

# APPLICATION OF A GEOGRAPHIC INFORMATION SYSTEM FOR REGRIDDING A GROUND-WATER FLOW MODEL OF THE COLUMBIA PLATEAU REGIONAL AQUIFER SYSTEM, WALLA WALLA RIVER BASIN, OREGON-WASHINGTON

By Michael E. Darling and Lawrence E. Hubbard

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GLOSSARY OF GEOGRAPHIC INFORMATION SYSTEMS  
AND GROUND-WATER TERMINOLOGY

2-D: Two-dimensional.

3-D: Three-dimensional.

Attribute: A unique parameter that describes mapped features such as label points, arcs, and polygons. These parameters are stored in INFO data files. For this study, ground-water parameters such as hydraulic conductivity and vertical conductance are treated as attributes that describe each cell.

Arc: A digital representation of a line segment. Many Arcs can represent a line feature such as a river or the border of an enclosed area.

ARC/INFO<sup>1</sup>: This is a Geographic Information System (GIS) that is commercially available from Environmental Systems Research Institute (ESRI). This GIS comprises two major subsystems, ARC and INFO. ARC is the subsystem that comprises subroutines (utilities) that create, manage, and analyze geographic digital data. INFO is a relational data-base management system (DBMS) which is utilized by the ARC subsystem for the storage of registration ticks and map boundaries as well as attribute information.

ASCII flat file: A system file that can be viewed in the system's editor programs. Data in the flat file are in tabular format with one record per line.

Grid cell: A ground-water modeling block that has a finite size and location as well as ground-water attributes.

Coverage: Geographic data that comprise mapping features (such as arcs, label points, and polygons) and attributes (such as hydrography or topography) that describe a specific theme.

CPL: A Prime computer system language known as control process language.

Digital line graph (DLG): Line map information in digital form, available from the National Cartographic Information Center as part of the U.S. Geological Survey National Mapping Program.

Ethernet: A hardware medium and software communications protocol used as a high-speed local-area network for inter-computer communications.

GIS: Geographic Information System (see ARC/INFO).

Grid: A geographic network of cells, identified by rows and columns, depicting a project study area for ground-water modeling

<sup>1</sup> The use of brand names in this report is for identification purposes only and does not constitute an endorsement by the U.S. Geological Survey.

Label points: A digital representation of point features such as well locations and elevations. It can be used to identify arcs, polygons, or point features.

Node: The center location of a ground-water modeling cell.

Overlay: A function of GIS systems that allows the user to superimpose digital data sets, with the transfer of attributes between these coverages.

PAT: Point or polygon attribute file stored in INFO. This file contains information about mapping features and can be used to create different mapping and tabular output.

Polygons: A digital representation of closed areas bounded by a series of arcs. These areas may include grid cells, geologic units, soil boundaries, or land use categories.

PRIME: The U.S. Geological Survey minicomputer system; the term refers to hardware, computation, and storage systems, as well as to the operating system.

Primenet: A software communications package that provides a medium for remote file transfer and remote user access. Primenet software meets the Consultative Committee for International Telephone and Telegraph (CCITT) 1980 networks.

Subroutine: A sequence of computer instructions used for performing a specific task (in GIS, for example, inputting data, transforming data coordinates, analyzing data, producing maps).

Thematic Information: Geographic data that share a common subject, such as topology, physiography, culture, political boundaries, or hydrography.

TIN: A surface contouring "module" that directly interfaces with the ARC/INFO system. The "module" is called Triangular Irregular Network.

Topology: A set of GIS system files that represent mapping features (for example, arcs, points and areas) and their attributes, which can perform all software functions for analysis, editing, and map production.

## CONVERSION FACTORS, INCH-POUND TO METRIC

For readers who prefer to use metric (International System) units rather than the inch-pound terms used in this report, the following conversion factors may be used:

Multiply inch-pound units	By	To obtain metric units
<u>Length</u>		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
<u>Area</u>		
square mile (mi <sup>2</sup> )	2.590	square kilometer (km <sup>2</sup> )

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

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ABSTRACT

Computerized Geographic Information Systems (GIS) have become viable and valuable tools for managing, analyzing, creating, and displaying data for three-dimensional finite-difference ground-water flow models. Three GIS applications demonstrated in this study are: (1) regridding of data arrays from an existing large-area, low resolution ground-water model to a smaller, high resolution grid; (2) use of GIS techniques for assembly of data-input arrays for a ground-water model; and (3) use of GIS for rapid display of data for verification, for checking of ground-water model output, and for the creation of customized maps for use in reports. The Walla Walla River Basin was selected as the location for the demonstration because (1) data from a low resolution ground-water model (Columbia Plateau Regional Aquifer System Analysis [RASA]) were available and (2) concern for long-term use of water resources for irrigation in the basin.

The principal advantage of regridding is that it may provide the ability to more precisely calibrate a model, assuming that a more detailed coverage of data is available, and to evaluate the numerical errors associated with a particular grid design. Regridding gave about an 8-fold increase in grid-node density. Several FORTRAN programs were developed to load the regridded ground-water data into a finite-difference modular model as model-compatible input files for use in a steady-state model run. To facilitate the checking and validating of the GIS regridding process, maps and tabular reports were produced for each of eight ground-water parameters by model layer. Also, an automated subroutine that was developed to view the model-calculated water levels in cross-section will aid in the synthesis and interpretation of model results.

INTRODUCTION

A typical ground-water modeling project includes gathering, compiling, interpreting, and integrating data. Presently, this involves a great deal of time-consuming map and paper work. For example, much time can be expended on locating wells on maps, writing in measured values next to these wells, contouring the data, using a model-grid overlay and allocating values to model nodes, and then keying these and other data into a digital array. Other time-intensive steps involve interpretation of model results during calibration of the model, the creation of publication products, and reformatting data for storage in existing data bases. A large part of this effort is usually expended to relate these data temporally and spatially. The time required for these tasks adds greatly to the cost of a calibrated and verified model, and because of this, a modeling approach to hydrologic problems commonly is regarded as "too lengthy" or "too costly."



After a report is published, the ease of producing additional products such as maps and tables is limited by the availability and format of the data. Some of these data are available only on worksheets or maps, whereas other data are fixed to a particular model format in digital files. New modeling projects that overlap already-studied areas usually cannot use existing digital data or worksheets because the model-grid size, grid-orientation, or grid-geometry is represented differently.

The need for a standard and computerized data-base system for storing and manipulating statewide and regional ground-water data becomes evident when reviewing existing digital data bases. A computerized digital system should be able to store spatially referenced point, line, and polygon data, as well as tabular data; be able to update, overlay, and analyze these data easily; and be able to reformat data into differently sized and oriented grids. As a corollary, the need exists to integrate the myriad of small data-handling programs presently used in models into a menu-driven procedure for automating the whole process of constructing model arrays, calibrating models, and reporting model results.

A number of Geographic Information System (GIS) packages have been developed that use a variety of different hardware systems and software packages for handling spatial data bases. One such package is called ARC/INFO (produced by Environmental Systems Research Institute). This software has the capacity to tie thematic information to topological features in a wide variety of coordinate systems and projections with rescaling capabilities. With ARC/INFO, digital-mapping features can be overlayed to create integrated coverages, or digitized maps containing the same thematic feature can be joined together to create wider geographic coverages. A variety of editing functions are available for topological and thematic information, and digital information can be read into the system by a variety of techniques and from a variety of sources. Because of these characteristics, ARC/INFO was used in this demonstration project to regrid a model, to check for errors in data arrays, to assist in the calibration process, and to create a data-handling interface. Other GIS packages do have or are in the process of developing similar analysis, maintenance, and storage tools; however, additional evaluation would be necessary to determine if these packages could accomplish all of our project tasks.

### Purpose and Scope

The purpose of this report is to evaluate GIS technology as a tool to reduce the lengthy and costly data-handling required to produce ground-water data arrays for models and reports on ground-water flow systems. The Walla Walla River Basin was selected as the demonstration site for this project. The basin is part of a larger regional aquifer study, the Columbia Plateau Regional Aquifer System Analysis (RASA), which includes section of eastern Washington, eastern Oregon, and western Idaho.

When beginning a ground-water study of an area where other modeling studies have been made, it may be advantageous to start with data compiled from these studies. However, some of the previous grids may be aligned differently with respect to the redesigned ground-water flow model, such as in anisotropic aquifers, or the previous model cell size may not match the

size needed for the new study. This was the situation encountered with the Walla Walla River Basin; data were available from the RASA study, but the cell size was too large to provide the detailed definition needed for the Walla Walla study area. The Walla Walla River Basin offered an opportunity to demonstrate the use of GIS in regriding a model. By using GIS techniques, the coarse-grid RASA data were reformatted to a fine-resolution grid cell to allow additional detail and definition of smaller hydrologic features, such as small canal systems or the closely spaced pumping centers that exist in the area.

The scope of this study was limited to the application of GIS techniques to convert data from one ground-water modeling study for use in another. In this report, the following applications were demonstrated and evaluated: (1) the feasibility of using GIS capabilities for regriding data arrays from an existing ground-water-flow model for use in a redesigned ground-water-flow model; (2) the rapid display of model data in the form of customized maps and reports; (3) the use of GIS in the assembly and verification of data-input arrays for a ground-water model; (4) creation of a data-base-management system interface to a ground-water model with some capabilities for screen display, storage, retrieval (report generation), and the construction of model input data.

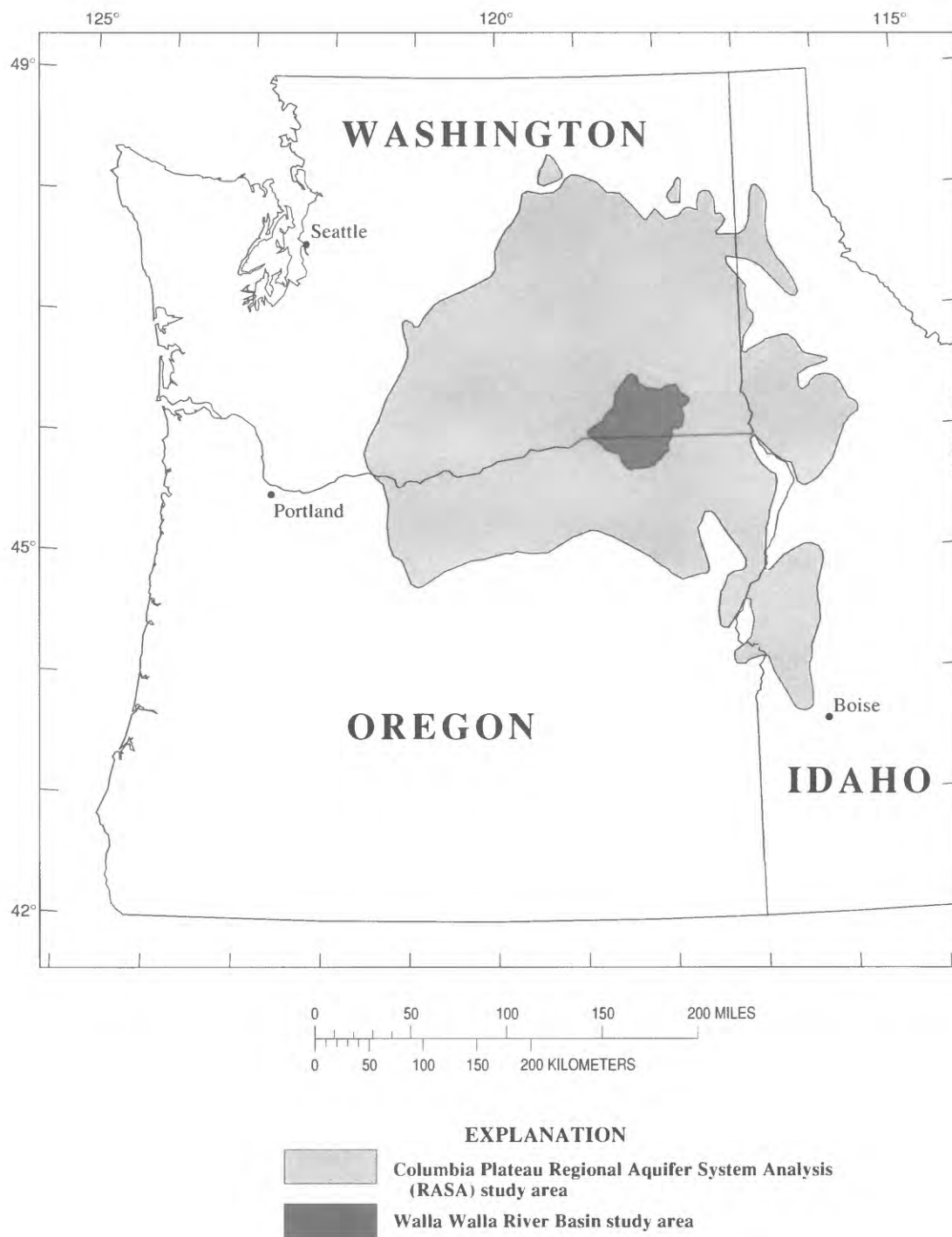
### Project Study Area

Newcomb (1965) has published one of the most complete discussions of the geology and hydrology of the Walla Walla River Basin. The following excerpted discussion is a general overview of the basin from the abstract (p. 1-2) of that report. A site map for the basin is shown in figure 1.

The Walla Walla River, whose drainage basin of about 1,330 square miles lies astride the Washington-Oregon boundary, drains westward to empty into the Columbia River. The basin slopes from the 5,000-foot crest of the Blue Mountains through a structural and topographic basin to the terraced lands adjoining the Columbia River at an altitude of about 340 feet. The main unit of the topographic basin is the valley plain, commonly called the Walla Walla Valley, which descends from about 1,500 feet at the foot of the mountain slopes to about 500 feet in altitude where the river cuts through the bedrock ridge near Divide. . .

The growing season is long and the climate dry but equable. The average annual precipitation ranges from more than 40 inches on the higher uplands to less than 10 inches on the lower parts of the basin. The storm runoff is highly seasonal and typical of drainage from a maturely dissected upland. In consequence of the small amount of rainfall in summer, the streamflow is far short of irrigation requirements in the late summer months. . .

The only consolidated rock in the basin is the Columbia River Basalt. These accordantly layered lava flows are the bedrock exposed in the canyons and other declivities. Beneath the valley plains the bedrock is covered by



**Figure 1.** Location of Walla Walla River Basin study area and the Columbia Plateau Regional Aquifer System Analysis study area.

unconsolidated sedimentary deposits. The basalt dips westward from the Blue Mountains, southward down the "Touchet slope," northward from the Horse Heaven ridge, and eastward from a divide ridge in the lower valley. These dips converge into a synclinal trough whose bedrock surface extends below sea level in at least two places west of Walla Walla. In places faults cut the basalt and cause displacements in the even slopes that characterize the basalt of most of the basin.

The basalt is overlain by unconsolidated deposits of Pleistocene and Recent age. The oldest, thickest, and most extensive unit of these deposits consists of the old clay, up to 500 feet or more thick, that partly fills the Walla Walla synclinal trough. The old clay is interfingered with the old gravel which descends in a tabular stratum from the mouths of the canyons. Successively younger deposits--the Palouse Formation, the deposits of the upper valley terraces, the Touchet beds, and the Recent alluvium--in places overlies the basalt as well as the old gravel and clay of Pleistocene age.

Significant ground-water storage occurs in two rock units--in the old gravel, which in places has a mantle of water-bearing alluvium of Recent age, and in the basalt. The regimen of the ground water in the two materials is considerably different. The ground water in the gravel is recharged directly by the infiltration of precipitation, by water from the surface streams, and by water infiltrated from irrigation; it percolates downvalley below the surface of the alluvial fans to its discharge points in springs and seepage areas. The ground water in the permeable parts of the basalt is recharged through the outcrops of permeable rock and by percolation of water from the overlying sedimentary deposits.

The basin is economically dependent on irrigated agriculture with no importation of water to the basin (Newcomb, 1965). The use of ground water as an irrigation source has increased with time, resulting in a lowering of water levels and reduction of ground-water discharge from springs and streams (experienced as early as the mid 1960's). Irrigation practices have recently changed from flood irrigation to sprinkler systems, resulting in the development of more irrigated acreage. As a result, more water is being used, with a resultant lowering of ground-water levels and further decrease in spring discharges in some areas. As the area continues to undergo changes in irrigation practices, increasing agricultural growth, and increasing demands for water, both the Oregon and Washington State Legislatures have become concerned with the long-term effects on the basin's ground-water resource.

#### Overview of Geographic Information Systems

The use of a GIS in ground-water studies provides important capabilities to both technical and nontechnical users. For the technical user, there is the capability of making rapid revision of ground-water data, either in tabular or digital mapping form. Sophisticated spatial correlations can be made, such as land use in relation to surficial

geology. For the nontechnical user, GIS is an excellent visual aid for presenting complicated analysis results. A GIS is a good tool for communicating the essential scientific information necessary to make sound management decisions about resources. Maps and reports can be produced within minutes if digital data are available on the system. The types of thematic data that a GIS can handle for ground-water studies is diverse. These data include, but are not limited to arrays depicting cell number, flow boundary arrays, areal extent of aquifers, water levels, depth to aquifer, vertical hydraulic conductivity, lateral hydraulic conductivity, recharge ratios and distribution, location of rivers and drains, location and ratio of withdrawal. The reader is referred to G. K. Moore and others (1983) for detailed discussions of GIS's.

#### Overview of Ground-water Flow Models

Data for the basin were available from two previous and one ongoing ground-water study: (1) a digital simulation of a basalt aquifer system, Walla Walla River Basin, Washington and Oregon (MacNish and Barker, 1976); (2) a digital simulation of the unconsolidated materials and gravels for the Walla Walla River Basin, Washington and Oregon, (Barker and MacNish, 1976); and (3) the RASA of the Miocene Columbia River Basalt Group (Vaccaro, 1984) currently near completion. Both MacNish and Barker studies used a 2-D ground-water flow model developed by Pinder and Bredehoeft (1968). The RASA analysis has used a modified version of the 3-D finite-difference modular model developed by McDonald and Harbaugh (1984) and covers a 70,000-square-mile area (fig. 1) that includes the Walla Walla River Basin. Initial results from the RASA study indicated a need for a more detailed definition of flow in the basin than was described using the grid for the RASA model. A Walla Walla River Basin project was begun to build new model arrays in order to demonstrate the feasibility of constructing a more detailed grid for the ground-water flow model using available data and ARC/INFO software. The same modular ground-water flow model used in the RASA study (McDonald and Harbaugh, 1984) is used in this demonstration project.

#### Reasons for Regridding an Existing Ground-water Model

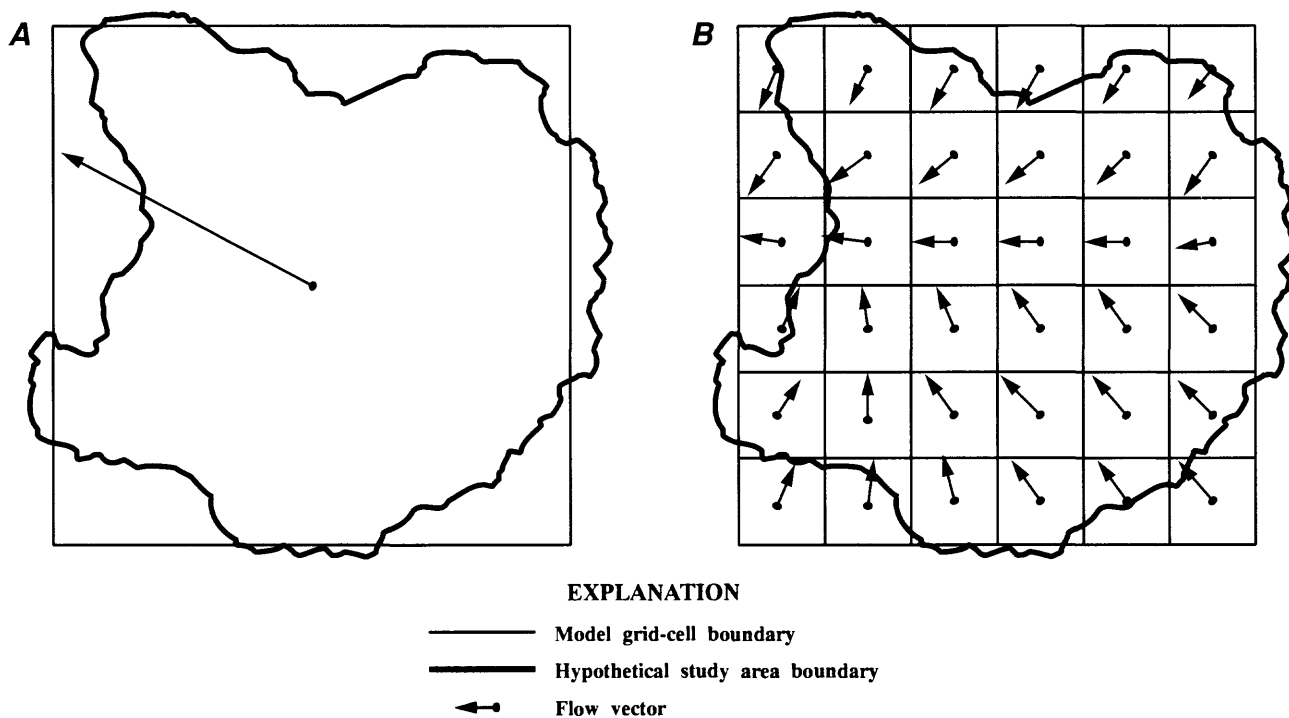
The RASA study of the Miocene Columbia River Basalt Group, which includes the Saddle Mountains Basalt and older Grande Ronde Basalt, has data arrays for a ground-water flow model for the light shaded area shown in figure 1. The model cells are relatively large, each measuring approximately 8,000 feet east to west and 15,000 feet north to south. This demonstration study has used the capabilities of the GIS to regrid the RASA model data to a finer cell size and slightly different cell orientation. The process involved creating a new, smaller cell size and developing GIS user-assisted computer programs to make a new set of ground-water data arrays for this new grid. The cell size selected for the new grid was 4,000 feet by 4,000 feet oriented north to south. The selection of this size was based on the scale of the hydrologic features arbitrarily assumed to need representation by the new model and by the computation time required to run the model (small cell size results in a larger number of active cells, therefore increasing the model run time significantly). There were no other major considerations, because the project is primarily for demonstration purposes. It is hoped that, in the future, GIS will be

able to assist in the direct solution of the optimum grid size based on the scale and homogeneity of features being modeled, on the well density, and other such considerations which are beyond the scope of this study.

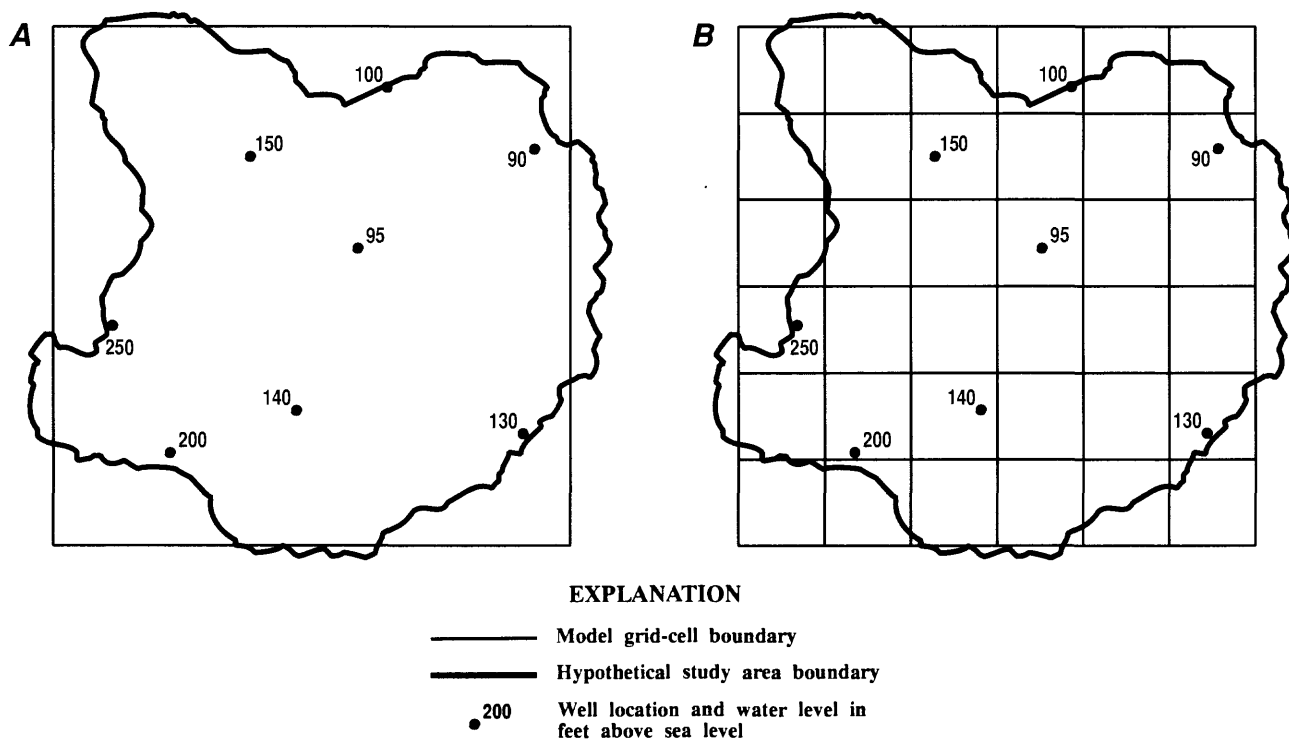
The finite-difference model for determining ground-water flow can be thought of as a series of cells in which flow in each of the cells is described as a resultant vector from six sides. If we consider the case where the grid for the model is so large that only one cell would cover the project area, the resultant vector for the area would be linear across the whole area. However, substantially reducing the cell size over the same area would provide greater definition of flow in terms of general direction and magnitude, as needed to solve a specific problem within that area. For example, two hypothetical models shown in figure 2 (one cell and 36 cells) show that regriding the one ground-water cell to a finer modeling grid with 36 cells allows the model to define greater detail of the flow system. Another example showing the effect of the density of water-level measurements on cell size is illustrated in figure 3, where only one cell covers the project area and many observed water levels must be used to estimate a single effective value for use during calibration of the model. If there is a large variation between this observed water level and the model-calibrated water level, the calibration process may be inaccurate. However, a finer grid would allow matching of more, if not all, of the observed water levels to model-calibrated values. The model assumes that the wells are at the center of each cell, thus their location would be more accurately placed in a finer grid. Therefore, a finer grid could improve the accuracy of the calibration process in modeling a local flow system and, accordingly, increase the usefulness of the results. This additional detail is especially helpful in regions of large hydraulic gradients associated with large changes in hydraulic conductivity or withdrawals, or in areas where the hydrologic features (such as streams and canals) to be modeled are much smaller than the model grid size of the previous studies. Another advantage, not addressed in this report, is the reorientation of the grid aligned to the geometry of the basin. Realignment might allow better cell representation of irregularly shaped boundaries and would require fewer cells to be created in the model, thereby reducing computer storage requirements and reducing the time needed to compute a modeling result. If intermediate or regional modeling is the objective then the emphasis is on a different aspect of the flow system and regriding may not be a desired result.

#### LOADING THE MODEL AND GROUND-WATER DATA INTO GIS

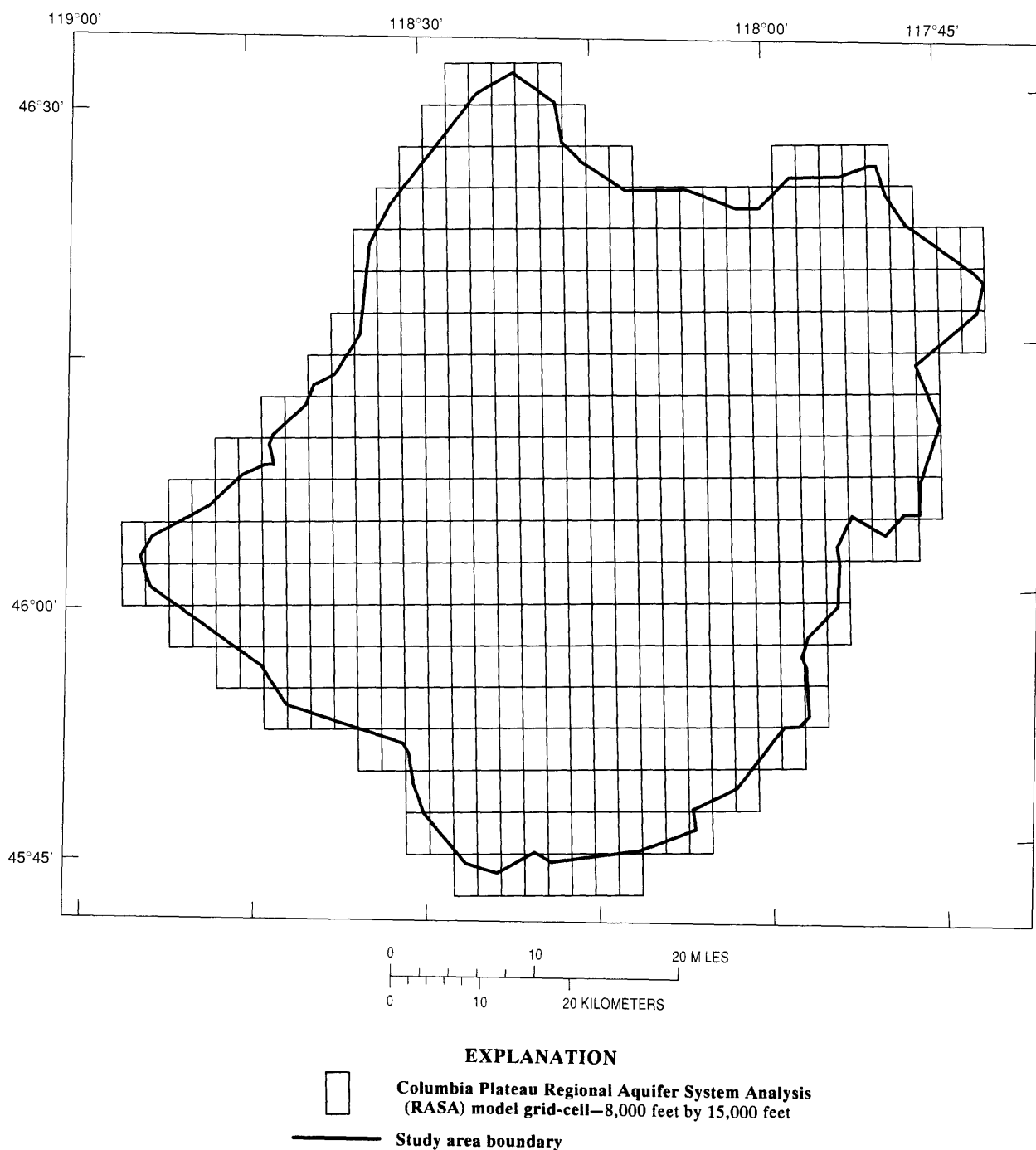
An ASCII flat file for grid coordinates was available from the RASA project. The file contained a unique row, column identifier for each cell, along with coordinates for the corners of each cell in the RASA area. Using custom FORTRAN and INFO programs in conjunction with standard ARC/INFO routines, the RASA grid with layer, row, and column identifier was input to the GIS. In addition, the number of cells in grid for the entire RASA boundary was reduced in size to include only the study area for the Walla Walla River Basin. The model boundary for the Walla Walla River Basin was obtained from previously digitized hydrologic-unit boundary maps covering the states of Oregon and Washington. The modified RASA model grid for the Walla Walla River Basin model area is shown in figure 4.



**Figure 2.** Flow vectors derived from a hypothetical flow model for (A) one-cell and (B) 36-cell representations of an aquifer.



**Figure 3.** Hypothetical water levels for (A) one-cell and (B) 36-cell representations of an aquifer.



**Figure 4.** Plan view of finite-difference grid for the Columbia River Plateau Regional Aquifer System Analysis in the Walla Walla River Basin.

Once the grid and cell identification had been created in the GIS, RASA-altitude data arrays for the tops and bottoms of aquifers, hydraulic conductivities, recharge, initial water levels, boundaries, drains, and rivers were entered into INFO attribute files for the GIS coverage of the model grid. The process of moving the data into GIS is discussed below.



Each RASA data array by layer was originally formatted as a horizontal string in an ASCII file. A FORTRAN program was written to reformat these arrays and produce an ASCII flat file for each ground-water modeling parameter, along with the appropriate cell identifier for layer, row, and column. The ASCII flat files, including only those cells in the Walla Walla River Basin, then were loaded into INFO and merged with the GIS attribute files for the polygon coverage of the modified RASA grid.

#### CREATING THE NEW MODEL GRID IN GIS

An automated subroutine contained in ARC/INFO allowed creation of a new polygon coverage of the ground-water model grid for the Walla Walla River Basin. The data for the new model grid included coordinates for the lower left corner of the grid, a coordinate on the west border of the coverage to orient the new grid rotationally, the grid cell size, and the number of layers, rows, and columns. After the model grid was created, a row-column cell identification number was attached to the attributes for each cell of that grid coverage. A map of the new grid is shown in figure 5.

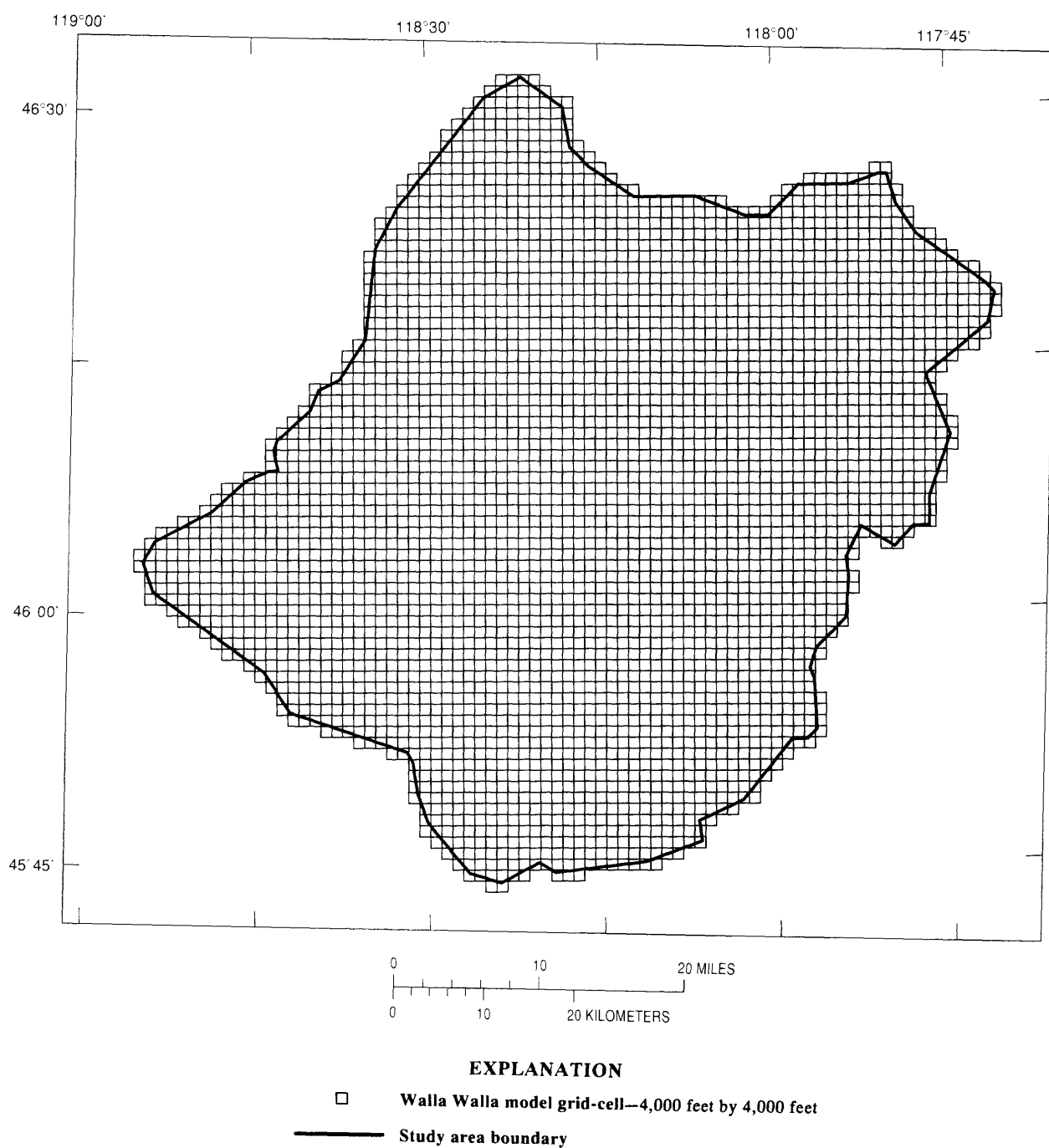
#### TRANSFERRING THE GROUND-WATER DATA FROM ONE MODEL GRID TO ANOTHER, UTILIZING AN AREA-WEIGHTED PROCESS

The GIS was used to merge Walla Walla model grid coverage with the RASA model grid coverage, creating a new combined-model grid coverage (Walla Walla plus RASA coverage). This coverage had the attributes for both Walla Walla and RASA model grids (fig. 6). An INFO program was written to relate the attribute file for the combined model-grid coverage (Walla Walla and RASA) to the attribute file for the Walla Walla model-grid coverage and to transfer all ground-water data to the Walla Walla attribute file. An outline of the process, an area-weighted transfer method, is shown in figure 7. A hypothetical representation of this transfer process is shown in figure 8. In order to assure that this transfer process accurately reflects the original data distribution and is consistent with the hydrologic system, maps of the transferred ground-water data arrays for the Walla Walla model grid coverage were created for each parameter. These maps were shaded for aggregated type data, such as hydraulic conductivities, or drawn as contour lines for parameters, such as water levels, that show gradients. An example of a shaded map for a ground-water model grid is shown in figure 9, and a contour map for both ground-water model grids is shown in figure 10.

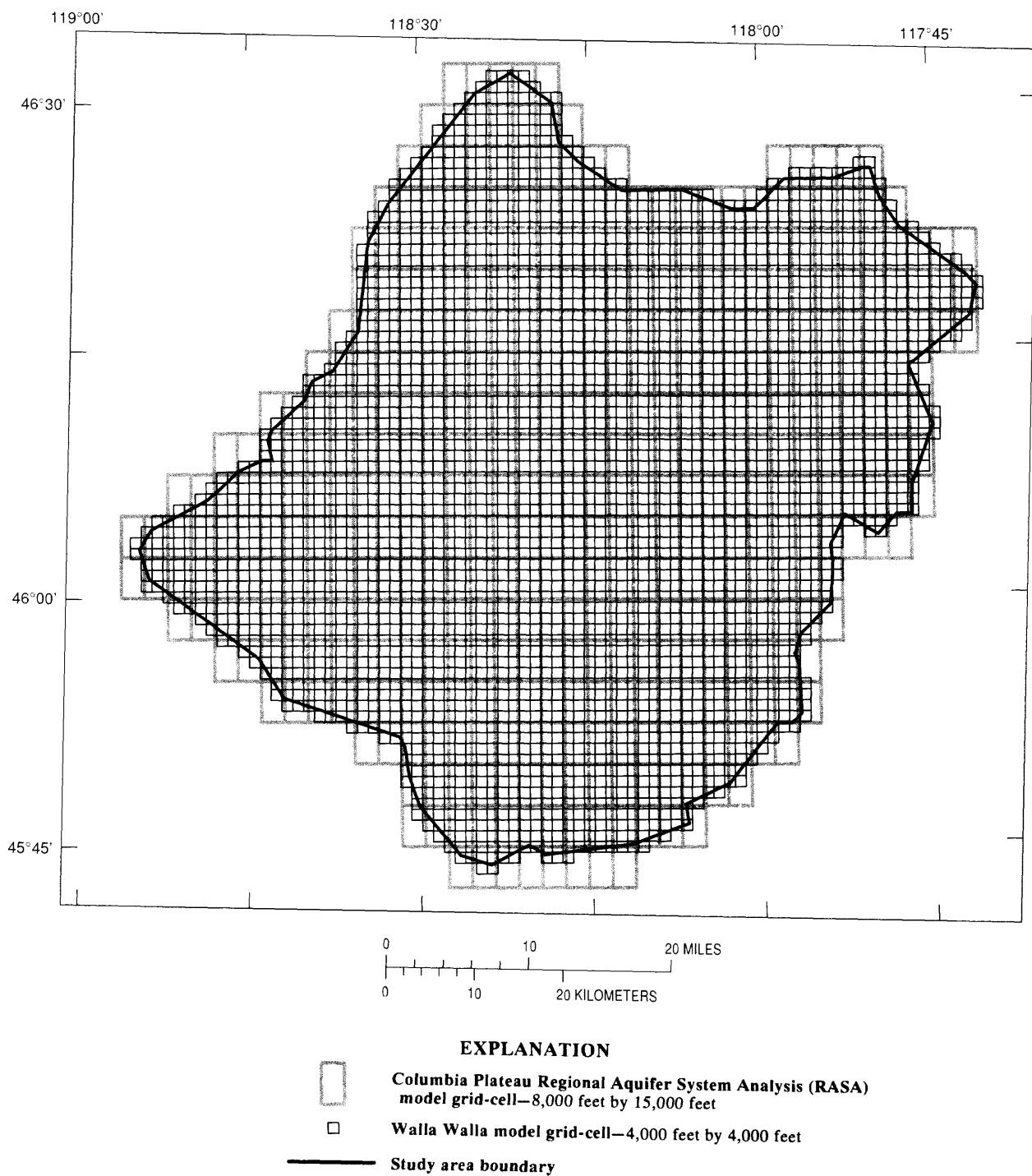
#### TRANSFER OF DRAINS AND RIVER FILES BETWEEN MODEL GRIDS, BY USE OF POINT- AND LINE-WEIGHTED PROCESSES

##### Drains

Drain information came from RASA files as point locations and not as areas. These data were loaded into GIS in a different manner from that previously discussed. ASCII flat files containing drain information (drain elevations, conductance values) and RASA row and column identification numbers were loaded into INFO as individual files for each layer. These information files were joined with the GIS attribute file for a point coverage representing the center of every cell in the RASA grid. Drain information was transferred from the RASA



**Figure 5.** Plan view of a new finite-difference grid for the Walla Walla River Basin.



**Figure 6.** Plan view of two finite-difference grids.

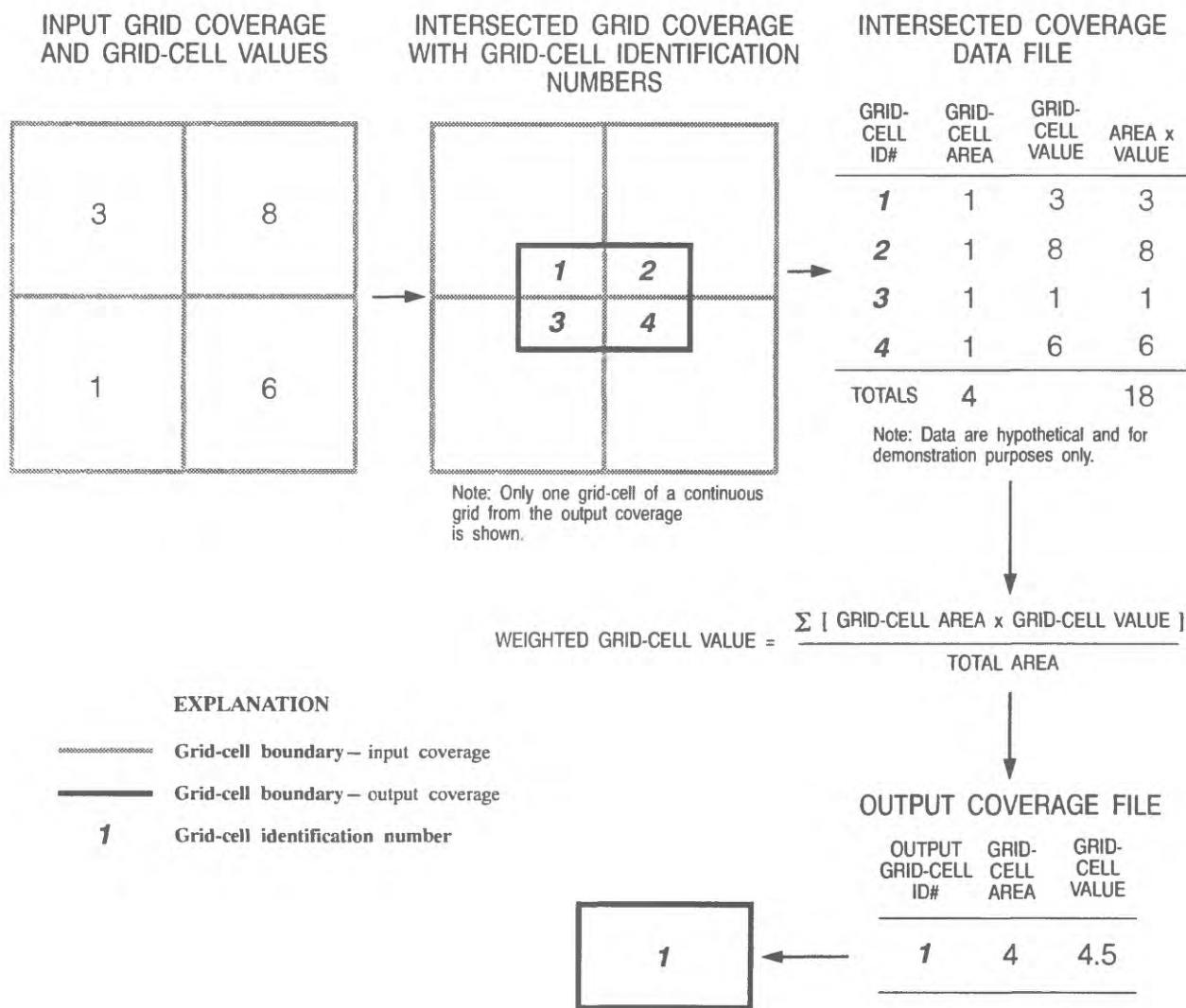
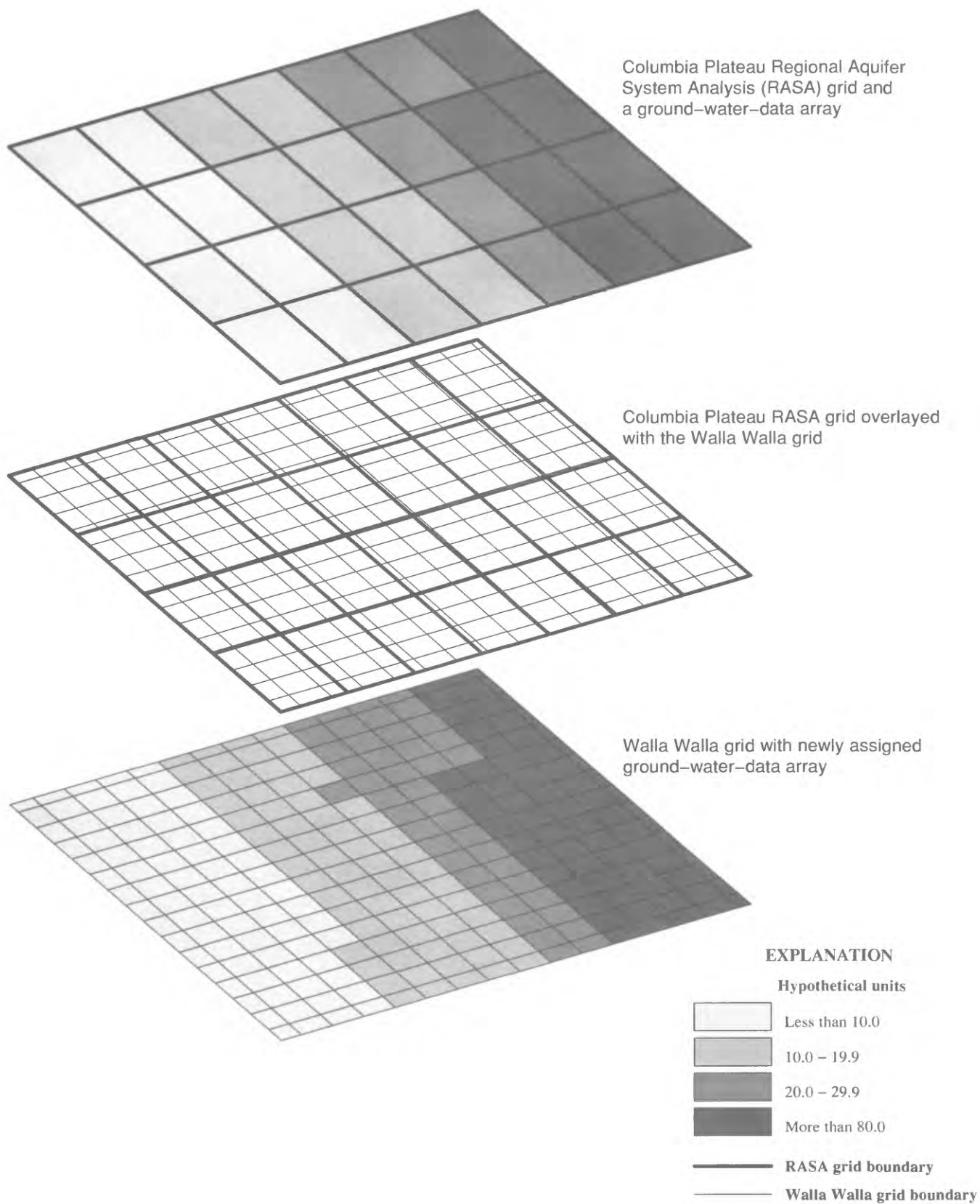
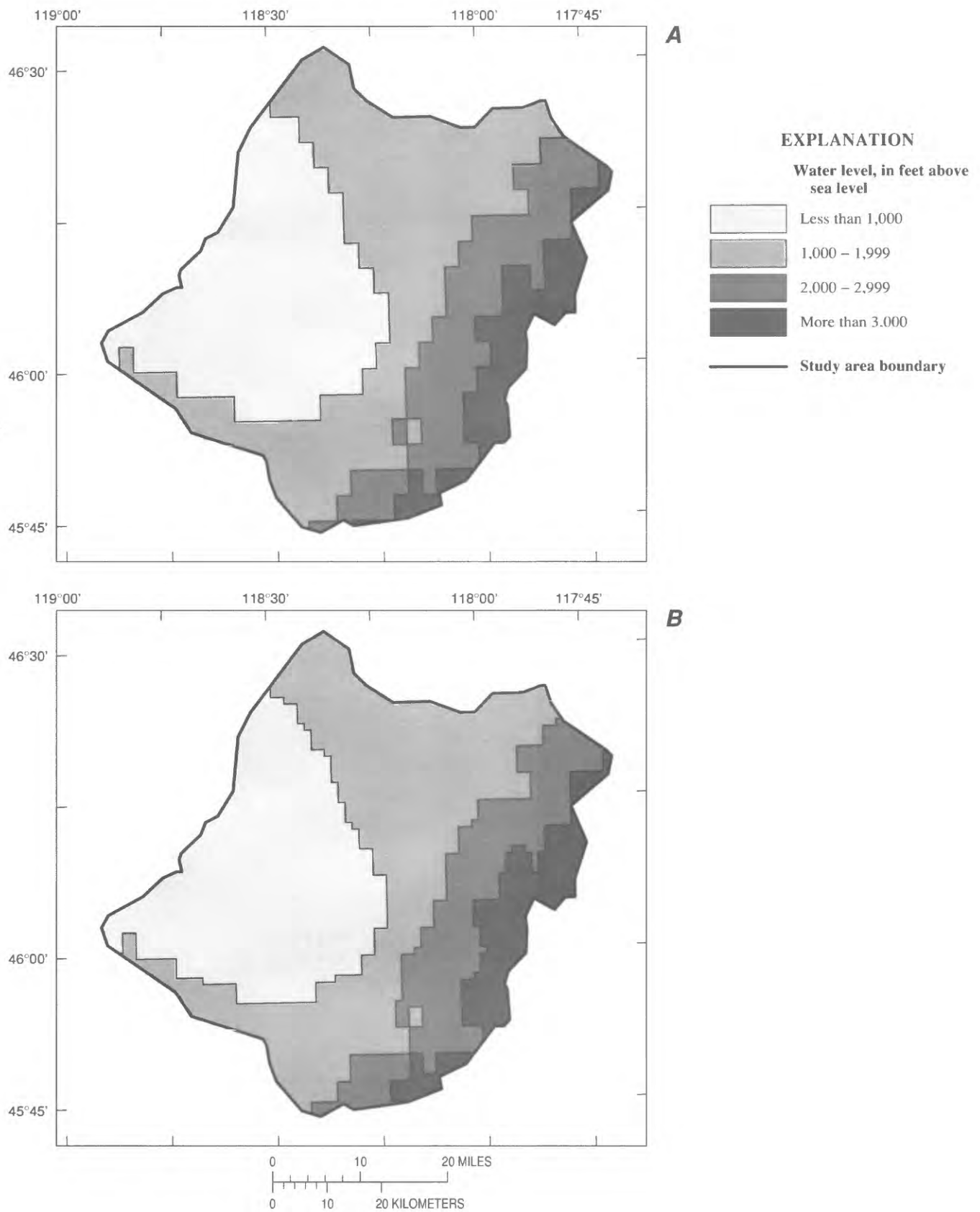


Figure 7. A program for transferring ground-water data between two modeling grids.

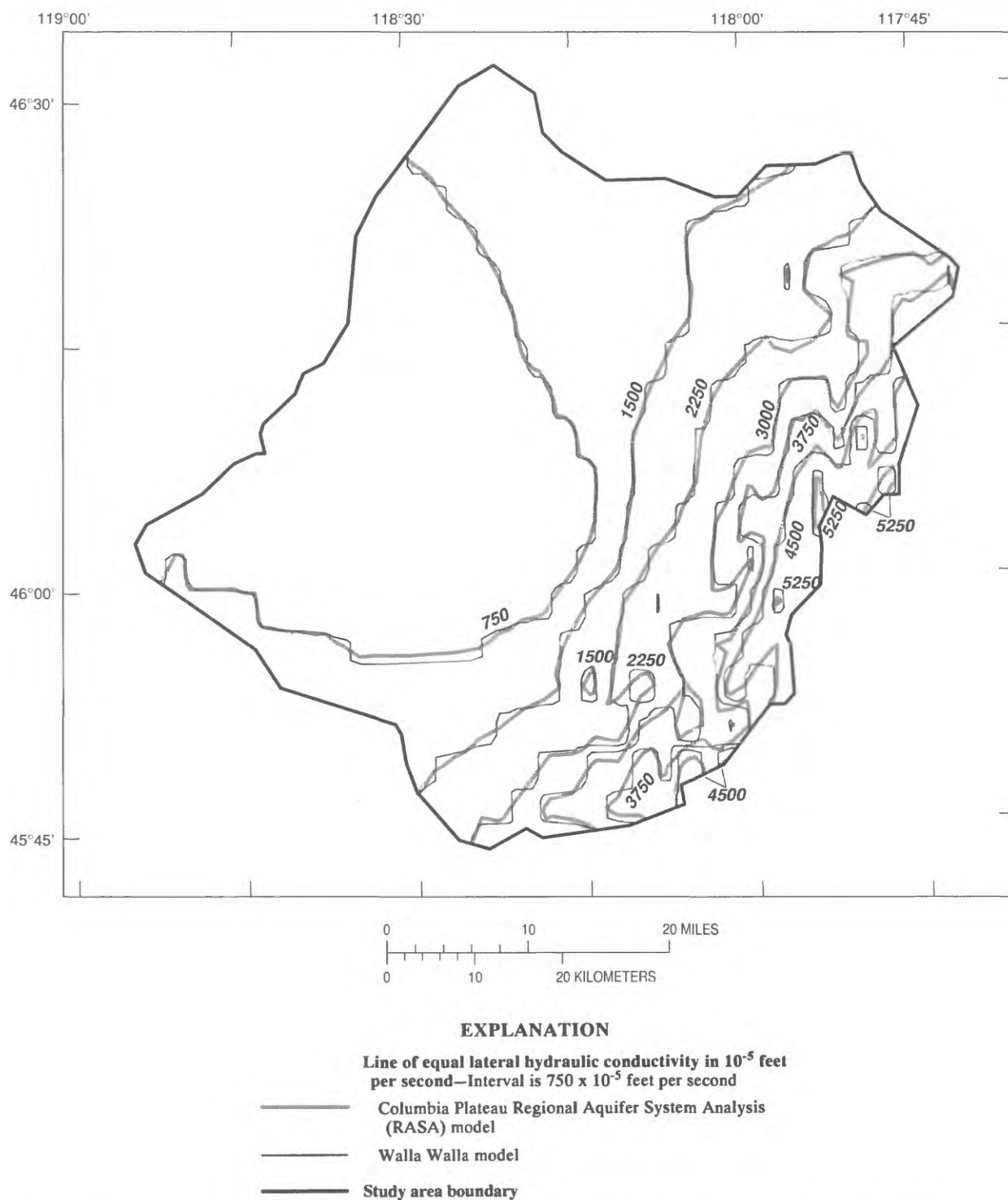
point coverage to the Walla Walla grid by utilizing the map overlay capabilities of ARC/INFO and some interactive INFO file manipulation. The product of this overlay function is the addition of the Walla Walla row and column attributes to the RASA point INFO file. This INFO file then was related to the Walla Walla grid INFO file using the Walla Walla row and column attribute; drain attributes were passed to the Walla Walla grid INFO file. An INFO program was written to relate to the file and to transfer the attributes. In addition, this program will average attributes if two or more drains intersect a Walla Walla grid cell. The results of this transfer process is shown in figure 11. A more elaborate transfer process, which would include use of a river coverage, may be required with some ground-water models where the drain arrays should include data for every model cell in which the river is related.



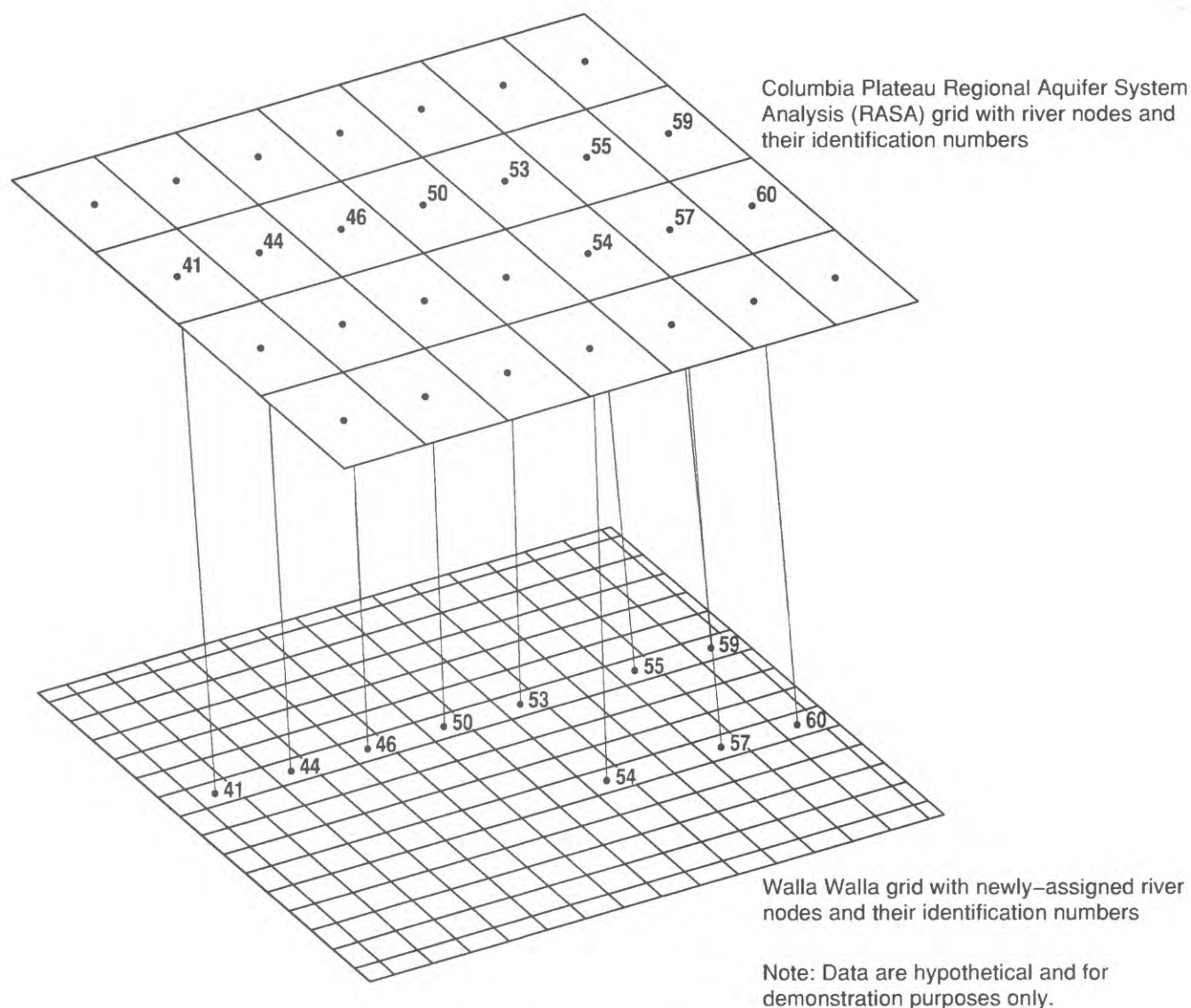
**Figure 8.** An area-weight transfer of an areal ground-water parameter between modeling grids. The data are hypothetical and for demonstration purposes only.



**Figure 9.** The distribution of water levels in the upper part of the Grand Ronde hydrogeologic unit for (A) the Columbia Plateau Regional Aquifer System Analysis model grid and (B) the Walla Walla model grid.



**Figure 10.** Lines of equal value for lateral hydraulic conductivity for the upper part of the Grand Ronde hydrogeologic unit in the Columbia Plateau Regional Aquifer System Analysis model grid and the Walla Walla model grid. Contour values were added for clarity.



**Figure 11.** A process for transferring drain-data arrays from the Columbia Plateau Regional Aquifer System Analysis model grid to the Walla Walla model grid.

### Rivers

The RASA project files containing the river information for streambed conductance, average annual stage, and stream width for each RASA model-grid cell were loaded into INFO as separate files for each layer. River data, as with drains, required a special set of processes in order to transfer this information to the model grid, because the features are represented as a set of lines. These files were merged with the attribute files for the RASA model-grid coverage. A digital-line graph (DLG) river file at a resolution of 1:2,000,000 was obtained for the Walla Walla River Basin. This river coverage was overlaid with the RASA model-grid coverage containing the river data, thereby transferring the river data from the RASA model grid in the form of



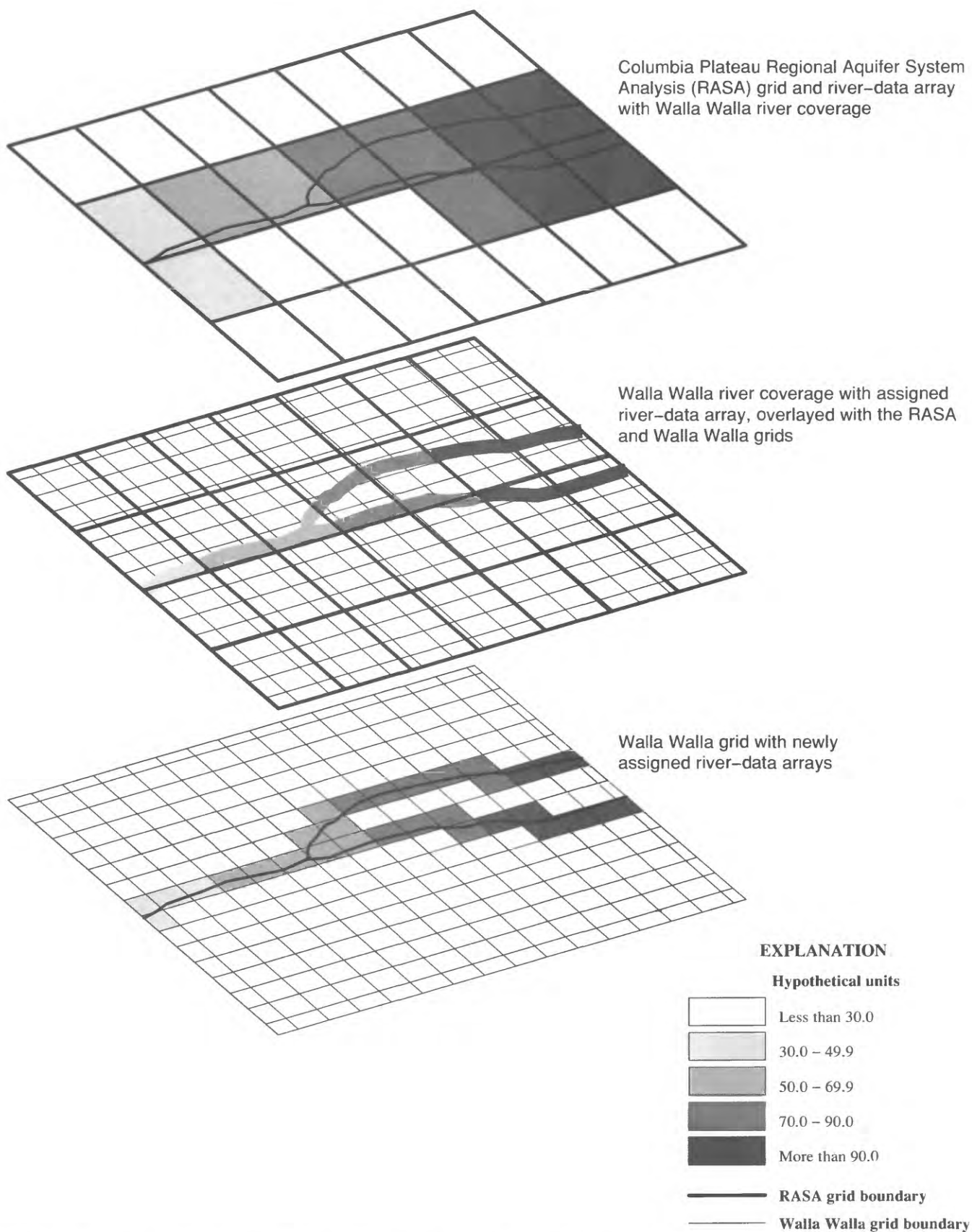
attributes attached to associated stream segments. The river coverage also was overlaid with the Walla Walla model-grid coverage, thereby transferring the Walla Walla row column block identifiers to the river coverage. Finally, an INFO program was used to conduct line-weight transfers of the data from the river attribute file to the Walla Walla grid attribute file. A line-weight program was required because more than one stream segment containing the RASA river attributes could be intersected in a Walla Walla grid cell. The line-weight INFO program operates in a similar manner to the area-weight INFO program, except that it uses line length instead of area as a weighting factor in the calculation. A diagram that illustrates this process is shown in figure 12. Because the data originally came from the RASA grid, the resolution remains the same; however, the accuracy in the transfer process is preserved.

#### DATA INPUT TO THE WALLA WALLA GROUND-WATER MODEL

Once all ground-water data arrays were transferred from the RASA grid to the Walla Walla grid and verified, a method was developed to transfer the INFO data from the ARC/INFO coverages to a set of files that could be input to the model. The method used to get data into a compatible model file consisted of several steps. A series of ASCII flat files was created from the INFO attribute file for the Walla Walla model-grid coverage. These files included all ground-water arrays required for use with the ground-water model. Each of these ASCII flat files was reformatted to a horizontal array. This reformatting process used a FORTRAN program (McKillop, U.S. Geological Survey, written commun., 1987). These files then were concatenated into four files by layer and loaded into the ground-water model.

Initial model runs with the Walla Walla ground-water arrays produced a high percentage of dry cells, which blocked any further movement of water vertically or horizontally across them. After plotting data arrays with the GIS utilities, it was shown that in several nodes the altitudes of the top of an aquifer layer were above the bottom surface altitudes of the overlying aquifer. Using the INFO utilities, a rapid calculation was made for the differences between these two data values and a listing of these differences was quickly produced. When it was determined that stratigraphic data from the RASA model had to be reevaluated, these data sets were modified by RASA project personnel and returned to us. We then repeated the previously-described transfer process with each modified data set and began model calibration for steady-state conditions by adjusting vertical and lateral conductance values using a multiplier provided in the model. We were able to obtain reasonable results from the model for the total water budget after several model runs. It was not the intent of this study to complete the model calibration process. However, ARC/INFO provides the tools necessary to facilitate the entire process.

Ground-water modeling can require management of large volumes of data, as was the case for this study. After regriding the RASA data, ARC/INFO was used to manage 50,000 kilobytes of data (6,889 cells per layer, 4 layers, 6 parameters per layer, plus miscellaneous parameters and data). These data items were maintained in two separate ARC/INFO coverages (RASA and Walla Walla). More than 30 separate data arrays were needed for model input and data-base management; these were created

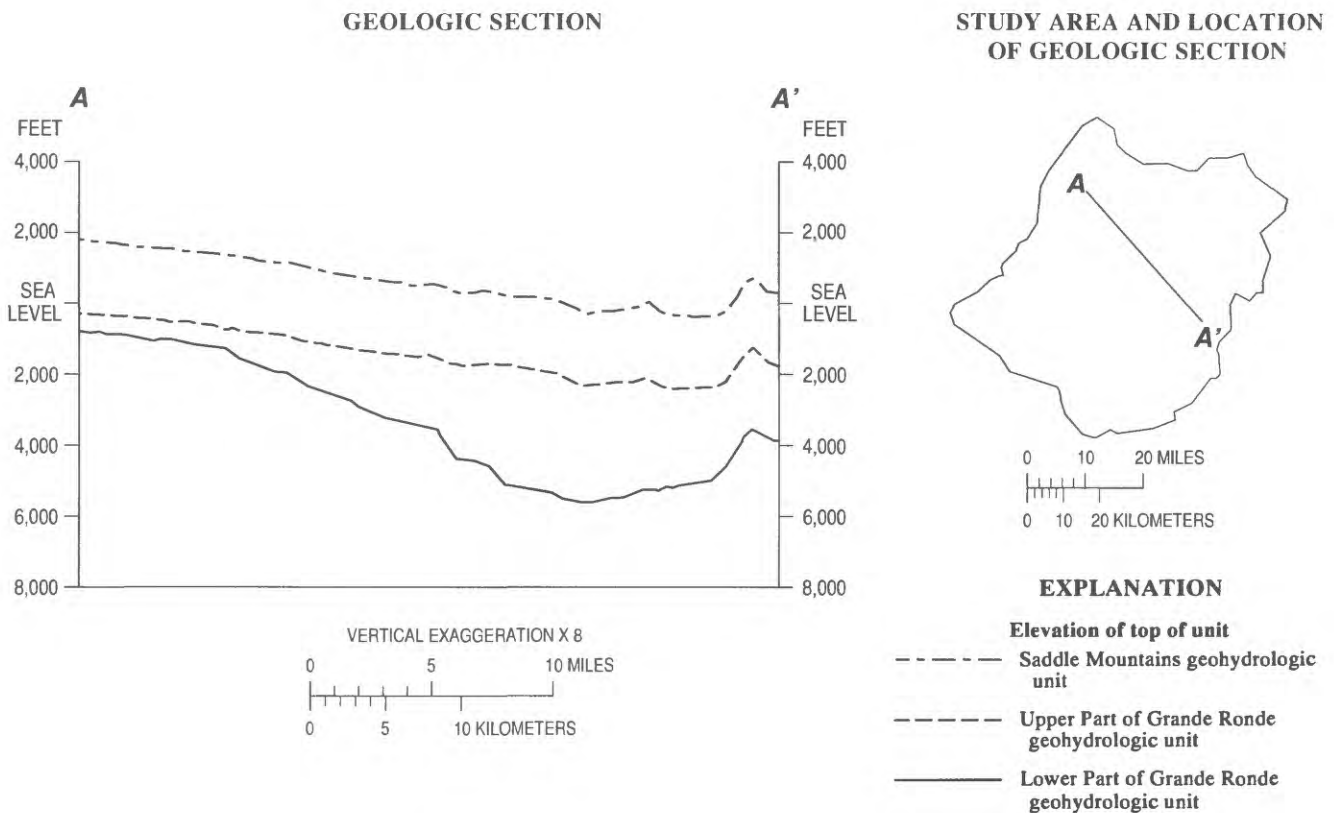


**Figure 12.** Transfer of a river-data array from the Columbia Plateau Regional Aquifer System Analysis model grid to the Walla Walla model grid. The data are hypothetical and for demonstration purposes only.

from the Walla Walla coverage. Transferring this volume of data between modeling grids without the capabilities of GIS would have taken substantially longer to accomplish, and could have resulted in more data errors generated and less accuracy.

#### CROSS-SECTIONAL VIEW OF GROUND-WATER MODELING RESULTS BY USING A GIS

A demonstration program was produced to create cross-sectional profiles of ground-water data arrays in order to get a three-dimensional perspective of the data. This program used ARC/INFO and CPL subroutines and can be applied to any modeling result. The user does not need any experience with ARC/INFO and is interactively prompted throughout the session. The profiles can be drawn on a graphic-capable computer terminal or drawn with a plotter. An example of one of these profiles is seen in figure 13. Data arrays as illustrated in figure 3 can also be viewed as cross-sectional profiles. A profile of the boundary between aquifer units, along with calculated water levels for each layer, could be used for calibration purposes. This application can be enhanced to display any number of data layers on the same profile.



**Figure 13.** Output from a program that plots the base elevation of several hydrogeologic units when cross sections are given interactively on a graphic-capable computer terminal.

## CONCLUSIONS

This demonstration has shown that ground-water data previously compiled for one modeling project can be easily regridded and incorporated into a subsequent modeling project. The process for this study, including program development, took approximately 2 months to accomplish, a relatively short time considering the volume of data processed. No new field data were collected or compiled for this study. The original (model) data were re-distributed over a smaller cell-size grid, either by using an area-weighted transfer method, a line-weighted transfer method (river data), or a direct point-to-point transfer (drain data). The transfer did not generate new data, but provided for even (generalized) distribution of those data to the new modeling grid. The process is comparable to a smoothing algorithm used in filtering data. The results produced from these transfer methods do not increase the accuracy of the data; however, the results do allow improved resolution of head and flow direction especially in regions near pumped wells.

A GIS can efficiently and effectively handle large volumes of digital ground-water data from diverse sources and types, and quickly assemble ground-water arrays for any new modeling grid of different cell size or orientation. As demonstrated in this project, a GIS has the capability of easily generating a wide variety of graphical displays, maps, and reports that can be used in verifying these new data arrays. As previously discussed, the system was able to detect a problem with the elevations of the tops of some aquifers. Cross-sectional views of ground-water modeling results also have been developed to enhance this data review. In addition to review and display capabilities, storage of these ground-water data arrays in the GIS data-base-management system has made data retrievals easy. This project has shown the capability of GIS in providing ground-water data retrievals that are compatible as ground-water input to the McDonald Harbaugh modular model. How fine a model grid should be to achieve an accurate and acceptable calibrated result is a question not easily answered by the modeler. However, this GIS application will provide the tools to create a new model with a finer or coarser grid with which to calibrate and address the question of grid resolution. The regridding application that was accomplished in this study, along with the development of a GIS data-base-management system integrated to a ground-water model, will be of considerable use to ground-water modeling now and in the future.

## FUTURE NEEDS FOR GEOGRAPHIC INFORMATION SYSTEM GROUND-WATER INTERFACES

Geographic processing of data has been developing along many fronts. Some of these GIS/ground-water interfaces (not included in this report) include the following tasks:

- \* to develop a user interface for inexperienced GIS personnel to regrid models, produce graphic and tabular displays, produce customized maps and reports, and modify data arrays;
- \* to provide automated routines for pre-processing and post-processing requirements for ground-water models;

- \* to create data aggregation routines, such as algorithms, which select the most predominant data class for each cell block;
- \* to write documentation for editing coverages and loading of a diversity of available digital ground-water data into GIS;
- \* to provide procedures for the storage and use of GIS data from off-line storage devices, use of ground-water data in a local area network (LAN), such as Ethernet, or use of ground-water data through a distributed information system such as Primenet.

It is anticipated that eventually there will be a totally integrated GIS interface to ground-water modeling, but this will require considerable effort and coordination.

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