A Hydrogeologic Approach to Identify Land Uses That Overlie Ground-Water Flow Paths, Broward County, Florida

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U.S. GEOLOGICAL SURVEY
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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
square foot (ft^2)	0.09290	square meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
foot squared per day (ft^2/d)	0.09290	meter squared per day

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Transmissivity: The standard unit for transmissivity (T) is cubic foot per day per square foot times foot of aquifer thickness $[(ft^3/d)/ft^2]ft$. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

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Abstract

A hydrogeologic approach that integrates the use of hydrogeologic and spatial tools aids in the identification of land uses that overlie ground-water flow paths and permits a better understanding of ground-water flow systems. The U.S. Geological Survey used this approach to develop a procedure to identify the land uses that overlie flow paths leading to ground-water quality monitor wells in the Broward County ground-water monitoring network. A mathematical model was used to simulate the ground-water flow system, particle-tracking software was used to determine flow paths leading to the monitor wells, and a geographic information system was used to identify which land uses overlie the flow paths.

A step-by-step procedure using a geographic information system to evaluate the output from a ground-water flow model has been documented. The ground-water flow model was used to represent steady-state conditions during selected wet- and dry-season months, and an advective flow particle-tracking program was used to simulate the direction of ground-water flow in the surficial aquifer system. Digital spatial data layers were created from the particle pathlines that lead to the vicinity of the open interval of selected wells in the ground-water quality monitoring network. Buffer zone data layers were created, surrounding the particle pathlines to represent the area of contribution to the water sampled from the monitor wells. Spatial data layers, combined with a land-use data layer, were used to identify the land uses that overlie the ground-water paths leading to the monitor wells.

The simulation analysis was performed on five Broward County wells with different characteristics to identify land uses in buffer zones surrounding selected particle pathlines in the vicinity of the wells. The flow paths that lead to the grid cells containing three of the wells did not vary between the wet- and dry-season conditions. Changes in the area of contribution for the other two wells were attributed to variations in rainfall patterns, well-field pumpage, and surface-water management practices. Additionally, it was found that using a different open interval at a site can result in a very different area that overlies the flow path leading to the monitor well.

INTRODUCTION

The population of Broward County increased more than 30 percent during the 1980's to more than 1.25 million people (South Florida Water Management District, 1991, chap. IV, p. 4). The population growth resulted in an increased demand for water from the Biscayne aquifer, the sole source of public-water supply for Broward County (Federal Register Notice, 1979). Average daily withdrawals for public supply increased from 184 Mgal/d in 1980 to 266 Mgal/d in 1990 (James M. Montgomery, Consulting Engineers, Inc., 1985, chap. 3, p. 18; South Florida Water Management District, 1991, chap. IV, p. 14). An additional 36 Mgal/d was withdrawn from the Biscayne aquifer for other purposes, primarily irrigation and mining. Because of the increasing demand for water, a growing need exists to improve methods for managing the county's ground-water resources.

A number of tools are available that can be used to assist in the management of these water resources. Regional ground-water flow models use the hydrologic

and geologic characteristics of an aquifer system to simulate the effects of various stresses on the flow of water within the system. Ground-water quality monitoring networks are used to indicate the physical, chemical, and biological characteristics of ground water (Loaiciga and others, 1992, p. 11). A geographic information system (GIS) is used to analyze spatial data (manmade, topographic, hydrologic, and hydrogeologic features). Integrating the data from regional ground-water flow models, ground-water quality monitoring networks, and a GIS can provide a better understanding of the hydrologic system.

The design of monitoring networks to determine the effects of land use on ground-water quality is difficult in Broward County. Land use varies spatially and temporally, and the area of flow contribution to wells is not readily discernible and can vary with changing hydrologic conditions. The nature of any potential contaminant sources must also be considered. There are two broad categories of contaminant source, point and nonpoint. Point sources of contamination, such as leaking underground storage tanks, are limited in space and time. Monitoring systems to detect contamination can be developed based on the location of the point source in space and time. Nonpoint sources of contamination can significantly affect the characteristic regional (ambient) ground-water quality of an aquifer. The placement of wells to monitor such effects is not a simple procedure.

Two types of general approaches for ground-water quality monitoring network design are described by Loaiciga and others (1992, p. 19-30) as follows:

- *Hydrogeologic approach*: This approach is best suited for site-specific studies, such as detection of compliance network design where there is sufficient hydrogeologic data to develop a ground-water flow model.

- *Geostatistical techniques*: This approach is best suited for regional studies, such as the development of an ambient ground-water quality monitoring network.

Previous investigators have often relied on estimates of ground-water flow direction to determine the placement of monitor wells (Waller, 1983; Howie and Waller, 1986; Yurewicz and Rosenau, 1986; Waller and others, 1987; and Howie, 1992). Rutledge (1987) related the quality of water obtained from selected monitor wells to the land use surrounding the wells. The use of a ground-water flow model and a particle-tracking program allows for a more accurate estimation of the area of contribution to monitor wells.

A ground-water quality monitoring network was developed in 1983 to determine the areal, vertical, and seasonal water quality in the Biscayne aquifer and to identify areas where contamination is evident or where there is a potential for contamination (Waller and Cannon, 1986, p. 1-2). For identifying land uses that overlie the flow paths leading to these monitor wells, a hydrogeologic approach was possible because of the existence of a suitable regional ground-water flow model (Restrepo and others, 1992). The U.S. Geological Survey, in cooperation with the Broward County Department of Natural Resource Protection and the South Florida Water Management District, developed techniques to analyze the network using this hydrogeologic approach. Final network design requires the use of geostatistical techniques, which was beyond the scope of this study.

Purpose and Scope

This report describes a hydrogeologic approach used to identify the land uses that overlie flow paths leading to ground-water quality monitor wells and presents examples of land-use identification at selected sites. The approach requires the use of a ground-water flow model, a particle-tracking program, and a GIS. The modular model, MODFLOW (McDonald and Harbaugh, 1988), was used to simulate the ground-water flow system for representative wet and dry seasons assuming steady-state conditions. Ground-water flow pathlines were computed from the steady-state simulations of the ground-water flow model using the advective flow particle-tracking program, MODPATH (Pollock, 1989). Spatial data layers were created and combined with a land-use data layer using ARC/INFO[1] GIS software to identify the land uses that overlie flow paths leading to the ground-water quality monitor wells.

An existing ground-water flow model of the surficial aquifer system in Broward County (Restrepo and others, 1992) was used to perform a simulation analysis on selected monitor wells within the Broward County ground-water quality monitoring network. May and August 1989 calibration data were selected from the model to represent conditions in the dry and

[1]Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

wet seasons, respectively. Ground-water flow pathlines were computed as part of the analysis and are presented in this report.

Well-construction and location data for the monitor wells were obtained from the Ground-Water Site Inventory data base maintained by the U.S. Geological Survey. Model and well data were converted to digital spatial data using a GIS. A land-use data layer for eastern Broward County was obtained from a digital spatial data base (Sonenshein, 1992, p. 24-25). All digital spatial data were stored and analyzed using ARC/INFO software.

Previous Studies

Rating systems based on hydrogeologic characteristics, such as the LeGrand system (LeGrand, 1983) and DRASTIC (Aller and others, 1985), have been developed to quantify the potential for contamination of an aquifer. Ground-water contamination susceptibility maps can be developed from these types of rating systems. A GIS was used to facilitate the development of a ground-water contamination susceptibility map for the State of Wisconsin (Wisconsin Department of Natural Resources and Wisconsin Geological and Natural History Survey, 1987), a statewide ground-water monitoring network was developed based on ground-water contamination susceptibility maps for the State of Illinois (O'Hearn and Schock, 1985), and a DRASTIC analysis was made for Broward County by Herr (1990, p. 23).

Numerical computer models have been developed to simulate ground-water flow systems. A regional ground-water flow model for eastern Broward County (Restrepo and others, 1992) was constructed using the U.S. Geological Survey modular, three-dimensional, ground-water flow model, MODFLOW (McDonald and Harbaugh (1988). An advective flow particle-tracking program package, MODPATH, was developed by Pollock (1989) to compute three-dimensional ground-water flow paths using output from steady-state simulations of the modular model. Hutchinson (1990) used MODPATH to delineate ground-water flow paths and approximate zones of well-field capture for the A-sand aquifer at Paramaribo, Suriname.

General Hydrogeology

Broward County is located in southeastern Florida and encompasses an area of about 1,220 mi². The study area contains a highly regulated network of manmade canals and lakes (fig 1). These surface-water bodies have a major effect on the ground-water flow system, primarily acting as drains (Fish, 1988, p. 68). Canal water levels are controlled by a network of gates and pumps (fig. 1), thus controlling water levels in the surficial aquifer system. Certain coastal areas in Broward County are generally unaffected by the operation of these control structures.

The Biscayne aquifer, the most permeable part of the surficial aquifer system, was defined by Fish (1988, p. 20) using geologic and hydraulic characteristics. The aquifer consists of highly permeable limestone and calcareous sandstone of Pleistocene and Pliocene age. Hydraulic conductivities often exceed 10,000 ft/d in solution-riddled zones. The Biscayne aquifer pinches out at land surface in western Broward County; the base of the aquifer lies at more than 320 ft below sea level at the coastline (Fish, 1988, fig. 7b). In developing the ground-water flow model, Restrepo and others (1992) did not consider the deeper zones as part of the Biscayne aquifer because the extent of these deeper zones of the Biscayne aquifer along the coast is not well defined.

Recharge to the surficial aquifer system is from two sources, rainfall and canals (Fish, 1988, p. 66). Average annual rainfall is more than 60 in. and ranges from 30 to 100 in. (Jordan, 1984, p. 19-20). Rainfall follows a seasonal pattern, with about 70 percent of the annual rainfall usually occurring during the wet season, June to October (Jordan, 1984, p. 22). Excess rainfall infiltrates directly into the aquifer. During dry periods, water stored in impoundments in water-conservation areas (fig. 1) to the west and north is moved by gravity and pumps in the canals toward the coast; water leaks into the aquifer as it moves along the canals. Discharge from the surficial aquifer system is by evapotranspiration, ground-water flow to canals and the sea, and pumping wells for municipal, industrial, domestic, and agricultural supplies (Fish, 1988, p. 66).

Generalized regional ground-water flow directions in the surficial aquifer system are influenced by pumping from the large municipal well fields (fig. 2) and by surface-water management. Prior to these manmade controls, flows were from the interior wetlands (the Everglades) toward the ocean, generally in an
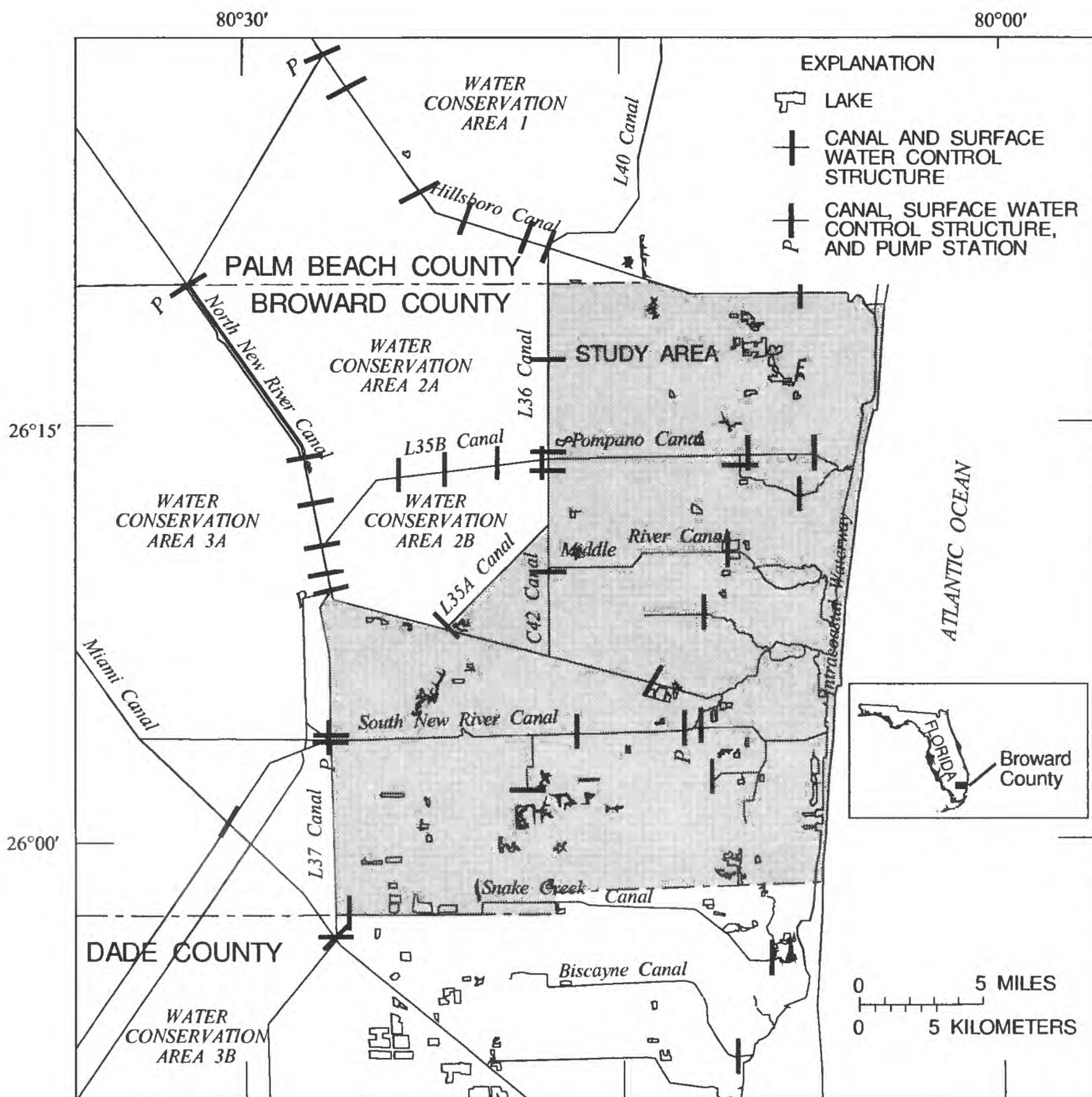
Figure 1. Eastern Broward County showing the study area, selected lakes and primary canals, control structures, and pump stations.
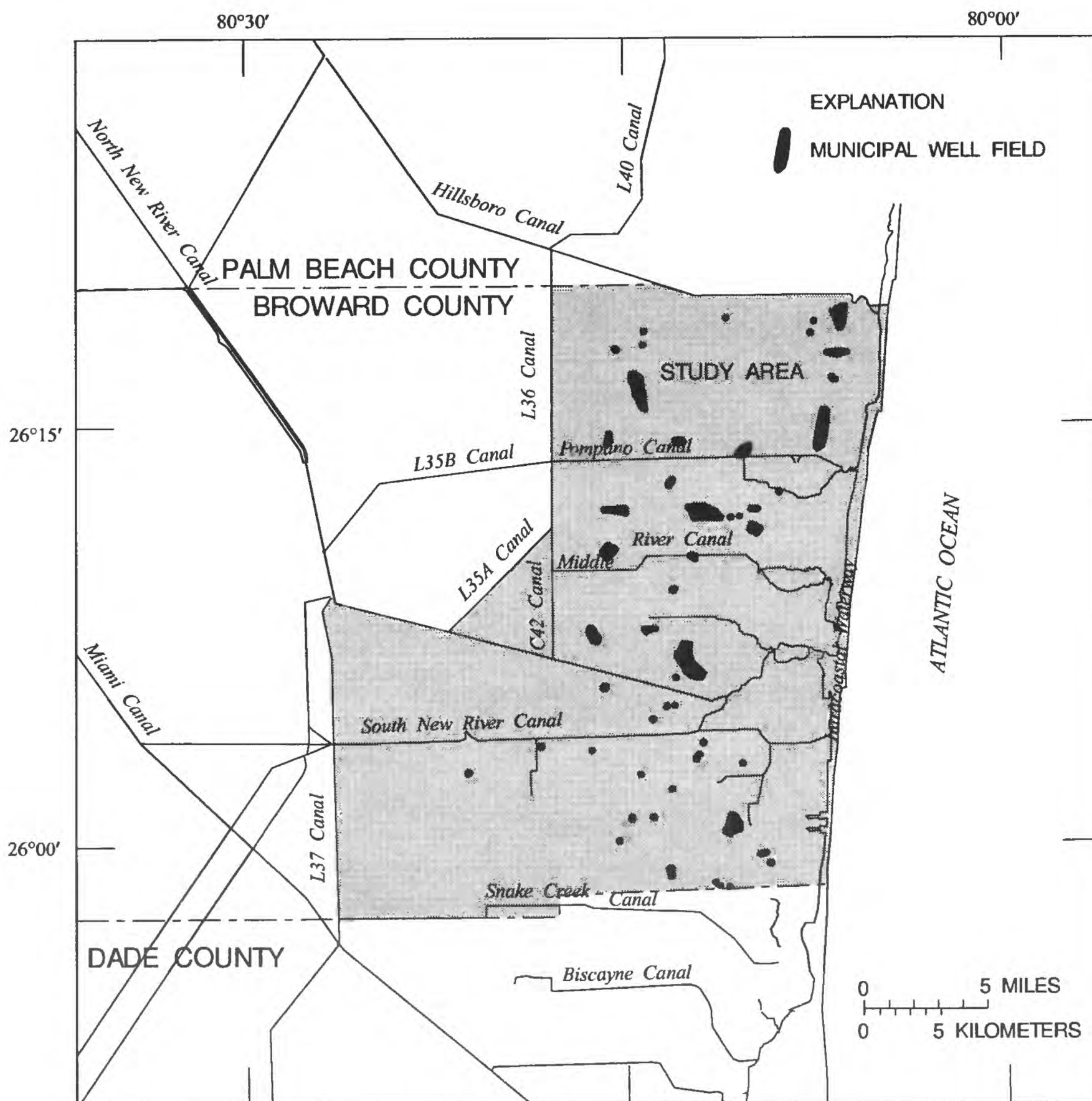
Figure 2. Eastern Broward County showing municipal well fields.

easterly or southeasterly direction. Well fields, levees, and canals have altered these natural flows. Levees used to impound surface water create high ground-water gradients. The canals were divided into three classes by Fish (1988, p. 69) as gaining, losing, and crossflow. Gaining canals discharge water from the aquifer, losing canals recharge water to the aquifer, and crossflow canals have little effect on the aquifer with ground water passing across or under the canal. A canal can be in different classes during different times of the year, or different reaches of a canal can be in different classes during the same time period.

For a short period, localized ground-water flow directions can be different than the generalized regional flow direction. For example, brief, local, intense thunderstorms, which are common during the wet season (June-October), can result in significant localized recharge events that cause water to enter the ground-water system and locally raise water levels, temporarily changing generalized flow patterns. The opening and closing of surface-water gates and the operating of surface-water pumps can alter the stage in a canal, changing it from a gaining to a losing canal or conversely. This condition could result in the reversal of ground-water flow directions in the vicinity of the canal. The area affected by such a reversal is influenced by many factors, including the amount of time the new operating conditions are in effect. The operation of surface-water gates and pump stations is usually determined either by stages in the canal or by gradients across the gate or pump station. If the conditions requiring the change in the operation of the gate or pump station exist for a relatively short time, the reversal of ground-water flow directions could be brief and the area of influence could be relatively small.

The withdrawal of ground water from small municipal well fields and for domestic supply, irrigation, or other uses might also temporarily change ground-water flow directions over a small area. These types of water use do not require continuous operation of the well pumps as is common for large municipal well fields. Additionally, the volume of water withdrawn from each well is relatively small compared to the total flow through the surficial aquifer system around the well. The effect of these wells on the ground-water flow system is generally not considered in regional analyses.

One result of the natural and manmade changes in the flow system is that flow paths to wells can change in a complex manner over time. These changes

in land uses overlying the flow paths can be reflected in the quality of water sampled from wells. Thus, an understanding of the variation of flow paths in time leading to wells is important to an understanding of changes in ground-water quality over time.

HYDROGEOLOGIC APPROACH TO IDENTIFY LAND USES OVERLYING GROUND-WATER FLOW PATHS

The hydrogeologic approach used to identify the land uses that overlie the flow paths leading to monitor wells, as described in this report, required several steps. The first step was to simulate the ground-water flow system using a mathematical model. Next, the flow paths leading to the monitor wells were determined using particle-tracking software. Finally, a GIS was used to identify which land uses overlie the flow paths.

The modular model, MODFLOW, was used to simulate the ground-water flow system for representative wet and dry seasons assuming steady-state conditions. A transient simulation, which permits a more realistic representation of the ground-water flow system, would have been preferred for the analysis. However, the current version of the MODPATH program requires the output from a steady-state solution. The MODPATH program uses the modular model input stress data sets and the ground-water head and cell-by-cell flux data output by the modular model to compute the flow paths of ground water.

The variations in the particle paths resulting from different hydrologic conditions can be estimated by comparing the particle paths from different stressed steady-state simulations. Steady-state conditions for representative 1-month periods in the wet and dry seasons were used to determine this variability in particle paths in this report.

Several particles at different locations are used to represent flow to a well to account for the uncertainty and discretization in the flow model. The flow-direction variability is significant in the Biscayne aquifer. Water levels and flow directions might change rapidly in water-table aquifers because of changes in the recharge rate, well-field pumping rate, and surface-water controls. Additionally, flow paths generally do not converge at the monitor wells. Backtracking from the well location would not show the flow direction in the areas that are not directly along the particle path simulated by steady-state conditions. Thus, particles

are placed at the edges of the grid cell instead of back-tracking particles from the location of the open interval of the well.

A spatial data layer of the pathlines computed by the MODPATH program is created using the MODPATHARC program (Sonenshein, 1992). Each pathline consists of a series of connected line segments (arcs) with associated MODPATH, ARC/INFO, and user-specified attributes (table 1). The beginning and ending points of each line segment are defined as the points where the value of one of the MODPATH attributes changes.

The pathlines computed by MODPATH can be different from the actual pathlines because of three factors: (1) the pathlines depict an average path of travel for particles of water that are sampled from a monitor well under steady-state conditions for a given time period; (2) the ground-water flow model assigns data values to the center of grid cells that represent an average of the conditions within the cell over a given time period; and (3) the flow paths of individual particles tend to deviate from the average flow path of all of the water particles due to dispersion. Therefore, a region around each pathline is selected to represent the area through which the actual pathline can pass. These regions represent the potential contributing area for water sampled from each monitor well.

The land uses that occur in these regions overlie the flow paths leading to each monitor well. The particle pathline represents steady-state conditions only. Under very short-term transient conditions, there might be vertical gradients in areas of the ground-water flow system, especially the highly conductive zones, which are not present in these areas under steady-state conditions. Also, the model uses an average recharge rate for each grid cell for a given time period. However, recharge actually occurs during relatively brief parts of that time period. During the actual recharge events, relatively high vertical gradients are created in the ground-water flow system. Water infiltrating at the surface will move progressively down through the aquifer system. This component of particle movement is not present under steady-state conditions. Additionally, diffusion and dispersion, which can cause vertical motion of contaminants, are not simulated by an advective-flow particle-tracking program. Thus, all land uses in the region defined above each particle pathline could have a potential effect on the quality of water sampled from each monitor well, even though the particle-tracking program does not indicate this situation.

The subsequent sections of this report document the hydrogeologic approach by presenting a procedure that can be used to identify the land uses overlying

Table 1. Selected attributes in the line attribute table for the pathline data layer

Attribute name	Attribute source	Attribute definition
LENGTH	ARC/INFO	Length of line segment
"Layer-name"-ID	User specified	ARC/INFO line segment identification number
BDEPTH	MODPATH	Beginning depth of line segment
EDEPTH	MODPATH	Ending depth of line segment
BLAYER	MODPATH	Beginning layer of line segment
ELAYER	MODPATH	Ending layer of line segment
BTIME	MODPATH	Beginning time of line segment
ETIME	MODPATH	Ending time of line segment
BROW	MODPATH	Beginning row of line segment
EROW	MODPATH	Ending row of line segment
BCOL	MODPATH	Beginning column of line segment
ECOL	MODPATH	Ending column of line segment
PARTICLE	User specified	MODPATH particle number

ground-water flow paths. This approach integrates the use of the ground-water flow model, particle-tracking software, and a GIS. Model limitations and other applications are also described. Additionally, a description of the ground-water flow model and land-use data layer is presented in appendix 1, a step-by-step procedure for creating the data layers and INFO files necessary to perform the analysis is presented in appendix 2, and the source code for the INFO, Fortran, and ARC/INFO Arc Macro Language programs (not documented in previous publications) is presented in appendix 3.

Creating Digital Spatial Data Layers

The initial step in the procedure is to prepare a polygon data layer of the grid used in the ground-water flow model. This data layer can be created using the MODELGRID program described by Sonenshein (1992, p. 12). The program assigns row and column values and a unique sequence number to each polygon (grid cell) in the grid. The unique sequence number is defined as:

COLUMN NUMBER + ([ROW NUMBER - 1]
x TOTAL NUMBER OF COLUMNS).

Model data sets required for the analysis or the display of the results are loaded into INFO data files, which can be related to the attribute tables for the grid data layer and other INFO data files by the sequence number. The data files include general head boundary cells, river cells, drain cells, well cells, and layer data files (one data file for each model layer and one data record in each data file for each model grid cell). The altitude of the top and bottom of each layer as well as the horizontal and vertical hydraulic conductivity are stored in these layer data sets. The IBOUND values, which indicate if a grid cell is active or inactive, are also stored in the layer data sets.

A point data layer containing location and information about the wells in the existing monitoring network must also be created. The CREATEPOINT program described by Sonenshein (1992, p. 10) can be used to create this data layer. The input data set required for the program can be obtained from the Ground-Water Site Inventory data base. Data fields required for the network analysis or for creating the data layer are the local well number, latitude, longitude, depth of well, depth to bottom of casing, depth to top of open interval, and depth to bottom of open interval. A geometric intersection (ARC/INFO

INTERSECT) of the well data layer with the model grid data layer is executed to determine the grid row, column, and sequence numbers where each monitor well is located.

A data layer of land-use polygons is required for the procedure. This data layer can be created specifically for this procedure or can be obtained from existing sources. The layer must have one or more attributes defining the land use in each polygon. However, documentation of the creation of the land-use data layer is not required for an understanding of this procedure.

Creating MODPATH Pathline Files

After creating the data layers, the next step in the procedure is to create a particle starting point file in the format required for input into the MODPATH program. Sixteen particles were selected in the following examples to backtrack from each grid cell containing a well (fig. 3). Four particles are located on each vertical face of the grid cell in which the open interval of the well is located, two at the top and two at the bottom of the open interval of the well. Each particle is located on the cell face at a distance from the edge of the cell face equal to one third of the total width of that face. To

EXPLANATION

● 1,2   STARTING LOCATION FOR PARTICLE IN A MODEL GRID CELL. ODD NUMBER IS PARTICLE AT BOTTOM OF OPEN INTERVAL OF WELL. EVEN NUMBER IS PARTICLE AT TOP OF OPEN INTERVAL OF WELL
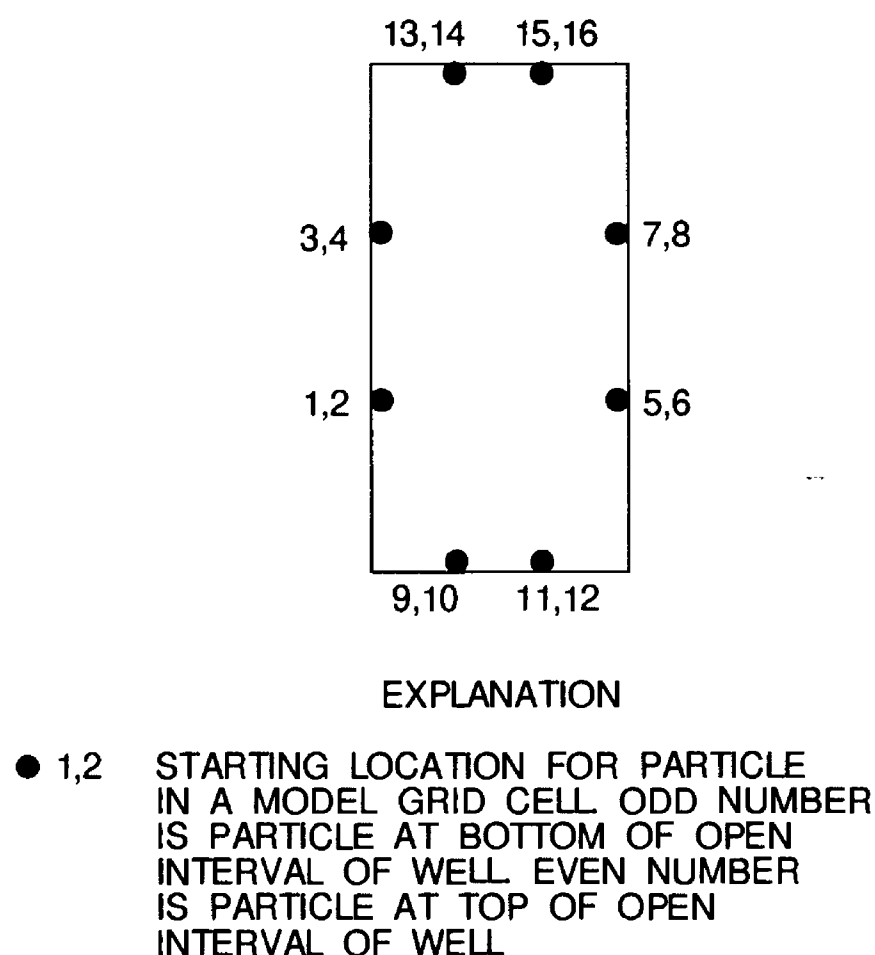
Figure 3. A model grid cell showing the starting location of particles used for MODPATH simulations.

Table 2. Output variables from the layer data file and the point attribute table for the well data layer

Variable name	Type	Width	Definition
NETID	Integer	6	User-defined identification number
IROW	Integer	5	MODFLOW row number
JCOLUMN	Integer	5	MODFLOW column number
KDEPTH	Integer	5	Total well depth (feet)
KBCASING	Integer	5	Bottom of cased interval (feet)
KTOPEN	Integer	5	Top of open interval (feet)
KBOPEN	Integer	5	Bottom of open interval (feet)
SURF	Real	8.2	Land-surface elevation (feet, sea level)
BOT(I)	Real array	8.2	Bottom elevation of model layer I (feet, sea level)
LOCAL	Character	10	Local well identification number

create the input file, the point attribute table for the well data layer is related to the layer data files, and a file is created with the data fields given in table 2. This output file is reformatted to create a file in MODPATH format.

Steady-state simulations of the MODFLOW model were run for selected time periods. Time periods should be selected from the calibration period to simulate variations in flow paths under different hydrologic conditions. For example, May and August can be used to represent the dry and wet seasons in southern Florida. The output head and flux files from these simulations along with the MODFLOW stress package data sets are used by the MODPATH program to compute particle paths to the monitor wells. The starting particle locations are input from the file previously created from the well data layer. Options specified as part of the execution of the MODPATH program are as follows: (1) output data are stored as flow-line coordinates, (2) particle locations are not computed at intermediate times, (3) particles are tracked backward toward recharge locations, (4) particles are allowed to pass through cells with weak sinks (these cells contain sinks that discharge only part of the water entering the cell according to Pollock [1989, p. 19]), (5) no zones are specified in which to stop particles whenever they enter these zones, and (6) recharge and evapotranspiration are assigned to the top face of cells. Options 4, 5, and 6 might have a different choice, depending on the

area being studied. Pathline data layers are created from the MODPATH output pathline files using the MODPATHARC program (Sonenshein, 1992).

The MODPATH program requires a porosity value for each model grid cell to calculate the time of travel for each particle. These porosity values are not part of the input data set for the MODFLOW steady-state solution and have no effect on the flow path. The time of travel is directly proportional to the porosity, with time of travel increasing with increasing porosity. Only approximate traveltimes are required for the procedure presented in this report; therefore, detailed porosity data are not required. For the examples in this report, a porosity of 0.3 (30 percent) was assigned to every model grid cell based on values reported by Fish (1988, p. 37) for selected rock samples. Particle velocities presented in the report were calculated by dividing the length of a particle pathline segment by the time of travel for that segment.

Selecting Particle Pathlines

The indicated area of contribution for a well determined by particle-tracking analysis depends upon the location of the well within the model grid cell. Using the example shown in figure 4, particles 1, 2, 9, and 10 would be selected if a monitor well were located at site A; particles 3, 4, 11, 12, 13, and 14 would be selected at site B; and particles 5, 6, 7, 8, 11, 12, 13, 14,
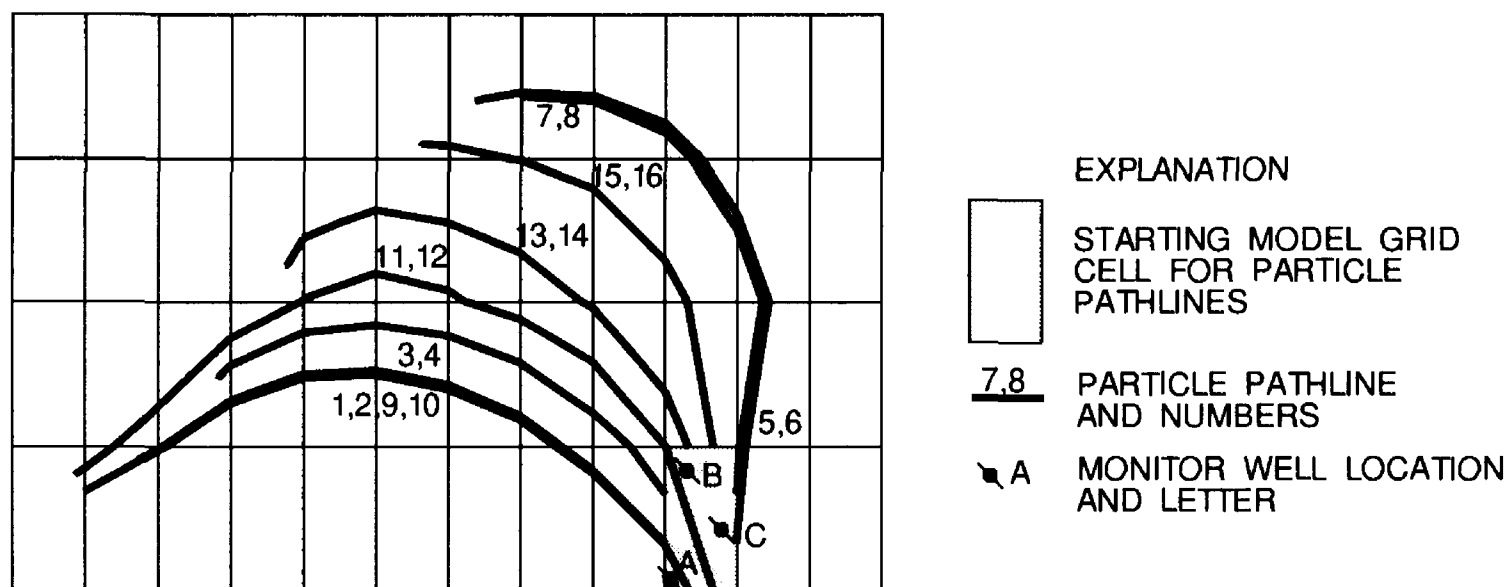
Figure 4. A model grid showing particle paths calculated by MODPATH.

15, and 16 would be selected at site C. Different areas of contribution might be indicated for different time periods because of the variability in flow paths under different hydrologic conditions.

The selected pathlines are placed into separate data layers to prevent ARC/INFO commands from merging pathlines together in subsequent processing steps. The pathlines are three-dimensional data stored by ARC/INFO as geographic coordinates in two dimensions. The third dimension, depth above or below a datum, is stored in ARC/INFO as attributes (BDEPTH and EDEPTH) of each pathline segment. Pathline segments that have the same geographic coordinates but different depths would be stored by ARC/INFO as coincident features. Certain commands, such as the IDENTITY command, would cause these features to merge.

Identifying Land-Use Category

The next step in the procedure is to identify the land-use category for each pathline segment. A geometric intersection (ARC/INFO IDENTITY) is performed on each pathline data layer with the land-use data layer. This command splits the pathline segments at the point where a land-use boundary line crosses the middle of a pathline segment. This command also assigns the attributes of the land-use polygon through which each of the resulting pathline segments passes to that pathline segment. The pathlines are then recombined into one data layer using the ARC/INFO APPEND command. The line topology is updated

using the ARC/INFO BUILD command. The resulting data layer consists of pathline segments that contain MODPATH attributes for beginning and ending depths and times that represent the original pathline segments. Pathline segments split by the geometric intersection will not have the correct values for these attributes but will contain the correct land use overlying that arc. A schematic of a land-use data layer showing the results of the geometric intersection on a particle pathline is shown in figure 5, and the results of the geometric intersection on the values of line attributes are given in table 3. The MODPATH program uses a simple linear interpolation to produce a continuous velocity field within each cell (Pollock, 1989, p. 5), that is used to determine the particle pathlines. By making the assumption that the attributes also vary linearly along the original line segments, the attributes can be updated to reflect the new line segments.

A limitation of the IDENTITY command is the size of the arcs permitted in the output data layer, known as the "fuzzy tolerance." Arcs smaller than a size determined by the dimensions of the data layer will not be included in the output data layer. Because only the horizontal length is stored as the length of an arc, predominantly vertical particle pathline segments could have a horizontal length less than the "fuzzy tolerance." These arcs will not be placed in the output data layer. To evaluate this problem, a relation is set up between the input and output data layers using the unique identification number "layer-name"-ID assigned by the MODPATHARC program as the related item. This identification number was also assigned to the pathline segments created by the
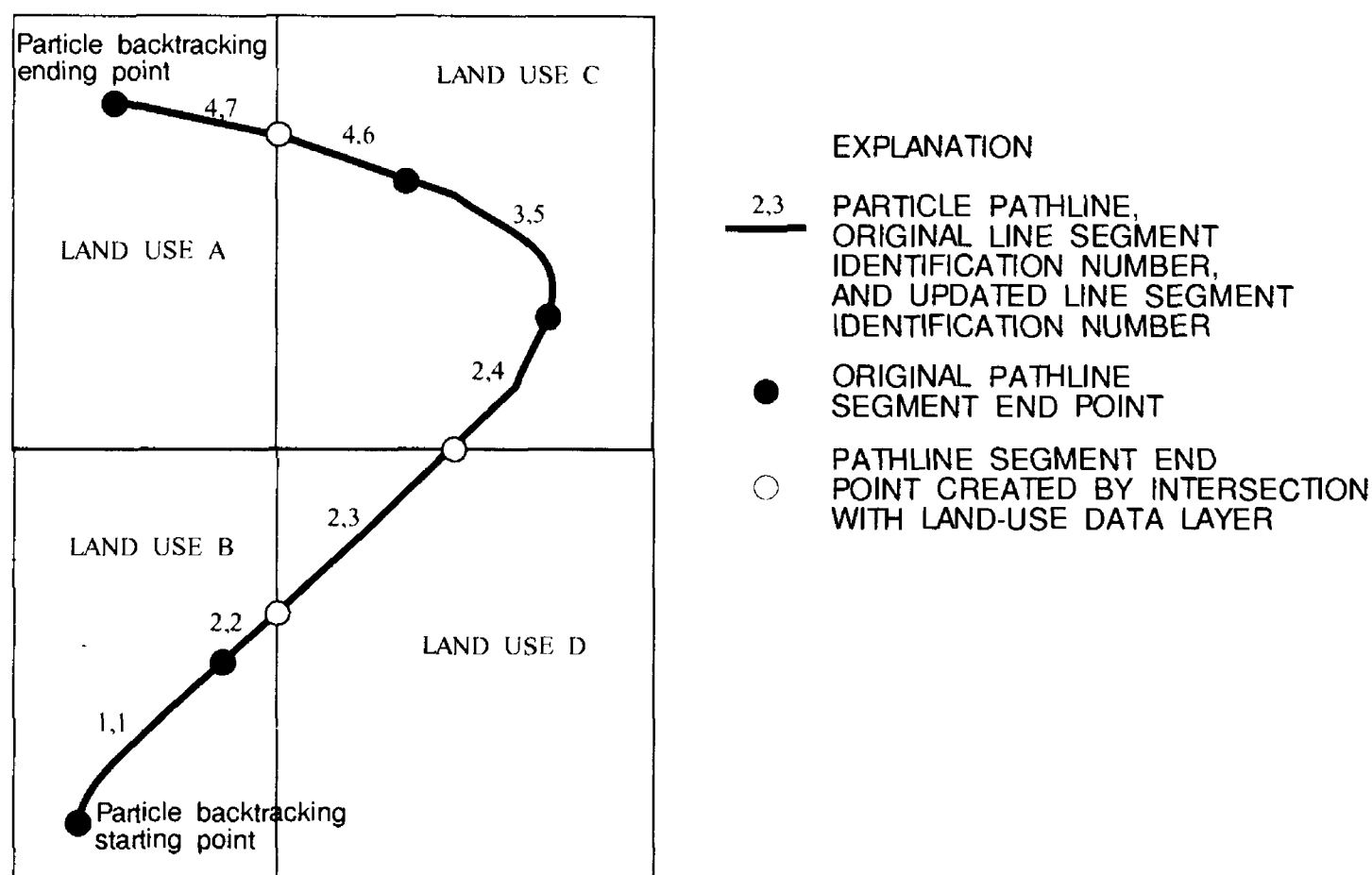
Figure 5. Example particle pathline showing the results of an intersection with a land-use data layer.

IDENTITY command. Thus, the two sets of pathline segments can be related by the "layer-name"-ID. The input data layer pathline segments whose identification numbers are not in the output data layer are added to the output data layer. These pathline segments will only have values for the MODPATH attributes and not for the intersecting (land use) data-layer attributes.

The procedure for updating the MODPATH attributes requires the use of the "layer-name"-ID assigned to each line segment in the original pathline data layer. By comparing the length of each line segment to the length of the original line segment, correct values for the depth and time attributes can be calculated as given in table 4. The begin time and end time for the segments after intersection for line segments 2 and 4, respectively, are different in tables 3 and 4.

Before updating the MODPATH attributes, the records for the pathline segments in the line attribute table must be sorted by pathline and by time for each pathline. The IDENTITY command sorts the output table geographically in two dimensions without regard to the attribute values. The unique identification number, "layer-name"-ID, increases with time along each pathline in the original data layer, so it can be used to sort the output line attribute table. Because the

IDENTITY command splits the pathline segments at the land-use polygon boundaries, the output data layer will usually contain one or more instances where consecutive segments have the same "layer-name"-ID (the first number of the paired numbers in fig. 5). Therefore, the "layer-name"-ID is assigned a new value that increases with time along each pathline (the second number of the paired numbers in fig. 5).

Five attributes required for subsequent processing steps and analyses are added to the line attribute table: DTIME, DDEPTH, TLENGTH, BLENGTH, AND CLENTH. DTIME is the amount of time required for a particle to pass from one end of a pathline line segment to the other end. DDEPTH is the change in depth from one end of a pathline segment to the other end. TLENGTH is the total horizontal distance from the start of the pathline to the end of the pathline segment. BLENGTH is the total distance traveled (horizontal and vertical) along the pathline segment. CLENGTH is the total distance traveled (horizontal and vertical) from the start of the pathline to the end of the pathline segment. ARC/INFO programs are used to calculate the value of these attributes with DTIME and DDEPTH being used to calculate the correct values for begin and end depth and time.

Table 3. Results of intersection of land-use data layer on the values of line attributes

Before intersection				After intersection				
Line segment number	Length	Begin time	End time	Line segment number	Length	Begin time	End time	Land-use category
1	100	0	10	1	100	0	10	B
2	200	10	25	2	20	10	25	B
					100	10	25	D
					80	10	25	C
3	100	25	30	3	100	25	30	C
4	150	30	40	4	75	30	40	C
					75	30	40	A

A data layer consisting of a horizontal buffer zone of 500 ft around each pathline (one half of the minimum grid cell dimension) is created using the ARC/INFO BUFFER command. This represents an arbitrary area that might have an influence on the quality of water sampled from the monitor well. The ARC/INFO CLIP command is used to create a new land-use data layer of those areas that fall within the buffer zone.

The source code for the programs (appendix 3) used to automate the procedure was written in three computer languages (INFO, Fortran, and ARC/INFO Arc Macro Language). The INFO program NET is used to create the input data set for the Fortran program (net.rfmt). This program is used to create a MODPATH particle starting point data set and requires the input of a formatted data set. Three ARC/INFO Arc Macro Language programs (PARTICLE, MPSORT, and DEPTH) were written to automate the procedure after the pathline data layers were created.

The ARC/INFO Arc Macro Language program PARTICLE has two results:

- The program selects the specified particles from the pathline data layer and performs the geometric intersection (IDENTITY) with the specified polygon land-use data layer. This results in a new line data layer consisting of particle paths that have been split along the boundaries in the polygon data layer. Arcs that are smaller than the "fuzzy tolerance" are included in the output data layer.
- The program creates the buffer-zone data layer from the polygon land-use data layer.

The input parameters required for this program are the pathline data layer name, the polygon data layer name, the buffer distance, and the name of the file containing the selected particle numbers (one particle number per line).

The ARC/INFO Arc Macro Language program MPSORT assigns a new value to the "layer-name"-ID attribute in the output pathline data layer that increases with time along each pathline. The ARC/INFO Arc Macro Language program DEPTH updates the MODPATH time and depth attributes and calculates the values for the attributes DTIME, DDEPTH, TLENGTH, BLENGTH, and CLENGTH. The input required for this program is the output pathline data layer name for the PARTICLE program, an output data layer name, the units (feet or meters) for the input data layer and the MODPATH depth attributes, and the desired units (feet or meters) for the calculated attributes TLENGTH, BLENGTH, and CLENGTH. The ARC/INFO Arc Macro Language program MPSORT must be executed on the pathline data layer before the program DEPTH can be executed.

Model Limitations

The ground-water flow model is an idealized approximation of reality; therefore, the particle-tracking analysis only provides a representation of particle movement in this idealized approximation (Pollock, 1989, p. 20-21). Several limiting factors need to be

Table 4. Results of corrections to MODPATH line attributes

Before intersection				After intersection					
Line segment number	Length	Begin time	End time	Line segment number Original	Line segment number Updated	Length	Begin time	End time	Land-use category
1	100	0	10	1	1	100	0	10	B
2	200	10	25	2	2	20	10	11.5	B
					3	100	11.5	19	D
					4	80	19	25	C
3	100	25	30	3	5	100	25	30	C
4	150	30	40	4	6	75	30	35	C
					7	75	35	40	A

considered when interpreting the output from the ground-water flow model and the MODPATH advective flow particle-tracking program. The uncertainty in hydrogeologic parameters and boundary conditions is the most important limitation in a model of a ground-water system (Pollock, 1989, p. 20). A sensitivity analysis of the Broward County ground-water flow model indicated that the model is most sensitive to hydraulic conductivity and canal bed conductance changes (Restrepo and others, 1992, p. 35).

A second limitation is the use of a discrete network of finite-difference cells to represent the ground-water flow system. As the cell size increases, the accuracy of the model in representing the ground-water flow system decreases. For example, the width of the canals in Broward County (generally no more than 100 ft) are significantly less than the dimensions of the grid cells in the regional ground-water flow model for eastern Broward County (1,000 by 2,000 ft). Therefore, the effects of the canals on the ground-water system are represented at a coarser scale than the actual effects of the canals.

The limitation of the MODPATH particle-tracking program that is most important is the inability of the current version of MODPATH to deal with transient flow systems. This limitation results from the desire to design an efficient computer program that produces a manageable amount of numerical output (Pollock,

1989, p. 19). Thus, the variations in flow direction for time periods that exceed the length of the steady-state conditions in the model will not be represented by the current version of MODPATH. The flow paths determined by MODPATH may be very different from the actual flow paths. Also, the vertical movement of particles in the surficial aquifer system in Broward County in response to transient events, such as localized rainfall events and changes in the state of a canal control structure that can result in the downward movement of particles from land surface, is not represented by MODPATH.

Many of the limitations associated with the steady-state capture area analyses presented in this report are due to the use of dual steady-state flow simulations to represent the wet and dry periods, as described above. An alternative approach that could be used effectively in future studies is to base capture area analyses on a single steady-state simulation that represents the average annual hydrologic conditions. A steady-state simulation of average annual conditions better represents pathlines that develop over periods of several years. In many cases, the use of an average annual steady-state simulation will produce capture areas that are very close to those predicted by a complete transient flow analysis of the system (D.W. Pollock, U.S. Geological Survey, oral commun., 1994).

Other Applications

The hydrogeologic approach used to identify land uses that overlie ground-water flow paths, as described in this report, is not limited to areas of contribution to monitor wells. This approach can be used to determine the contributing area to any point in a ground-water flow system. Examples of other points of interest are pumping wells and other discharge points, such as rivers, canals, and springs. Multiple regressions can be performed between water-quality data and the land-use data in the contributing areas to determine if there is a relation between land use and ground-water quality.

EXAMPLES OF LAND-USE IDENTIFICATION AT SELECTED SITES

A simulation analysis was performed on five monitor wells at four sites within the Broward County ground-water quality monitoring network to identify land uses in buffer zones surrounding particle pathlines in the vicinity of the wells. The wells (G-2345X, G-2355, G-2369, G-2373, and G-2373A) are located in areas representative of the various hydrologic conditions present in the study area (fig. 6). Well G-2345X is in an area influenced by a public-supply well field, well G-2355 has a localized area of ground-water flow contribution, well G-2369 has a relatively large area of contribution, and wells G-2373 and G-2373A are in a large rangeland area. A description of the monitor wells selected for analysis is presented in table 5.

May and August 1989 calibration data were selected from the existing ground-water flow model of the surficial aquifer system in Broward County to

represent conditions in the dry and wet seasons, respectively. Because there is little difference in the pathline directions between the dry- and wet-season conditions for wells G-2355, G-2373, and G-2373A, only the dry-season conditions (May 1989) were selected for analysis. The particle pathlines for the selected wells are shown in figure 7, and the seasons and particles selected for the analyses are given in table 6.

Table 6. Particles selected for example analysis

Monitor well number	Season	Selected particle numbers
G-2345X	Dry	9,10
	Wet	1,2,3,4,9,10,13,14
G-2355	Dry	7,8,15,16
G-2369	Dry	5,6,9,10
	Wet	5,6,9,10,11,12
G-2373	Dry	5,6
G-2373A	Dry	5,6

Well G-2345X

Ground-water flow to well G-2345X is predominantly influenced by a large municipal well field that surrounds the well. Additionally, the flow pattern is influenced by a second municipal well field northwest of the well, a major drain north of the well, and rivers west and south of the well (fig. 8). A significant difference exists between the wet- and dry-season flow

Table 5. Description of ground-water monitor wells selected for example analysis

Monitor well number	USGS station identification number	Latitude	Longitude	Open interval (feet below land surface)	Model row	Model column	Model layer
G-2345X	260641080123520	26°06'41"	80°12'35"	100 - 103	57	86	4
G-2355	261828080101301	26°18'28"	80°10'13"	93 - 96	22	98	2
G-2369	260046080190701	26°00'46"	80°19'07"	68 - 71	75	50	3
G-2373	260752080253701	26°07'52"	80°25'37"	55 - 60	54	14	5
G-2373A	260752080253702	26°07'52"	80°25'37"	17 - 22	54	14	1
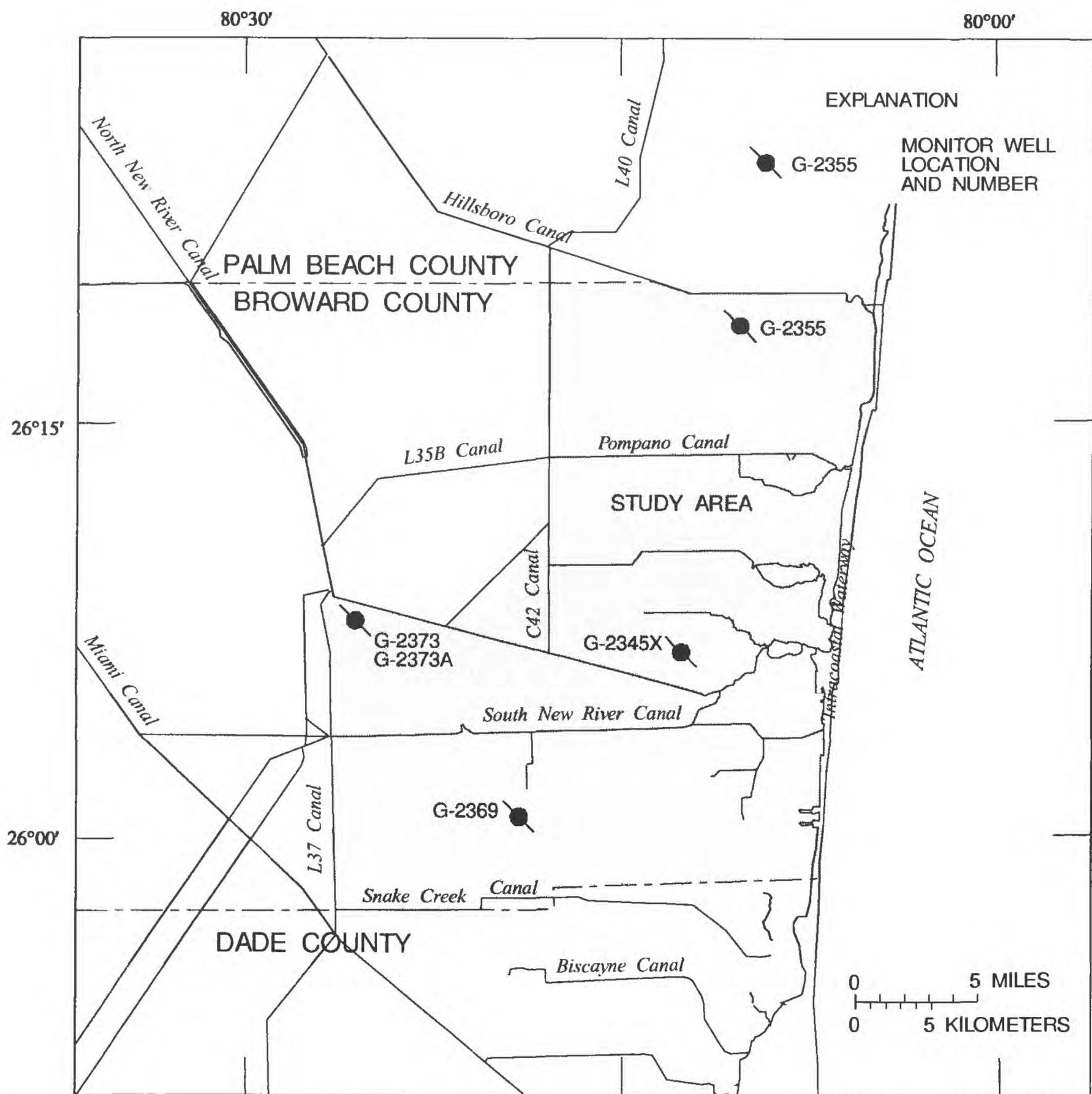
Figure 6. Selected wells used for example analyses.

Figure 7. Particle pathlines leading to selected wells.

COLUMNS

ROWS

DRY-SEASON PATHLINES AND
MODEL STRESS CELLS

WET-SEASON PATHLINES AND
MODEL STRESS CELLS

EXPLANATION

MODEL STRESS CELL

▬▬▬ PARTICLE PATHLINE

■ DRAIN

SIMULATED POTENTIOMETRIC
CONTOUR IN MODEL LAYER 3--
Shows altitude at which
water level would have
stood in tightly cased
wells. Hachures indicate
depression. Contour
interval 0.5 foot. Datum
is sea level

□ RIVER

⌀ WITHDRAWAL

⌀ MONITOR WELL

Figure 8. Source of ground-water stress and selected particle pathlines in the vicinity of well
G-2345X.

COLUMNS
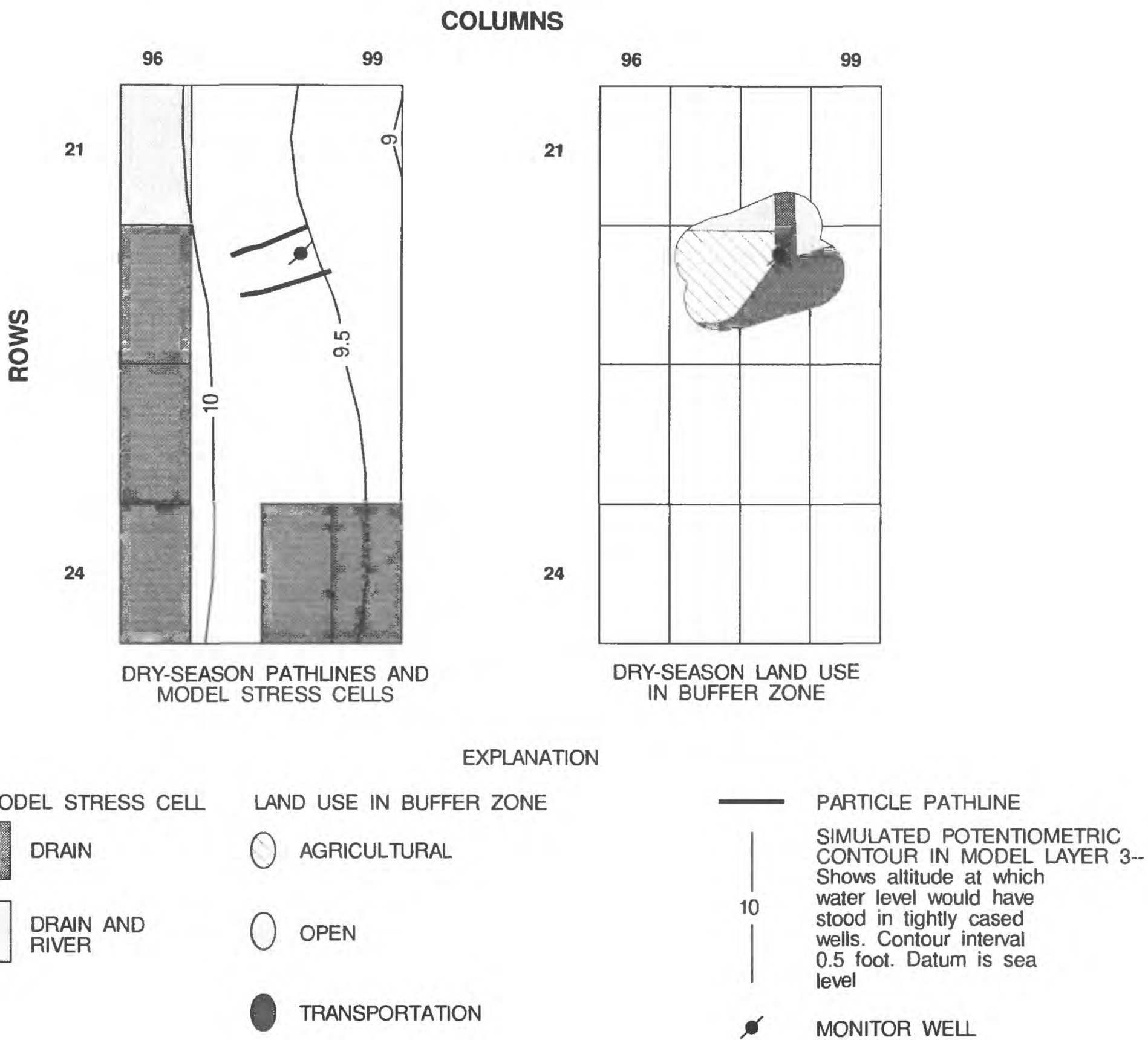
Figure 9. Source of ground-water stress, selected particle pathlines, and land use in buffer zones in the vicinity of well G-2355.
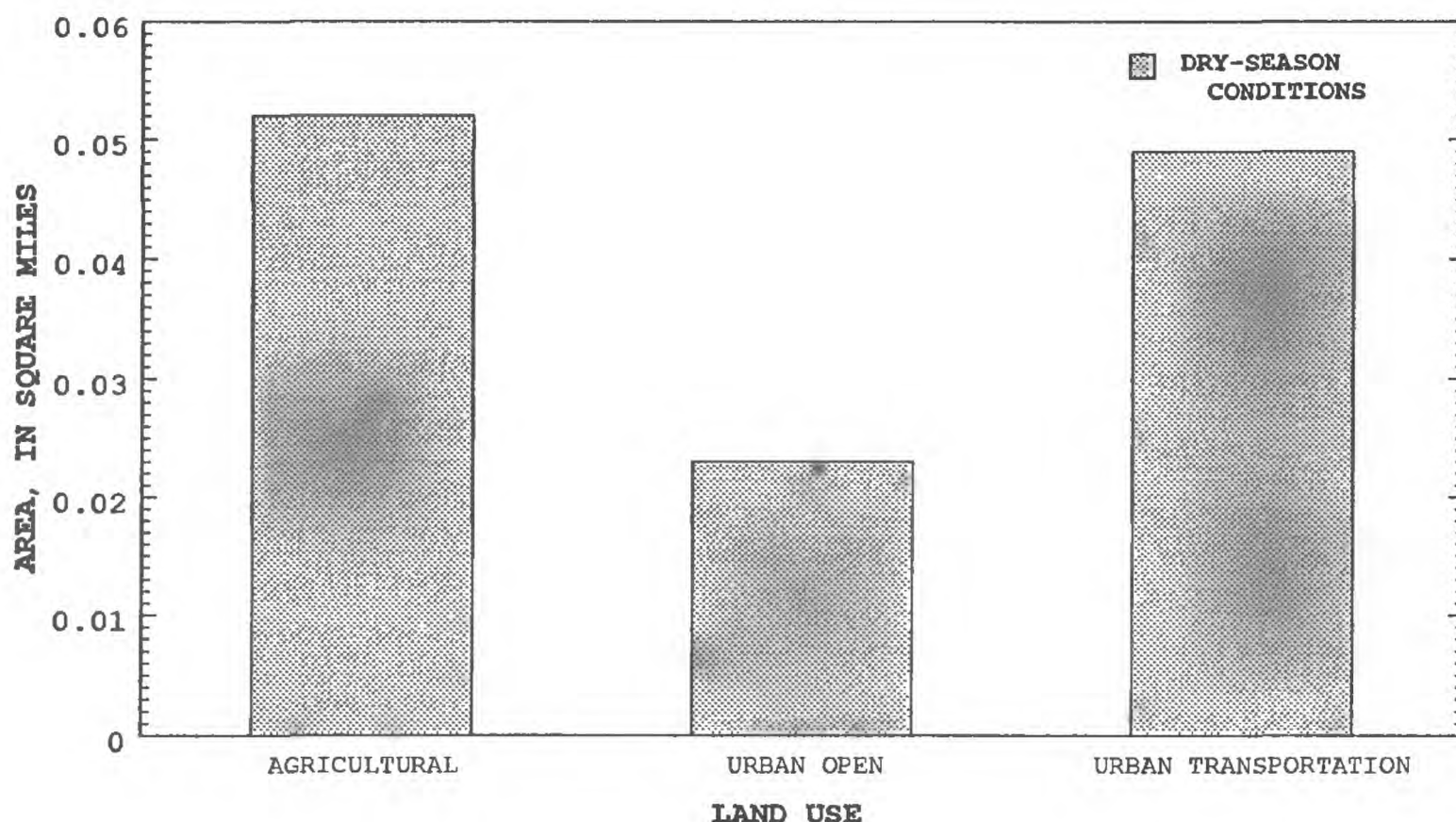
Figure 10. Land-use areas in the particle pathline buffer zones in the vicinity of well G-2355.

patterns. During the dry-season simulation, recharge to the well is from the west with a ground-water divide to the northwest between the two well fields. During the wet-season simulation, recharge to the well is from the north with ground-water divides to the north between the drain and the well field and to the northwest between the two well fields. Due to this seasonal variation in the flow patterns, the actual flow paths leading to well G-2345X may be very different from those shown in figure 8. Thus, the area of contribution cannot be determined for well G-2345X using this procedure.

Well G-2355

Ground-water flow to well G-2355 is primarily influenced by a large ground-water mound west of the well. Nearby rivers and drains have no apparent effect on the flow pattern, and municipal well fields are not close enough to the well to influence the flow pattern. Wet- and dry-season flow patterns are similar.

The particle pathlines leading to well G-2355 (fig. 9) indicate that recharge to the well is from a small area west of the well. The total length of the longest particle pathline is less than 1,350 ft, flow direction is from the west under wet- and dry-season conditions, and flow paths are about 300 ft longer under dry-season conditions. Land use surrounding the well

is a transportation zone, and the particle pathlines reach the surface in an agricultural cropland zone (figs. 9 and 10). Total traveltime for the particles ranges from 25 to 40 years, which corresponds to an average particle velocity of about 0.025 ft/d. Particle velocities are significantly less than those for well G-2345X because the particle pathlines never reach the high-permeability materials in layers 3 and 4 in the model that represent the Biscayne aquifer.

Well G-2369

Ground-water flow to well G-2369 is predominantly influenced by drains east of the well. The large variation between seasons for the particles on the west side of the well is a result of the effect of the drains on the ground-water flow pattern. The influence of the drains on the flow pattern would be more evident if additional time periods were analyzed.

The particle pathlines leading to well G-2369 (fig. 11) indicate that areas to the northwest and southwest contribute to water sampled from the well. A comparison of wet- and dry-season simulated conditions indicates that a difference between seasons only exists between some of the particle pathlines. The particle pathlines on the south side of the well come from the southwest under both sets of simulated conditions.

COLUMNS

DRY-SEASON PATHLINES AND
MODEL STRESS CELLS

WET-SEASON PATHLINES AND
MODEL STRESS CELLS

EXPLANATION

MODEL STRESS CELL

DRAIN

RIVER

DRAIN AND
RIVER

━━━ PARTICLE PATHLINE

SIMULATED POTENTIOMETRIC
CONTOUR IN MODEL LAYER 3--
Shows altitude at which
water level would have
stood in tightly cased
wells. Contour interval
0.5 foot. Datum is sea
level.

MONITOR WELL
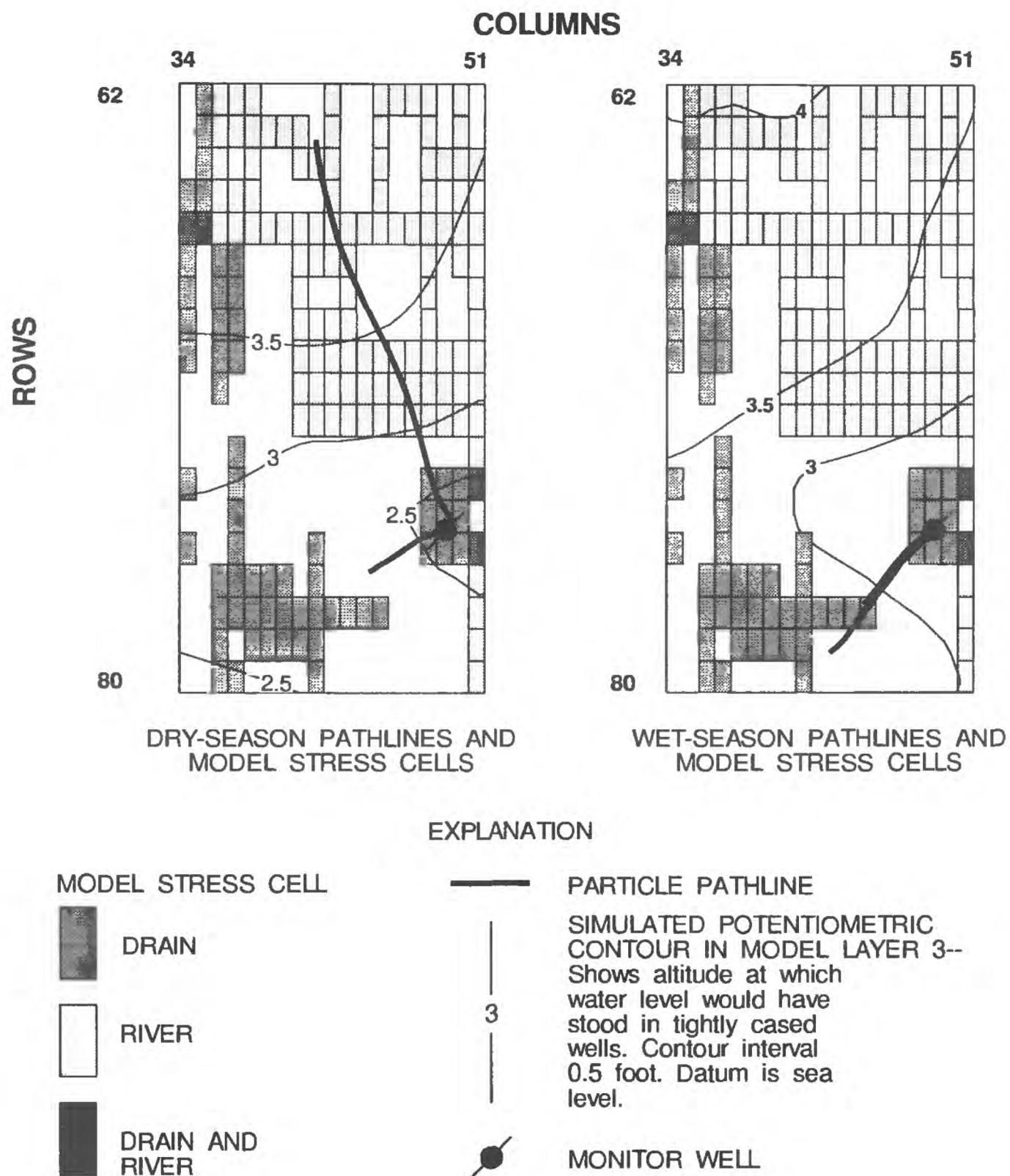
Figure 11. Source of ground-water stress and selected particle pathlines in the vicinity of well G-2369.

However, the particle pathlines on the west side of the well come from the southwest under wet-season simulated conditions and from the northwest under dry-season simulated conditions. Due to this seasonal variation in the flow patterns, the actual flow paths leading to well G-2369 may be very different from those shown in figure 11. Thus, the area of contribution cannot be determined for well G-2369 using this procedure.

Wells G-2373 and G-2373A

The particle pathlines leading to well G-2373 (fig. 12) indicate that the area north of the well, including Water Conservation Area 2B (fig. 1), contributes to the water sampled from the well. There is little difference in the pathlines between the wet- and dry-season simulations. The area is predominantly rangeland with barren land, urban open, water, and wetlands also present (figs. 12 and 13). Because flow to the well comes from the model boundary, the particle-tracking software provides no information on the starting point for particles that backtrack to the boundary. However, it is assumed that the starting point for these particles is in the conservation area. Traveltime to the conservation area is about 30 years.

The particle pathlines leading to well G-2373A (fig. 7) indicate that the water sampled from the well enters the aquifer in the area immediately surrounding the well. The particles enter the water table close to the well and reach the well within 2 years. Well G-2373A is adjacent to well G-2373 and has an open interval in layer 1 compared to an open interval in layer 5 for well G-2373. This difference in open interval results in the large difference in length of particle pathlines and in traveltimes for the two wells located at the same site.

SUMMARY

A hydrogeologic approach that integrates the use of hydrogeologic and spatial tools, such as ground-water flow models and a GIS, aids in the identification of land uses that overlie ground-water flow paths and allows for a better understanding of ground-water flow systems. This approach was used in a study conducted by the U.S. Geological Survey to develop a procedure to identify the land uses that overlie flow paths leading to monitor wells in the Broward County ground-water

quality monitoring network. A mathematical model, MODFLOW, was used to simulate the ground-water flow system, particle-tracking software was used to determine flow paths leading to the monitor wells, and a GIS was used to identify which land uses overlie the flow paths.

A procedure using a GIS to manipulate the output from a ground-water flow model has been documented. The ground-water flow model was used to represent steady-state conditions during representative wet- and dry-season months, and an advective flow program, MODPATH, was used to simulate the direction of ground-water flow in the surficial aquifer system. Digital spatial data layers were created from the particle pathlines that lead to the vicinity of the open interval of selected wells in the Broward County ground-water quality monitoring network. Buffer zone data layers were created, surrounding the particle pathlines to represent the area which might contribute to the water sampled from the monitor wells. The pathline and buffer zone data layers were combined with a land-use data layer to identify the land uses that overlie the ground-water flow paths leading to the monitor wells.

The particle pathlines computed by MODPATH might be different from the actual ground-water flow paths because of three factors: (1) the pathlines depict an average path of travel under steady-state conditions; (2) the ground-water flow model assigns data values to the center of grid cells, which represent an average of the conditions within the cell; and (3) discrete particles of ground water tend to spread from the average flow path due to dispersion. A transient simulation would permit a more realistic representation of the ground-water flow system; however, the current version of the MODPATH program requires the output from a steady-state simulation. This potential variability can be accounted for by using several particles at different locations to represent flow to a well, by comparing the pathlines from different steady-state simulations, such as wet and dry seasons, and by including a buffer zone around the pathlines for analysis.

A simulation analysis was performed on five monitor wells within the Broward County ground-water quality monitoring network to identify land uses in buffer zones surrounding selected particle pathlines in the vicinity of the wells. Because one purpose of the network is to determine the effects of land use on ground-water quality, well sites should be selected with flow paths leading to the well that did not vary over

COLUMNS

DRY-SEASON PATHLINES AND
MODEL STRESS CELLS

DRY-SEASON LAND USE
IN BUFFER ZONE

EXPLANATION

MODEL STRESS CELL

DRAIN

RIVER

DRAIN AND
RIVER

LAND USE IN BUFFER ZONE

BARREN LAND   WATER

OPEN   WETLANDS

RANGELAND

PARTICLE PATHLINE

SIMULATED POTENTIOMETRIC
CONTOUR IN MODEL LAYER 3--
Shows altitude at which
water level would have
stood in tightly cased
wells. Contour interval
0.5 foot. Datum is sea
level

MONITOR WELL

Figure 12. Source of ground-water stress, selected particle pathlines, and land use in buffer zones in the vicinity of well G-2373.

0.20

0.15

AREA, IN SQUARE MILES

0.10

0.05

0

| BARREN LAND | RANGELAND | URBAN OPEN | WATER | WETLANDS |

LAND USE

DRY-SEASON CONDITIONS
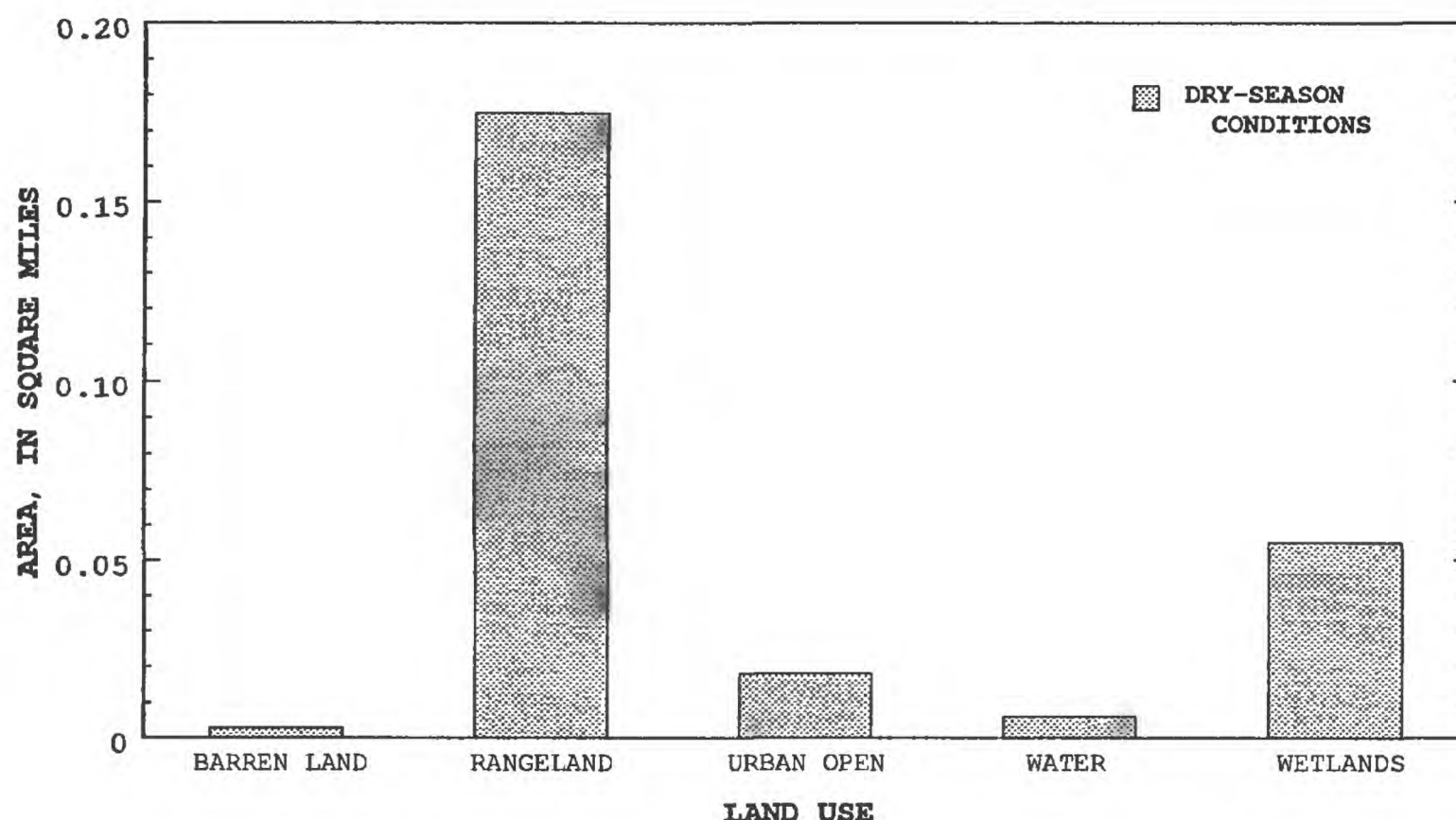
Figure 13. Land-use areas in the particle pathline buffer zones in the vicinity of wells G-2373 and G-2373A.

time. The flow paths leading to the grid cells containing wells G-2355, G-2373, and G-2373A did not vary between the different time periods selected and were generally parallel to each other. The determination of the contributing area to a monitor well can be difficult when the flow paths vary significantly over time. Variations in rainfall patterns, well-field pumpage, and surface-water management practices can all change the ground-water flow pattern. These factors were apparent in the simulation analyses for wells G-2345X and G-2369. An additional factor to be considered is the depth of the open interval. As was noted for wells G-2373 and G-2373A, a different open interval at a site can result in a different area contributing the water to the zone monitored by the well.

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APPENDIXES

APPENDIX 1. DESCRIPTION OF GROUND-WATER FLOW MODEL AND LAND-USE DATA LAYER

A three-dimensional ground-water flow model of the surficial aquifer system in eastern Broward County was developed by the South Florida Water Management District. The objective was to develop a model for the Broward County Water Supply Plan (Restrepo and others, 1992, p. 1). The U.S. Geological Survey modular, three-dimensional, ground-water flow model code, MODFLOW (McDonald and Harbaugh, 1988), was used and is capable of simulating ground-water flow in anisotropic, heterogeneous, and layered aquifer systems (Restrepo and others, 1992, p. 5). A block-centered finite-difference approach was employed in the model to simulate ground-water levels and flow, using data that quantify aquifer characteristics (transmissivity, specific yield and storage, and horizontal and vertical conductance) and aquifer stresses (recharge, evapotranspiration, well withdrawals, and surface-water interactions). A three-dimensional model was required because of the vertical heterogeneity within the surficial aquifer system. The model was calibrated using steady-state and transient simulations.

The model area encompasses about 630 mi^2 and includes all of eastern Broward County, parts of Dade and Palm Beach Counties, and parts of the water-conservation areas (fig. A1). Because the primary objective of the model was to simulate ground-water conditions in eastern Broward County, areas in Dade and Palm Beach Counties are also included to provide suitable boundary conditions for the model. The Dade County area included in the simulation lies north of the Biscayne Canal and east of the Miami Canal. The Palm Beach County modeled area lies south and east of the L-42 Canal, E-4 Canal, L-40 Canal, and the C-15 Canal and extends into the water-conservation areas.

The model grid consists of 13,400 uniform grid cells totaling 2,000,000 ft^2 each, of which 8,455 are active (figs. A1 and A2) and 4,945 are inactive (no flow). The grid consists of 100 rows with a spacing of 1,000 ft and 134 columns with a spacing of 2,000 ft. Vertically, the model contains five layers of varying thicknesses to represent the surficial aquifer system. The range of top and bottom elevations, thickness, and hydraulic parameters for each layer are given in table A1.

The top two layers simulate the low permeability surface sediments. Layer 1 simulates soil conditions and surface features. All river, drain, recharge, and evaporation cells are included in this layer. The second layer extends down to the top of the highly permeable limestones of the Biscayne aquifer. Layers 3 and 4 represent the Biscayne aquifer. The midpoint of the Biscayne aquifer was used to define the bottom of layer 3 (top of layer 4). The less-permeable sands, silts, and shell fragments of the surficial aquifer system below the Biscayne aquifer are represented by layer 5.

The land-use data layer was developed using a classification system used by the South Florida Water Management District (Restrepo and others, 1992, p. 88-91). The classification system consists of seven primary (level 1) land-use categories (table A2), all of which are present in Broward County. These categories have been divided into secondary (level 2) and tertiary (level 3) land-use categories. The Broward County land-use digital spatial data base contains 24 level 2 categories (table A2) and 78 level 3 categories. Only level 1 and level 2 land-use categories were used for the procedure presented in this report.
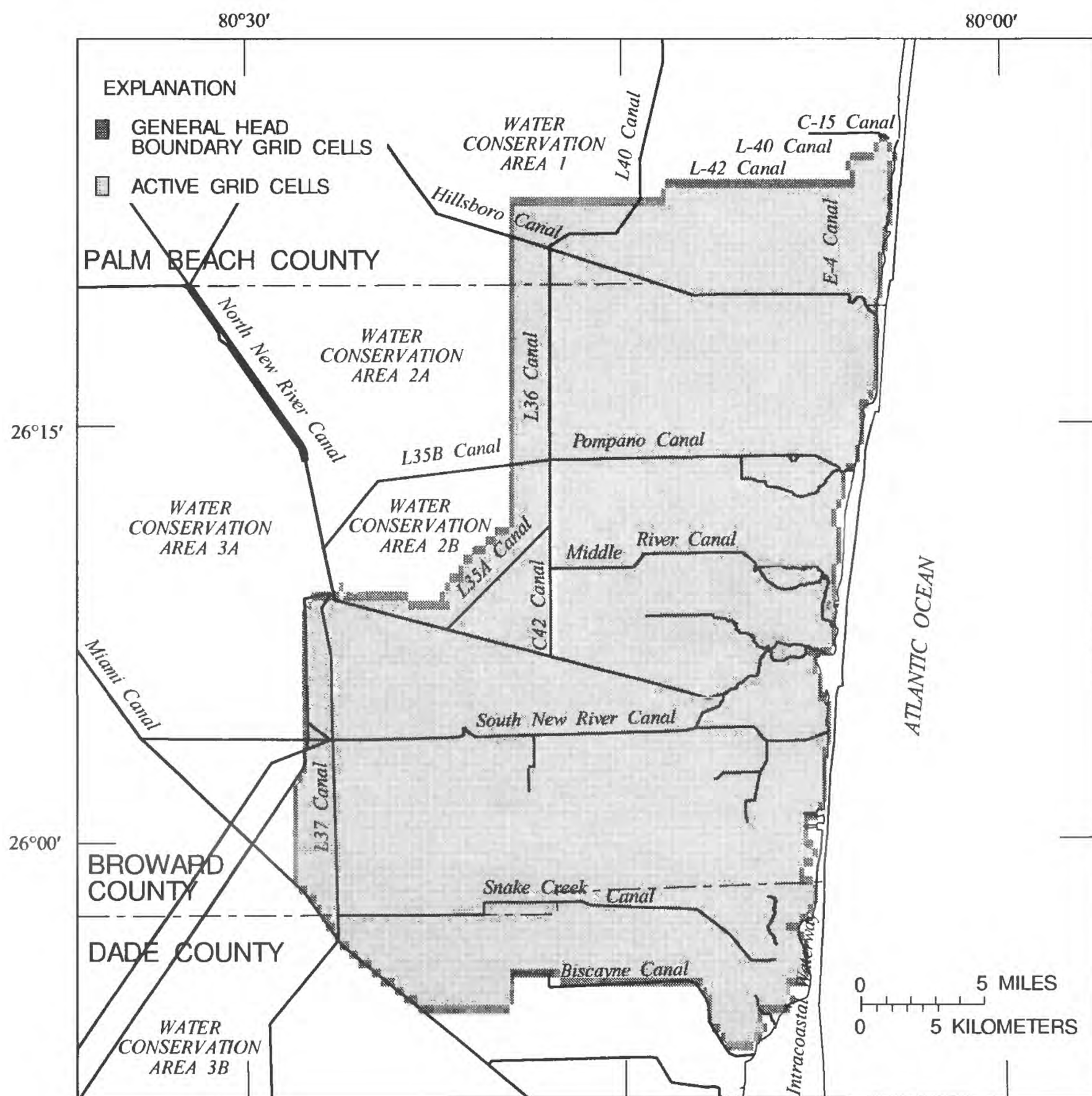
Figure A1. The model area showing general head boundary and active grid cells.
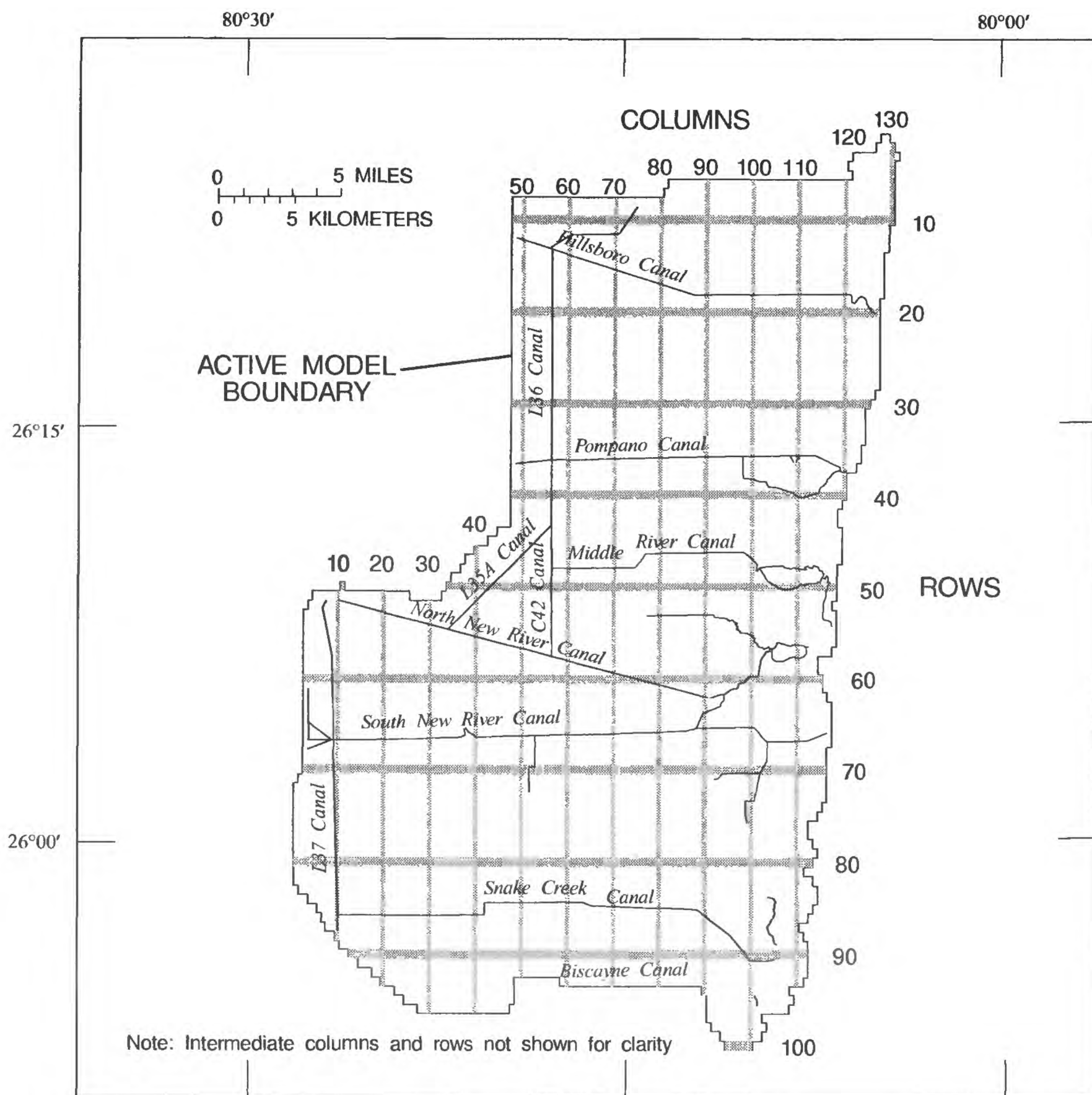
Figure A2. Model grid and lateral boundaries.

Table A1. Ranges of elevations, thickness, and hydraulic values of the model layers

[Dashes indicate not applicable]

Layer number	Top elevation (feet above or below sea level	Bottom elevation (feet below sea level)	Thickness (feet)	Hydraulic conductivity (feet per day)	Transmissivity (feet squared per day)	Vertical leakance[1] (units per day)
1	1.0 to 19.8	-16.5 to -5.0	14.9 to 25.0	25 to 527	--	0.0206 to 18.50
2	-16.5 to -5.0	-90.0 to -10.6	5.0 to 82.4	33 to 1,119	322 to 13,851	.0248 to 13.00
3	-90.0 to -10.6	-126.4 to -28.6	2.9 to 60.0	60 to 14,908	180 to 595,337	.2330 to 75.70
4	-126.4 to -28.6	-168.6 to -36.6	2.9 to 60.0	60 to 14,908	180 to 595,337	.0332 to 4.28
5	-168.6 to -36.6	-320.2 to -109.0	10.0 to 230.3	33 to 93	536 to 15,178	--

[1]Vertical leakance is used by MODFLOW to define vertical flow from a layer to the layer below and is defined by McDonald and Harbaugh (1988, p. 5-11 to 5-12)

Table A2. Level 1 and 2 land-use codes

[From Restrepo and others, 1992, p.88-91]

Level 1		Level 2	
Land-use code	Description	Land-use code	Description
A	Agricultural	AC	Cropland
		AF	Confined feeding operations
		AM	Groves, ornamentals, nurseries, tropical fruits
		AP	Pasture
B	Barren land	BB	Beaches
		BL	Levees
		BP	Extractive (strip mines, quarries, gravel pits)
		BS	Spoil areas
F	Forested uplands	FE	Coniferous forests
		FM	Mixed forests
		FO	Nonconiferous forests
H	Water		
R	Rangeland	RG	Grassland
		RS	Scrub and brushland
U	Urban land	UC	Commercial and services
		UI	Industrial
		UO	Open and other urban
		UR	Residential
		US	Institutional
		UT	Transportation
W	Wetlands	WF	Forested fresh wetlands
		WM	Nonforested salt wetlands
		WN	Nonforested fresh wetlands
		WS	Forested salt wetlands
		WX	Mixed forested and nonforested fresh wetlands

(page 33 follows)

APPENDIX 2. PROCEDURE FOR CREATING DATA LAYERS AND INFO FILES

[Command formats and user input to programs in **_bold italics_**]

1. Create ARC/INFO input data layers.

   a. **_MODELGRID GRIDFILE GRID_** (ARC/INFO AML documented in Sonenshein, 1992)--Creates polygon data layer (GRID) of the grid for the ground-water flow model; the input file GRIDFILE used for this report is as follows:

   > 100 134
   >
   > 0
   >
   > 553088.5096 2922795.4873
   >
   > 100*609.6
   >
   > END
   >
   > 134*304.8
   >
   > END

   with the origin coordinates in units of UTM meters (zone 17) and the grid spacing in meters; the model data files were imported into INFO and sequence numbers were calculated.

   b. **_CREATEPOINT GWSIFILE WELL_** (ARC/INFO AML documented in Sonenshein, 1992)--Creates point data layer (WELL) of ground-water quality monitor well network; the required GWSI data fields for the input data file (GWSIFILE) with the INFO item definitions are:

GWSI field name	GWSI field	INFO item name	Width	Output	Type	No. of decimals
Station name	C12	LOCAL	10	10	C	--
Latitude	C9	LAT	7	7	C	--
Longitude	C10	LONG	8	8	C	--
Depth of well	C28	DEPTH	6	6	N	0
Depth to bottom of casing	C78	CSNG-BOT	6	6	N	0
Depth to top of open interval	C83	OPEN-TOP	6	6	N	0
Depth to bottom of open interval	C84	OPEN-BOT	6	6	N	0

   c. Create a polygon data layer for overlaying on pathlines. The land-use data layer (LANDUSE) used for this report was obtained from an existing data base (Sonenshein, 1992).

2. **_INTERSECT WELL GRID WELLGRID POINT_** (ARC/INFO command)--Determines the row and column for every well in the WELL data layer; creates a new point data layer (WELLGRID) which is the same as WELL with the addition of row, column, and grid sequence number values in the point attribute table.

3. Create MODPATH particle starting point file.

    a. Create input file for Fortran net.rfmt program. The input file consists of seven lines of data for each well. The Fortran format for this first line is:

FORMAT (I6,2(I5),4(2X,I5),1X,A10)

The input variables for this line are a user-defined well identification number, model grid row, model grid column, depth of well, depth to bottom of casing, depth to top of open interval, depth to bottom of open interval, and station name. All depths are in feet below land surface. The line of data for each well is followed by one line for land surface at the well and one line for the base of each layer in the model for the grid cell where the well is located. The format for these data lines is F8.2, and the units are in feet above or below sea level. A sample input file for three wells and a five-layer model is:

```
   144    75    50    71    68    68    71    G-2369
     4.00
   -15.00
   -34.90
   -70.10
  -105.30
  -126.91
   158    54    14    60    55    55    60    G-2373
     7.00
   -15.00
   -27.10
   -37.20
   -47.40
  -177.49
   160    54    14    22    17    17    22    G-2373A
     7.00
   -15.00
   -27.10
   -37.20
   -47.40
  -177.49
```

If only a few wells are being analyzed, the input file can be created manually. If a large network is being analyzed, the following procedure can be used:

(1) Create one INFO file for each data layer (LAYER1, LAYER2, etc.) which contains the following items (other items may be included):

Item definition	Item name	Width	Output	Type	No. of decimals
Grid sequence number	SEQNUM	8	5	I	--
Elevation of top of layer (feet, sea level)	TOP	8	7	N	2
Elevation of bottom of layer (feet, sea level)	BOTTOM	8	7	N	2

(2) **NET** (INFO program)--Creates a file (net.data) in the format required by net.rfmt.

b. **net.rfmt** (Fortran program)--Creates a particle starting point file in the format required for MODPATH; sample output from this program is shown here:

Enter name of input file
net.data
Enter name of output file
net.mp
Enter number of layers
5
Enter integer missing value for well data
-99

DATA REFORMATTED FOR MODPATH FROM FILE net.data
OUTPUT IS IN FILE net.mp
PARTICLE NUMBERS AND WELL NAMES ARE IN FILE net.rfmt.cnt
PROBLEMS ARE IN FILE net.rfmt.err

The output file net.mp is shown here:

```
50        75        3     0.0100    0.3300    0.0881
50        75        3     0.0100    0.3300    0.1733
50        75        3     0.0100    0.6700    0.0881
50        75        3     0.0100    0.6700    0.1733
50        75        3     0.9900    0.3300    0.0881
50        75        3     0.9900    0.3300    0.1733
50        75        3     0.9900    0.6700    0.0881
50        75        3     0.9900    0.6700    0.1733
50        75        3     0.3300    0.0100    0.0881
50        75        3     0.3300    0.0100    0.1733
50        75        3     0.6700    0.0100    0.0881
50        75        3     0.6700    0.0100    0.1733
50        75        3     0.3300    0.9900    0.0881
50        75        3     0.3300    0.9900    0.1733
50        75        3     0.6700    0.9900    0.0881
50        75        3     0.6700    0.9900    0.1733
14        54        5     0.0100    0.3300    0.9570
14        54        5     0.0100    0.3300    0.9954
14        54        5     0.0100    0.6700    0.9570
14        54        5     0.0100    0.6700    0.9954
14        54        5     0.9900    0.3300    0.9570
14        54        5     0.9900    0.3300    0.9954
14        54        5     0.9900    0.6700    0.9570
14        54        5     0.9900    0.6700    0.9954
14        54        5     0.3300    0.0100    0.9570
14        54        5     0.3300    0.0100    0.9954
14        54        5     0.6700    0.0100    0.9570
14        54        5     0.6700    0.0100    0.9954
14        54        5     0.3300    0.9900    0.9570
14        54        5     0.3300    0.9900    0.9954
14        54        5     0.6700    0.9900    0.9570
14        54        5     0.6700    0.9900    0.9954
14        54        1     0.0100    0.3300    0.0000
14        54        1     0.0100    0.3300    0.2273
14        54        1     0.0100    0.6700    0.0000
```

```
14        54         1    0.0100    0.6700    0.2273
14        54         1    0.9900    0.3300    0.0000
14        54         1    0.9900    0.3300    0.2273
14        54         1    0.9900    0.6700    0.0000
14        54         1    0.9900    0.6700    0.2273
14        54         1    0.3300    0.0100    0.0000
14        54         1    0.3300    0.0100    0.2273
14        54         1    0.6700    0.0100    0.0000
14        54         1    0.6700    0.0100    0.2273
14        54         1    0.3300    0.9900    0.0000
14        54         1    0.3300    0.9900    0.2273
14        54         1    0.6700    0.9900    0.0000
14        54         1    0.6700    0.9900    0.2273
```

The fields in this file are column, row, layer, local x coordinate, local y coordinate, and local z coordinate. The Fortran format for each line in this file is:

FORMAT (3(I10),3(4X,F6.4)).

4. Run the MODFLOW model using a steady-state simulation for each time period selected. The head and flux files are required to be output in binary format for the next step.

5. Run the MODPATH program for each time period using the file created in step 3 (net.mp) as the particle starting point file, the MODFLOW data sets, and the MODFLOW binary head and flux files created in step 4. The output is a pathline file (PATHLINE_WET_FILE and PATHLINE_DRY_FILE) for each time period. A sample batch run file (TERMIN.PTH) is shown here:

```
BATCH
files.mp
1
n
1
net.mp
1
0
n
y
y
n
n
n
```

6. ***MODPATHARC pathline_wet_file PATH_WET LINE 553088.5096 2922795.4873 100 609.6*** (ARC/INFO AML documented in Sonenshein, 1992)--Creates a line data layer from pathline_wet_file with attributes for particle number, beginning and ending time, depth, row, column, and layer for each pathline segment. In the example shown, the output data layer is PATH_WET, the LINE option is used, and the origin of the grid (northwest corner), the number of rows, and the row spacing (in data layer units) are specified.

7. ***PARTICLE PATH_WET PATHID_WET LANDUSE LUBU_WET particle_file 152.4*** (ARC/INFO AML)--Overlays the attributes of the polygon (LANDUSE) data layer on selected pathlines in the input data layer (PATH_-WET) to create a new line data layer (PATHID_WET); extracts polygons from the polygon data layer (LANDUSE) which overlap a specified buffer zone (152.4 meters in data layer units) around the pathlines to create a new polygon data layer (LUBU_WET); the particle file particle_ file consists of a list of the selected particles, with one particle number per line; a sample of the output from this program is shown here:

Arc:**&R PARTICLE PATH_WET PATHID_WET LANDUSE LUBU_WET particle_file 152.4**

Checking for particle 73
Checking for particle 134
Checking for particle 269
Processing particle 73
Particle 73 contains 1 arcs which were removed by
the IDENTITY command due to FUZZY tolerance - adding arcs....
Note: these arcs have no values from the IDENTITY coverage

Processing particle 134

Processing particle 269

APPENDing particle coverages...

===>> Identity cover PATHID_WET created from PATH...
===>> Clip cover LUBU_WET created from LANDUSE...

8. **SORT PATH_ID** (ARC/INFO AML)--Assigns a new value to the PATH_ID-ID attribute that increases with time along each pathline.

9. **DEPTH PATHID_WET PATHUPT_WET METERS FEET FEET** (ARC/INFO AML)--Updates the MODPATH time and depth variables in the arc attribute table for the PATHID_WET data layer using INFO programming, and adds the variables DTIME, the amount of time required for a particle to pass from one end of a pathline segment to the other end; DDEPTH, the change in depth from one end of a pathline segment to the other end; TLENGTH, total horizontal distance from the start of the pathline to the end of the pathline segment; BLENGTH, total distance traveled (horizontal and vertical) along the pathline segment; and CLENGTH, total distance traveled (horizontal and vertical) from the start of the pathline to the end of the pathline segment. The updated values are stored in the arc attribute table for the data layer PATHUPT_WET. The input data layer is unchanged. The last three arguments on the command line indicate that the data layer units are in meters, the MODPATH depth variables BDEPTH and EDEPTH units are in feet, and the new variables TLENGTH, BLENGTH, and CLENGTH units will be in feet. The choices for these three required arguments are FEET or METERS.

(page 39 follows)

APPENDIX 3. PROGRAM SOURCE CODE

INFO Program NET

Fortran Program net.rfmt

ARC/INFO AML Program PARTICLE

ARC/INFO AML Program MPSORT

ARC/INFO AML Program DEPTH

The source code for INFO, Fortran, and ARC/INFO AML programs not
documented in other reports are presented in this appendix.

INFO Program NET

```
PROGRAM SECTION ONE
CALC $COMMA-SWITCH = -1
CALC $NM = 1
SEL WELLGRID.PAT
RELATE 1 LAYER1 BY SEQNUM LINK
RELATE 2 LAYER2 BY SEQNUM LINK
RELATE 3 LAYER3 BY SEQNUM LINK
RELATE 4 LAYER4 BY SEQNUM LINK
RELATE 5 LAYER5 BY SEQNUM LINK
OUTPUT ../net.data INIT
PROGRAM SECTION TWO
PRINT NETWORK-ID, ROW, COL, DEPTH, CSNG-BOT, OPEN-TOP, OPEN-BOT, LOCAL
PRINT $1TOP
PRINT $1BOTTOM
PRINT $2BOTTOM
PRINT $3BOTTOM
PRINT $4BOTTOM
PRINT $5BOTTOM
PROGRAM END
```

Fortran Program net.rfmt

```
C  - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C
C   Command name: NET.RFMT
C   Language: F77
C
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C
C   Purpose: Reads data output from MODFLOW data sets (LAYER
C            BOTTOM for layers 1 to NLAY, ROW and COLUMN) and
C            well construction data (DEPTH, CASING BOTTOM,
C            OPEN TOP, OPEN BOTTOM) and creates a MODPATH
C            particle starting point input data set.
C
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C
C   Arguments:
C      Variable name, I/O,    Type,           Definition
C      - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C      INFIL             input   character*40 Input file name
C      OUTFIL            input   character*40 Output file name
C      NLAY              input   integer      Number of model layers
C      KMISS             input   integer      Missing value for well data
C   :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C
C   History:
C        Author/Site,   Date,    Event
C        - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C        Roy S. Sonenshein    11/23/92  Version 1.0
C        (SUNSHINE@sflmia.er.usgs.gov)
C
C   :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C
C   Notes:
C   The input file format is as follows:
C   For each well, the first line is of the format
C
C   5004 FORMAT (I6,2(I5),4(2X,I5),1X,A10)
C
C   with the variables identification number, row number, column number,
C   depth of well, depth of casing, top of open interval, bottom of open
C   interval.
C   This line is followed by N lines for each well, where N is equal to
C   the number of layers plus one. The format for each of these lines is:
C
C   5005 FORMAT (F8.2)
C
C   The variable on the first line is land surface elevation, the variable
C   on each successive line is the depth to the bottom of each model layer,
C   starting with layer 1.
C
C   Sixteen particles are used, 4 on each vertical face of each grid cell
C   specified in the input data set. The particles are placed two thirds of
C   the distance from each edge to the center of each face at the top and
C   bottom of the open interval for each well.
C
C   - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C                                 /*File name of input file
         CHARACTER*40 INFIL
C                                 /*File name of output file
```

```
      CHARACTER*40 OUTFIL
C                                 /*File name of error output file
C     INTEGER NLAY                /*Number of layers
C     INTEGER KMISS               /*Missing value for well data
      CHARACTER*40 ERRFIL
C                                 /*File name of particle number/well output file
      CHARACTER*40 CNTFIL
C The following are input variables from INFIL
C     INTEGER NETID               /* Well ID number from ARC/INFO
C     INTEGER IROW                /* Row number
C     INTEGER JCOL                /* Column number
C     INTEGER KDEPTH              /* Depth of well (feet)
C     INTEGER KBCSNG              /* Bottom of casing (feet)
C     INTEGER KTOPEN              /* Top of open interval (feet)
C     INTEGER KBOPEN              /* Bottom of open interval (feet)
C                                 /* Well station name
      CHARACTER*10 LOCAL
C                                 /* Bottom of layer I+1 (feet, msl)
C                                 /* BOT(1) = top of layer 1
C                                 /* which is land surface elevation (feet, msl)
C                                 /* Array size of 100 may be increased
      REAL     BOT(100)
C The following are variables used in the calculations
C                                 /* Bottom of layer I+1 (feet, lsd)
C                                 /* Array size of 100 may be increased
      REAL     DBOT(100)
C     REAL     DEPTH              /* Depth of well (feet)
C     INTEGER KLAY                /* Layer number
C     REAL     TOP                /* Top of layer
C     REAL     BOTTOM             /* Bottom of layer
C     REAL     XLMIN              /* Minimum local x-coordinate in JCOL
C     REAL     XL1                /* 1/3 local x-coordinate in JCOL
C     REAL     XL3                /* 2/3 local x-coordinate in JCOL
C     REAL     XLMAX              /* Maximum local x-coordinate in JCOL
C     REAL     YLMIN              /* Minimum local y-coordinate in IROW
C     REAL     YL1                /* 1/3 local y-coordinate in IROW
C     REAL     YL3                /* 2/3 local y-coordinate in IROW
C     REAL     YLMAX              /* Maximum local y-coordinate in IROW
C     REAL     ZLMIN              /* Minimum local z-coordinate in KLAY
C     REAL     ZLMAX              /* Maximum local z-coordinate in KLAY
C     Note: The z-coordinate system is in the same direction as the
C     msl coordinate system (i.e. z-values increase with msl values)
C
C
C -----------------------------------------------------------------------
C
C.... Get input and output file names.  Open files
 5001 FORMAT (A128)
 5002 FORMAT (I10)
      WRITE (*,*) ' Enter name of input file'
      READ (*,5001) INFIL
      WRITE (*,*) ' Enter name of output file'
      READ (*,5001) OUTFIL
      WRITE (*,*) ' Enter number of layers'
      READ (*,5002) NLAY
      WRITE (*,*) ' Enter integer missing value for well data'
      READ (*,5002) KMISS
C Add 1 to the number of layers since the BOT(I) array requires the reading
C of the bottom of each layer and the top of layer one.
      NLAY = NLAY + 1
      ERRFIL = 'net.rfmt.err'
      CNTFIL = 'net.rfmt.cnt'
      OPEN (UNIT=10,FILE=INFIL,STATUS='OLD',ERR=8000)
```

```
          OPEN (UNIT=11,FILE=OUTFIL,STATUS='NEW',ERR=8100)
          OPEN (UNIT=12,FILE=ERRFIL,STATUS='NEW',ERR=8110)
          OPEN (UNIT=13,FILE=CNTFIL,STATUS='NEW',ERR=8110)
C.... Read INFILE one well at a time
 5004 FORMAT (I6,2(I5),4(2X,I5),1X,A10)
 5005 FORMAT (F8.2)
          ICNT = 0
 5020 READ (10,5004,END=30,ERR=8200) NETID,IROW,JCOL,KDEPTH,KBCSNG,
      1KTOPEN,KBOPEN,LOCAL
          DEPTH = FLOAT(KDEPTH)
          DO 5030 I = 1,NLAY
              READ (10,5005,END=30,ERR=8200) BOT(I)
              DBOT(I) = BOT(1) - BOT(I)
 5030 CONTINUE
C.... Determine layer for bottom of well (DEPTH)
          KLAY = 0
          DO 5040 I = 2,NLAY
          IF (DEPTH .LE. DBOT(I)) THEN
              KLAY = I - 1
              TOP = DBOT(I-1)
              BOTTOM = DBOT(I)
              GOTO 5050
          END IF
 5040 CONTINUE
 5050 CONTINUE
          IF (KLAY .EQ. 0) THEN
              GOTO 7000
          END IF
C.... Set default values for local coordinates
          XLMIN = 0.01
          XL1   = 0.33
          XL3   = 0.67
          XLMAX = 0.99
          YLMIN = 0.01
          YL1   = 0.33
          YL3   = 0.67
          YLMAX = 0.99
          ZLMAX = 0.10
          ZLMIN = ((BOTTOM - DEPTH)/(BOTTOM - TOP))
C.... Recalculate values for ZLMIN and ZLMAX based on values of KBCSNG,
C.... KTOPEN, and KBOPEN (casing bottom or open interval).
C.... Missing value is KMISS
C
C.... If casing bottom is known, recalculate ZLMAX
 5100 IF (KBCSNG .NE. KMISS) THEN
              TOPEN = FLOAT(KBCSNG)
              ZLMAX = 1 - ((TOPEN - TOP)/(BOTTOM - TOP))
              IF (ZLMAX .GE. 1) ZLMAX = .99
          END IF
C.... If open interval top is known, recalculate ZLMAX
C.... This takes precedence over casing bottom
 5200 IF (KTOPEN .NE. KMISS) THEN
              TOPEN = FLOAT(KTOPEN)
              ZLMAX = 1 - ((TOPEN - TOP)/(BOTTOM - TOP))
              IF (ZLMAX .GE. 1) ZLMAX = .99
          END IF
C.... If open interval bottom is known, recalculate ZLMIN
 5300 IF (KBOPEN .NE. KMISS) THEN
              BOPEN = FLOAT(KBOPEN)
              ZLMIN = ((BOTTOM - BOPEN)/(BOTTOM - TOP))
          END IF
          GO TO 6010
C Write to OUTFIL unit 11
```

```
6005 FORMAT (3(I10),3(4X,F6.4))
6006 FORMAT (I4,',',A10)                              .
6010 WRITE (11,6005) JCOL,IROW,KLAY,XLMIN,YL1,ZLMIN
     WRITE (11,6005) JCOL,IROW,KLAY,XLMIN,YL1,ZLMAX
     WRITE (11,6005) JCOL,IROW,KLAY,XLMIN,YL3,ZLMIN
     WRITE (11,6005) JCOL,IROW,KLAY,XLMIN,YL3,ZLMAX
     WRITE (11,6005) JCOL,IROW,KLAY,XLMAX,YL1,ZLMIN
     WRITE (11,6005) JCOL,IROW,KLAY,XLMAX,YL1,ZLMAX
     WRITE (11,6005) JCOL,IROW,KLAY,XLMAX,YL3,ZLMIN
     WRITE (11,6005) JCOL,IROW,KLAY,XLMAX,YL3,ZLMAX
     WRITE (11,6005) JCOL,IROW,KLAY,XL1,YLMIN,ZLMIN
     WRITE (11,6005) JCOL,IROW,KLAY,XL1,YLMIN,ZLMAX
     WRITE (11,6005) JCOL,IROW,KLAY,XL3,YLMIN,ZLMIN
     WRITE (11,6005) JCOL,IROW,KLAY,XL3,YLMIN,ZLMAX
     WRITE (11,6005) JCOL,IROW,KLAY,XL1,YLMAX,ZLMIN
     WRITE (11,6005) JCOL,IROW,KLAY,XL1,YLMAX,ZLMAX
     WRITE (11,6005) JCOL,IROW,KLAY,XL3,YLMAX,ZLMIN
     WRITE (11,6005) JCOL,IROW,KLAY,XL3,YLMAX,ZLMAX
     ICNT = ICNT + 1
     MIN = ((ICNT - 1) * 16) + 1
     MAX = MIN + 15
     DO 6050 IPART = MIN,MAX
         WRITE (13,6006) IPART,LOCAL
6050 CONTINUE
     GO TO 5020
7000 WRITE (12,7010) LOCAL
7010 FORMAT ('WELL ',A10,' IS BELOW BOTTOM MODEL LAYER')
     GO TO 5020
8000 WRITE (*,*) 'FILE DOES NOT EXIST OR PROBLEM OPENING FILE ',INFIL
     GO TO 40
8100 WRITE (*,*) 'FILE EXISTS OR PROBLEM OPENING FILE ',OUTFIL
     GO TO 40
8110 WRITE (*,*) 'FILE EXISTS OR PROBLEM OPENING FILE ',ERRFILE
     GO TO 40
8200 ICNT = ICNT + 1
     WRITE (*,*) 'PROBLEM READING FROM ',INFIL
     WRITE (*,*) 'WELL NUMBER',ICNT, ' IN FILE'
     GOTO 40
30   WRITE (*,*)
     WRITE (*,*) 'DATA REFORMATTED FOR MODPATH FROM FILE ', INFIL
     WRITE (*,*) 'OUTPUT IS IN FILE ',OUTFIL
     WRITE (*,*) 'PARTICLE NUMBERS AND WELL NAMES ARE IN FILE ', CNTFIL
     WRITE (*,*) 'PROBLEMS ARE IN FILE ', ERRFIL
40   CONTINUE
     CLOSE (UNIT=10,STATUS='KEEP')
     CLOSE (UNIT=11,STATUS='KEEP')
     CLOSE (UNIT=12,STATUS='KEEP')
     STOP
     END
```

ARC/INFO AML Program PARTICLE

```
/*
/*  *********************************************************************
/*  *   PROGRAM: PARTICLE
/*  *    AUTHOR: ROY S. SONENSHEIN (original coding)
/*  *
/*  *    SYSTEM: ARC/INFO 6.1                           RELEASE: REV92.1
/*  * LANGUAGE: AML                                     DATE: 11/30/92
/*  *********************************************************************
/*  *     CALLS:
/*  *              (VARIOUS ARC 6.1 SYSTEM COMMANDS)
/*  *              (INFO SUBSYSTEM)
/*  *********************************************************************
/*
/*  *********************************************************************
/*  * PURPOSE:  Overlays a polygon coverage on the line coverage created
/*  *           by MODPATHARC.  The overlay is performed separately on
/*  *           each particle pathline selected.  This avoids the splitting
/*  *           and merging of intersecting arcs which would be caused by
/*  *           the IDENTITY command.  Also creates a buffer coverage of
/*  *           the selected pathlines at a user specified buffer distance.
/*  *********************************************************************
/*
/*     USAGE: PARTICLE <input.coverage> <output.line.coverage>
/*     <overlay.polygon.coverage> <output.buffer.coverage>
/*     <input.particle.number.file> <buffer distance>
/*
/*     ARGUMENTS:
/*
/*         <input.coverage> - The line coverage created by MODPATHARC.
/*
/*         <output.coverage> - The line coverage to be created from the
/*                             IDENTITY on the input coverage.
/*
/*         <overlay.polygon.coverage> - The polygon coverage which will
/*                             be used for the IDENTITY command. This will
/*                             usually be a coverage which reflects land
/*                             surface features which may contribute to the
/*                             water quality of the ground water. An example
/*                             is land use.
/*
/*         <output.buffer.coverage> - The polygon coverage to be created
/*                             from the CLIP of the overlay polygon coverage
/*                             using the BUFFER of the input.coverage as the
/*                             clip cover
/*
/*         <input.particle.number.file> - Sequential access file containing
/*                             the number(s) of the MODPATH particles to be
/*                             used for the analysis.  Each particle number
/*                             is on separate line of the file.
/*
/*         <buffer.distance> - The distance to be used as a buffer around
/*                             each particle pathline to create a CLIP
/*                             coverage of the overlay polygon coverage.
/*
/*  *********************************************************************
/*
/*  *********************************************************************
/*  * MODIFICATIONS:
/*  *********************************************************************
/*
```

```
/* ************************************************************************
/* *       GLOSSARY OF GLOBAL VARIABLES AND/OR SUBROUTINE ARGUEMENTS      *
/* *                                                                      *
/* ************************************************************************
/*
/*
/* Disclaimer:
/*   Although this program has been used by the U.S. Geological Survey, no
/* warranty, expressed or implied, is made by the USGS as to the accuracy
/* and functioning of the program and related program material nor shall the
/* fact of distribution constitute any such warranty, and no responsibility
/* is assumed by the USGS in connection herewith.
/*
/*-----------------------------------------------------------------------
&args incov outcov inpoly outpoly inparticle buffdist
&severity &warning &ignore
&severity &error &routine fail
&messages &off
/*
/* Error trap input arguments
/*
&if [null %incov%] &then &goto error
&if [null %outcov%] &then &goto error
&if [null %inpoly%] &then &goto error
&if [null %outpoly%] &then &goto error
&if [null %inparticle%] &then &goto error
&if [null %buffdist%] &then &goto error
&s incov = [translate %incov%]
&s outcov = [translate %outcov%]
&s inpoly = [translate %inpoly%]
&s outpoly = [translate %outpoly%]
&if ^ [exists %incov% -line] &then &do
     &type
     &type ERROR>>> Coverage %incov% does not exist
     &type          or does not have line topology!!!
     &goto error
&end
&if [exists %outcov% -cover] &then &do
     &type
     &type ERROR>>> Coverage %outcov% already exists!!!
     &goto error
&end
&if ^ [exists %inpoly% -polygon] &then &do
     &type
     &type ERROR>>> Coverage %inpoly% does not exist
     &type          or does not have polygon topology!!!
     &goto error
&end
&if [exists %outpoly% -cover] &then &do
     &type
     &type ERROR>>> Coverage %outpoly% already exists!!!
     &goto error
&end
&if ^ [exists %inparticle% -file] &then &do
     &type
     &type ERROR>>> File %inparticle% does not exist!!!
     &goto error
&end
&s bufftype [type %buffdist%]
&if %bufftype% > 0 &then &do
     &type
     &type ERROR>>> Buffer distance must be a number
     &type
```

```
      &goto error
&end
   &s path :=  [dir [pathname *]]
   &s infohome $ARCHOME/programs/info
   &s infosub = %path%/info
&s openunit = [open %inparticle% openstat -read]
&if %openstat% > 0 &then &do
      &type
      &type ERROR opening file %inparticle%
      &goto error
&end
/* reader = return status of [read] function, 102 = end of file
&s reader = 0
/* count = number of particles
&s count = 0
/* parterr = flag for error in particle file
&s parterr = 0
/* part%count% = index variable for particle numbers
&s reader = 0
&do &while %reader% = 0
      &s count = %count% + 1
      &s part%count% = [ read %openunit% reader ]
      &s ptype = [type [value part%count%]]
      &if %ptype% ne -1 and %reader% = 0 &then
      &do
         &type
         &type Line %count% in %inparticle% contains an invalid value
         &type [value part%count%]
         &type Value must be an integer
         &type
         &s parterr = 100
      &end
&end
&if %reader% = 101 or %reader% = 103 &then &goto readerr
&if %parterr% = 100 &then &goto closeall
&s count = %count% - 1
&if %count% = 0 &then &do
      &type
      &type no valid particle numbers read from %inparticle%
      &goto closeall
&end
/* resel = check for error of no arcs for a specified particle
&s resel = 0
/*
/* start of DO loop for each particle
&do I = 1 &to %count%
      &s J = [value part%I%]
      &type
      &type Checking for particle %J%
      &if [exists xxcov%J% -cover] &then KILL xxcov%J%
      /* start of RESELECT command
RESELECT %incov% xxcov%J% LINE
RESELECT PARTICLE = %J%
[unquote ' ']
N
N
      /* end of RESELECT command
      &describe xxcov%J%
      /* if no arcs were selected for the particle, then there is a problem
      &if %DSC$ARCS% = 0 &then &do
         &type
         &type An error occurred in the RESELECT command for particle %J%
         &type Please check to see if particle %J% exists
```

```
              &s resel = -1
         &end
    &end
    /* if error with any particle, then stop
    &describe %inpoly%
    &s fuzzyinpoly = %dsc$fuzzy%
    &if %resel% = -1 &then &goto cleanup
TOLERANCE %inpoly% FUZZY 0.05
    /* end of DO loop for each particle
    /* start of DO loop for each particle
    &do I = 1 &to %count%
         &s J = [value part%I%]
         &type
         &type Processing particle %J%
         &if [exists xxid%J% -cover] &then KILL xxid%J%
TOLERANCE xxcov%J% FUZZY 0.05
IDENTITY xxcov%J% %inpoly%  xxid%J% LINE 0.05 JOIN
INDEXITEM xxid%J%.AAT xxcov%J%-ID
    /* start of RELATE
RELATE ADD
XXPATH
xxid%J%.AAT
INFO
xxcov%J%-ID
xxcov%J%-ID
LINEAR
RO
[unquote ' ']
    /* end of RELATE
    &if [exists xxcov%J%a -cover] &then KILL xxcov%J%a
    /* start of RESELECT command
RESELECT xxcov%J% xxcov%J%a LINE
RESELECT  xxcov%J%-ID NE XXPATH//xxcov%J%-ID
[unquote ' ']
N
N
    /* end of RESELECT command
    /* start of RELATE command
RELATE DROP
XXPATH
[unquote ' ']
    /* end of RELATE command
    /* start of DROPITEM - DO NOT INDENT
DROPITEM xxid%J%.AAT xxid%J%.AAT
xxcov%J%#
xxcov%J%-ID
END
    /* end of DROPITEM
    &describe xxcov%J%a
    /* if arcs were selected for the particle, then they were smaller
    /* than the minimum fuzzy tolerance for the IDENTITY command
    /* and need to be appended to the IDENTITY coverage
    /* start of DO loop for lost arcs
    &if %DSC$ARCS% gt 0 &then &do
       &type Particle %J% contains %DSC$ARCS% arcs which were removed by
       &type the IDENTITY command due to FUZZY tolerance - adding arcs....
       &type Note: these arcs have no values from the IDENTITY coverage
       &type
       &if [exists xxid%J%a -cover] &then KILL xxid%J%a
    /* start of APPEND command
APPEND xxid%J%a NOTEST NONE
xxid%J%
xxcov%J%a
```

```
END
        /* end of APPEND command
BUILD xxid%J%a LINE
ADDITEM xxid%J%a.AAT xxid%J%a.AAT xxid%J%# 4 5 B
        /* start of TABLES command
TABLES
SEL xxid%J%a.AAT
CALCULATE xxid%J%# = xxid%J%a#
SEL xxcov%J%a.AAT
UNLOAD xxcov.aat delimited init
Q STOP
        /* end of TABLES command
        &workspace %infosub%
/* use info ADD FROM because TABLES ADD FROM requires the %polycov%
/* attributes to be in the ASCII file
/* the INFO commands must not be indented
        &data %infohome% > /dev/null
ARC
SEL XXID%J%.AAT
ADD FROM %path%/xxcov.aat
Q STOP
        &end
   &workspace %path%
/*
JOINITEM xxid%J%a.AAT xxid%J%.AAT xxid%J%a.AAT xxid%J%# xxid%J%a-ID LINK
        &if [exists xxid%J% -cover] &then KILL xxid%J%
        /* start of DROPITEM
DROPITEM xxid%J%a.AAT xxid%J%a.AAT
xxid%J%#
xxid%J%-ID
END
        /* end of DROPITEM
        &if [exists xxid%J%a -cover] &then  RENAME xxid%J%a xxid%J%
     &end
     /* end of DO loop for lost arcs
     &if [exists xxcov%J% -cover] &then KILL xxcov%J%
     &if [exists xxcov%J%a -cover] &then KILL xxcov%J%a
&end
/* end of DO loop for each particle
/*
&type APPENDing particle coverages...
&type
TOLERANCE %inpoly% FUZZY %fuzzyinpoly%
/* start of APPEND
&severity &error &ignore
APPEND %outcov% LINE NONE
&do I = 1 &to %count%
     &s J = [value part%I%]
     xxid%J%
&end
END
/* end of APPEND
&do I = 1 &to %count%
     &s J = [value part%I%]
     &s lengther = [length %J%]
     &if %lengther% > 0 &then &do
        &if [exists xxid%J% -cover] &then KILL xxid%J%
     &end
&end
BUILD %outcov% LINE
/* The item PATHID is required for future processing to relate
/* using INFO back to the original PATHLINE coverage
ADDITEM %outcov%.AAT %outcov%.AAT PATHID 4 5 B # %outcov%-ID
```

```
TABLES
SEL %outcov%.AAT
CALC PATHID = %outcov%-ID
Q STOP
&if [exists xxbuff -cover] &then KILL xxbuff
BUFFER %outcov% xxbuff # # %buffdist% 1 LINE
CLIP %inpoly% xxbuff %outpoly% POLY
&if [exists xxbuff -cover] &then KILL xxbuff
LOG %outcov% ADD
PARTICLE %incov% %outcov% %inpoly% %outpoly% %inparticle% %buffdist%
&type
&type ===>> Identity cover %outcov% created from %incov%...
&type ===>> Clip cover %outpoly% created from %inpoly%...
&type
&type        !!---NOTE---NOTE---NOTE---NOTE---NOTE---NOTE---!!
&type
&type ===>> The item %incov%-ID must be updated in %outcov%.AAT
&type ===>> to allow the AAT file to be sorted in time sequence
&type ===>> prior to executing DEPTH.AML!!!
&type
/*
/*
/* File clean-up
/*
&label cleanup
&severity &error &ignore
&s count = %count% + 2
&do I = 1 &to %count%
    &s J = [value part%I%]
    &s lengther = [length %J%]
    &if %lengther% > 0 &then &do
      &if [exists xxcov%J% -cover] &then KILL xxcov%J%
      &if [exists xxid%J% -cover] &then KILL xxid%J%
      &if [exists xxcov%J%a -cover] &then KILL xxcov%J%a
      &if [exists xxid%J%a -cover] &then KILL xxid%J%a
    &end
&end
&if %resel% = 0 &then TOLERANCE %inpoly% FUZZY %fuzzyinpoly%
&s deleter [delete xxcov.aat -file]
&label closeall
&s closer = [close -all]
/*
&messages &on
&return
/*
/*  Error routines
/*
/*&label openerr
/*    &do
/*      &type ERROR %err%>>> OPENING TEMPORARY FILE
/*      &goto cleanup
/*    &end
/*
&label readerr
    &do
      &type ERROR %reader% >>> reading from %inparticle%
      &goto cleanup
    &end
/*
&label error
  &message &on
  &type
  &type Usage: PARTICLE <input.coverage> <output.line.coverage>
```

```
  &type          <overlay.polygon.coverage> <output.buffer.coverage>
  &type          <input.particle.number.file> <buffer distance>
  &type          (-- output.coverage.names maximum of 8 characters --)
  &type
  &s count = 1
  &s closer = [close -all]
  &return
/*
&routine fail
  &type
  &type An unspecified error has occurred in the program PARTICLE
  &type
  &s count = 1
&goto cleanup
&return
```

ARC/INFO AML Program MPSORT

```
/*
/* ********************************************************************
/* *   PROGRAM: MPSORT
/* *    AUTHOR: ROY S. SONENSHEIN (original coding)
/* *
/* *    SYSTEM: ARC/INFO 6.1                        RELEASE: REV92.1
/* *  LANGUAGE: AML                                 DATE: 4/8/93
/* ********************************************************************
/* *     CALLS:
/* *              (VARIOUS ARC 6.1 SYSTEM COMMANDS)
/* *              (INFO SUBSYSTEM)
/* ********************************************************************
/*
/* ********************************************************************
/* * PURPOSE: After execution of the PARTICLE.AML program, the item
/* *          %incov%-ID must be updated so that the AAT file can sorted
/* *          by the pathline time sequence.  The IDENTITY command
/* *          executed in PARTICLE.AML splits arcs and performs a CLEAN,
/* *          which can scramble the arcs from the proper time sequence.
/* *
/* ********************************************************************
/* ********************************************************************
/*
/*    USAGE: SORT <input.coverage>
/*
/*    ARGUMENTS:
/*
/*    incov  <input.coverage> - The line coverage created by PARTICLE.
/*
/*
/* ********************************************************************
/*
/* ********************************************************************
/* * MODIFICATIONS:
/* *                                                                  *
/* ********************************************************************
/*
/* ********************************************************************
/* *      GLOSSARY OF GLOBAL VARIABLES AND/OR SUBROUTINE ARGUEMENTS   *
/* *                                                                  *
/* ********************************************************************
/*
/* ********************************************************************
/*
/*
/* Disclaimer:
/*   Although this program has been used by the U.S. Geological Survey, no
/* warranty, expressed or implied, is made by the USGS as to the accuracy
/* and functioning of the program and related program material nor shall the
/* fact of distribution constitute any such warranty, and no responsibility
/* is assumed by the USGS in connection herewith.
/*
/*-------------------------------------------------------------------
&args incov
&messages &off
&if [null %incov%] &then &goto error
&if ^ [exists %incov% -line] &then &do
    &type
    &type ERROR>>> Coverage %incov% does not exist
    &type          or does not have line topology!!!
```

```
      &goto error
&end
&if   ^  [iteminfo %incov% -ARC BTIME -exists] or ~
  ^  [iteminfo %incov% -ARC PARTICLE -exists] &then &do
      &type
      &type One or both of the items BTIME and PARTICLE, do not exist.
      &type %incov% may not be a coverage which was output from the
      &type PARTICLE.AML.
      &goto error
&end                                                        .
&s incov [translate %incov%]
&s inatt %incov%.AAT
&s inlb %incov%#
&s iditem %incov%-ID
&s path :=  [dir [pathname *]]
&s infohome $ARCHOME/programs/info
&s infosub = %path%/info
&if [exists XXFREQ -info] &then; &s dele := [delete XXFREQ -info]
&if [exists XXTNODE -info] &then; &s dele := [delete XXTNODE -info]
/* calculate incov-ID = 1 for BTIME = 0.00
&type  Checking for multiple begin time = 0 for coverage %incov%....
TABLES
COPY %inatt% XXTNODE
SELECT XXTNODE
SORT TNODE#
RELATE ADD
XXNODE
XXTNODE
INFO
FNODE#
TNODE#
ORDERED
RO
[unquote '']
SELECT %inatt%
RESEL FNODE# NE XXNODE//TNODE#
RESELECT BTIME = 0.00 AND %iditem% GT 0
CALCULATE %iditem% = 1
Q STOP
IDEDIT %incov% LINE
/* create frequency file for list of particles to use with INFO
FREQUENCY %inatt% XXFREQ
PARTICLE
END
END
&type  Executing INFO program for coverage %incov%...
   &workspace %infosub%
   &data %infohome%  > /dev/null  /* the INFO commands must not be indented
ARC
ERASE XXSORT.PG
Y
PROGRAM XXSORT.PG
FORMAT $NUM1,5,5,I
FORMAT $NUM2,5,5,I
FORMAT $NUM3,5,5,I
FORMAT $NUM4,5,5,I
FORMAT $NUM5,5,5,I
FORMAT $NUM6,5,5,I
FORMAT $NUM7,5,5,I
SEL XXFREQ
SORT PARTICLE
CALC $NUM1 = $NOREC
CALC $NUM2 = 1
```

```
DO WHILE $NUM2 LE $NUM1
  SEL XXFREQ
  RESEL $RECNO = $NUM2
  CALC $NUM2 = $NUM2 + 1
  CALC $NUM3 = PARTICLE
  SEL %inatt%
  RESELECT PARTICLE = $NUM3 and %iditem% = 1
  CALCULATE $NUM4 = TNODE#
  NSELECT
  RESELECT PARTICLE = $NUM3
  CALCULATE %iditem% = 9999
  CALCULATE $NUM5 = 1
  CALCULATE $NUM6 = 1
  DO UNTIL $NUM6 NE 1
    RESELECT FNODE# = $NUM4
    CALCULATE $NUM6 = $NOSEL
    CALCULATE $NUM5 = $NUM5 + 1
    CALCULATE %iditem% = $NUM5
    CALCULATE $NUM4 = TNODE#
    DISPLAY PARTICLE, FNODE#,TNODE#,%incov%-ID,BTIME
    ASELECT
    RESELECT PARTICLE = $NUM3
  DOEND
DOEND
[unquote '']
COMPILE XXSORT.PG
RUN XXSORT.PG
ERASE XXSORT.PG
Y
Q STOP
  &end
  &workspace %path%
IDEDIT %incov% LINE
/*clean-up
&if [exists XXFREQ -info] &then; &s dele := [delete XXFREQ -info]
LOG %incov% ADD
SORT2 %incov%
&messages &on
&RETURN
&label error
  &message &on
  &type
  &type Usage: SORT <input.coverage>
  &type
  &type        The <input.coverage> must be in the current workspace
  &type
&return
```

ARC/INFO AML Program DEPTH

```
/*
/* ********************************************************************************
/* *    PROGRAM: DEPTH
/* *     AUTHOR: ROY S. SONENSHEIN (original coding)
/* *
/* *     SYSTEM: ARC/INFO 6.1                           RELEASE: REV92.1
/* *   LANGUAGE: AML                                     DATE: 1/29/93
/* ********************************************************************************
/* *      CALLS:
/* *              (VARIOUS ARC 6.1 SYSTEM COMMANDS)
/* *              (INFO SUBSYSTEM)
/* ********************************************************************************
/*
/* ********************************************************************************
/* * PURPOSE:  To update the MODPATH attributes after a overlay function
/* *           has been performed on a MODPATH coverage created by
/* *           MODPATHARC.AML
/* ********************************************************************************
/*
/*    USAGE: DEPTH <input.coverage> <output.coverage> <input.units>
/*                 <depth.units> <output.units>
/*
/*    ARGUMENTS:
/*
/*    incov  <input.coverage> - The line coverage created by PARTICLE.
/*
/*    outcov  <output.coverage> - The line coverage with the updated
/*                                ARC ATTRIBUTE table
/*
/*    iunit  <input.units> - METERS | FEET - units for coverage LENGTH
/*                           variable
/*
/*    dunit  <depth.units> - METERS | FEET - units for attribute table
/*                           BDEPTH and EDEPTH variables
/*
/*    ounit  <output.units> - METERS | FEET - units desired for new
/*                            variables TLENGTH, BLENGTH, and CLENGTH
/*
/* ********************************************************************************
/*
/* ********************************************************************************
/* * MODIFICATIONS:
/* *                                                                             *
/* ********************************************************************************
/*
/* ********************************************************************************
/* *       GLOSSARY OF GLOBAL VARIABLES AND/OR SUBROUTINE ARGUEMENTS             *
/* *                                                                             *
/* ********************************************************************************
/*
/* ********************************************************************************
/* * NOTE: After execution of the PARTICLE.AML program, the item
/* *       %incov%-ID must be updated (using SORT.AML,ARCEDIT,TABLES,
/* *       INFO,etc...) so that the AAT file can sorted by the pathline
/* *       time sequence.  The IDENTITY command executed in PARTICLE.AML
/* *       splits arcs and performs a CLEAN, which can scramble the arcs
/* *       from the proper time sequence.
/* *
/* ********************************************************************************
/*
```

```
/*
/* Disclaimer:
/*    Although this program has been used by the U.S. Geological Survey, no
/* warranty, expressed or implied, is made by the USGS as to the accuracy
/* and functioning of the program and related program material nor shall the
/* fact of distribution constitute any such warranty, and no responsibility
/* is assumed by the USGS in connection herewith.
/*
/*-----------------------------------------------------------------------
&args incov outcov iunit dunit ounit
&messages &off
/*
/* Error trap input arguments
/*
&s incov = [translate %incov%]
&s outcov = [translate %outcov%]
&s iunit = [translate %iunit%]
&s dunit = [translate %dunit%]
&s ounit = [translate %ounit%]
&if [null %incov%] &then &goto error
&if [null %outcov%] &then &goto error
&if [null %iunit%] &then &goto error
&if [null %dunit%] &then &goto error
&if [null %ounit%] &then &goto error
&if ^ [exists %incov% -line] &then &do
    &type
    &type ERROR>>> Coverage %incov% does not exist
    &type         or does not have line topology!!!
    &goto error
&end
&if [exists %outcov% -directory] &then &do
    &type
    &type ERROR>>> Coverage or directory %outcov% already exists
    &goto error
&end
&s iu = [keyword %iunit% METERS FEET]
&s du = [keyword %dunit% METERS FEET]
&s ou = [keyword %ounit% METERS FEET]
&if %iu% = 0 or %du% = 0 or %ou% = 0 &then; &do
  &type
  &type units must be either METERS or FEET
  &goto error
&end
&s path := [dir [pathname *]]
&s infohome $ARCHOME/programs/info
&s infosub = %path%/info
&type
&type  Checking for correct items...
&if ^ [iteminfo %incov% -ARC PATHID -exists] or ~
 ^  [iteminfo %incov% -ARC BDEPTH -exists] or ~
 ^  [iteminfo %incov% -ARC EDEPTH -exists] or ~
 ^  [iteminfo %incov% -ARC BTIME -exists] or ~
 ^  [iteminfo %incov% -ARC ETIME -exists] or ~
 ^  [iteminfo %incov% -ARC PARTICLE -exists] &then &do
    &type
    &type One or more of the items BDEPTH,EDEPTH,BTIME,ETIME,PARTICLE,
    &type PATHID do not exist.  %incov% may not be a coverage which
    &type was output from the PARTICLE.AML.
    &goto error
&end
/*
&if [exists XXSTAT -info] &then; &s dele := [delete XXSTAT -info]
/* Check for items to be ADDED
```

```
&if [iteminfo %incov% -ARC DTIME -exists] or ~
   [iteminfo %incov% -ARC DDEPTH -exists] or ~
   [iteminfo %incov% -ARC TLENGTH -exists] or ~
   [iteminfo %incov% -ARC BLENGTH -exists] or ~
   [iteminfo %incov% -ARC CLENGTH -exists] &then &do
      &type
      &type One or more of the items DTIME,DDEPTH,TLENGTH,BLENGTH,CLENGTH
      &type already exist in %incov%.AAT.  Please delete or change the
      &type name of these items.
      &goto error
&end
/*
COPY %incov% %outcov%
ADDITEM %outcov%.AAT %outcov%.AAT DTIME 4 12 F 2 ETIME
ADDITEM %outcov%.AAT %outcov%.AAT DDEPTH 4 9 F 2 EDEPTH
ADDITEM %outcov%.AAT %outcov%.AAT TLENGTH 4 12 F 3 PATHID
ADDITEM %outcov%.AAT %outcov%.AAT BLENGTH 4 12 F 3 TLENGTH
ADDITEM %outcov%.AAT %outcov%.AAT CLENGTH 4 12 F 3 BLENGTH
STATISTICS %outcov%.AAT XXSTAT PATHID
SUM LENGTH
END
/* dconv1 = conversion factor for DDEPTH units to LENGTH units
&s dconv1 = 1
&if %iu% = 1 and %du% = 2 &then &s dconv1 = 0.3048   /* FEET to METERS
&if %iu% = 2 and %du% = 1 &then &s dconv1 = 3.2808   /* METERS to FEET
/* dconv2 = conversion factor for LENGTH units to desired output units
/* for TLENGTH, BLENGTH, and CLENGTH
&s dconv2 = 1
&if %iu% = 1 and %ou% = 2 &then &s dconv2 = 3.2808   /* METERS to FEET
&if %iu% = 2 and %ou% = 1 &then &s dconv2 = 0.3048   /* FEET to METERS
&type  Executing INFO program...
   &workspace %infosub%
   &data %infohome%  > /dev/null   /* the INFO commands must not be indented
ARC
ERASE XXDEPTH.PG
Y
PROGRAM XXDEPTH.PG
SEL %outcov%.AAT
SORT PARTICLE,%outcov%-ID
RELATE 1 XXSTAT BY PATHID
FORMAT $NUM1,4,12,F,3
FORMAT $NUM2,4,12,F,3
FORMAT $NUM3,4,12,F,3
FORMAT $NUM4,4,12,F,3
FORMAT $NUM5,4,12,F,3
FORMAT $NUM6,4,4,I
FORMAT $NUM7,4,12,F,3
CALC $NUM6 = 0
 PROGRAM SECTION TWO
IF $NUM6 NE PARTICLE
   CALC $NUM1 = BDEPTH
   CALC $NUM2 = 0
   CALC $NUM3 = 0
   CALC $NUM4 = BTIME
ENDIF
CALC $NUM5 = LENGTH / $1SUM-LENGTH
CALC DDEPTH = ( EDEPTH - BDEPTH ) * $NUM5
CALC DTIME = ( ETIME - BTIME ) * $NUM5
CALC BDEPTH = $NUM1
CALC EDEPTH = BDEPTH + DDEPTH
CALC $NUM1 = EDEPTH
CALC $NUM7 = ( DDEPTH * DDEPTH ) ** 0.5
CALC BLENGTH = LENGTH + ( $NUM7 * %dconv1% )
```

```
CALC CLENGTH = BLENGTH + $NUM2
CALC $NUM2 = CLENGTH
CALC TLENGTH = LENGTH + $NUM3
CALC $NUM3 = TLENGTH
CALC BTIME = $NUM4
CALC ETIME = BTIME + DTIME
CALC $NUM4 = ETIME
CALC $NUM6 = PARTICLE
 PROGRAM SECTION THREE
CALC BLENGTH = BLENGTH * %dconv2%
CALC TLENGTH = TLENGTH * %dconv2%
CALC CLENGTH = CLENGTH * %dconv2%
SORT %outcov%#
 PROGRAM SECTION FOUR
 PROGRAM END
[unquote ' ']
COMPILE XXDEPTH.PG
RUN XXDEPTH.PG
ERASE XXDEPTH.PG
Y
Q STOP
  &end
  &workspace %path%
/*
/* File clean-up
/*
&label cleanup
/*
&if [exists XXSTAT -info] &then; &s dele := [delete XXSTAT -info]
/*
LOG %outcov% ADD
DEPTH %incov% %outcov% %iunit% %dunit% %ounit%
&type
&type ===>> Depth and time attributes in %outcov%.AAT updated
&type ===>> Lengths calculated
&type
/*
&messages &on
&return
/*
/*   Error routines
/*
&label error
  &message &on
  &type
  &type Usage: DEPTH <input.coverage> <output.coverage> <input.cover.units>
  &type                <input.depth.units> <output.depth.units>
  &type          specify FEET or METERS for units
  &type
  &type          !!---NOTE---NOTE---NOTE---NOTE---NOTE---NOTE---!!
  &type
  &type          The item <input.coverage>-ID must be updated in
  &type          <input.coverage>.AAT to allow the AAT file to be
  &type          sorted in time sequence prior to executing DEPTH.AML!!!
  &type          The program SORT.AML will do this function.
&return
```