MODELS, DATA AVAILABLE, AND DATA REQUIREMENTS FOR ESTIMATING THE EFFECTS OF INJECTING SALTWATER INTO DISPOSAL WELLS IN THE GREATER ALTAMONT-BLUEBELL OIL AND GAS FIELD, NORTHERN UINTA BASIN, UTAH

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CONVERSION FACTORS

For those readers who prefer to use metric (International System) units, conversion factors for the inch-pound units used in this report are listed below:

Multiply inch-pound units		By	To obtain metric units
acre		0.4047	hectare
degrees Fahrenheit	(°F)	°C = (°F-32)/1.8	degrees Celcius (°C)
foot	(ft)	0.3048	meter
foot per day	(ft/d)	0.3048	meter per day
foot squared per day	(ft^2/d)	0.09290	meter squared per day
gallon	(gal)	3.785	liter
gallon per minute	(gal/min)	0.06308	liter per second
inch	(in.)	25.4	millimeter
inch per year	(in/yr)	25.4	millimeter per year
mile	(mi)	1.609	kilometer
square mile	(mi^2)	2.590	square kilometer
pound per square inch	(lb/in^2)	6.895	kilopascal

Chemical concentrations are reported only in milligrams per liter (mg/L). Milligrams per liter is a unit expressing the solute per unit volume of water. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

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 "Mean Sea Level of 1929".

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ABSTRACT

Permits for disposing of salty oil-production water have been issued for 19 wells in the Greater Altamont-Bluebell field. During 1986 more than 500 million gallons of production water were injected into the Duchesne River, Uinta, and Green River Formations through 18 of these wells. The physical and chemical effects of injecting this water into aquifers containing potable water are poorly understood. Interfingering and the structural configuration of these formations add complexity to the description of the geometry and hydrogeology of the ground-water system.

A preliminary assessment of the problem indicates that numerical modeling may offer a method of determining the effects of injection. Modeling possibilities include variable-density, three-dimensional flow, sectional-transport, and areal-transport models. Data needed to develop these models can be derived from a synthesis of geologic, hydrologic, and hydrochemical data already available in the files of State and Federal agencies, oil companies, and private companies. Results from each modeling phase would contribute information for implementing the following phase. The result will be a better understanding of how water moves naturally through the ground-water system, the extent of alterations of both vertical and horizontal flow near the disposal wells, and an overall concept of the effects of deep injection on near-surface aquifers.

INTRODUCTION

The Greater Altamont-Bluebell field is a major oil- and gas-producing area in the northern Uinta Basin of Utah. The U.S. Geological Survey, in cooperation with the Utah Division of Oil, Gas, and Mining, agreed to determine the feasibility of using a numerical model to assess the impact of saltwater injection in the area. The area lies north of Duchesne and west of Vernal in northeastern Utah and includes approximately 465 mi^2 (fig. 1). Infill drilling has joined the older Roosevelt (1949), Bluebell (1955), Cedar Rim (1969), Altamont (1970), and Flat Mesa fields into the Greater Altamont-Bluebell field. Several other smaller fields are located just to the south and east of the Greater Altamont-Bluebell field. Oil- and gas-producing horizons are chiefly in the Green River and Wasatch Formations of Tertiary age (Clem, 1985). According to records of the Utah Division of Oil, Gas, and Mining, the Altamont, Bluebell, and Cedar Rim fields produced about 7.5 billion gallons of mostly saltwater from 1970 through 1985.

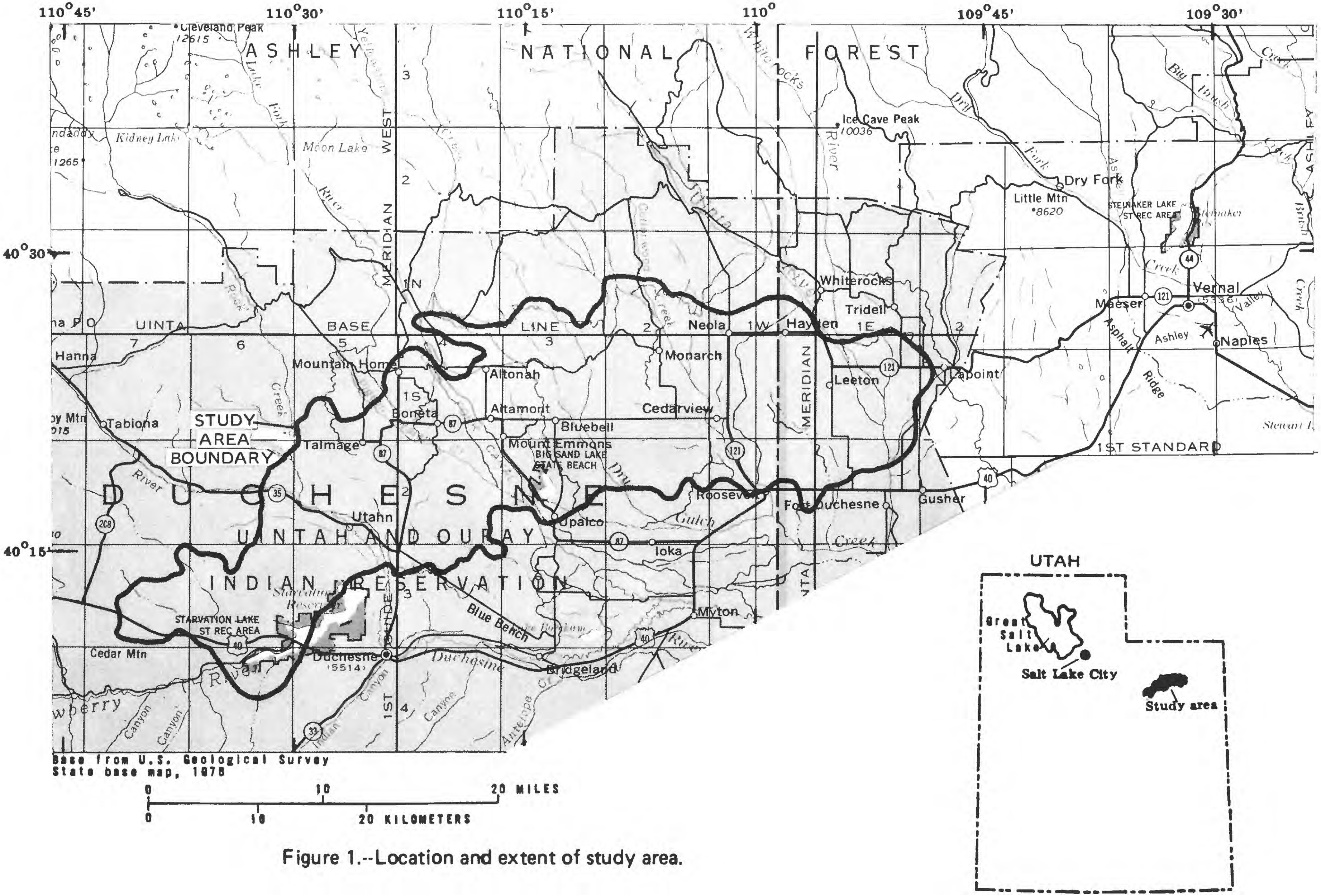

Figure 1.--Location and extent of study area.

Disposal of oil-production water in the Greater Altamont-Bluebell field has changed from primarily surface disposal to injection disposal. This trend is likely to continue because efforts by regulatory agencies to protect shallow ground water from contamination by surface disposal of salty oil-production water in evaporation ponds are making this disposal method less economical to the petroleum industry (Baker and Brendecke, 1983). Injection into formations that already contain saltwater is thought to be more environmentally sound as well as moderately cost effective.

Problems

The Utah Division of Oil, Gas, and Mining is responsible for issuing disposal-well permits. According to records provided by well operators, more than 500 million gallons of saltwater were injected beneath the Greater Altamont-Bluebell oil and gas field during 1986. Injection is taking place in the Duchesne River, Uinta, and Green River Formations at depths ranging from 1,759 to 9,468 ft below land surface. Approximate injection pressures range from 1,000 to 1,500 lbs/in^2. The effects of these large sustained injection pressures and the subsequent dispersion of chemical solutes within the receiving formation need to be examined to protect existing potable water supplies in overlying formations.

Specific questions posed by the Division of Oil, Gas, and Mining are: (1) Does saltwater, either injected or natural, migrate through fractures into overlying freshwater aquifers; (2) how are injection pressures at disposal wells affecting the distribution of hydraulic heads in the receiving formation and in other overlying consolidated and unconsolidated aquifers, and how would these effects be altered by changing injection pressures; (3) what quantity of oil-production water can the receiving formations store; (4) to what extent is the chemical quality of the native water in these formations being changed by mixing with the oil-production water, and how will these changes affect freshwater aquifers if vertical migration occurs; (5) how far from the point of injection do these changes occur; and (6) what information is needed prior to issuing an injection-well permit that would indicate the environmental suitability of a proposed injection interval?

Purpose and Scope

The purpose of this report is to describe numerical models, data available, and data requirements for estimating the effects of injecting saltwater into disposal wells in the Greater Altamont-Bluebell oil and gas field in the northern Uinta Basin in northeastern Utah. Information in this report will lay the foundation for the Utah Division of Oil, Gas, and Mining to establish a plan of study for less-detrimental disposal of oil-production water in this field and, perhaps, elsewhere in the Uinta Basin.

The objective of this document is to describe the types and areal density of data needed to develop numerical models for uniform and variable-density flow or solute transport by reviewing the applicable model codes and then evaluating the availability of needed information for the Greater Altamont-Bluebell field. On the basis of this evaluation, specific modeling analyses can be implemented. If all necessary data are not available, methods of obtaining the required data, directly or indirectly, are discussed.

Previous Investigations

The Uinta Basin has been the subject of numerous reports emphasizing geology, energy resources, reconnaissance hydrology, and site-specific hydrologic problems. Investigations pertinent to this planning phase are cited in the text and are listed at the end of this report.

Well-numbering System

The system of numbering wells in Utah is based on the cadastral land-survey system of the U.S. Government. Wells in the Greater Altamont-Bluebell field are surveyed around the Uintah base line and Meridian, a small area in Utah not included in the survey covered by the Salt Lake Meridian. In this land-survey system, the area included in the Uintah base line and Meridian survey is divided into four quadrants by the uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The Uintah base line and Meridian is designated by the letter "U," which precedes the parentheses. The number after the parentheses indicates the section, and is followed by three letters indicating the quarter section (160-acre tract), the quarter-quarter section (40-acre tract), and the quarter-quarter-quarter section (10-acre tract). The letters a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each tract.

Thus, U(C-1-2)11bba designates a well in the NE$\frac{1}{4}$ of the NW$\frac{1}{4}$ of the NW$\frac{1}{4}$ of section 11, T. 1 S., R. 2 W. of the Uinta Special meridian survey. The numbering system is illustrated in figure 2.

Acknowledgments

Special appreciation is extended to the personnel from the Utah Division of Oil, Gas, and Mining, who provided assistance in examining disposal-well files.

HYDROGEOLOGIC SETTING

In the Greater Altamont-Bluebell field, oil-production water is used either in secondary-recovery operations (reinjected into producing zones), is transported and put into evaporation ponds, or is injected into strata that overlie the principal oil- and gas-producing zones. These overlying strata are, from youngest to oldest, the Duchesne River, Uinta, and Green River Formations of Tertiary age. The stratigraphic relation of these formations, the overlying unconsolidated Quaternary deposits, and the underlying Tertiary Wasatch Formation, are shown diagrammatically in figure 3.

The Greater Altamont-Bluebell field lies just to the south of the Uinta Basin synclinal axis. The strata generally dip to the north-northwest toward this axis, except in the eastern half of the field where a west-plunging anticline is superimposed on the inclined surface (fig. 4). A structure-contour map showing the apparent altitude of the top of the Green River Formation, based on logs from petroleum test holes, shows the complex inclined surface in the west half of the field and the relatively flat surface in the east half (fig. 5). The central part of the field was not contoured because

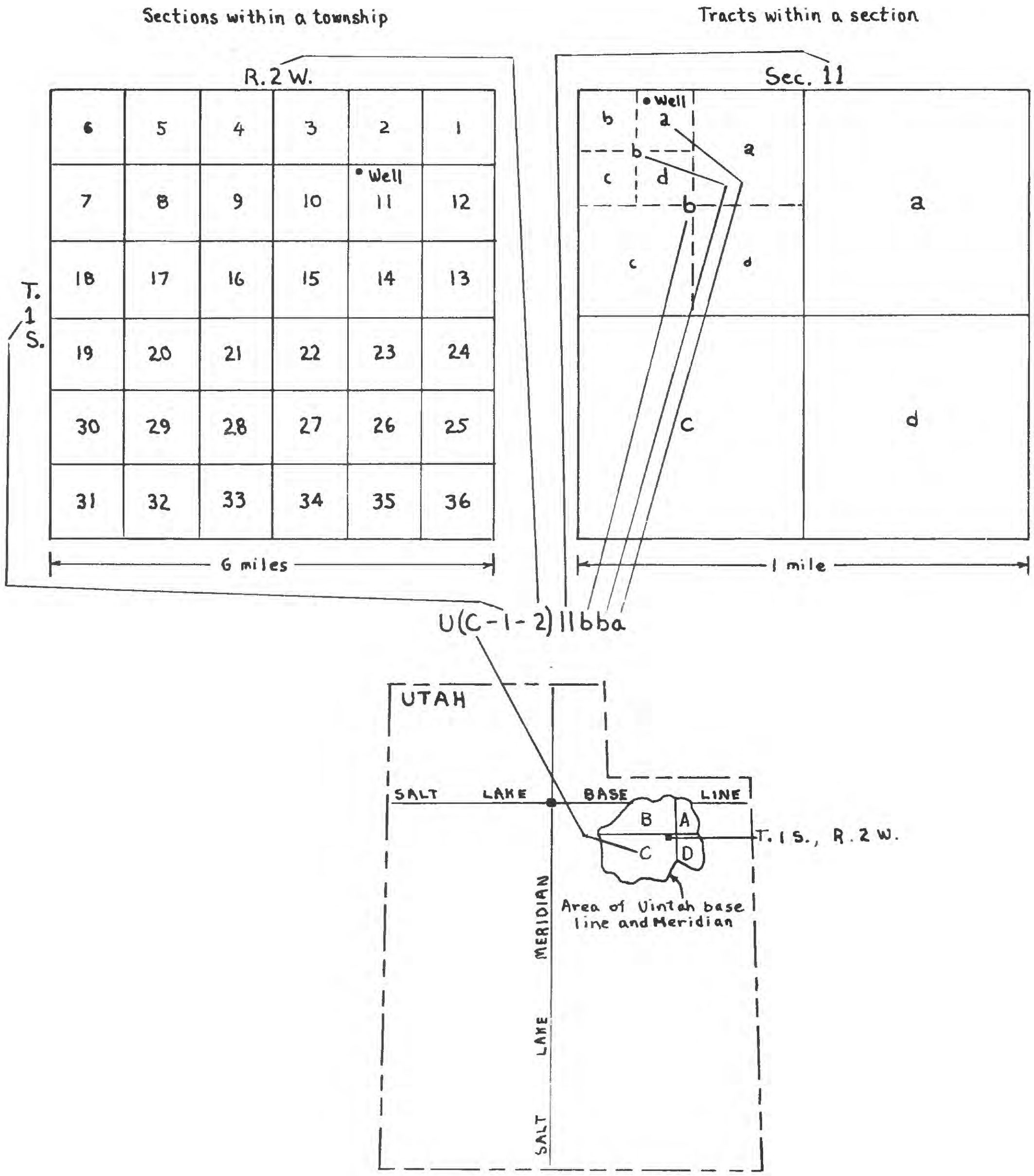

Figure 2. -Well-numbering system.

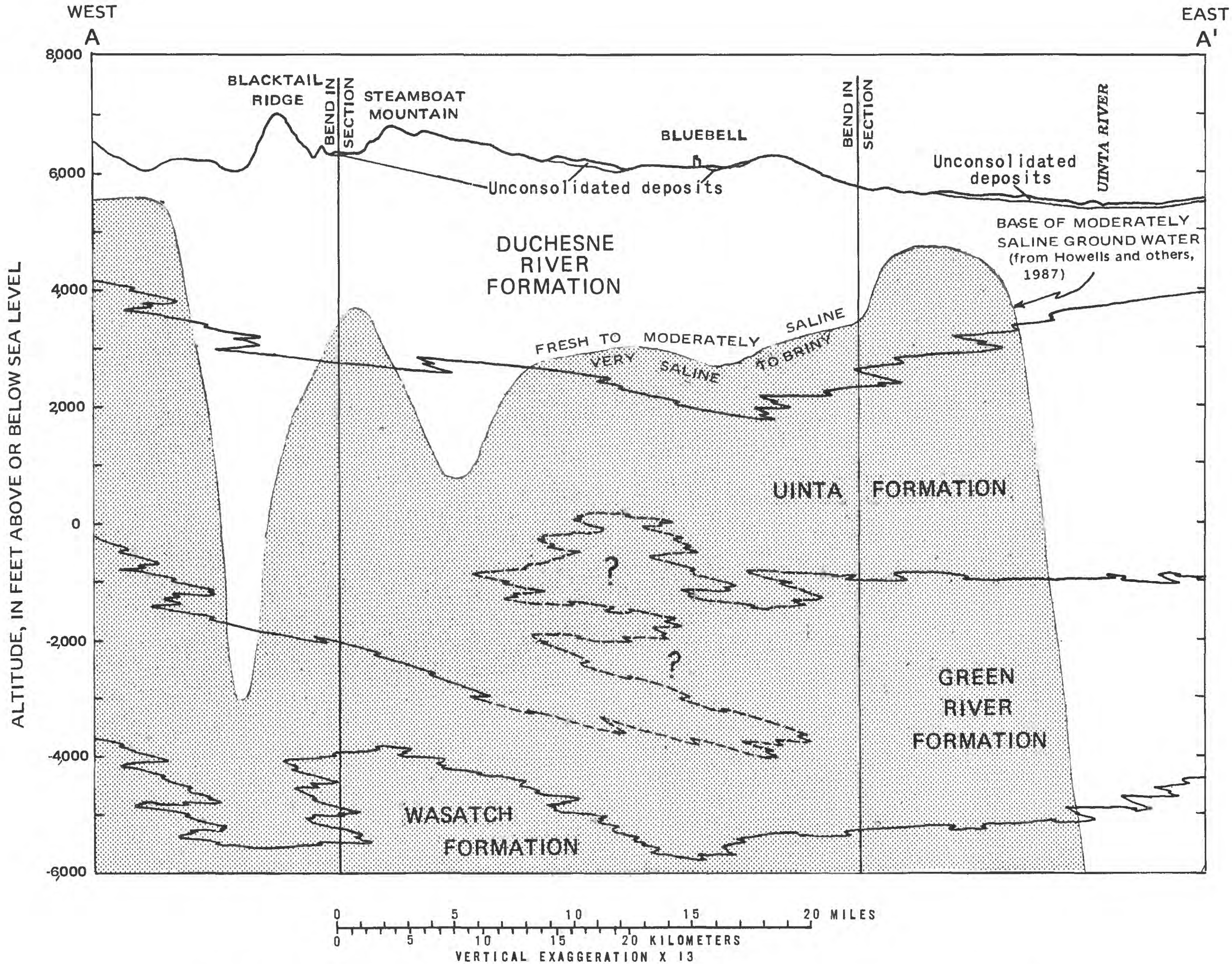

Figure 3.- Approximate stratigraphic relation among geologic formations underlying the Greater Altamont-Bluebell field (trace of section shown in fig. 5).

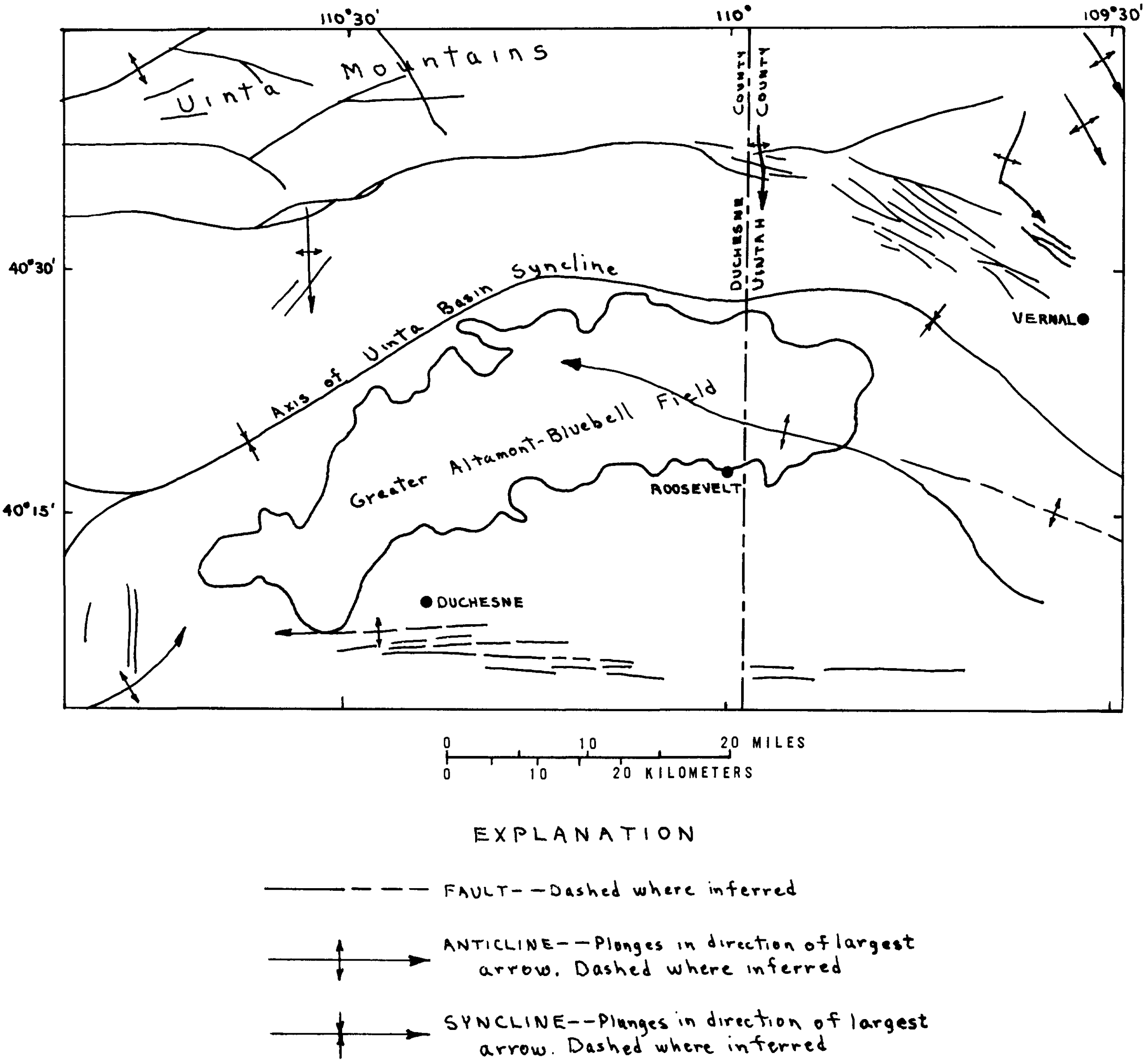

Figure 4.--Tectonic features in vicinity of the Greater Altamont-Bluebell field.

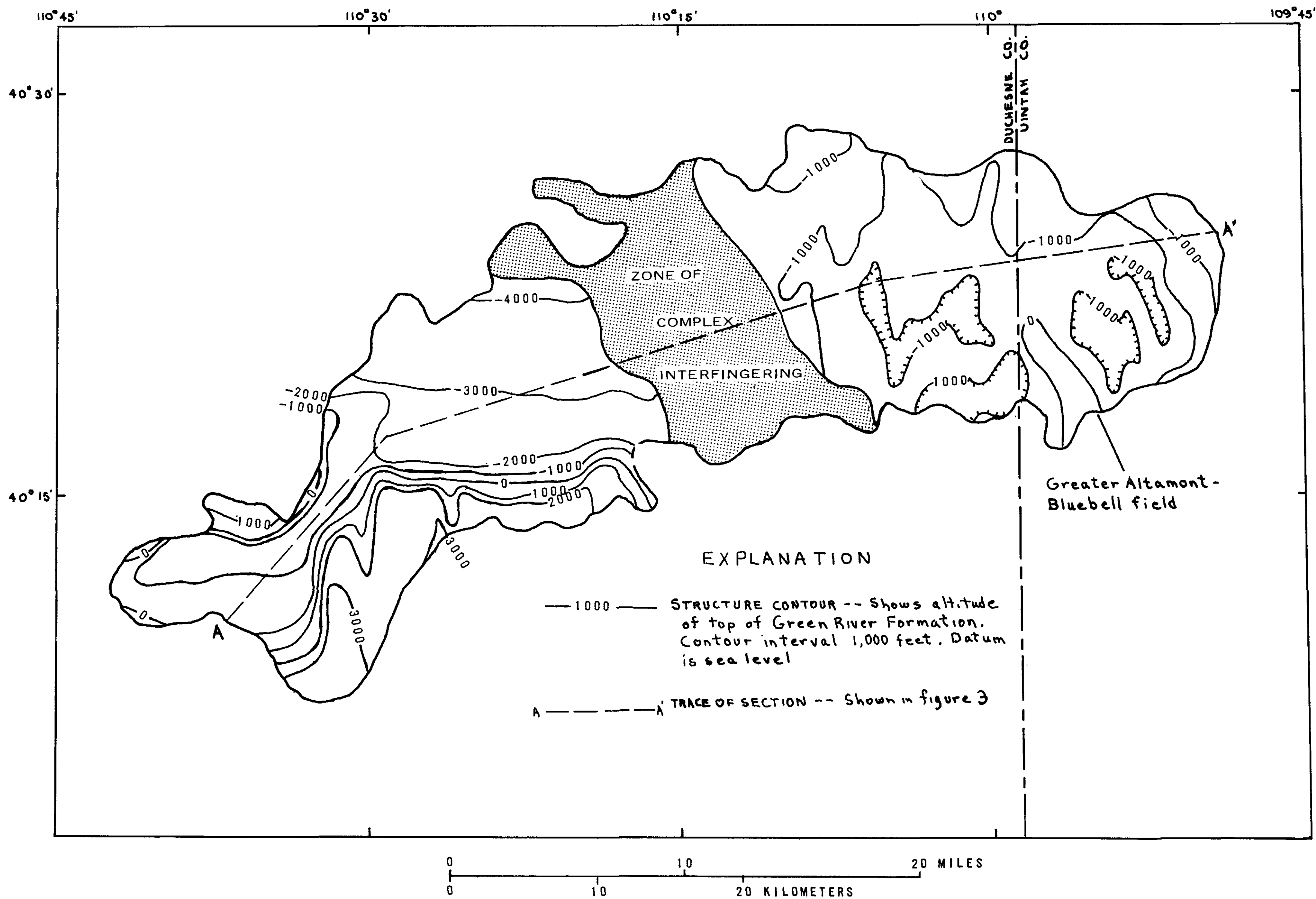

Figure 5. -Structural configuration of the top of the Green River Formation.

of the complexity introduced by the interfingering of the Green River Formation with the overlying Uinta Formation.

Based on log data from petroleum test holes, thickness of the Green River Formation within the study area ranges from 1,235 to 6,560 ft. Thickness of the Uinta Formation, from 30 data points, ranges from 2,466 to 5,040 ft. The Duchesne River Formation is exposed at land surface, and pre-erosion thickness could not be determined. Meager data within the study area indicate existing thickness of the Duchesne River Formation ranges from 1,331 to 5,305 ft. Table 1, modified from Hood (1976), indicates the variability in lithologic and hydrologic character of these formations.

Previous investigations have, in a generalized way, identified the hydrologic character of the formations that underlie the Greater Altamont-Bluebell field. Most formations are extremely variable in lithologic character and are considered to be aquifers where they are coarse-grained or extensively fractured and confining layers where they are unfractured or fine-grained. On a regional scale, the Duchesne River, Uinta, Green River, and Wasatch Formations were designated "aquifers and confining layers" for purposes of the Upper Colorado Regional Aquifer-System Analysis (Taylor and others, 1986). Locally, based on hydrologic characteristics, the Duchesne River and Uinta Formations are considered more permeable, overall, than the Green River and Wasatch Formations.

The hydrogeologic units that may be affected by injection are the deep confining unit (the Green River and Wasatch Formations), the Uinta aquifer (the Uinta and Duchesne Formations), and the overlying locally important unconsolidated aquifer (unconsolidated Quaternary deposits). The unconsolidated Quaternary deposits consist of glacial deposits, alluvium, and terrace gravels of the Pleistocene, and alluvium, landslides, terrace gravels, and wind-blown deposits of the Holocene Epoch (Hood, 1976, p. 9). Combined thickness of these unconsolidated deposits is generally less than 200 ft.

MODELING TECHNIQUES

Numerical modeling offers the unique ability of simulating hydrologic and chemical processes that take place within a geohydrologic environment and of determining how these processes change through space and time. No other method can combine the physical dimensions of various layers, their flow quantities and properties, and the physical and chemical dispersion of fluids into a single integrated analysis. However, there are limitations that should be recognized. These limitations arise from incomplete knowledge of how to numerically express the movement of chemical constituents through heterogeneous porous media and from the quantity and quality of the physical, lithologic, hydrologic, and chemical data that are used to develop a model. As long as these limitations are acknowledged and compensated for in final interpretations, numerical models usually offer the best methods for evaluating the feasibility of a hydrologic or hydrochemical concept.

Numerous models are available for simulating ground-water flow and the dispersion and transport of chemical solutes or thermal energy. Flow models and solute-transport models usually solve the partial differential equations used to numerically approximate saturated flow, heat transport, and solute

Table 1.--**Description of Tertiary and Quaternary-age formations affected by saltwater injection in the Greater Altamont-Bluebell field**

Geologic unit	Range in thickness (feet)	Lithologic character	Hydrologic character	Hydrogeologic unit
Unconsolidated Quaternary sediments	1 to 200	Alluvial material, terrace deposits, glacial outwash, dune sand, talus and landslide deposits consisting of clay, silt, sand, gravel, cobbles, boulders, and large angular blocks.	Slightly permeable to permeable. Glacial outwash and related coarse-grained deposits comprise the most prolific aquifer. Terrace deposits, talus and landslides, and wind-blown deposits usually thin and higher than the water table, but form the main recharge areas for thicker saturated deposits. Hydraulic conductivity of glacial outwash estimated to range from 2 to 1,800 feet per day.	Unconsolidated aquifer
Duchesne River Formation	1,331 to 5,305	Sandstone, shale, siltstone, claystone, and conglomerate, exposed throughout the study area except locally where buried by relatively thin younger, stream-channel and terrace deposits. Sandstone constitutes about half the formation and predominates in the upper and lower parts of the formation. Silty claystone and claystone are more prevalent in the middle of the formation (Andersen and Picard, 1972, p. 13).	Virtually impermeable to permeable. Hydraulic conductivity of 19 sandstone samples ranged from 0.000033 to 3.28 feet per day (Hood, 1976, table 3). Total porosity ranges from 7 to 32 percent. Yield to wells and springs range from less than 1 to more than 300 gallons per minute. Water movement may be impeded locally by gilsonite dikes. Fracturing enhances permeability and water is fresh where recharge occurs at outcrops. At depth, the water is slightly saline to to briny. Near Roosevelt artesian heads may exceed 100 feet above land surface.	Uinta aquifer
Uinta Formation	2,466 to 5,040	Primarily calcareous lake deposits consisting of shale, limestone, claystone, siltstone, and sandstone.	Virtually impermeable to permeable. Hydraulic conductivity of four sandstone samples ranged from 0.021 to 0.36 foot per day, but the formation is generally finer grained and less permeable than the Duchesne Formation. Permeability greatly enhanced by fracturing. The formation generally yields only a few gallons per minute of saltwater to wells.	
Green River Formation	1,235 to 6,560	Mainly lacustrine shale with some limestone, siltstone, and sandstone. Interfingers with both the overlying Uinta Formation and the underlying Wasatch Formation.	Virtually impermeable except where fractured. Hydraulic conductivity, estimated from results of drill-stem tests, ranged from less than 0.0001 to 2.9 foot per day. The formation yields mostly saline and briny water to petroleum wells.	Deep confining unit
Wasatch Formation	Unknown	Mainly lacustrine shale, sandstone, and conglomerate. Interfingered with overlying Green River Formation.	Virtually impermeable except where fractured. Porosity of sandstone in the Bluebell field reported to be 4 to 5 percent (Peterson, 1973). Water yielded to oil wells is mostly moderately saline to saline and is less mineralized than water from the Green River Formation.	

transport by using finite-difference or finite-element methods or by using the method of characteristics.

The model most commonly used for simulating the flow of constant-density ground water is the modular three-dimensional finite-difference ground-water flow model (McDonald and Harbaugh, 1984). Model codes applicable to the situation described for the Greater Altamont-Bluebell field that also simulate variable-density ground-water flow and solute or heat transport are (1) a two-dimensional finite-element ground-water flow and heat- or solute-transport model (Voss, 1984), (2) a two-constituent solute-transport model for variable-density water (Sanford and Konikow, 1985), and (3) a three-dimensional finite-difference heat- and solute-transport model (Kipp, 1987).

Because of the numerous uncertainties about lateral and vertical hydraulic connection between formations, and the hydrologic boundaries for the Greater Altamont-Bluebell field, plans call for a study to be done in four phases: (1) develop a generalized variable-density model of a single injection well to determine the effects of high-pressure injection using a reasonable range of hydraulic conductivity and storage coefficient and to determine if temperature and density variations are significant in defining the flow environment; (2) if temperature and density are determined to be insignificant, a flow model will be developed to help describe and verify the initial conceptual model of the ground-water system; (3) a sectional model will be developed for specific individual disposal wells for which adequate data are available; and (4) an areal-transport model will be developed for all or parts of the Greater Altamont-Bluebell field. Each subsequent modeling phase would depend on the completeness and reliability of results in the previous phase.

Variable-Density Modeling

The variable-density modeling would be generalized in nature because its purpose is to determine if temperature and density of the formation water and the injected water are sufficiently variable to have an appreciable effect on the direction and rate of ground-water movement. The two-dimensional variable-density model by Voss (1984) would be used to represent a single injection well. Model results from several different combinations of hydrologic properties and fluid properties would be used to determine if the modular, constant-density ground-water flow model by McDonald and Harbaugh (1984) could be used to adequately simulate the ground-water system in three dimensions. If the effects of temperature and density are determined to be negligible, then the flow-modeling phase will proceed. Approximate length of time for this initial modeling phase would be 6 months.

Flow Modeling

A flow model, without the additional complexity of solute transport, will be developed to represent the three-dimensional flow system residing within the upper 10,000 ft of Tertiary formations underlying the Greater Altamont-Bluebell field. Because water being injected through disposal wells is usually less saline than the natural water in the injected zone, this flow-modeling phase may be sufficient to answer the remaining questions posed by the Division of Oil, Gas, and Mining. The area simulated would be determined by the location of the most well-defined natural hydrologic boundaries. These boundaries probably would not coincide with the boundaries of the Greater Altamont-Bluebell field but would define a larger area that includes the field. The regional model developed by Glover (written communication, 1987) could be used as a starting point for this representation of the flow system, but some refinement in both lateral and vertical discretization would be necessary.

Following completion of the regional model, a smaller flow model would be developed to represent the flow system in the area defined by the Greater Altamont-Bluebell field. Boundary conditions for this smaller flow model would be extracted from corresponding areas represented in the regional simulation. The flow-modeling phase would be the most time consuming because a detailed hydrogeologic characterization of the field would have to be formulated from interpretation of several hundred geophysical logs and drill-stem tests. This phase would require approximately 2 years to complete.

Sectional-Transport Modeling

Sectional-transport modeling, if required, will be designed to address specific characteristics of the flow and transport mechanisms working in the vicinity of a single disposal well. Sites chosen for sectional modeling will be those for which ground-water flow directions and rates, hydrostratigraphic delineation, and hydrologic properties can be reasonably well-established from existing data and verified using the variable-density and flow models developed during the first two phases. The sectional-transport two-dimensional simulation of flow and solute transport would be designed to narrow the range of values for vertical leakance, horizontal hydraulic conductivity, solute dispersivity, and the boundary fluxes needed for an areal-transport simulation. Sectional models also would be used to test the dispersion of a single conservative chemical constituent (probably chloride) into the overlying freshwater zone as a result of the large injection pressure used to operate the disposal well. The type and location of additional data needed can be determined during the final stages of this modeling phase, and additional data collection and compilation can be done. The time required for this phase will depend on the number of injection wells for which models will be developed. The phase would likely be designed to investigate those injection-well sites thought to pose the greatest threat to overlying freshwater aquifers.

Areal-Transport Modeling

To obtain an area-wide concept of the effects of injecting oil-production water into various stratigraphic zones at different locations, an area-wide, three-dimensional, flow and transport model will be the final phase of the study. The feasibility of developing such a model will depend on whether or not data requirements, defined during the previous phases, can be met. The success of this areal-transport model will depend also on the reliability of the areal distributions of hydrologic properties, how realistically the upper, lower, and lateral boundaries of the model have been defined, and the accuracy of the data used to characterize the geometry of the ground-water system. Based on the quantity and quality of data available, a model of this type will not be a calibrated solute-transport simulation but rather a tool to examine some of the possible results of disposal within the Greater Altamont-Bluebell field. If the results from the previous phases indicate that areal-transport modeling would be a fruitless effort, this part of the study would be omitted.

INFORMATION NECESSARY FOR MODELING

Simulating constant-density ground-water flow in all of the previously mentioned models requires the following information:

(1) Identification of the dimensions of aquifers and confining layers. This constitutes the geometry of the hydrostratigraphic units.

(2) Definition of the hydrologic boundaries (including hydraulic head or pressure along the boundaries).

(3) Estimates of the hydrologic properties of aquifers and confining layers and the connection between layers.

(4) The quantity and location of discharge and recharge occurring for each hydrostratigraphic unit.

(5) Estimates of the hydraulic head or pressure at points within the system.

Simulating the flow of variable-density fluids and the transport of one or two chemical constituents in this fluid requires data that describe the chemical and physical properties of the formation fluid, the injected fluid, and the porous media. These data generally would consist of:

(1) Physical and chemical attributes of the formation fluid (density and viscosity).

(2) Physical and chemical attributes of the injected fluid (density and viscosity).

(3) Characteristics of the solute (concentrations and mass-flux rate for transport simulations).

(4) Physical attributes of the porous media (dispersivity, hydraulic conductivity, porosity, and storage coefficient).

Table 2 summarizes the data requirements for each model thought to be applicable to the Greater Altamont-Bluebell saltwater injection study.

DATA AVAILABLE

Information already available for the Greater Altamont-Bluebell field is sufficient to obtain preliminary estimates of the size and extent of the formations, the type of hydrologic boundaries present, the typical ranges in hydrologic properties, recharge and discharge quantities and locations, the physical and chemical characteristics of the formation water and injected water, and the lithologic characteristics of the porous media forming the aquifers and confining layers. This existing information needs to be supplemented to meet the requirements for developing numerical models.

Table 2.--**Requirements for flow and transport models**

Data category	Modular flow model (McDonald and Harbaugh, 1983)	Saturated-unsaturated two-dimensional flow and transport model (Voss, 1984)	Two-constituent solute-transport model for variable density ground water (Sanford and Konikow, 1985)	Three-dimensional flow and solute transport model (Kipp, 1987)
FLOW COMPONENTS				
Geometry	Top and bottom of layers. Lateral extent of each aquifer and confining layer.	Finite-element size and scale. Node-wise scale. Orientation of coordinates with gravity. Top and bottom of layers. Lateral extent of each aquifer and confining layer.	Elevation difference between source bed and aquifer. Width of aquifer cross section. Thickness of aquifer.	Finite-difference cell dimensions. Angle of x, y, and z axes with vertical. Radius of cylindrical-coordinate system. Top and bottom of layers Lateral extent of each aquifer and confining layer.
Hydrologic boundaries	Potentiometric surfaces. Location of rivers, drains, and areas of evapotranspiration. Lateral boundary types.	Pressure and elevation heads at boundaries . Temperature distribution.	Initial fluid pressure. Boundary types.	Water-table-elevation distribution. Initial-condition pressure distribution. Type of boundary conditions. Pressure and elevation heads on lateral boundaries.
Hydrologic properties	Horizontal hydraulic conductivity. Transmissivity. Storage coefficient. Specific yield. Vertical hydraulic conductivity.	Transmissivity.	Ratio of vertical to horizontal hydraulic conductivity. Storage coefficient. Leakance coefficient.	Storativity Permeability
Flow quantities	Quantity and distribution of recharge. Quantity and distribution of discharge.	Quantity of injected fluids. Location of and flow quantities of sources and sinks.	Location of injection wells and their rate of injection.	Mass flux per unit volume at boundaries. Specified well-flow rates.

Table 2.--**Requirements for flow and transport models--Continued**

Data category	Modular flow model (McDonald and Harbaugh, 1983)	Saturated-unsaturated two-dimensional flow and transport model (Voss,1984)	Two-constituent solute-transport model for variable density ground water (Sanford and Konikow, 1985)	Three-dimensional flow and solute transport model (Kipp, 1987)
		TRANSPORT COMPONENTS		
Fluid physics and chemistry (formation and injected fluids).	-------	Compressibility. Density. Viscosity. Specific heat. Solute concentration. Coefficient of density change with concentration. Adsorption parameters.	Initial concentration of trace constituent. Initial concentration of density-controlling constituent. Slope and intercept of linear relation between dissolved solids and density and dissolved solids and viscosity. Molecular diffusion coefficient. Concentration of injected water (trace and density controlling constituents).	Density at reference conditions and minimum and maximum mass fraction. Reference temperature, pressure, and mass fraction. Compressibility. Viscosity distribution. Heat capacity. Thermal conductivity. Coefficient of thermal expansion.
Solute information	-------	Rate of first order production of solute mass in the immobile phase and adsorbate mass in the fluid phase. Diffusivity. Solute-decay-rate constant.	Solute mass-flux rate. Specified concentration.	Effective molecular diffusivity. Solute-decay-rate constant.
Porous-media properties.	-------	Compressibility. Specific heat. Dispersivity. Density. Thermal conductivity. Porosity.	Effective porosity. Intrinsic permeability. Longitudinal dispersivity. Ratio of transverse to longitudinal dispersivity.	Longitudinal and transverse dispersivity. Intrinsic permeability in three directions. Bulk vertical compressibility. Porosity at reference pressure. Thermal conductivity. Heat capacity in three directions. Dimensionless linear-equilibrium-distribution coeffient.

Formation Geometry

Driller's, lithologic, and geophysical logs contain information concerning the top, bottom, thickness, and general structural configuration of the Duchesne River, Uinta, and Green River Formations. Data needed to describe the most basic geometry of the system are the (1) altitude of the top of the Green River Formation, (2) thickness of the Green River Formation, and (3) depth to the top of the Uinta Formation. The location of wells for which this basic geometry has been described by the drilling company is shown in figure 6. Thickness of the Duchesne River Formation is poorly defined because information identifying the depth to the top of the Uinta Formation is available from only 38 well logs. Determination of formation contacts through interpretation of geophysical logs is expected to improve the description of this basic geometry and also may improve stratigraphic correlation of individual sandstone, shale and limestone beds that make up the aquifers and confining layers locally.

Hydrologic Boundaries

Hydrologic boundaries are defined largely by the configuration of the potentiometric surface for each aquifer system. Previous investigations indicate that movement of water in the Uinta aquifer and in the overlying unconsolidated aquifers underlying the Greater Altamont-Bluebell field is from the northwest to the southeast (Hood and Fields, 1978, fig. 15, plate 2). This indicates that the northwest and southeast sides of the study area are constant-flow boundaries under steady-state conditions. These are not ideal boundaries to use in developing an areal flow model because estimating flow across these boundaries will be based on values of hydraulic conductivity or transmissivity that vary laterally. Many aquifer tests would be required to obtain an indication of the degree of this variability, thus allowing these boundaries to be accurately represented in an areal simulation. The northeast and southwest boundaries of the area lie approximately parallel to the direction of ground-water flow. These two sides of the area could be considered no-flow boundaries as long as induced stresses have not altered the flow directions. Local outflow boundaries for the unconsolidated aquifers are along stream channels where discharge by stream seepage and evapotranspiration take place.

Movement of water in the Green River Formation has not been defined. There are about 80 oil-production wells or petroleum test holes from which an equivalent freshwater head can be obtained (fig. 7). Drill-stem tests at different depths in the same well indicate that large differences in pressure with depth exist and that the vertical hydraulic-head gradient in the Green River Formation may be important in describing ground-water flow. Because of these vertical gradients, the potential flow direction is usually upward, but a downward flow potential is indicated in a few wells in the southwestern and eastern parts of the field. Flow boundaries for the Green River Formation have not been determined; however, analysis of the pressure-head data available, along with the effects of fluid-density variations in the formations, should provide a preliminary concept of the direction and rate of ground-water movement.

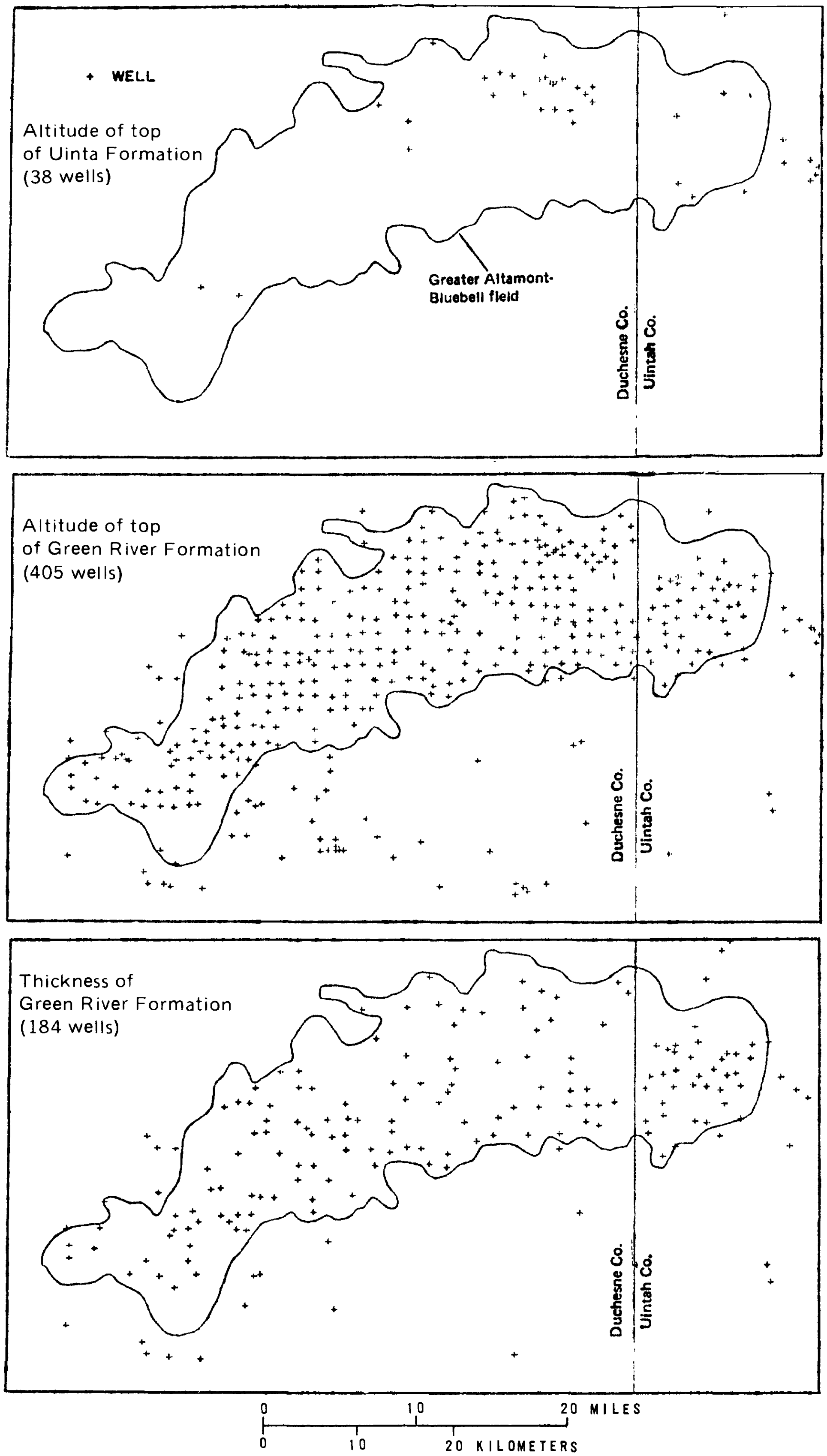

Figure 6.--Location of wells where logs indicate formation altitudes or thicknesses.

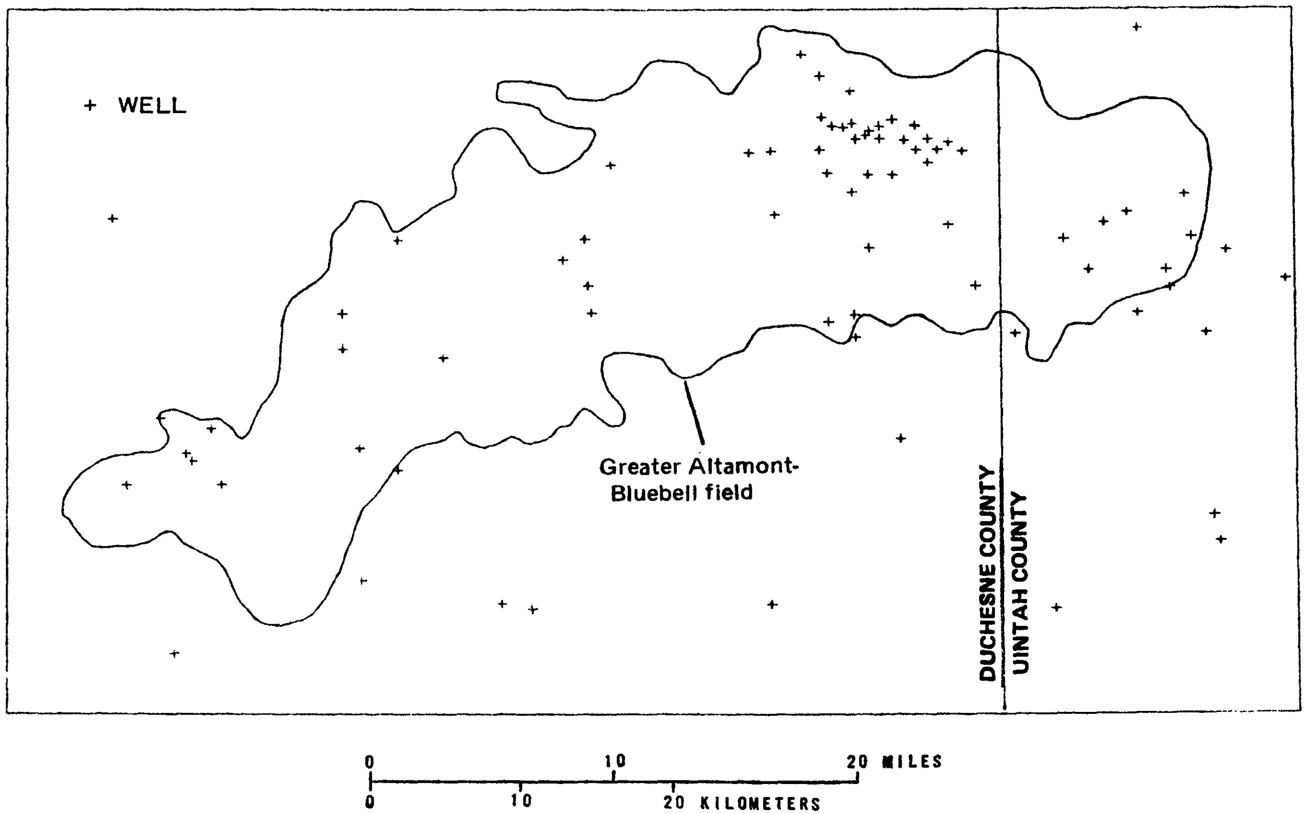

Figure 7.--Location of wells for which drill-stem tests provide an equivalent freshwater head in the Green River Formation.

Hydrologic Properties

Values for hydrologic properties, such as horizontal and vertical hydraulic conductivity, transmissivity, storage coefficient, specific yield, and leakance coefficient, are used to quantitatively assess the occurrence and movement of water in the aquifers and confining layers. Data that can be used to calculate or estimate values for hydrologic properties are meager.

Most available data are derived from testing a small volume of the formation and, thus, may not result in values for hydrologic properties that represent fractured parts of the system. Transmissivity for the Uinta aquifer was determined to be about 900 ft^2/d from the results of one aquifer test (Hood, 1976, p. 52). The storage coefficient determined from this test was 0.0002. Other test results also indicated that the aquifer is nonhomogeneous and has a smaller transmissivity in the west. Horizontal hydraulic-conductivity values for rock samples, determined using laboratory methods, ranged from 0.00003 to 3.3 ft/d, and vertical hydraulic-conductivity values ranged from 0.000005 to 0.8 ft/d (Hood, 1976, table 3). Vertical hydraulic conductivity is used in conjunction with formation thickness to obtain a leakance coefficient.

Based on the analysis of pressure curves from three drill-stem tests at depths ranging from 7,493 to 9,466 ft, hydraulic-conductivity values for the Green River Formation ranged from 0.00056 to 0.1 ft/d (Teller and Chafin, 1986, p. 20-21). Values based on drill-stem tests for which no pressure curve were available are less reliable, but they are available throughout the study area and may provide some indication of how hydraulic conductivity varies laterally and vertically within the formations where injection is occurring. The location of wells where estimated hydraulic-conductivity values are available for the Green River Formation is shown in figure 8. The estimated hydraulic-conductivity values ranged from 0.0001 to 2.9 ft/d.

Flow Quantities

Hood and Fields (1978, p. 32) state that ground-water recharge in the Uinta Basin stems primarily from infiltrating winter precipitation, with less important inflows occurring from stream losses and lateral subsurface flow. Because the Greater Altamont-Bluebell field is a smaller area near the center of the northern Uinta Basin where precipitation is small, subsurface inflow from the surrounding area is more likely to be the main component of recharge. Results from a regional ground-water flow model of the Uinta Basin (K. C. Glover, U.S. Geological Survey, written commun., 1986) indicated that no recharge from precipitation occurs to the Duchesne River Formation in the southeastern one-third of the Greater Altamont-Bluebell field and that recharge of less than 0.1 in/yr occurs over much of the central part of the field. Only a small area along the northwestern boundary of the field has a rate of recharge of as much as 0.2 in/yr. Because areal recharge from precipitation is small in the Greater Altamont-Bluebell field and because the majority of this recharge to the Duchesne River Formation flows into the unconsolidated aquifers, it probably can be ignored in the description and analysis of ground-water occurrence in formations several thousand feet deep.

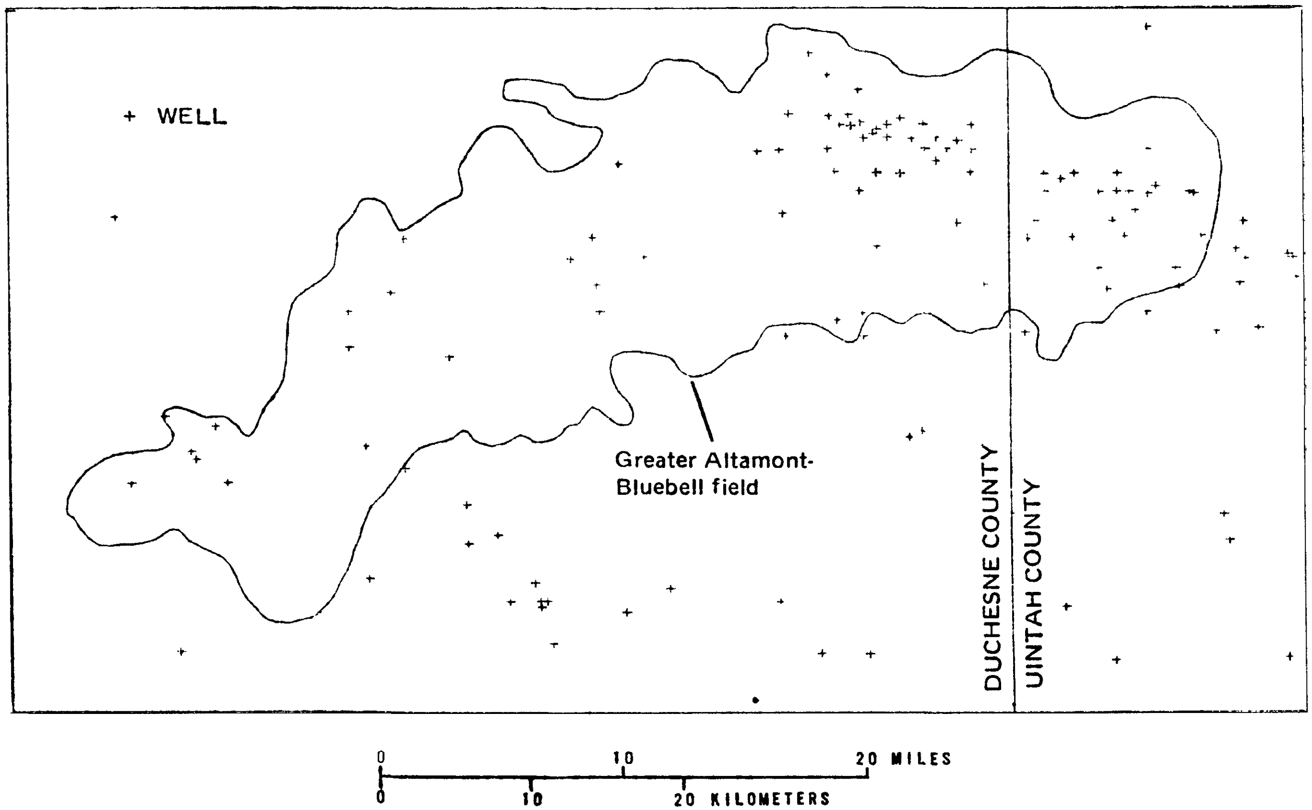

Figure 8.--Location of wells for which drill-stem tests provide an estimate of hydraulic conductivity in the Green River Formation.

The quantity of water discharging from the study area because of ground-water inflow to streams and evapotranspiration can be estimated from previous investigations and from streamflow records; however, discharge occurring by these two mechanisms probably represents a negligible part of the flow system in the Uinta aquifer and the underlying confining layer of primary concern in this investigation and probably can be ignored.

The quantity of ground water entering the study area at its northwest boundary as subsurface flow to the Duchesne River, Uinta, and Green River Formations, and the quantity exiting the study area at its southeast boundary can be estimated from a flow-net analysis using equivalent freshwater heads, hydraulic conductivity, and aquifer thickness. The subsurface inflow can be estimated also from the calibration process of a regional ground-water flow model that includes the Greater Altamont-Bluebell field. Flow quantities at the flow boundaries of the Greater Altamont-Bluebell field then could be obtained. Reliability of the flow quantities would depend on the reliability of all other parameters used in the regional flow model.

For a solute-transport model, the quantity and variability of saltwater injection taking place through the disposal wells are of great importance. Records dating back to 1970 have been compiled by the Utah Division of Oil, Gas, and Mining and include the quantity and variability of injection rates and the injection pressure used at each disposal well. This information is needed to determine the physical effects on the formations receiving the injected saltwater and the chemical effects on formation water in and near the injection zone.

Characteristics of Formation Water

Data that describe the physical and chemical characteristics of native formation water where injection is taking place are available for 15 of the 19 injection sites. Obtaining a permit for a disposal well requires submitting a chemical analysis of native water in the formation into which oil-production water is to be injected. The analyses available for 15 of the disposal wells generally provide concentrations of dissolved solids and concentrations of the major cations and anions (table 3). Chemical analyses of water from various depths above and below the injection zones show that chemical characteristics can change abruptly through a vertical section of rock. Most native formation water is a sodium chloride type, but sodium sulfate type water is present also. Analyses of water from various depths in disposal wells U(C-2-4)32adb, U(C-3-5)17adb, and U(C-3-6)24acd indicate that the concentration of dissolved solids increases with depth. Analyses of water from wells U(C-2-1)10bbb and U(C-2-5)27cdd indicate that the concentration of dissolved solids changes only slightly with depth, and analyses of water from wells U(C-1-2)3ddd, U(C-1-2)11bba, and U(C-1-2)28cab indicate that there are zones where native formation water is significantly less saline than water from overlying or underlying zones. This variability attests to the complexity of the hydrochemical system in these Tertiary formations.

Table 3.--**Physical and chemical characteristics of native formation**
[Concentrations are in milligrams

Disposal-well number (see fig. 2)	Disposal-well name	Date sampled (month-day-year)	Formation sampled	Depth to base of freshwater (feet)	Interval sampled (feet below land surface)	Date of first injection (month-year)	Injection interval (feet below land surface)	pH[1]	Specific gravity[2]	Calcium (mg/L)
U(C-1-2) 3ddd	1-3A2	01-08-68	Duchesne River	1,630	2,735- 2,815	1-70	2,708-3,053	7.4	--	390
		05-13-68	do.		10,384-10,410			7.9	--	87
U(C-1-2)11bba	Boren Fee 1-11A2	03-06-68	Green River	1,700	8,913- 9,012	2-84	9,216-9,468	8.5	--	61
		04-26-68	do.		9,027- 9,180			8.1	--	6.0
		03-10-69	do.		9,333- 9,451			8.2	--	6.0
		12-04-67	do.		9,651-11,128			8.0	--	68
U(C-1-2)13cca	Powell Fee 3	--	Duchesne River	1,060	--	4-79	2,129-2,386	--	--	--
U(C-1-2)26cad	Hamblin 2-26A2	11-04-76	Duchesne River	1,385	--	11-76	2,102-3,322	8.6	--	200
		06-25-74	do.		--			7.1	0.994	250
		08-27-75	do.		--			9.4	1.019	4.3
U(C-1-2)28dba	Anderson 2-28A2	--	Uinta and Duchesne River	2,054	2,256- 2,280	8-76	2,254-3,330	8.3	1.023	170
		12-11-74			2,506- 2,698			8.0	1.007	470
		12-10-74	do.		3,148- 3,330			6.9	1.060	4,800
		07-16-76	do.		--			8.0	1.004	87
U(C-1-3)16aab	Allred 2-16A3	04-24-75	Duchesne River	420	--	1-76	3,593-4,424	7.9	1.010	23
		04-09-75	do.		--			--	--	--
U(C-1-3)31aac	Hartman 3-31A3	11-10-75	Uinta and Duchesne River	2,310	3,576- 3,686	1-76	3,576-4,660	7.4	1.065	1,800
U(C-1-4)27ccd	Shell Fee 1-27A4	11-04-74	Duchesne River	1,000	3,701- 3,870	8-75	3,662-4,780	7.7	.988	520
U(C-1-5)35aac	Birch 2-35A5	04-08-75	Duchesne River	420	3,556- 4,500	11-78	3,604-4,422	--	--	--
		04-10-75	do.		--			7.7	1.008	52
U(C-2-1)10bbb	2-10B1	06-06-75	Duchesne River	940	1,801- 1,881	9-75	1,926-2,102	6.2	--	840
		06-13-75	do.		1,900			--	--	1,000
		06-06-75	do.		2,002- 2,134			--	--	860
U(C-2-2)15ac	F.J. Fenzl 1	04-24-75	Green River	2,500	10,237-12,390	3-86	6,158-6,329	6.9	1.009	1,800
U(C-2-3) 4ccd	Hanson 2-4B3	11-19-74	Duchesne River	1,000	3,000- 3,292	1-76	3,000-6,026	6.3	--	1,500
U(C-2-4)32adb	Russell 2-32B4	04-17-75	Duchesne River	1,500	2,464- 2,470	7-76	2,464-3,726	8.9	1.014	51
		04-18-75	do.		2,548- 3,726			8.3	1.015	270
U(C-2-5)11cab	Erich 2-11B5	--	Duchesne River	1,000	--	8-75	3,749-5,810	--	--	
U(C-2-5)27cdd	LDS Church 2-27B5	01-16-75	Duchesne River	1,000	2,088- 2,383	1-75	2,088-2,866	10.0	--	3.0
		01-16-75	do.		2,817- 2,860			9.7	--	3.0
U(C-3-5)17adb	Saleratus 2-17B5	07-28-75	Green River	1,720	900- 2,100	10-75	2,017-3,286	9.2	1.003	3.3
		09-02-75	do.		2,017- 2,156			9.5	1.017	1.0
		09-02-75	do.		2,303- 3,286			9.5	1.021	3.1
U(C-3-6)18bbc	Ute Tribal 1A	--	Green River	0	--	4-76	4,290-4,340	--	--	--
U(C-3-6)24acd	Altamont 1	07-09-75	Green River	0	3,100- 3,148	12-75	3,100-3,148	10.3	--	50
		07-09-75	do.		3,502- 4,002			5.8	--	1,600
U(C-4-4)16ca	Ute Tribal 4	02-27-62	Uinta	238	1,900- 2,100	6-83	1,759-1,934	10.0	1.052	--

[1] pH is the negative base-10 log of the hydrogen ion activity in moles per liter.
[2] Specific gravity is the ratio of the density of the fluid to that of distilled water at 3.98 degrees Celsius (1.000 gram per
[3] Small sulfate concentration may indicate that sampled water has undergone sulfate reduction or the values could be

water from the disposal wells in the Greater Altamont-Bluebell field
per liter (mg/L)]

Selected cations			Selected anions				Dis-solved solids (mg/L)	Remarks and source of analysis
Magnes-ium (mg/L)	Sodium plus potassium (mg/L)	Iron, total (mg/L)	Bicar-bonate (mg/L)	Carbon-ate (mg/L)	Sulfate (mg/L)	Chlor-ide (mg/L)		
150	20,000	--	780	--	6,100	27,000	53,700	Chemical and Geological Laboratories, Casper, Wyoming
8.0	11,000	--	1,600	--	4,800	12,000	28,900	Do.
15	9,900	--	2,900	240	870	13,000	25,300	Do.
1.0	3,100	--	2,300	--	540	3,000	7,780	Do.
3.0	9,500	--	2,900	--	720	12,000	23,900	Do.
13	9,500	--	1,700	--	4,000	11,000	25,300	Do.
--	--	--	--	--	--	--	--	--
110	5,300	21	460	84	1,500	1,100	14,100	Ute Research Laboratories, Ft. Duchesne, Utah
160	4,400	22	110	--	110	7,400	12,500	Do.
0.8	8,700	0.9	1,200	4,900	80	8,300	--	Do.
9.8	7,000	1.2	310	--	840	8,000	16,400	Do.
120	5,300	.2	240	--	3,600	6,600	14,400	Do.
1,200	48,000	2.7	32	--	2,600	85,000	154,000	Do.
8.3	2,200	.1	560	--	180	3,100	6,930	Do. -- sample from stock tanks
22	5,600	.7	1,100	--	2,000	5,800	11,200	Do. -- Zone 2
--	--	--	--	--	--	4,400	10,000	Do. -- Zone 1
480	30,000	12	83	--	4,700	49,000	85,200	Do.
100	9,800	.4	56	--	3,600	14,000	30,500	Do.
--	--	--	--	--	--	4,400	12,400	Do.
17	4,500	.2	720	--	3,300	7,600	11,000	Do.
210	10,000	--	140	--	6,900	13,000	31,500	Utah Division of Health, Salt Lake City, Utah
260	10,000	10	--	--	--	13,000	32,100	Ute Research Laboratories, Ft. Duchesne, Utah
220	10,000	--	--	--	--	14,000	--	Utah Division of Health, Salt Lake City, Utah
140	4,800	.8	110	--	8.5[3]	7,400	13,100	Ute Research Laboratories, Ft. Duchesne, Utah
4.0	18,000	23	42	--	6,400	30,000	61,100	Utah Division of Health, Salt Lake City, Utah
30	4,900	1.1	260	92	2,600	9,600	17,400	Ute Research Laboratories, Ft. Duchesne, Utah
110	8,400	2.6	360	--	1,500	12,000	20,100	Do.
--	--	--	--	--	--	--	--	--
3.0	7,100	.2	1,000	2,200	500	8,000	19,600	Utah Division of Health, Salt Lake City, Utah
1.0	7,100	--	3,500	3,000	220	5,800	18,300	Do.
.8	1,800	1.2	1,200	780	140	1,600	4,240	Ute Research Laboratories, Ft. Duchesne, Utah
.1	5,000	.4	2,100	4,000	120	5,700	16,400	Do.
.6	7,800	2.3	2,800	5,200	180	8,800	20,800	Do.
--	--	--	--	--	--	--	--	--
6.0	58,000	--	7,600	34,000	1,100	53,000	150,000	Utah Division of Health, Salt Lake City, Utah
2,000	130,000	--	150	73	28,000	180,000	311,000	Do.
--	--	--	--	3,000	--	--	--	Continental Oil Co., Ponca City, OK (Shut in)

liter).
incorrectly reported.

The classification of water quality used in this report, in terms of concentrations of dissolved solids is as follows:

Classification	Concentration, in milligrams per liter
Fresh	Less than 1,000
Slightly saline	1,000-3,000
Moderately saline	3,000-10,000
Very saline	10,000-35,000
Briny	More than 35,000

Characteristics of Injected Water

Oil-production zones generally are deeper than the injection intervals used in the 19 disposal wells. One might assume that the concentration of dissolved solids in the water produced with the oil is greater than the concentration in the shallower formation water where injection is taking place; however, a comparison of the concentration of chloride in formation water with the average concentration of chloride in the oil-production water being injected (table 4) shows that most of the disposal wells are receiving injected water that has chloride concentrations from slightly smaller to as little as 1/25 that of the formation water. Degradation of formation water in the injection intervals by chloride is not likely (1987). Concentrations of sulfate are large enough in water injected into five of the wells (U(C-1-2)11bba, U(C-2-2)15ac, U(C-2-5)27cdd, U(C-3-5)17adb, and U(C-3-6)24acd) to increase the sulfate concentration of formation water in the injection intervals.

Characteristics of Porous Media

Based on operators' descriptions, the rocks into which injection is occurring are sandstone, siltstone, shale, and limestone. Geophysical logs of some type are available for all of the disposal wells; however, a sufficient combination or suite of logs that would enable a more detailed characterization of the porous media of the injection interval are available for only about one-third of the disposal wells. Probably the most useful combination of logs for this purpose would include gamma ray, neutron, caliper, sonic, density, and electric-induction logs. Similar suites of logs for other wells throughout the study area can be used to determine the lateral and vertical variability in formation characteristics.

REQUIREMENTS FOR ADDITIONAL DATA

Additional data required for use in developing the models consist of geophysical logs, drill-stem tests, oil-well water-production rates and rate variability with time, and variability of water temperatures and chemistry. These data should be available, in part, from records of the Utah Division of Oil, Gas, and Mining, oil-company records, files of the Petroleum Information Corporation, the American Stratigraphic Company, the Office of the Utah Geological and Mineral Survey, and the U.S. Bureau of Land Management, and records of the U.S. Geological Survey.

Table 4.--**Chemical characteristics of water being injected into disposal** wells in the Greater Altamont-Bluebell field
[Concentrations are in milligrams per liter (mg/L)]

Ratios give some indication of how concentrations of the 2 anions are changing in the formation as a result of salt-water injection. Numbers less than 1 indicate an increase in the concentration of the constituents and numbers greater than 1 indicate a decrease in concentration.

Disposal-well location number (see fig. 2)	Disposal-well name	Date analyzed	Selected cations				Selected anions				Dissolved solids (mg/L)	Chloride ratios[1]	Sulfate ratios[2]
			Calcium (mg/L)	Magnesium (mg/L)	Sodium plus potassium (mg/L)	Iron, total (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)			
U(C-1-2) 3ddd	1-3A2	10/82	120	340	2,600	--	1,500	6.4	150	4,200	8,930	6.3 to	4 to
		3/87	36	--	--	--	1,500	--	1,500	3,500	--	7.6	40
U(C-1-2)11bba	Boren Fee	3/87	30	4.0	--	0.4	1,400	--	3,000	3,500	--	3.5	0.2
	1-11A2												
U(C-1-2)13cca	Powell Fee 3	4/87	60	--	--	.3	950	--	750	2,500	6,620	--	--
U(C-1-2)26cad	Hamblin	9/83	48	13	2,500	1.4	1,300	--	3.0[3]	3,300	7,140	--	--
	2-26A2	3/87	190	--	--	--	960	--	300	9,900	--		
U(C-1-2)28dba	Anderson	9/83	85	28	3,200	.2	1,800	21	190	4,000	9,330	1.3 to	0.4 to
	2-28A2	3/87	72	7.0	--	.4	1,100	--	2,400	5,000	--	21.2	19
U(C-1-3)16aab	Allred	4/87	40	5.0	--	--	1,100	48	760	2,900	--	1.5 to	2.6
	2-16A3												
U(C-1-3)31aac	Hartman	10/82	96	100	310	--	920	120	200	11,000	12,400	1.3 to	0.06 to
	3-31A3	3/87	6.0	--	--	.9	52,000	--	78,000	39,000	--	4.6	23.5
U(C-1-4)27ccd	Shell Fee	3/87	39	--	--	.3	1,400	--	750	3,200	8,320	4.2	4.9
	1-27A4												
U(C-1-5)35aac	Birch	4/87	92	5.0	--	--	770	32	1,900	2,200	--	2.0	--
	2-35A5												
U(C-2-1)10bbb	2-10B1	10/82	180	270	7,800	--	3,700	--	300	11,000	22,900	1.3 to	--
		3/87	18	--	--	--	3,100	--	--	5,700	--	2.4	
U(C-2-2)15ac	F.J. Fenzl	5/85	96	--	--	--	1,200	--	15[3]	2,000	4,850	3.7 to	0.6
	1	3/87	250	19	--	2.5	800	--	--	600	2,030	12.3	
U(C-2-3) 4ccd	Hanson	3/87	43	10	--	1.5	1,100	--	2,000	2,300	8,300	13.1	3.2
	2-4B3												
U(C-2-4)32adb	Russell	4/87	29	7.0	--	--	1,400	72	390	5,800	--	1.6 to	3.9 to
	2-32B4											2.0	6.7
U(C-2-5)11cab	Erich	4/87	91	8.0	--	.8	1,400	--	11,000	2,500	21,600	--	--
	2-11B5												
U(C-2-5)27cdd	LDS Church	4/87	85	1.0	--	.3	1,200	--	750	2,600	7,130	2.2 to	0.3 to
	2-27B5											3.1	.7
U(C-3-5)17adb	Saleratus	9/83	54	22	--	.3	2,100	--	4,800	4,200	--	1.3 to	0.02 to
	2-17B5	3/87	42	--	--	1.0	1,200	--	2,400	2,500	--	3.6	0.08
U(C-3-6)18bbc	Ute Tribal	7/76	1,700	240	4,100	4.0	610	49	3,400	6,000	20,900	--	--
	1A	3/87	160	12	--	.5	--	--	320	2,000	--		
U(C-3-6)24acd	Altamont	3/87	120	22	--	--	1,100	--	2,500	2,100	8,560	25.8	0.4
	1												
U(C-4-4)16ca	Ute Tribal	5/87	260	--	--	1.8	1,100	--	450	4,300	9,070	--	--
	4												

[1] Chloride ratio: Ratio of chloride concentration in formation water to chloride concentration in injected water.
[2] Sulfate ratio: Ratio of sulfate concentration in formation water to sulfate concentration in injected water.
[3] Small sulfate concentration may indicate that sampled water has undergone sulfate reduction or the values could be incorrectly reported.

Geophysical Data

The greatest resource available for hydrostratigraphic correlation and lithologic characterization is contained in the geophysical logs routinely recorded by drilling companies. There are approximately 500 wells in the Greater Altamont-Bluebell field on which various suites of geophysical logs are available. Sets of logs for a representative distribution of wells can be purchased as strip charts and then digitized. Interpretation of these logs to obtain formation-storage properties and stratigraphic correlation then could be expedited using existing computer software and graphics techniques. Thousands of hours of log-interpretation time could be reduced significantly, but manual spot checking still would be necessary to assure accuracy and consistency.

The log types available are listed for each well in the "PI Well/Log Locator" issued monthly by Petroleum Information Corporation (Denver, Colorado). A typical suite of logs available for any one well includes a natural gamma, neutron, dual-induction electric, compensated sonic, and formation-density logs. From these logs, lithology, porosity, water content, clay-mineral fraction, shale fraction, water resistivity, and bulk density can be estimated. Fracturing in the formations sometimes can be recognized using compensated acoustic logs designed for this purpose, but fracture aperture and interconnection can not be determined.

The American Stratigraphic Company (Denver, Colorado) does stratigraphic studies, based on geophysical logs, for selected wells. As of 1984, about 60 of these studies were available for wells in the Greater Altamont-Bluebell field. A representative distribution of these studies would help to define the geometry of the ground-water flow system and would be invaluable in developing a three-dimensional flow model.

Hydrologic Data

Pressure heads and hydraulic-conductivity values can be estimated from the results of drill-stem tests. Drill-stem tests commonly are conducted on specific formation intervals to assess possible oil productivity. Data already available include only tests conducted prior to 1984 and compiled by the Petroleum Information Corporation. The specific formation interval is isolated with packers and allowed to reach a state of equillibrium with the atmosphere. It is then shut in and allowed to recover to formation pressure. If no mechanical malfunction occurred and if recovery time was long enough, this shut-in pressure can be assumed to be the original formation pressure and is converted to an equivalent freshwater head. A compilation of these pressures in similar parts of the formations that correlate to injection intervals will provide a record of how pressures have changed during development of the disposal-well network in the Greater Altamont-Bluebell field. This type of information would be available from the Petroleum Information Corporation, the Utah Division of Oil, Gas, and Mining, the U.S. Bureau of Land Management, or from individual disposal-well operators.

If fluid recovery consisted primarily of water, the hydraulic conductivity of the tested interval can be derived from the change in pressure with time, the quantity of fluid recovered, and the dynamic viscosity of the fluid as determined from temperature. As of 1983, approximately 554 tests were available for the Green River Formation, but no tests were available for the Duchesne River, Uinta, and Wasatch Formations. Additional tests need to be obtained from oil companies or from updated information compiled by the Petroleum Information Corporation.

Water levels in the Duchesne River and Uinta Formations generally are recorded by drillers when water-supply wells are drilled or have been measured during previous investigations (Holmes, 1980; Hood, 1976; Hood and Fields, 1978; Hood and others, 1976; Price and Miller, 1975). A review of the records of the Utah Division of Water Rights likely would yield an update of additional wells drilled into these formations since the last hydrologic investigation in the area. Additional information about water levels, well yields, and water quality will be compiled from these new well records.

Oil-Production Water Quantity and Quality

The quantity and quality of the water produced with oil is monitored periodically, and the information is available in the files of the Utah Division of Oil, Gas, and Mining, Utah Geological and Mineral Survey, and oil companies. In some cases, this information has already been compiled and published (Goode and Feltis, 1962). Examination of these records will produce documentation of the quantity, quality, and ultimate destination of oil-production water in the Greater Altamont-Bluebell field, and how these parameters have changed throughout the 35-year life of this field. The records can be spot checked with the injection rates submitted by disposal-well operators, and adjustments can be made where the information is missing, incomplete, or too generalized.

FEASIBILITY OF APPLYING MODELING TECHNIQUES

The feasibility of applying the modeling techniques described in this report depends on the availability of hydrologic, lithologic, and fluid data. The first phase would be feasible with only a minimal data-compilation effort. A generalized variable-density model could be developed using previously published ranges for hydrologic properties. An example of the lithologic variability near a "typical" injection site could be obtained from interpretation of geophysical logs from selected wells near this "typical" site. Injection rates and water-quality analyses of injected water are available for most of the injection wells. The remaining data needed would be varied within established limits for each model simulation to obtain information about the possible effects of temperature and density variations on movement of ground water.

The feasibility of executing the areal ground-water flow modeling phase is less certain because (1) its adequacy will be determined from results of the variable-density modeling phase and (2) the general availability of geophysical logs and additional drill-stem tests has not been determined. Thus, it is not known if a reliable stratigraphic correlation can be created, or if an adequate distribution of hydrologic properties and water levels can be extracted from analyses of new drill-stem tests. Large variability in the distribution and hydrologic properties of non-vertical fractures could also make conclusions somewhat uncertain. The feasibility of sectional- and areal-transport modeling cannot be assessed until all data sources have been obtained and the information analyzed in detail.

CONCLUSIONS

The Greater Altamont-Bluebell field is an oil- and gas-producing area in the northern part of the Uinta Basin, Utah. Saltwater, typically produced with oil, is being disposed of by injecting it into intervals in the Duchesne River, Uinta, and Green River Formations that are above the oil- and gas-producing intervals. Injection pressures in the 18 operating disposal wells usually range from 1,000 to 1,500 lbs/in^2. Effects of this disposal on potable water supplies that are within 2,000 ft of land surface can be evaluated using numerical-modeling techniques.

Regional ground-water movement in the Duchesne River and Uinta Formations generally is from the northwest to the southeast, but complex interfingering of formations, changing lithology, and fractures may alter this locally. Vertical hydraulic-head gradients in the Green River Formation indicate vertical flow is mostly upward. Because of variations in lithology, hydraulic-conductivity values vary by five or six orders of magnitude. Vertical hydraulic-conductivity values are about one order of magnitude smaller than horizontal hydraulic-conductivity values. The effects of fracturing on movement of ground water is probably important locally. Recharge to the aquifers underlying the Greater Altamont-Bluebell field is primarily by subsurface flow from the northwest. Recharge from precipitation that infiltrates directly or along stream channels is minor within the study area because annual precipitation is small. Discharge from deeper formations is by subsurface flow to the southeast. Discharge from shallow aquifers is to streams and by evapotranspiration.

The chemical quality of natural water in the formations where oil-production water is being injected usually is moderately saline to briny (dissolved-solids concentrations larger than 3,000 mg/L). Quality of the oil-production water usually is in the same range, but is almost always less saline than formation water in the injected interval. Most of the water is a sodium chloride type and less frequently a sodium sulfate type.

A plan of study includes development of numerical models to determine the effect of variable-density fluids on ground-water movement in the porous media, to determine the adequacy of previous concepts of the ground-water system, and to track the dispersion of chemical solutes vertically and horizontally from the points of injection. To develop models that will evaluate the effects of injection disposal, geophysical, stratigraphic, hydrologic, and chemical data will need to be compiled and organized to allow extraction of specific information required for pre-injection and post-injection simulations. Developing a generalized variable-density model for a typical injection site is feasible with minimal data compilation and analysis. Feasibility for developing models for three-dimensional ground-water flow and solute transport cannot be determined until each prior modeling phase is completed, and until a large quantity of hydrologic and lithologic information has been derived from geophysical logs and drill-stem tests.

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