAT(///,8X,
     *'                                                      TOTAL   COMPRE
     *SSED',/,8X,
     1' TIME   PRECIPITATION  INFILTRATION    EXCESS       MASS    TIM
     1E',/,8X,
     2'(hours)    ( cm )        ( cm/hr )   ( cm/hr )     ( cm )   (hou)
     2rs)',/,8X,
     3'------- ------------- ------------- ---------   ----------  ----
     3---',/)
 1090 FORMAT(8X,I4,2F14.3,4X,F8.3,4X,F8.3,F10.2)
 1100 FORMAT(///,6X,'TOTAL MASS = ',8F8.2,11(/,19X,8F8.2))
 1110 FORMAT(A1)
 1120 FORMAT('DATA SET 1?:   SOURCE/SINK DATA SET, INFILTRATION')
 1130 FORMAT(21D10.3)
      END
C
C  FUNCTION TO GET MASS BALANCE ON THE INFILTRATION CURVE
C
      FUNCTION TMASS(PSIFN,HR,K,FS)
      COMMON IHR,GMASS,FOLD,FC,F
      REAL*4 K,LHS,GMASS(100)
      LOGICAL FLAG,FLAGC,FLAG1
      FLAG = .TRUE.
      FLAGO = .TRUE.
      FLAG1 = .FALSE.
      RHS = K*HR
      TINC = .05
      PALL = 0.025
      TMASS = FS-.05
C     WRITE(21,998) IHR,FOLD,FC,F
  998 FORMAT(//,' REAL TIME = ',I4,4X,'OLD MASS =',F10.4,
     14X,'CURR MASS =',F10.4,5X,'INFLT =',F7.4)
C
C  BEGINNING THE BALANCE LOOP
C
  100 TMASS = TMASS+TINC
      LHS = TMASS-PSIFN*LOG(1.+TMASS/PSIFN)
      IF (LHS.LT.RHS.AND.FLAG) GOTO 150
      IF (FLAGO) THEN
```

APPENDIX B (continued)

```
          TMASS = TMASS-TINC
          FLAG = .FALSE.
          FLAGO = .FALSE.
          TINC = .001
      ENDIF
      IF (FLAG1) THEN
          TMASS = TMASS - 2.*TINC
          TINC = 0.0001
          PALL = 0.05
          FLAG1 = .FALSE.
      ENDIF
      PDIF = ABS((RHS-LHS)/RHS)
C      IF(IHR.EQ.17) type 888,tmass,lhs,rhs,pdif
  888 FORMAT(1X,'TMASS = ',F8.5,'   LHS = ',E12.5,'   RHS = ',E12.5,
     1          '   PDIF = ',F6.4)
C *** PALL IS THE PERCENT DIFFERENCE ALLOWED.
      IF (PDIF.LE.PALL) GOTO 200
      IF (LHS.GT.RHS) FLAG1 = .TRUE.
  150 IF (TMASS.LT.50.) GOTO 100
  200 CONTINUE
C     WRITE(21,999) PSIFN,K,FS,HR,LHS,RHS,TMASS
  999 FORMAT(' PSIFN = ',F10.4,5X,'GandA K = ',F10.4,5X,'START MASS = ',
     1F10.5,/,' COMP TIME =',F7.4,4X,'LHS and RHS =',2F12.6,
     24X,'FINAL MASS =',F10.4)
      RETURN
      END
```

APPENDIX C

EXAMPLES OF FEWA INPUT DATA

ONE DIMENSIONAL STEADY-STATE DATA SET

```
   1 EIF NORTH SOUTH CROSS-SECTION STEADY STATE UNCONFINED AQUIFER
DATA SET 2: INTEGER PARAMETERS
  82   40    4   21    0    0    1    0    0   40    0    0    0    1    0   40    0
DATA SET 3: BASIC REAL PARAMETERS
     60.0        0.1       600.0 9999999.0    0.0001  0.000001     1000.0       9.8
   1.30-3        1.0        1.0        1.0
DATA SET 4: PRINTER, DISK STORE AND TIME RESETTING CONTROL
33
11
   1.0D20
DATA SET 5: MATERIAL PROPERTIES
      0.0        0.0    0.03D0    6.3D-7       0.0        0.0     0.25D0
      0.0        0.0    0.03D0    1.5D-6       0.0        0.0     0.25D0
      0.0        0.0    0.03D0    2.7D-7       0.0        0.0     0.25D0
      0.0        0.0    0.03D0    1.5D-6       0.0        0.0     0.25D0
DATA SET 6: BOTTOM ELEVATION
   1   81    1          200.0        0.0

   1   81    1           1.00

DATA SET 7: COORDINATE
   1   40    2            0.0       3.05    0.0000
   2   40    2            0.0       3.05    0.0000

   1   40    2            0.0        0.0       0.0
   2   40    2           3.05        0.0       0.0

DATA SET 8:ELEMENT INCIDENCES
   1    1    3    4    2   -1    1   40

DATA SET 9: MATERIAL TYPE CORRECTION
   1   10    1   -4
  12    3    1   -3
  16    5    1   -2

DATA SET 10: INITIAL CONDITIONS
   1   40    2          242.0     0.1875
   2   40    2          242.0    -0.1875

DATA SET 11: INTEGER PARAMETERS
   0    0    1    2    4    2    2    2    2    1    2    2    2    0
   1    2
DATA SET 12: SOURCES/SINKS
      0.0        0.0    1.0D50       0.0
      0.0     0.0D-8    1.0D50    0.0D 8
   1   15    1    1
  17    7    1    2
  25   15    1    1
```

APPENDIX C (continued)

```
DATA SET 13: DIRICHLET BOUNDARY CONDITIONS
       0.0      242.0     1.0D50      242.0
       0.0      234.5     1.0D50      234.5
   1    2   81   82
   1    1    1    1
   3    1    1    2

DATA SET 15: UPPER LEAKING AQUITARD [illegible]
       0.0      [illegible]     [illegible]      [illegible]
       0.0
   1   39    [illegible]

DATA SET 16: LOWER LEAKING AQUITARD INFORMATION
       0.0      230.0     1.0D50      230.0
       0.0      236.0     1.0D50      23[illegible]
       0.0        0.0
   1   14    1    1
  16    1    1    2
  18   22    1    1


/*
//
```

APPENDIX C (continued)

ONE-DIMENSIONAL TRANSIENT DATA SET

```
    2 ETF NORTH/SOUTH CROSS-SECTION *TRANSIENT CASE* UNCONFINED
DATA SET 2: INTEGER PARAMETERS
   82 40    4   21  384    1    1    0    0   40    0    0    0    1    0
    1
DATA SET 3: BASIC REAL PARAMETERS
     900.0      0.0      900.0 9999999.0    0.0001  0.000001     1000.0     9.8
    1.3D-3      1.0       1.0       1.4
DATA SET 4: PRINTER, DISK STORE AND TIME RESETTING CONTROL
33   2   2   2   2   2   2   2   2  2    2   2   2   2   2   2   2   2   2   2
   2   2   2   2   2   2       2      2        2       2       2       2
2       2      2          2       2      2             2              2
2              2                  2                     2             2
                          2                                    23




    1.0D20
DATA SET 5: MATERIAL PROPERTIES
       0.0      0.0    0.03D0    6.3D-7       0.0       0.0    0.03D0
       0.0      0.0    0.03D0    1.5D-6       0.0       0.0    0.03D0
       0.0      0.0    0.03D0    2.2D-7       0.0       0.0    0.03D0
       0.0      0.0    0.03D0    1.5D-6       0.0       0.0    0.03D0
DATA SET 6: BOTTOM ELEVATION AND AQUIFER THICKNESS
    1 81    1          220.0       0.0

    1 81    1           1.00       0.0

DATA SET 7: COORDINATE
    1 40    2            0.0      3.05    0.0000
    2 40    2            0.0      3.05    0.0000

    1 40    2            0.0       0.0       0.0
    2 40    2           3.05       0.0       0.0

DATA SET 8:ELEMENT INCIDENCES
    1  1    3    4    2   -1    1   40

DATA SET 9: MATERIAL TYPE CORRECTION
    1 10    1   -4
   12  3    1   -3
   16  5    1   -2

DATA SET 10: INITIAL CONDITIONS
    1 14    2          242.10   -0.19267
    2 14    2          242.10   -0.19267
```

APPENDIX C (continued)

```
31  3    2         239.21  -0.03750
32  3    2         239.21  -0.03750
39  1    2         239.06  -0.21000
40  1    2         239.06  -0.21000
43  1    2         238.64  -0.16500
44  1    2         238.64  -0.16500
47                 238.31
48                 238.31
49 16    2         238.21  -0.22125
50 16    2         238.21  -0.22125

DATA SET 11: INTEGER PARAMETERS
   0    0    1    2    4    2   47    2   27    1    2    1    2    0    1    2
DATA SET 12:   SOURCE/SINK DATA SET, INFILTRATION
 0.000D+00 0.000D+00 0.180D+05 0.106D-06 0.216D+05 0.499D-06 0.252D+05 0.275D-06
 0.288D+05 0.215D-06 0.324D+05 0.111D-07 0.360D+05 0.111D-07 0.396D+05 0.111D-07
 0.432D+05 0.111D-07 0.468D+05 0.111D-07 0.504D+05 0.111D-07 0.540D+05 0.111D-07
 0.576D+05 0.111D-07 0.612D+05 0.111D-07 0.648D+05 0.111D-07 0.684D+05 0.111D-07
 0.720D+05 0.111D-07 0.756D+05 0.194D-06 0.792D+05 0.359D-06 0.828D+05 0.275D-06
 0.864D+05 0.201D-06 0.900D+05 0.205D-06 0.936D+05 0.194D-06 0.972D+05 0.161D-06
 0.101D+06 0.000D+00  1.000D+06       0.0  1.000D+30       0.0
 0.000D+00 0.000D+00 0.180D+05 0.106D-06 0.216D+05 0.694D-06 0.252D+05 0.553D-06
 0.288D+05 0.327D-06 0.324D+05 0.111D-07 0.360D+05 0.111D-07 0.396D+05 0.111D-07
 0.432D+05 0.111D-07 0.468D+05 0.111D-07 0.504D+05 0.111D-07 0.540D+05 0.111D-07
 0.576D+05 0.111D-07 0.612D+05 0.111D-07 0.648D+05 0.111D-07 0.684D+05 0.111D-07
 0.720D+05 0.111D-07 0.756D+05 0.194D-06 0.792D+05 0.567D-06 0.828D+05 0.425D-06
 0.864D+05 0.278D-06 0.900D+05 0.414D-06 0.936D+05 0.301D-06 0.972D+05 0.161D-06
 0.101D+06 0.000D+00  1.000D+06       0.0  1.000D+30       0.0
    1   16    1    1
   18    5    1    2
   24   16    1    1

DATA SET 13: DIRICHLET BOUNDARY CONDITIONS
 0.000D+00     242.10 0.720D+04               242.10 0.108D+05     242.10 0.1 44D+05     242.10
 0.180D+05     242.11 0.216D+05               242.11 0.252D+05     242.11 0.2 88D+05     242.11
 0.324D+05     242.11 0.360D+05               242.11 0.396D+05     242.11 0.4 32D+05     242.11
 0.468D+05     242.12 0.504D+05               242.12 0.540D+05     242.12 0.5 76D+05     242.12
 0.612D+05     242.12 0.648D+05               242.12 0.684D+05     242.12 0.7 20D+05     242.12
 0.756D+05     242.13 0.792D+05               242.13 0.828D+05     242.13 0.8 64D+05     242.13
 0.900D+05     242.13 0.936D+05               242.13 0.972D+05     242.13 0.1 01D+06     242.14
 0.104D+06     242.14 0.108D+06               242.14 0.112D+06     242.14 0.1 15D+06     242.14
 0.119D+06     242.14 0.122D+06               242.14 0.126D+06     242.14 0.1 30D+06     242.15
 0.133D+06     242.15 0.137D+06               242.15 0.140D+06     242.15 0.1 44D+06     242.15
 0.148D+06     242.15 0.151D+06               242.15 0.155D+06     242.15 0.1 58D+06     242.16
 0.162D+06     242.16 0.166D+06               242.16 3.492D+05     242.16
 0.000D+00     234.67 0.360D+04               234.67 0.720D+04     234.67 0.1 08D+05     234.67
 0.144D+05     234.67 0.180D+05               234.71 0.216D+05     234.80 0.2 52D+05     234.92
 0.288D+05     234.89 0.324D+05               234.87 0.360D+05     234.83 0.3 96D+05     234.80
 0.432D+05     234.79 0.468D+05               234.78 0.504D+05     234.77 0.5 40D+05     234.76
 0.576D+05     234.75 0.612D+05               234.75 0.648D+05     234.74 0.6 84D+05     234.74
 0.720D+05     235.01 0.756D+05               235.71 0.792D+05     235.67 0.8 28D+05     235.47
```

APPENDIX C (continued)

```
0.864D+05     235.40 0.900D+05          235.30 0.936D+05     235.23 0.9 72D+05     235.19
0.101D+06     235.15 0.104D+06          235.12 0.108D+06     235.10 0.1 12D+06     235.08
0.115D+06     235.07 0.119D+06          235.06 0.122D+06     235.05 0.1 26D+06     235.03
0.130D+06     235.02 0.133D+06          235.02 1.404D+05     235.01 1.5 12D+05     235.00
1.584D+05     234.99 1.692D5            234.98 1.872D5       234.97 2.124D5        234.96
2.520D5       234.95 3.204D5            234.95 3.492D5       234.94
    1    2   81   82
    1    1    1    1
    3    1    1    2

DATA SET 15: UPPER LEAKING AQUITARD INFORMATION
       0.0     245.0    1.0050     245.0
       0.0
    1   39    1    1

DATA SET 16: LOWER LEAKING AQUITARD INFORMATION
       0.0     230.0    1.0050     230.0
       0.0
    1   39    1    1

/*
//
```

APPENDIX C (continued)

TWO-DIMENSIONAL TRANSIENT DATA SET

```
   1 ETF SITE FOR TWO-DIMENSIONAL GROUNDWATER FLOW MODELLING
DATA SET 2:  BASIC INTEGER PARAMETERS
  169  158    3    0  192    0         1    0    0   30    1    1    0    0    1  150
   0
DATA SET  3:  BASIC REAL PARAMETERS
    1800.      0.      1800.  2.592D+5   0.00100    0.0010     1000.      9.8
  1.300-3     0.5      1.0       1.5
DATA SET  4:  PRINTER CONTROL
33 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2   2   2   2   2   2   2   2
  2   2   2   2   2   2   2   2   2   2       2       2       2       2       2
      2       2       2       23
11 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1   1   1   1   1    1   1   1
  1   1   1   1   1   1   1   1.  1   1       1       1       1        1       1
      1       1       1       11
  1.00+20
DATA SET  5:   MATERIAL PROPERTIES
      0.0      0.0       0.04   1.260-6    6.3D-7       0.0      0.040
      0.0      0.0       0.04   3.000-6    1.5D-6       0.0      0.040
      0.0      0.0       0.04   4.400-7    2.2D-7       0.0      0.040
DATA SET  6:   BOTTOM ELEVATION AND AQUIFER THICKNESS
    1  168    1        220.0       0.0
    1  168    1          1.0       0.0
```

DATA SET 7: NODAL POINT COORDINATES FOR ETF 2-DIM

1	7226.76	39	7184.87
2	7220.84	40	7193.18
3	7230.03	41	7202.07
4	7215.05	42	7210.56
5	7224.27	43	7218.68
6	7233.51	44	7225.66
7	7209.05	45	7232.78
8	7218.14	46	7240.99
9	7227.39	47	7249.17
10	7236.82	48	7181.07
11	7203.74	49	7189.45
12	7212.86	50	7198.13
13	7222.11	51	7205.74
14	7231.35	52	7214.47
15	7239.90	53	7223.56
16	7198.06	54	7231.84
17	7207.37	55	7239.98
18	7216.53	56	7248.19
19	7225.95	57	7177.34
20	7234.29	58	7185.75
21	7242.62	59	7194.55
22	7192.48	60	7203.70
23	7201.73	61	7212.29
24	7211.03	62	7221.99
25	7220.55	63	7230.60
26	7229.07	64	7238.89
27	7238.45	65	7247.19
28	7234.88	66	7238.14
29	7246.23	67	7246.18
30	7242.51	68	7173.61
31	7188.54	69	7181.89
32	7197.13	70	7191.53
33	7206.25	71	7198.88
34	7216.62	72	7203.44
35	7225.45	73	7204.81
36	7233.79	74	7208.74
37	7242.24	75	7207.85
38	7250.15		

APPENDIX C (continued)

76	7213.24	127	7230.03
77	7212.74	128	7157.41
78	7215.72	129	7165.04
79	7221.78	130	7172.79
80	7227.83	131	7181.00
81	7235.69	132	7188.46
82	7242.95	133	7194.37
83	7171.07	134	7203.18
84	7178.79	135	7211.81
85	7188.42	136	7219.25
86	7196.40	137	7226.78
87	7200.86	138	7153.94
88	7202.21	139	7162.70
89	7205.86	140	7169.04
90	7211.38	141	7176.87
91	7215.51	142	7184.45
92	7220.42	143	7192.25
93	7224.55	144	7200.09
94	7232.56	145	7208.47
95	7239.76	146	7215.82
96	7166.43	147	7223.38
97	7174.47	148	7158.22
98	7183.75	149	7162.48
99	7196.28	150	7171.19
100	7199.49	151	7181.08
101	7201.86	152	7188.61
102	7207.90	153	7196.35
103	7213.23	154	7205.45
104	7221.06	155	7212.29
105	7228.83	156	7220.06
106	7236.45	157	7166.68
107	7193.10	158	7177.03
108	7199.14	159	7184.63
109	7204.64	160	7192.40
110	7209.47	161	7201.90
111	7190.38	162	7208.92
112	7194.69	163	7216.60
113	7202.46	164	7172.53
114	7207.56	165	7180.49
115	7217.96	166	7188.39
116	7225.60	167	7196.26
117	7233.13	168	7204.31
118	7162.02	169	7212.54
119	7169.83		
120	7178.99	1	4999.93
121	7186.06	2	5008.32
122	7192.08	3	5010.03
123	7199.51	4	5016.55
124	7206.92	5	5018.53
125	7215.12	6	5020.37
126	7222.53	7	5024.97

APPENDIX C (continued)

8	5026.98	59	5088.54
9	5028.97	60	5090.95
10	5030.95	61	5093.30
11	5032.44	62	5095.89
12	5034.45	63	5098.25
13	5036.50	64	5096.15
14	5038.45	65	5096.92
15	5040.26	66	5102.95
16	5040.40	67	5105.07
17	5042.44	68	5090.34
18	5044.36	69	5093.89
19	5046.44	70	5094.90
20	5048.18	71	5099.36
21	5048.41	72	5097.29
22	5048.75	73	5098.74
23	5050.43	74	5097.53
24	5052.23	75	5100.46
25	5054.15	76	5099.94
26	5055.84	77	5103.87
27	5054.50	78	5105.56
28	5060.00	79	5105.19
29	5059.75	80	5105.15
30	5065.66	81	5108.85
31	5057.28	82	5112.58
32	5060.33	83	5096.18
33	5062.68	84	5100.64
34	5065.18	85	5101.80
35	5067.65	86	5104.22
36	5069.73	87	5105.75
37	5070.50	88	5103.48
38	5071.73	89	5107.48
39	5065.47	90	5108.94
40	5068.86	91	5110.29
41	5071.85	92	5111.63
42	5073.47	93	5113.00
43	5075.37	94	5116.18
44	5076.88	95	5120.31
45	5078.21	96	5104.29
46	5079.32	97	5108.23
47	5080.21	98	5110.18
48	5073.81	99	5109.86
49	5077.23	100	5109.26
50	5080.68	101	5111.65
51	5082.19	102	5113.53
52	5083.99	103	5114.39
53	5085.83	104	5121.28
54	5087.54	105	5124.62
55	5087.52	106	5128.01
56	5088.60	107	5114.72
57	5082.12	108	5117.00
58	5085.24	109	5120.29
		110	5122.55

APPENDIX C (continued)

111	5119.40
112	5121.08
113	5124.39
114	5126.52
115	5128.92
116	5132.08
117	5135.53
118	5112.05
119	5116.36
120	5118.56
121	5121.99
122	5124.88
123	5128.40
124	5131.95
125	5135.80
126	5139.44
127	5143.35
128	5120.07
129	5124.96
130	5129.39
131	5130.95
132	5132.64
133	5133.82
134	5139.01
135	5143.77
136	5147.11
137	5150.93
138	5126.12
139	5129.24
140	5136.02
141	5138.51
142	5140.80
143	5143.22
144	5147.56
145	5151.93
146	5155.11
147	5158.79
148	5134.29
149	5142.40
150	5145.24
151	5148.54
152	5151.87
153	5155.21
154	5158.93
155	5163.18
156	5166.49
157	5150.48
158	5155.11
159	5159.03
160	5162.76
161	5167.33
162	5170.88
163	5174.28
164	5161.39
165	5165.82
166	5170.22
167	5174.71
168	5179.11
169	5183.75

DATA SET 8:ELEMENT INCIDENCES

1	1	3	2	0	-1
2	2	3	5	4	-1
3	3	6	5	0	-1
4	4	5	8	7	-1
5	5	6	9	8	-1
6	6	10	9	0	-1
7	7	8	12	11	-1
8	8	9	13	12	-1
9	9	10	14	13	-1
10	10	15	14	0	-1
11	11	12	17	16	-1
12	12	13	18	17	-1
13	13	14	19	18	-1
14	14	15	20	19	-1
15	15	21	20	0	-1
16	16	17	23	22	-1
17	17	18	24	23	-1
18	18	19	25	24	-1
19	19	20	26	25	-1
20	20	21	27	0	-1
21	20	27	28	26	-1
22	21	29	27	0	-1
23	27	29	30	28	-1
24	29	38	30	0	-1
25	22	23	32	31	-1
26	23	24	33	32	-1
27	24	25	34	33	-1
28	25	26	35	34	-1
29	26	28	36	35	-1
30	28	30	37	36	-1
31	30	38	37	0	-1
32	31	32	40	39	-1
33	32	33	41	40	-1
34	33	34	42	41	-1
35	34	43	42	0	-1
36	34	35	43	0	-1
37	35	44	43	0	-1
38	35	36	45	44	-1
39	36	37	46	45	-1
40	37	38	47	46	-1
41	39	40	49	48	-1

APPENDIX C (continued)

42	40	41	50	49	-1
43	41	42	51	50	-1
44	42	43	52	51	-1
45	43	44	53	52	-1
46	44	45	54	53	-1
47	45	46	55	54	-1
48	46	47	56	55	-1
49	48	49	58	57	-1
50	49	50	59	58	-1
51	50	51	60	59	-1
52	51	52	61	60	-1
53	52	53	62	61	-1
54	53	54	63	62	-1
55	54	55	64	63	-1
56	55	56	65	64	-1
57	57	58	69	68	-1
58	58	59	70	69	-1
59	59	72	71	70	-1
60	59	60	72	0	-1
61	60	61	74	72	-1
62	72	74	75	73	-1
63	61	62	76	74	-1
64	74	76	77	75	-1
65	76	78	77	0	-1
66	76	62	79	78	-1
67	62	63	80	79	-1
68	63	64	66	0	-1
69	64	65	67	66	-1
70	63	66	81	80	-1
71	66	67	82	81	-1
72	68	69	84	83	-2
73	69	70	85	84	-2
74	70	71	86	85	-2
75	71	88	87	86	-2
76	71	72	73	88	-1
77	73	75	89	88	-1
78	75	77	90	89	-1
79	77	78	91	90	-1
80	78	79	92	91	-1
81	79	80	93	92	-1
82	80	81	94	93	-1
83	81	82	95	94	-1
84	83	84	97	96	-2
85	84	85	98	97	-2
86	85	86	99	98	-2
87	86	87	100	99	-2
88	88	89	87	0	-2
89	100	89	101	0	-2
90	89	90	102	101	-2
91	90	91	103	102	-2
92	91	92	103	0	-2
93	92	93	104	103	-2
94	93	94	105	104	-2
95	94	95	106	105	-2
96	96	97	119	118	-3
97	97	98	120	119	-3
98	98	111	121	120	-3
99	98	107	111	0	-2
100	98	99	107	0	-2
101	99	101	108	107	-2
102	101	102	109	108	-2
103	102	103	110	109	-2
104	103	104	115	110	-2
105	107	108	112	111	-2
106	108	109	113	112	-2
107	109	110	114	113	-2
108	110	115	114	0	-2
109	104	105	116	115	-2
110	105	106	117	116	-2
111	111	112	122	121	-3
112	112	113	123	122	-3
113	113	114	124	123	-3
114	114	115	125	124	-3
115	115	116	126	125	-3
116	116	117	127	126	-3
117	118	119	129	128	-3
118	119	120	130	129	-3
119	120	121	131	130	-3
120	121	122	132	131	-3
121	122	123	133	132	-3
122	123	124	134	133	-3
123	124	125	135	134	-3
124	125	126	136	135	-3
125	126	127	137	136	-3
126	128	129	139	0	-2
127	129	130	140	139	-2
128	130	131	141	140	-2
129	131	132	142	141	-2
130	132	133	143	142	-2
131	133	134	144	143	-2
132	134	135	145	144	-2
133	135	136	146	145	-2
134	136	137	147	146	-2
135	128	139	148	138	-2
136	139	140	149	148	-2
137	140	141	150	149	-2
138	141	142	151	150	-2
139	142	143	152	151	-2
140	143	144	153	152	-2
141	144	145	154	153	-2

APPENDIX C (continued)

```
 142  145  146  155  154   -2
 143  146  147  156  155   -2
 144  149  150  157    0   -2
 145  150  151  158  157   -2
 146  151  152  159  158   -2
 147  152  153  160  159   -2
 148  153  154  161  160   -2
 149  154  155  162  161   -2
 150  155  156  163  162   -2
 151  157  158  164    0   -2
 152  158  159  165  164   -2
 153  159  160  166  165   -2
 154  160  161  167  166   -2
 155  161  162  168  167   -2
 156  162  163  169  168   -2
 157   87   89  100    0   -2
 158  100  101   99    0   -2

DATA SET 10:   PRE-INITIAL CONDITIONS
   1  168    1        238.00      0.024

DATA SET 11:   TRANSIENT INTEGER PARAMETERS
  28   30    1    2   16   15    2    2   27    1    2    1    2    0    0    0
DATA SET 12:   SOURCE/SINK DATA SET, INFILTRATION
 0.000D+00 0.000D+00 0.180D+05 0.106D-06 0.216D+05 0.365D-06 0.252D+05 0.211D-06
 0.288D+05 0.187D-06 0.324D+05 0.111D-07 0.360D+05 0.111D-07 0.396D+05 0.111D-07
 0.432D+05 0.111D-07 0.468D+05 0.111D-07 0.504D+05 0.111D-07 0.540D+05 0.111D-07
 0.576D+05 0.111D-07 0.612D+05 0.111D-07 0.648D+05 0.111D-07 0.684D+05 0.111D-07
 0.720D+05 0.111D-07 0.756D+05 0.194D-06 0.792D+05 0.250D-06 0.828D+05 0.200D-06
 0.864D+05 0.182D-06 0.900D+05 0.172D-06 0.936D+05 0.166D-06 0.972D+05 0.161D-06
 0.101D+06 0.000D+00  1.00D+06       0.0  1.00D+30       0.0
 0.000D+00 0.000D+00 0.180D+05 0.106D-06 0.216D+05 0.694D-06 0.252D+05 0.553D-06
 0.288D+05 0.327D-06 0.324D+05 0.111D-07 0.360D+05 0.111D-07 0.396D+05 0.111D-07
 0.432D+05 0.111D-07 0.468D+05 0.111D-07 0.504D+05 0.111D-07 0.540D+05 0.111D-07
 0.576D+05 0.111D-07 0.612D+05 0.111D-07 0.648D+05 0.111D-07 0.684D+05 0.111D-07
 0.720D+05 0.111D-07 0.756D+05 0.194D-06 0.792D+05 0.567D-06 0.828D+05 0.425D-06
 0.864D+05 0.278D-06 0.900D+05 0.414D-06 0.936D+05 0.301D-06 0.972D+05 0.161D-06
 0.101D+06 0.000D+00  1.00D+06       0.0  1.00D+30       0.0
    1   57    1    1
   59    7    1    2
   67    6    1    1
   74    6    1    2
   81    4    1    1
   86    7    1    2
   94    4    1    1
   99    8    1    2
  108   48    1    1
  157    1    1    2

DATA SET 13:   DIRICHLET HEAD BOUNDARY CONDITIONS
        0.0     232.50    1.00+30     232.50
        0.0     233.08    1.00+30     233.08
        0.0     232.88    1.00+30     232.88
        0.0     233.67    1.00+30     233.67
```

APPENDIX C (continued)

```
        0.0     233.29   1.0D+30     233.29
        0.0     234.26   1.0D+30     234.26
        0.0     233.70   1.0D+30     233.70
        0.0     234.78   1.0D+30     234.78
        0.0     234.06   1.0D+30     234.06
        0.0     235.33   1.0D+30     235.33
        0.0     234.39   1.0D+30     234.39
        0.0     235.90   1.0D+30     235.90
        0.0     234.80   1.0D+30     234.80
        0.0     235.30   1.0D+30     235.30
        0.0      242.1   1.0D+30      242.1
    1    2    3    4    6    7   10   11   15   16   21   22   29   38  164  165
    1   14    1    1    1
   16             15
```

DATA SET 14: NEUMANN BOUNDARY CONDITIONS

```
        0.0       0.0    1.0D+30        0.0
   31   39   48   57   68   83   96  118  128  138  148  149  157  166  167  168
  169  163  156  147  137  127  117  106   95   82   67   65   56   47

    1   29    1    1
    1   11    1    2    1    1
   13   15   14   15    1    1
```

DATA SET 15: UPPER LEAKY AQUIFER - DUMMY SET

```
        0.0     242.0    1.0D+30          242.0
        0.0
    1  157    1    1
```

DATA SET 16: LOWER LEAKY AQUIFER - DUMMY SET

```
        0.0     230.0    1.0D+30          230.0
        0.0
    1  157    1    1
```

ORNL/TM-9467

INTERNAL DISTRIBUTION

1. T. L. Ashwood
2. S. I. Auerbach
3. J. S. Baldwin
4. W. J. Boegly, Jr.
5. A. W. Campbell
6. R. O. Chester
7. R. B. Clapp
8. A. S. Croff
9. N. H. Cutshall
10-19. E. C. Davis
20. C. S. Haase
21. S. G. Hildebrand
22. D. D. Huff
23. R. S. Lowrie
24. L. E. McNeese
25. T. W. Oakes
26. C. R. Olsen
27. D. E. Reichle
28. C. R. Richmond
29. E. D. Smith
30. B. P. Spalding
31-35. L. E. Stratton
36. T. Tamura
37. G. T. Yeh
38. Central Research Library
39-53. ESD Library
54-55. Laboratory Records Dept.
56. Laboratory Records, ORNL-RC
57. ORNL Patent Section
58. ORNL Y-12 Technical Library

EXTERNAL DISTRIBUTION

59. M. Barainca, Program Manager, Low-Level Waste Management Program, U.S. Department of Energy, 550 Second Street, Idaho Falls, ID 83401
60. J. J. Blakeslee, Program Manager, Nuclear Waste Processing, Rocky Flats Plant, Rockwell International, P.O. Box 464, Golden, CO 80401
61. J. Thomas Callahan, Associate Director, Ecosystem Studies Program, Room 336, 1800 G Street, NW, National Science Foundation, Washington, DC 20550
62. T. C. Chee, R&D and Byproducts Division, DP-123 (GTN), U.S. Department of Energy, Washington, DC 20545
63. A. T. Clark, Jr., Division of Fuel Material Safety, U.S. Nuclear Regulatory Commission, Washington, DC 20555
64. Peter Colombo, Group Leader, Nuclear Waste Research, Brookhaven National Laboratory, Bldg. 701, Upton, NY 11973
65. E. F. Conti, Office of Nuclear Regulatory Research, Nuclear Regulatory Commission, MS-1130-SS, Washington, DC 20555
66-70. P. M. Craig, P.O. Box 22668, Knoxville, TN 37933
71. J. E. Dieckhoner, Acting Director, Operations and Traffic Division, DP-122 (GTN), U.S. Department of Energy, Washington, DC 20545
72. B. Dodge, Low Level Waste Management Program, EG&G, Idaho, Inc., P.O. Box 1625, Idaho Falls, ID 83415
73. G. J. Foley, Office of Environmental Process and Effects Research, U.S. Environmental Protection Agency, 401 M Street, SW, RD-682, Washington, DC 20460
74. Carl Gertz, Director, Radioactive Waste Technology Division, Idaho Operations Office, U.S. Department of Energy, 550 Second Street, Idaho Falls, ID 83401

75. C. R. Goldman, Professor of Limnology, Director of Tahoe Research Group, Division of Environmental Studies, University of California, Davis, CA 94616
76. W. H. Hannum, Director, West Valley Project Office, U.S. Department of Energy, P.O. Box 191, West Valley, NY 14171
77. J. W. Huckabee, Manager, Ecological Studies Program, Electric Power Research Institute, 3412 Hillview Avenue, P.O. Box 10412, Palo Alto, CA 94303
78. E. A. Jennrich, Program Manager, Low-Level Waste Management Program, EG&G Idaho, Inc., P.O. Box 1625, Idaho Falls, ID 83415
79. J. J. Jicha, Director, R&D and Byproducts Division, DP-123 (GTN), U.S. Department of Energy, Washington, DC 20545
80. E. A. Jordan, Low Level Waste Program Manager, Division of Storage and Treatment Projects, NE-25 (GTN), U.S. Department of Energy, Washington, DC 20545
81. George Y. Jordy, Director, Office of Program Analysis, Office of Energy Research, ER-30, G-226, U.S. Department of Energy, Washington, DC 20545
82. J. Howard Kittel, Manager, Office of Waste Management Programs, Argonne National Laboratory, 9700 S. Cass Ave., Bldg. 205, Argonne, IL 60439
83. L. T. Lakey, Waste Isolation, Pacific Northwest Laboratory, Richland, WA 99352
84. Leonard Lane, Los Alamos National Laboratory, P.O. Box 1663, Los Alamos, NM 87545
85. D. B. Leclaire, Director, Office of Defense Waste and Byproducts Management, DP-12 (GTN), U.S. Department of Energy, Washington, DC 20545
86. Helen McCammon, Director, Ecological Research Division, Office of Health and Environmental Research, Office of Energy Research, MS-E201, ER-75, Room E-233, Department of Energy, Washington, DC 20545
87. Michael McFadden, Waste Management, Albuquerque Operations Office, U.S. Department of Energy, Albuquerque, NM 37115
88. G. L. Meyer, Environmental Protection Agency, 401 M Street SW, MS-ANR459, Washington, DC 20460
89. Edward O'Donnell, Division of Radiation Programs and Earth Sciences, U.S. Nuclear Regulatory Commission, Mail Stop 1130 SS, Washington, DC 20555
90. J. W. Patterson, Program Director, Waste Management Program Office, Rockwell Hanford Operations, P.O. Box 800, Richland, WA 99352
91. Irwin Remson, Department of Applied Earth Sciences, Stanford University, Stanford, CA 94305
92. Jackson Robertson, USGS, 410 National Center, Reston, VA 22092
93. E. M. Romney, University of California, Los Angeles, 900 Veteran Avenue, Los Angeles, CA 90024
94. R. J. Starmer, HLW Technical Development Branch, Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission, Room 427-SS, Washington, DC 20555
95. J. G. Steger, Environmental Sciences Group, Los Alamos Scientific Laboratory, MS-K495, P.O. Box 1663, Los Alamos, NM 87545

96. R. J. Stern, Director, Office of Environmental Compliance, MS PE-25, FORRESTAL, U.S. Department of Energy, 1000 Independence Avenue, SW, Washington, DC 20585
97. M. T. Stewart, University of South Florida, Tampa, FL 33620
98. J. A. Stone, Savannah River Laboratory, E. I. DuPont de Nemours and Company, Bldg. 773-A, Room E-112, Aiken, SC 29808
99. S. B. Upchurch, University of South Florida, Tampa, FL 33620
100. Leonard H. Weinstein, Program Director of Environmental Biology, Cornell University, Boyce Thompson Institute for Plant Research, Ithaca, NY 14853
101. Raymond G. Wilhour, Chief, Air Pollution Effects Branch, Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, 200 SW 35th Street, Corvallis, OR 97330
102. Frank J. Wobber, Ecological Research Division, Office of Health and Environmental Research, Office of Energy Research, MS-E201, Department of Energy, Washington, DC 20545
103. M. Gordon Wolman, The Johns Hopkins University, Department of Geography and Environmental Engineering, Baltimore, MD 21218
104. Office of Assistant Manager for Energy Research and Development, Oak Ridge Operations, P.O. Box E, U.S. Department of Energy, Oak Ridge, TN 37831
105-131. Technical Information Center, Oak Ridge, TN 37831