SELECTION OF GEOHYDROLOGIC BOUNDARIES FOR GROUND-WATER FLOW MODELS, YUCCA MOUNTAIN, NEVADA

Joe S. Downey
U.S. Geological Survey
Denver, Colorado
K.E. Kolm
Colorado School of Mines
Golden, Colorado
E.D. Gutentag
U.S. Geological Survey
Denver, Colorado

ABSTRACT

The conceptual ground-water model of the southern Nevada/Death Valley, California, region presented in this paper includes two aquifer systems: a shallow, intermontane, mostly unconfined aquifer composed of unconsolidated or poorly consolidated sediments and consolidated, layered volcanics, and a deep, regional, multiple-layered, confined aquifer system composed of faulted and fractured carbonate and volcanic rocks. The potentiometric surfaces of both aquifer systems indicate that ground water leaks vertically from the deeper to the shallower geologic units, and that water in the shallower aquifer may not flow beyond the intermontane subbasin, whereas water in the deeper aquifer may indicate transbasinal flow to the playas in Death Valley. As a result, most of the hydrologic boundaries of the regional aquifer systems in the Yucca Mountain region are geologically complex and probably cannot be determined accurately with currently available financial resources.

Most of the existing numerical models simulating the ground-water flow system in the Yucca Mountain region are based on limited potentiometric-head data, elevation and precipitation estimates, and simplified geology. These models are two-dimensional, and are not adequate to represent past and future changes in the ground-water flow system.

The alternative approach to estimating unknown boundary conditions for the regional ground-water flow system at Yucca Mountain involves the following steps: (1) Incorporate known boundary-conditions data from the playas in Death Valley and the Ash Meadows spring line; (2) use estimated boundary data based on geological, pedological, geomorphological, botanical, and hydrological observations to develop initial boundary conditions for the remaining boundaries; (3) test these initial boundary conditions with three-dimensional models, both steady-state and transient; (4) back-calculate the boundary conditions for the northern, northwestern, northeastern and eastern flux boundaries, thereby obtaining new, improved boundary-condition estimates; (5) compare these calculated values with known data during model calibration steps; and (6) adjust the model. This alternative approach should provide reasonable boundary conditions, for both the paleo and present-day regional hydrologic system, and for studies of future ground-water flow systems that result from changes in climate, tectonic events, or water use.

INTRODUCTION

Purpose

This paper (1) describes the importance of boundary conditions to numerical modeling, (2) describes the past methods of boundary estimation used in the numerical simulation of ground-water flow systems in the Yucca Mountain area, and (3) presents an alternative method of boundary estimation for numerical simulations of regional ground-water flow systems in the Yucca Mountain area (Fig. 1). A brief introduction describing the numerical simulation of natural hydrologic boundaries is provided. The known and hypothesized hydrologic boundaries of the regional ground-water system near Yucca Mountain are discussed, and a conceptual model of the regional ground-water flow system in southern Nevada and Death Valley, California, is presented.

Ground-water Flow System Boundary Conditions

Geohydrologic boundaries occur in all ground-water flow systems. Boundary conditions may change with time, but most model simulations assume static boundary conditions. Therefore, the proper selection of boundary conditions for a ground-water model is important for the accuracy of steady-state and transient model simulation and calibration.

The model boundary conditions should replicate the real hydrological system as closely as possible (Downey, 1984). However, the actual hydrologic conditions frequently are unknown at the time of model development. Consequently, the initial boundary conditions must be estimated.

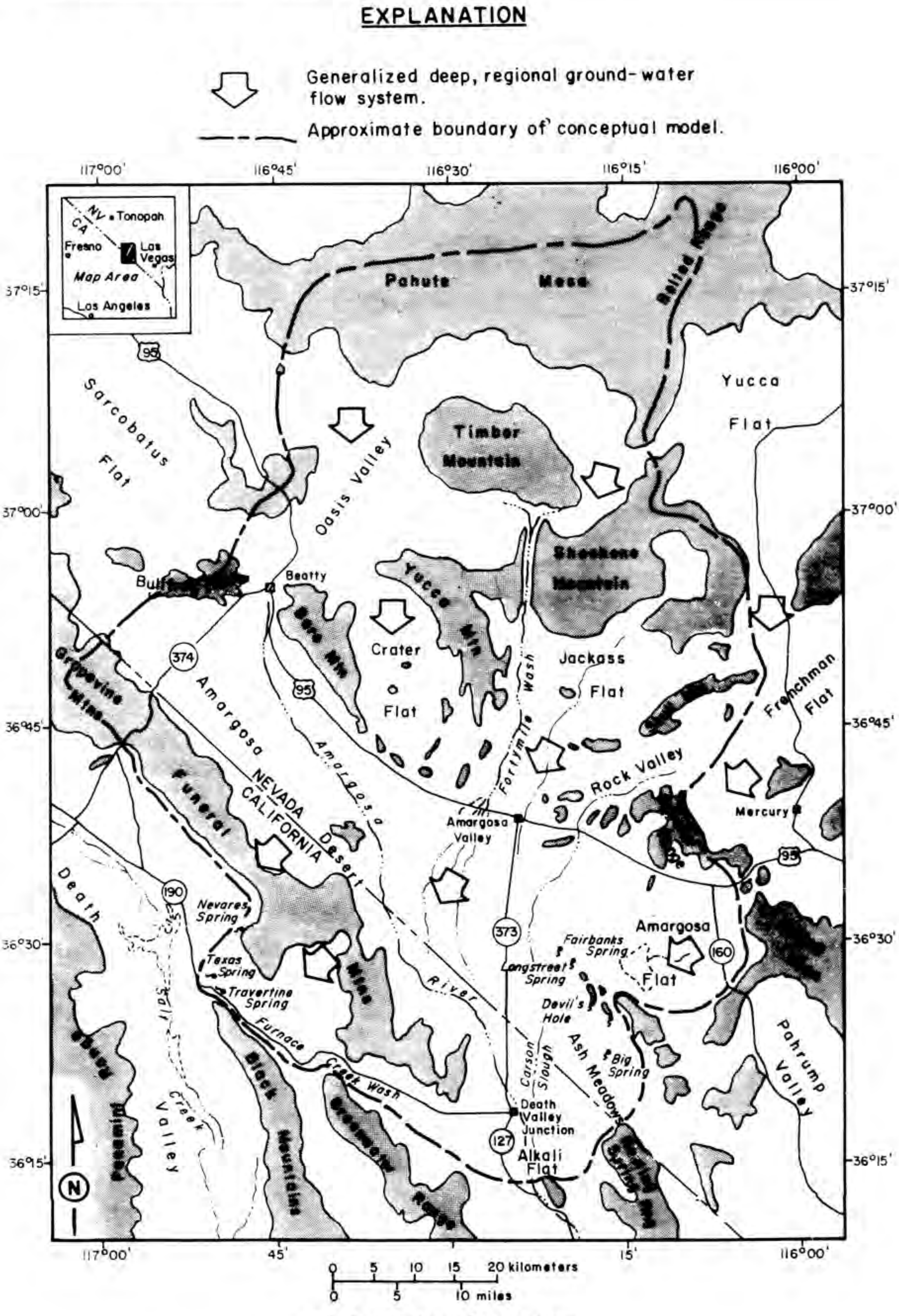

Fig. 1. Location of Study Area.

During model calibration, the model boundary conditions will likely require modification to achieve calibration. Depending on the purpose of the model and the accuracy required, different model boundary conditions may be equally satisfactory for describing the ground-water system. In such situations, the selection of "best" model boundaries depends on the skill and experience of the model builder, and on the conceptualization of real-world conditions.

All boundary conditions of a numerical model must be described mathematically. Four general types of boundary conditions (Fig. 2) are known and used in ground-water flow models: (1) Specified flux, (2) no-flow, where the specified flux is zero, (3) specified or constant head, and (4) vertical leakage.

Specified flux boundaries are used whenever volumes of water (fluxes) flow into or out of the ground-water system. These volumes may be known from fluid measurements, or may be estimated. Recharge to an aquifer as well pumpage or as evapotranspiration from the aquifer surface are two types of specified flux boundaries. Discharge from the aquifer, for example at springs, is another type of specified flux boundary condition.

Specified flux boundaries where the flux is zero are a special case, and are termed "no-flow boundaries." In the real hydrologic system, these no-flow boundaries may be regions with hydrological materials that are impermeable, so no water moves into or out of the region being modeled.

Specified or constant head boundaries are used when the water pressure or water table (head) in the aquifer system is fixed, such as along a river or lake, or when connection is made with another aquifer. In the case of transient model simulations, the potentiometric head must remain constant with each time step at those model nodes representing constant head boundaries. Specified head boundaries also can be used in numerical models to develop potentiometric-head gradients and to affect hydrologic flow paths within a model area of interest.

Vertical leakage boundaries are used in three-dimensional ground-water models to represent flow between aquifer layers through confining units or direct recharge to the system from geologic units external to the model region. In some three-dimensional models, vertical leakage is calculated directly by the model when the vertical hydraulic conductivity and thickness of a confining unit is known and specified.

CONCEPTUAL MODEL OF THREE-DIMENSIONAL REGIONALGROUND-WATER FLOW UNDERLYING YUCCA MOUNTAIN

The regional ground-water flow system underlying Yucca Mountain may be conceptualized as two types of connected aquifers: (1) An intermontane, shallow ground-water basin, and (2) a regional, deep ground-water flow system. The intermontane, shallow ground-water basin, composed of unconsolidated to poorly consolidated sediments of Tertiary to Holocene age and layered Tertiary volcanic rocks, is an unconfined to partially confined aquifer. The dominant flow direction in this aquifer is from north, northeast, and east to the south (Fig. 3). Ground-water flow in this system may be either matrix or fracture controlled.

The regional, deep ground-water flow system, composed of faulted and fractured carbonate rocks of Paleozoic and Mesozoic age and volcanic rocks of Tertiary age, is a multiple-layered group of confined aquifers. The dominant flow direction in these aquifers is from the north, northeast, and east to the south and southwest (Fig. 4). Ground-water flow in this system probably is fault and fracture controlled.

In general, the deeper, regional aquifer has greater heads than the shallow, intermontane aquifer in the Yucca Mountain region. As a result, ground-water leaks vertically from the deeper to the shallower aquifers, and ground-water mixing is observed frequently at regional discharge areas (Fig. 5). In addition, flow within the shallow aquifer may be restricted to the intermontane basin, whereas the deeper aquifer may show transbasinal flow (Fig. 5).

SELECTION OF DIGITAL MODEL BOUNDARIES, YUCCA MOUNTAIN AREA

General Background

Data defining the hydrologic boundaries of the regional aquifers in the Yucca Mountain region are lacking (Winograd and Thordarson,1975; Harrill and others, 1988; Plume and Carlton, 1988). As a result, most of the existing numerical models simulating the ground-water flow system in the Yucca Mountain region use expected boundary conditions to approximate the unknown hydrologic boundaries (Czarnecki and Waddell, 1984; Sinton and Downey, in preparation; Waddell, 1982). All boundary conditions used in prior models, except for the Ash Meadows spring line and playas of Death Valley, have been selected based on geology, limited potentiometric-head data, or other hydrologic factors. All of the models have estimated boundary conditions based on a two-dimensional flow system with homogeneous and isotropic, matrix ground-water flow. However, this two-dimensional approach does not accurately represent the regional system for paleohydrologic studies, nor studies of the future ground-water flow system, where boundary conditions, geologic framework, and climate may change with time.

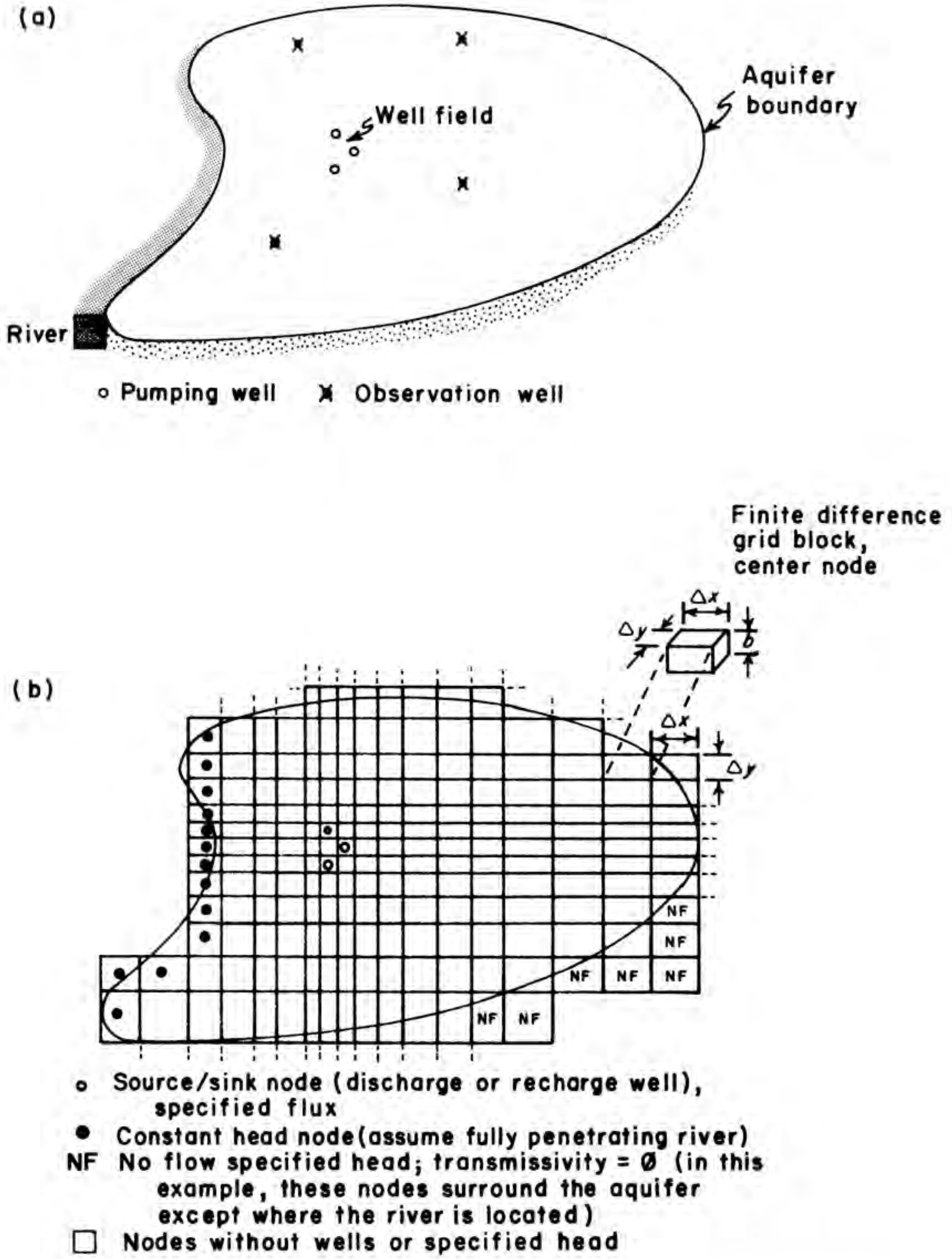

Fig. 2. Finite difference representations of an aquifer region. (a) Map view of aquifer showing well field, observation wells, and boundaries. (b) Finite difference grid with block-centered nodes, where Δx is the spacing in the x direction, Δy is the spacing in the y direction, and b is the aquifer thickness (modified from Wang and Anderson, 1982).

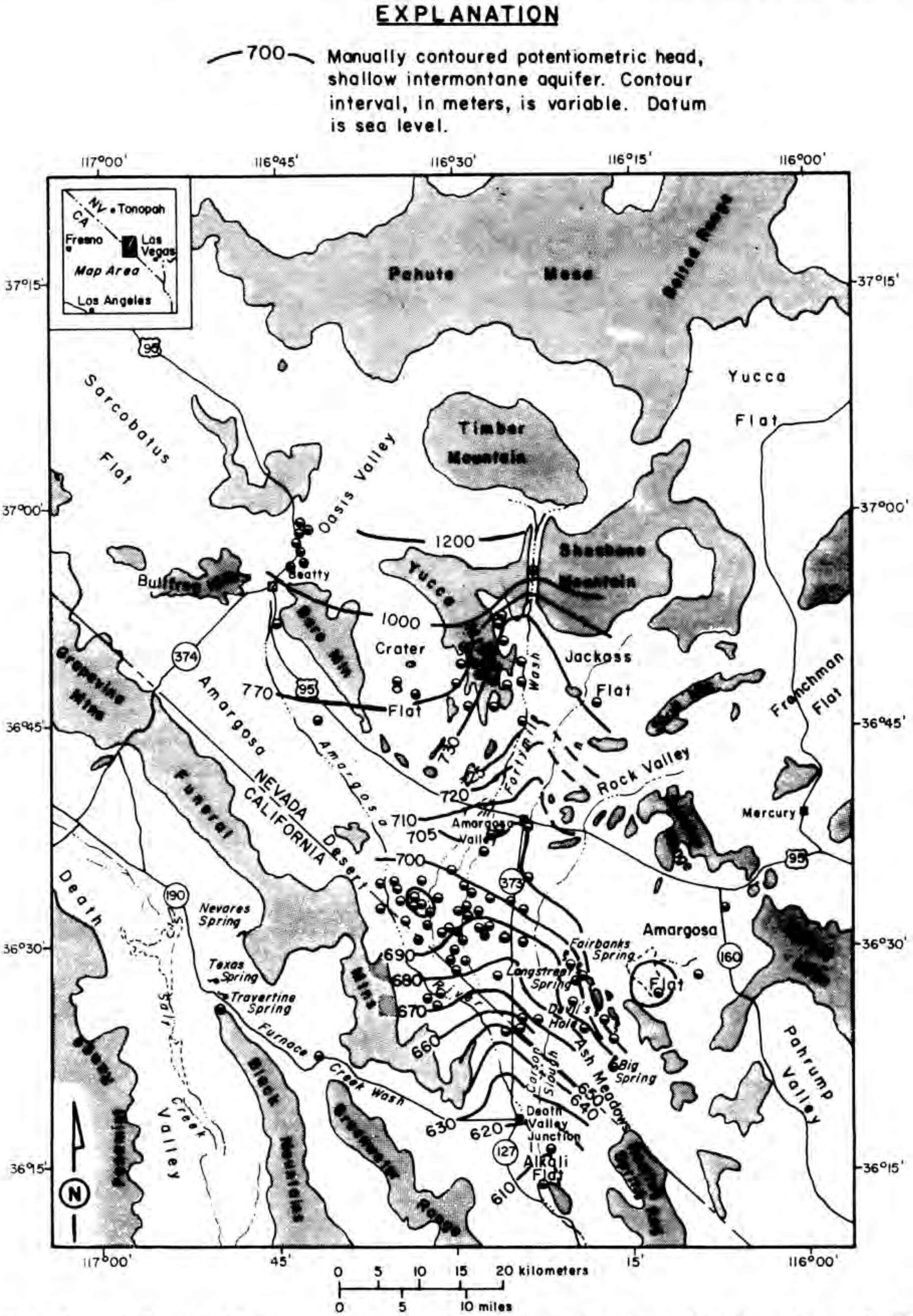

Fig. 3. Potentiometric Surface of Intermontane, Shallow Ground-Water Flow System Near Yucca Mountain, Nevada.

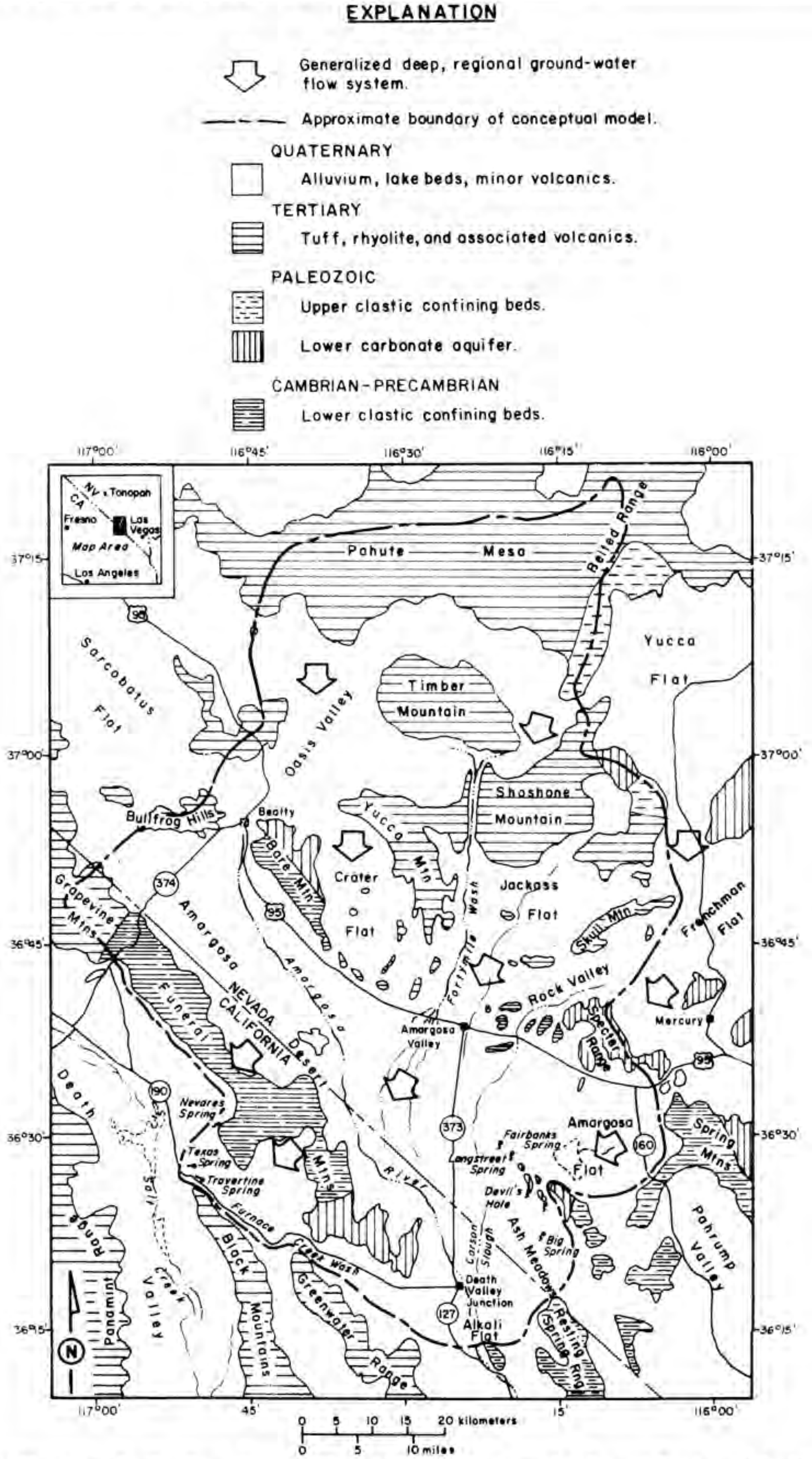

Fig. 4. Generalized Geology of a Southern Nevada Ground-Water Basin and Adjacent Regions (Modified after Waddell, 1982) and Flow Paths of the Deep, Regional Ground-Water Flow System.

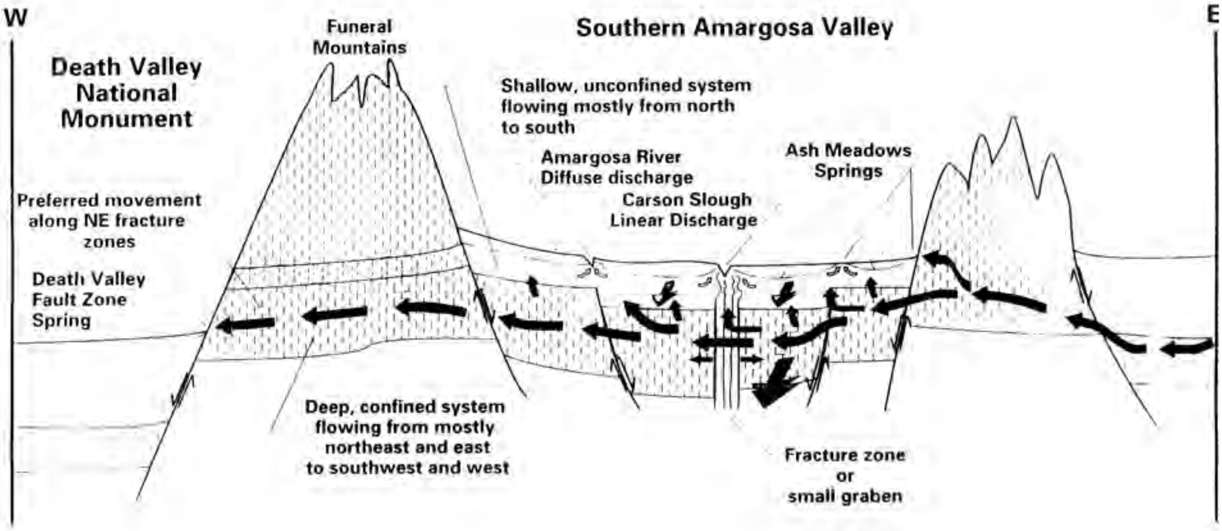

Fig. 5. Generalized Section of the Southern Nevada and Death Valley, California, Area Showing Three-Dimensional Ground-Water Flow.

Three-Dimensional Approach to Boundary Conditions

A three-dimensional approach of boundary selection and estimation needs to be developed for use in this region of complex geologic structure, arid climate, and limited data. Boundary conditions need to be selected on the basis of geological, pedological, geomorphological, botanical, and hydrological evidence, and need to be quantified on the basis of known relations to ground-water flow. By using this approach, the ground-water fluxes and boundary conditions can be back-calculated using three-dimensional models, both steady-state and transient, for areas where measured information is unavailable or difficult to collect. The new, improved estimates can be compared with known data during model-calibration steps, and the model can be adjusted accordingly. This approach is most applicable to simulating the paleo and future ground-water flow systems. In these situations, evidence of past geological, pedological, geomorphological, botanical, and hydrological conditions can be measured, and thus modeled; or future processes and responses can be predicted and converted into ground-water flow system changes.

Two known boundary conditions exist in the Yucca Mountain area: the playas in Death Valley and the springs in the Ash Meadows area. Currently, it is hypothesized that the Ash Meadows spring line is along a structural feature that delineates the Ash Meadows ground-water system from the Death Valley system (Winograd and Thordarson, 1975). This geologic feature has been used as a part of the eastern hydrologic boundary in the original flow model developed for the Ash Meadows subbasin (Czarnecki and Waddell, 1984).

In general, the lateral boundary conditions of the aquifer systems underlying the Yucca Mountain area (fig. 6) can be characterized as follows:

1. To the west, northwest, north, northeast and east, the real system boundaries are unknown and must be placed far from the primary areas of interest--Yucca Mountain and the Amargosa Desert. Accordingly, numerical simulation models may use specified flux and constant-head boundaries to describe flow into the Yucca Mountain system from these directions outside the modeled area. However, the accurate quantitative estimation of the hydrologic model conditions for these arbitrary boundaries is very difficult.
2. To the south and southwest, playas in Death Valley form an observable, real, hydrologic boundary, and

may be the ultimate hydrologic boundary for the deep, regional aquifer systems underlying Yucca Mountain. In such a case, the Death Valley playas would be a specified flux or constant-head boundary for any ground-water model simulation of the deeper, regional system. In this case, determination of model parameters is less difficult because measures of the discharge flux and altitude data from springs are available. Death Valley could be simulated as a constant-head boundary for numerical models that simulate paleohydrological or future conditions. The effects on the ground-water systems caused by the presence of Lake Manly at various times in the geologic past, and the possible re-emergence of similar lakes in Death Valley during future, wetter climates, could be modeled in this manner.

3. To the southeast, the springs in the Ash Meadows area form an observable and measurable boundary condition. This boundary may be simulated as a specified flux or constant head.

Recharge and discharge boundary conditions must also be estimated in the Yucca Mountain area. Exact recharge quantities in this arid area are very poorly known and have been estimated on the basis of elevation and precipitation. The alternative approach is to estimate recharge on the basis of vegetation communities and densities, type of soil and geomorphic materials, precipitation, elevation, slope steepness and slope aspect. Areas of recharge may include the Grapevine Mountains, the Timber Mountain/Pahute Mesa area, and the Spring Mountains (Fig. 6).

Vertical leakage from deeper to shallower aquifers may occur through fracture and fault zones. This form of recharge may be estimated by using gradient data, and values of hydraulic conductivity, potentiometric heads, and thicknesses of less permeable or confining geologic units. The areas of vertical leakage, and preferred horizontal flow paths, may be located by using lineament/fracture-zone analyses (Peters and others, 1988).

Discharge boundary conditions, determined on the basis of vegetation communities, geologic deposits, and locations of springs, may include the Alkali Flat and Carson Slough areas (Fig. 6). Again, discharge quantities will need to be estimated for those areas where indirect evidence, such as vegetation types and communities, is obtained. In areas where flowing springs are observed, for example in the Ash Meadows area, actual measurements may be used for discharge boundary conditions.

CONCLUSIONS

In summary, the conceptual ground-water model of the southern Nevada/Death Valley, California, region includes two aquifer systems: a shallow, intermontane, mostly unconfined aquifer composed of unconsolidated or poorly consolidated sediments and layered, Tertiary volcanic rocks, and a deep, regional, multiple-layered, confined aquifer system composed of faulted and fractured carbonate and volcanic rocks. The potentiometric surfaces of both aquifer systems indicate that ground-water leaks vertically from the deeper to the shallower geologic units, and that water in the shallower aquifer may not flow beyond the intermontane subbasin, whereas water in the deeper aquifer may indicate transbasinal flow to the playas of Death Valley. As a result, most of the hydrologic boundaries of the regional aquifer systems in the Yucca Mountain area are geologically complex and probably cannot be determined accurately with currently available financial resources.

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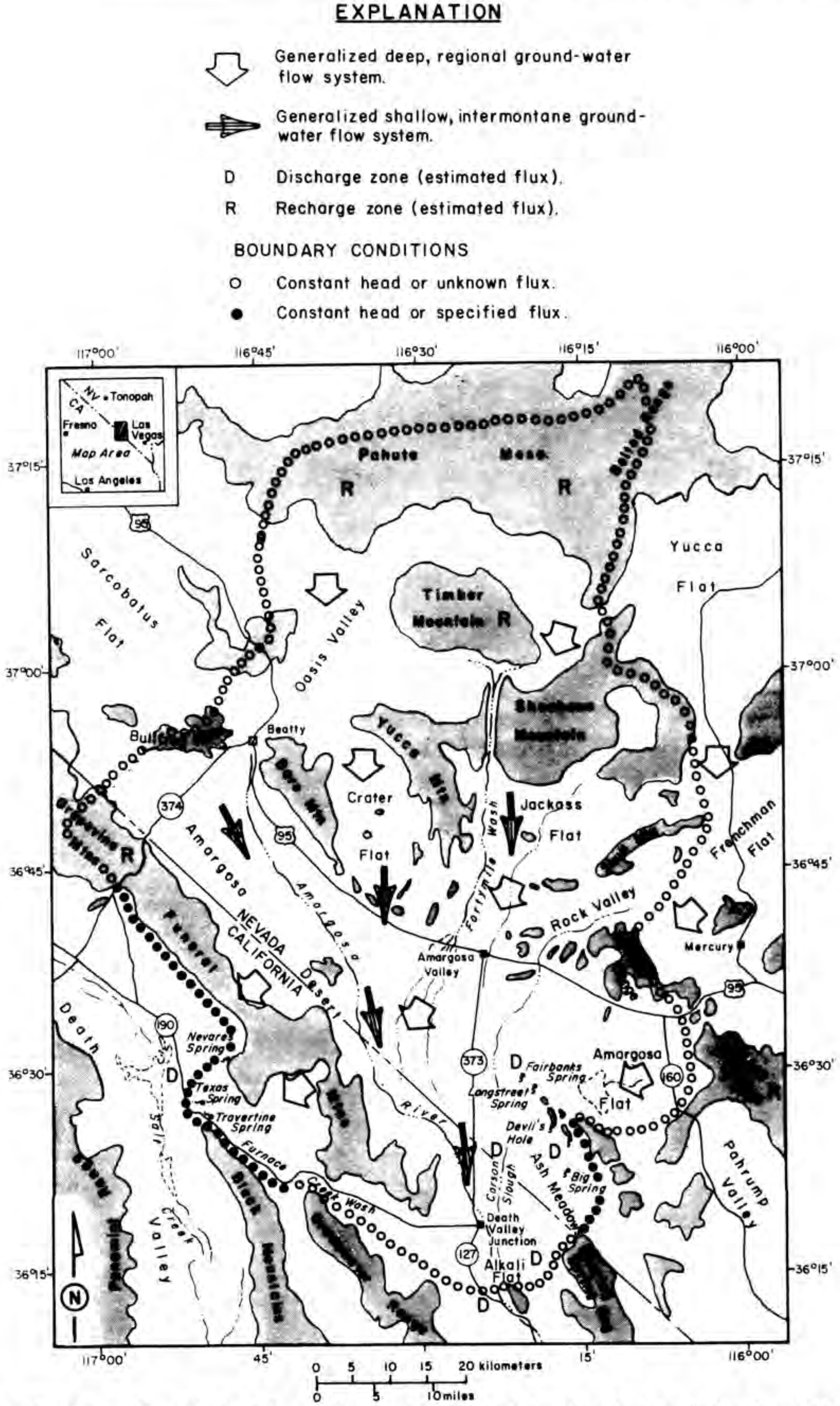

Fig. 6. Boundary Conditions Hypothesized for the Regional Ground-Water Flow Systems in the Yucca Mountain Area.

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