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A PLAN FOR HYDROLOGIC INVESTIGATIONS OF IN SITU, OIL-SHALE RETORTING NEAR ROCK SPRINGS, WYOMING

By Kent C. Glover, Everett A. Zimmerman,
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ILLUSTRATIONS

UNITS OF MEASUREMENT

For those readers interested in using the metric system, the following table may be used to convert inch-pound units of measurement used in this report to metric units.

Multiply	By	To obtain
mile	1.609	kilometer
square mile	2.589	square kilometer
inch	25.4	millimeter
foot (ft)	0.3048	meter
degree Fahrenheit (°F)	(°F - 32°) 5/9	degree Celsius (°C)
barrel	159.97	liter

National Geodetic Vertical Datum of 1929 is 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.

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ABSTRACT

The recovery of shale oil by the in situ retort process may cause hydrologic impacts, the most significant being ground-water contamination and possible transport of contaminants into unaffected areas. Although these impacts are site-specific, many of the techniques used to investigate each retort operation commonly will be the same. The U.S. Geological Survey has begun a study of hydrologic impacts in the area of an in situ retort near Rock Springs, Wyoming, as a means of refining and demonstrating these techniques. Geologic investigations include determining the areal extent and thickness of aquifers. Emphasis will be placed on determining lithologic variations from geophysical logging. Hydrologic investigations include mapping of potentiometric surfaces, determining rates of ground-water discharge, and estimating aquifer properties by analytical techniques. Water-quality investigations include monitoring solute migration from the retort site and evaluating sampling techniques by standard statistical procedures. A ground-water-flow and solute-transport model will be developed to predict future movement of the solute plume away from the retort.

INTRODUCTION

Development of the Nation's large oil-shale resource is becoming economically practical as the price of oil increases. Interest in oil shale has led to increased concern about hydrologic impacts that might be associated with its large-scale development. However, there is a general lack of understanding of these impacts and an incomplete understanding of how to monitor and predict them. This report presents a plan by the U.S. Geological Survey for studying the possible hydrologic impacts associated with the in situ method of oil-shale recovery. The results of the study should be useful in locating retort operations where hydrologic problems can be minimized and in designing engineering procedures to control the impact of existing retorts.

Purpose

The purpose of this report is to describe a plan of study for investigating hydrologic changes that may occur as a result of in situ, oil-shale retorting. The plan makes provisions for monitoring the migration of chemicals introduced to the ground-water system by the retort operation and evaluating the possible impact of this migration on presently used or potential water supplies. The plan of study addresses the following more specific project goals:

1. The hydrogeologic characteristics of the oil-shale formations and adjacent aquifers that may be important to a study of ground-water flow and solute transport are identified. Hydrogeologic data needs are discussed.

2. Previous investigations of ground-water quality in the study area are reviewed. A plan for additional data collection and interpretation is presented.

3. A discussion of tools, such as digital models, that can be used to evaluate the possible impacts of the retort process also is included.

Scope of Planned Study

The study plan presented in this report emphasizes site-specific data collection and interpretation. The areal extent of the study is, therefore, broadly defined by distances not hydrologically affected by the development of a single retorting operation. The exact boundaries of the study area are related to the magnitude of ground-water flow and transport processes and cannot be stated explicitly. However, it is doubtful that a study area for an in situ operation would exceed 50 square miles. Vertically, the geologic section of interest includes the oil-shale strata as well as usable aquifers below and above the retort interval.

Care will be taken to consider the retorts as uniform sources of chemical constituents. A minimum of effort will be made in defining small variations of hydraulic properties and water quality within each retort. However, methods for differentiating between disturbed and undisturbed areas are discussed.

The retort operation used throughout this study of in situ, oil-shale hydrology is located about 7 miles southwest of Rock Springs, Wyoming (fig. 1). This site was selected for study because it is the only location where sufficient time has passed since retorting to allow significant solute transport. Research projects sponsored by the Laramie Energy Technology Center, U.S. Department of Energy, at the Rock Springs site have evaluated methods of increasing permeability in the oil shale using electrolinking, hydraulic fracturing, various explosives, and sand propping.

Fracturing and retorting experiments were conducted at the study site from 1969 to 1979. No additional experiments are planned. The locations of these experiments are shown in figure 2. Retorting was accomplished by igniting a mixture of compressed air and combustible gas pumped into a central well. After a few hours, the gas was shut off, but compressed-air injection into the burning zone was continued where combustion was sustained by the organic material within the shale. The oil released by the heat was withdrawn from wells surrounding the central well.

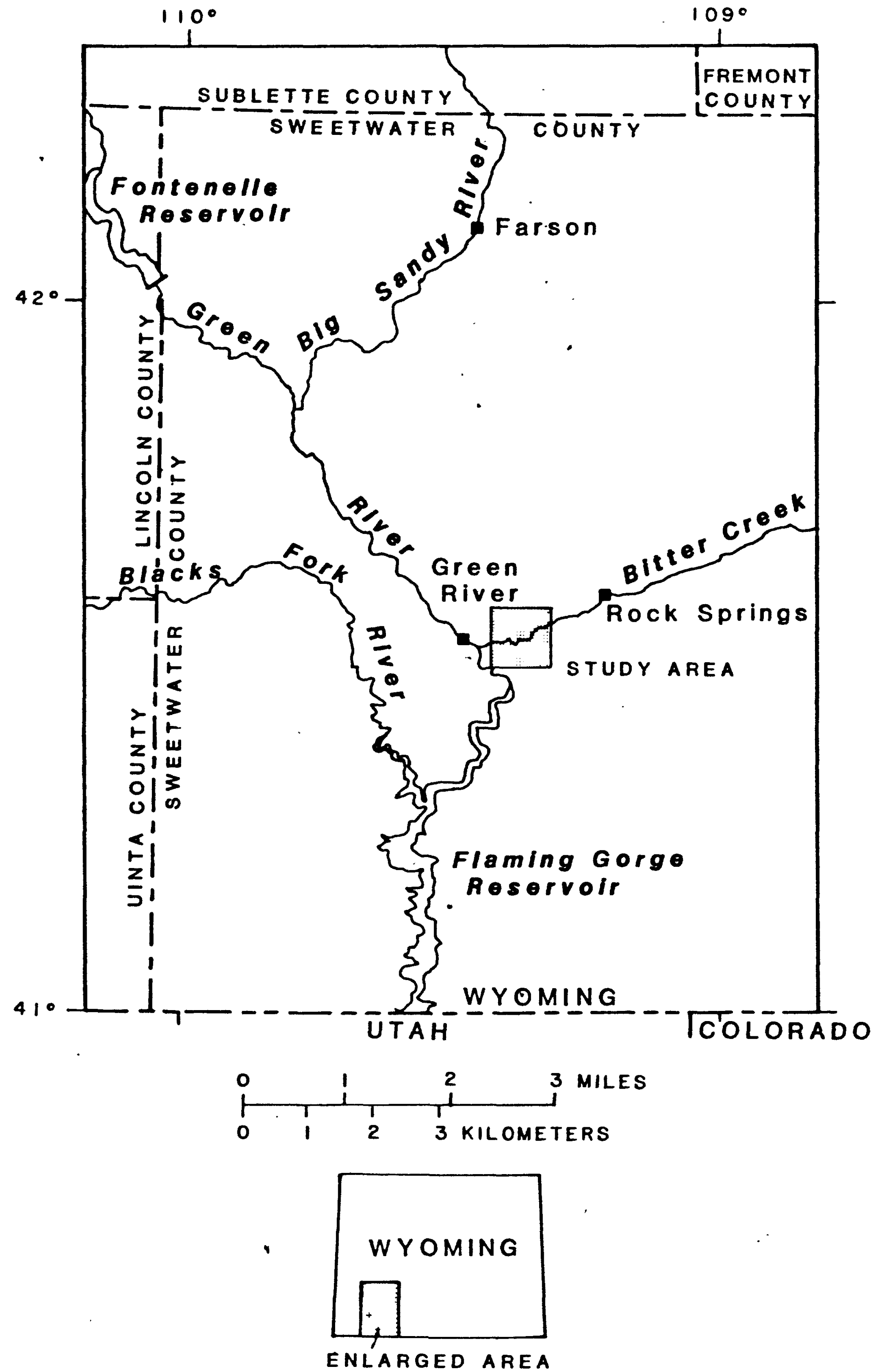

Figure 1.--Location of study area.

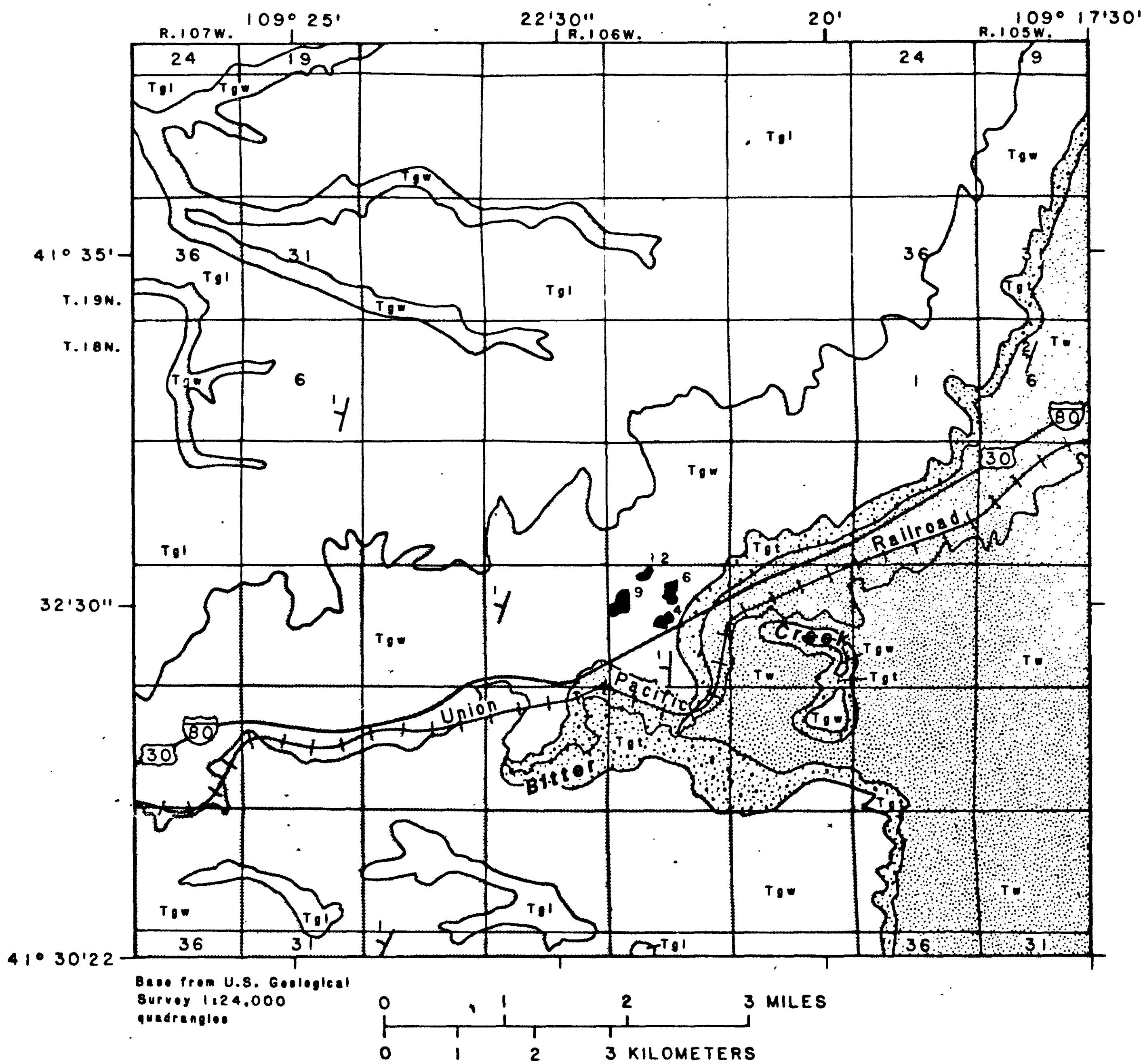

Figure 2.--Surface geology of Rock Springs study area (Modified from Bradley, 1964.)

EXPLANATION

TERTIARY

GREEN RIVER FORMATION

Tgl — LANEY SHALE MEMBER.--Massive bedded to thinly laminated buff, grey, and brown marlstone, shale, and muddy sandstone; white to brown tuff and tuffaceous sandstone

Tgw — WILKINS PEAK MEMBER.--Thin and regularly bedded greenish-grey, drab, to nearly white dolomitic mudstone, marlstone, and oil shale; white to brown tuff, tuffaceous sandstone, and marlstone beds

Tgt — TIPTON SHALE MEMBER.--Light, tawny brown to buff shale and organic marlstone in lower one-half; upper one-half is chippy to flaky light-bluish grey organic marlstone with a thick ledge of moderately rich oil shale near the top

Tw — WASATCH FORMATION.--Sandy grey mudstone containing lenses and irregular beds of muddy, buff sandstone; locally, mudstone contains red bands and the sandstone is red

CONTACT

2 — STRIKE AND DIP OF BEDS.--Determined photogrammetrically

6 — LOCATION OF OIL-SHALE RETORT EXPERIMENTS.--Number refers to site number used in text

Important geologic units at the Rock Springs site are the Wasatch Formation, and the Tipton Shale and Wilkins Peak Members of the Green River Formation (fig. 2). The burned zones are within the Tipton.

Bitter Creek crosses outcrops of all these units within 1 to 2 miles of the retort site. Bitter Creek flows into the Green River just upstream from Flaming Gorge Reservoir.

Background

The richest deposits of oil shale in the United States are found in the Green River basin of Colorado, Utah, and Wyoming. This area is sparsely populated; the economy is largely based on ranching and the production of oil and gas. The terrain is dominated by cliffs, buttes, and canyons that range in altitude from 4,600 to 8,500 feet. Precipitation ranges from 7 to 24 inches per year. Surface drainage is by the Green River and its tributaries.

Oil shale contains kerogen (insoluble organic material) that yields crude oil when heated to a temperature of 900°F. Several methods have been developed to extract the crude oil. One method, called surface retorting, is to mine the shale and retort it above ground. Two methods, called in situ retorting, have been developed to fracture the shale while it is underground. With "true" in situ retorting, the permeability of the oil shale is increased by the use of explosives without mining. Heat is introduced by partly burning and liquifying the kerogen, and the oil is recovered through wells. In modified in situ retorting, 20 to 40 percent of the shale is mined to form an underground cavity. The removed shale is processed by surface techniques. The shale that remains is explosively expanded into the voids to increase porosity and permeability, and is retorted in place.

Water-Resource Problems

The extraction of oil from shale can alter the hydrologic system in the vicinity of a retort site. It is important to understand what hydraulic and water-quality changes can be expected before a large in situ, oil-shale industry is established. Plans can then be made to minimize any water-resource problems that would occur during or after retorting.

The potential for ground-water quality changes is probably greater for an in situ operation than it is for surface retorting. Questions concerning water quality include:

1. What changes in water quality can be expected at the retort site?

2. Will the water quality of aquifers adjacent to the burned zones be unsatisfactorily altered?

3. Will chemicals introduced to the ground-water system by retort operation be transported into adjacent areas?

4. Will the quality of surface water be altered? If so, when will this occur?

5. How long will the quality of ground waters and surface waters continue to be affected by the retort operation?

6. Will any management technique, such as ground-water withdrawal at the retort sites, be effective in stopping the migration of chemicals in the ground-water system?

Approximately 4 barrels of water are needed in surface-retort operations for spent-shale disposal for each barrel of oil produced (Powers, 1980). Various consumptive uses account for 70 percent of the total water requirement. This water is not needed with the in situ process. However, a number of ground-water hydraulics problems are associated with the in situ retorting. The oil-shale formation to be mined is rarely an aquifer but is commonly associated with more permeable rocks. As a result, dewatering the oil shale and increasing the permeability of the shale may affect water levels in adjacent aquifers.

If the retort site is near streams, relationships between ground water and surface water also may be affected. The increased shale permeability could increase vertical movement of ground water and affect water levels of adjacent aquifers. This, in turn, could affect stream discharge.

GEOLOGY

An understanding of the geology of a projected or active oil-shale retort site is basic to any investigation of ground-water movement in the vicinity of the retort operation. Rocks are the containers in which the shale oil is found and the conduits through which the oil and the water pass. The presence and abundance of kerogen in the rocks, a function of the depositional history, will determine if they will ever be used for retorting. The porosity and permeability of the rocks determine if fluids can be stored in or transmitted through them. Structural deformation can increase the permeability and permit a flow pattern that is markedly different from one caused by primary permeability alone. A study of stratigraphy and geomorphology may help determine where ground-water recharge and discharge occurs--hence the direction in which fluids move through the rocks.

The rock minerals that are in contact with the contained fluids will largely determine the ground-water quality. All members of the Green River Formation near the Rock Springs study area contain large quantities of trona minerals (hydrous sodium carbonate and sodium bicarbonate) that are readily soluble in water and may be reactive with other chemical species. Some beds of tuff in the Green River Formation contain zeolite minerals (hydrous aluminosilicates) that promote ion exchanges and may considerably alter the mineral content of water.

Geologic information of several types will be needed to permit modeling of the hydrologic system and presentation of the results. Knowledge of the areal extent and distribution of the burned intervals and the aquifers likely to be affected will be needed. This information usually is displayed on geologic maps. Geologic maps commonly are available from published or proprietary sources and may result from other types of investigation. If suitable mapping is not available on a scale appropriate to support the modeling effort, it may be necessary to map the area of interest either by onsite or photogeologic methods.

The surface geology of the Rock Springs retort site has been mapped at a scale of 1:48,000 by R. J. Hackman using photogeologic methods and published in Bradley (1964). The part of the map including the site is shown in figure 2.

The characteristics of the rocks that compose the oil-shale resource, as well as associated aquifers and confining beds, are important to an understanding of the framework through which fluids move and the chemical reactions that are likely to occur. Bradley (1964) and Culbertson and others (1980) present much descriptive material pertaining to the formations present. Stratigraphic relations of the formations as described by Bradley (1964) are shown in figure 3. Measured sections are described in these reports. Extensive core drilling has been done in the exploration for oil shale and trona, and descriptions have been published or are obtainable from the U.S. Department of Energy and private companies.

Many geophysical well logs have been produced as a part of exploration for oil and gas in the Green River basin. These logs can be used to extend correlations of particular rock units within large areas. Certain units have been found to produce commonly recognizable responses on geophysical logs. Gamma-ray and interval transit-time-log responses to some of the rock units in the Wilkins Peak and Tipton Shale Members of the Green River Formation are shown in figure 4 (Culbertson and others, 1980).

Geophysical logging has been done in some of the holes used in the Rock Springs retort experiments, and the logs can be used to establish and extend correlations of the burned zones. Few wells have been drilled in areas adjacent to the retort experiments. In order to determine the nature, extent, thickness, and hydrologic characteristics of the rocks, it will be necessary to drill additional holes.

When holes are drilled, precise drillers' logs will be obtained, and a synoptic suite of geophysical logs will be obtained. Among the more useful logs are those that measure resistivity, spontaneous potential, gamma ray, neutron, gamma-gamma (density), temperature, and caliper. Some of these, such as the gamma-ray log, can be used to extend correlations. Temperature and resistivity logs may provide some information pertinent to water quality. The procedure outlined by Head and Merkel (1977) may be used to provide estimates of porosity and lithology. This

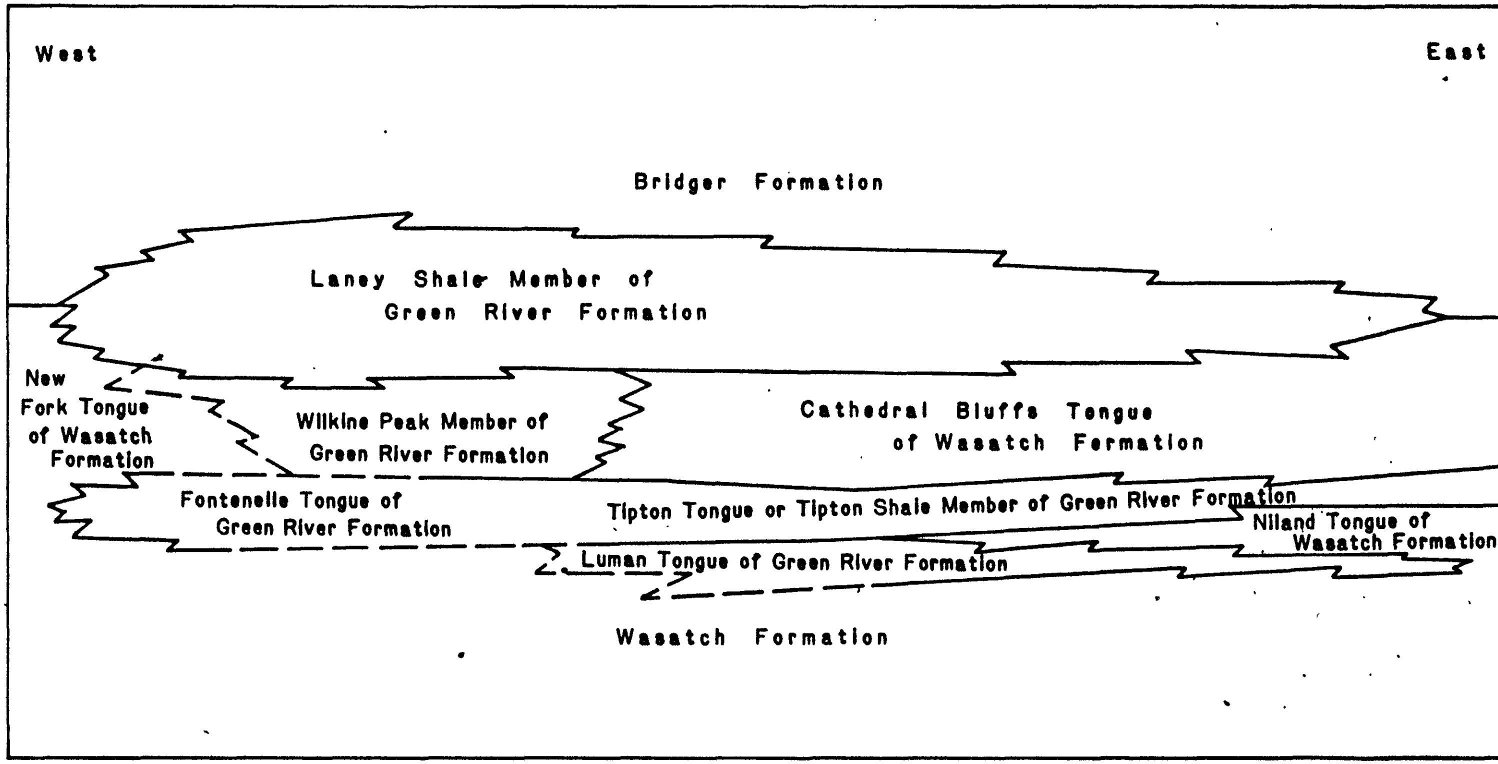

Figure 3.--Stratigraphic relations of the Wasatch, Green River, and Bridger Formations and their members. (From Bradley, 1964.)

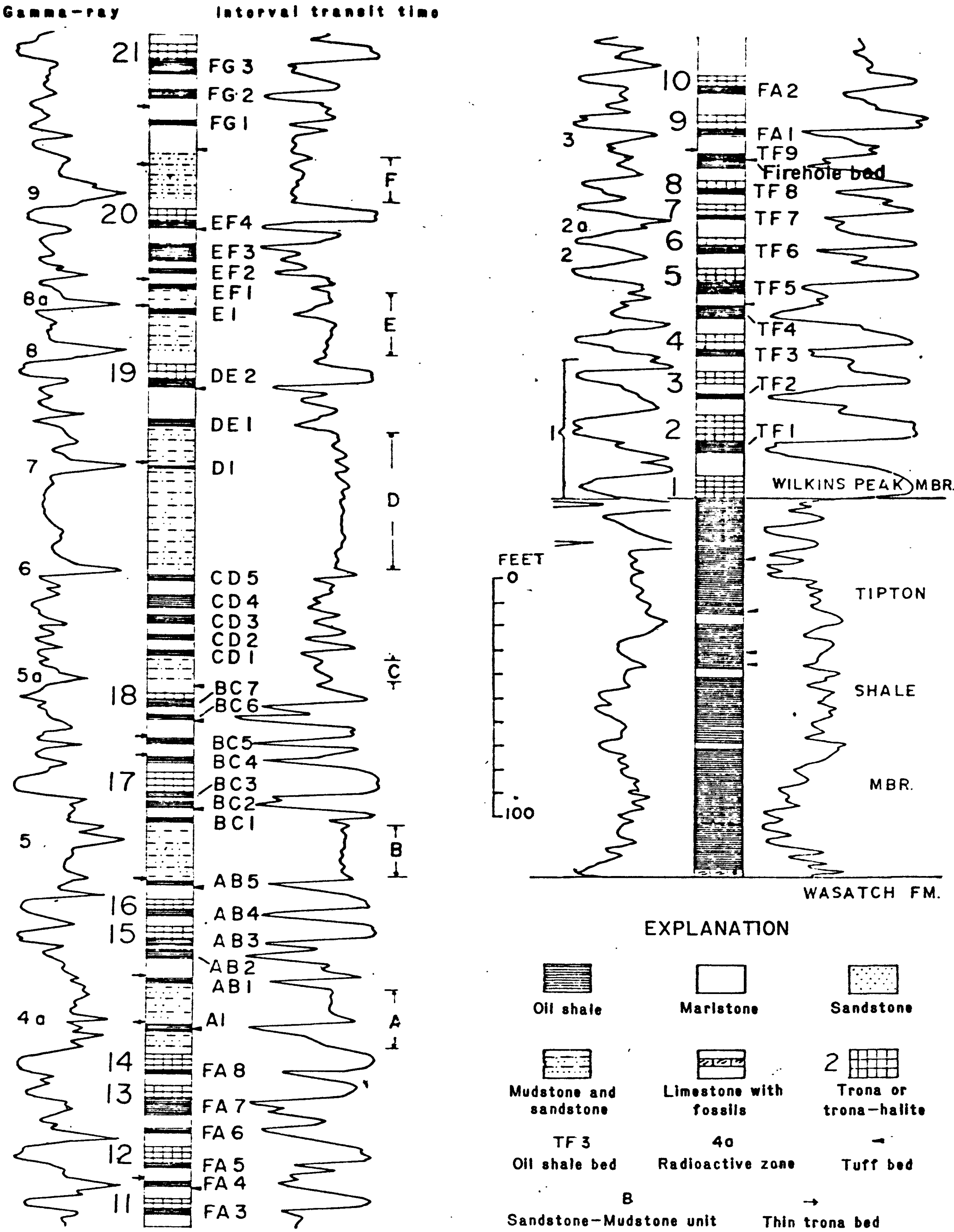

Figure 4.--Composite columnar section of the lower part of the Green River Formation (excluding the Luman Tongue) in the southeastern part of the Green River basin. (From Culbertson and others, 1980.)

procedure will be modified to include the effects of kerogen on the response of various geophysical tools. For example, figure 5 from Lowham and others (1976) shows results of geophysical logs cross correlated by computer analysis.

Natural and induced fractures in oil shale and associated rocks probably are a major factor in controlling the rate and direction of ground-water movement and solute transport. A great deal of work has been done at the Rock Springs study area to document the extent and principal directions of fractures both before and after explosives were used. Miller and others (1974) report that fracture density in oil shale prior to detonation of explosives is well correlated to the neutron-tool response. This relationship was verified by conducting airflow tests, making downhole camera surveys, and obtaining neutron logs. Directional properties of fractures after the retort experiment at site 4 were observed during an infrared survey to trend northeast to southwest and southeast to northwest (Carpenter and others, 1972). Stevens and others (1975) concluded that vertical fracturing was rare at site 9 prior to retorting.

Much of the information derived from the geologic data is to be used in furthering hydrologic and solute-transport modeling. Therefore, some illustrations and descriptions will be needed to provide background and documentation for the model. Geologic maps, refined to the degree indicated by the scale of modeling, will be prepared. Vertical geologic data will be provided by means of columnar sections, perhaps combined into geologic or lithologic sections. Structure-contour and thickness maps will be used to illustrate geologic aspects pertinent to an understanding of the hydrology.

GROUND-WATER HYDRAULICS

Ground-water hydraulics is the determination of natural or induced movement of water through permeable rock formations. Therefore, a thorough understanding of ground-water hydraulics in the vicinity of an in situ retort is an important prerequisite toward predicting changes in water supply and quality associated with oil-shale processing. This section of the report presents a plan for obtaining the hydraulic properties of rocks and hydraulic-head data needed to characterize the ground-water-flow system successfully near the retort site. Appropriate techniques for interpreting these data also are discussed.

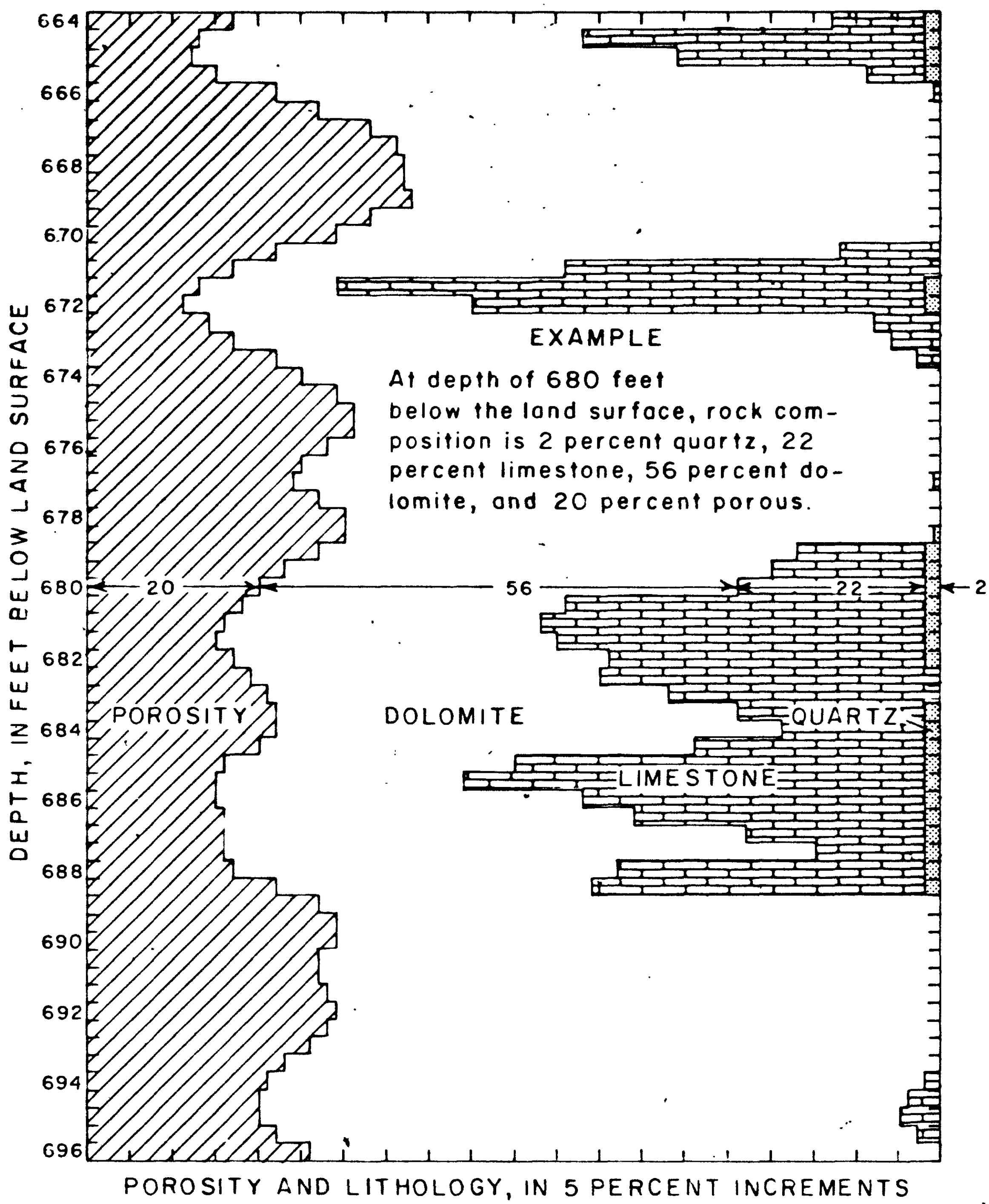

Figure 5.--Porosity and lithology as determined from an analysis of geophysical well logs. (From Lowham and others, 1976.)

Summary of Existing Data and Previous Studies

Before data collection can be fully planned, relevant existing data will be reviewed. An inventory of water-well information will be made that includes well location, formations open to the well, and a history of well construction and use. Water-level data distributed both areally and temporally will be obtained. It also is important to acquire records from any tests that were used to determine aquifer properties such as transmissivity and storage coefficient. Streamflow data will be obtained upstream and downstream from the retort site. An analysis of these data is extremely valuable in designing a plan for additional data collection.

Hydraulic data available at the Rock Springs study area primarily are available from wells used during retort operations. A large number of wells completed in the oil-shale strata are located within the areas underlain by burned zones; few wells have been drilled outside the areas underlain by burned zones. Water-level data were collected for only a short time prior to retorting the shale, if at all, and no useful streamflow data are available.

The Laramie Energy Technology Center, U.S. Department of Energy has conducted a ground-water monitoring program in compliance with regulations of the Wyoming State Department of Environmental Quality. Water-level data have been collected at more than 30 wells completed in the Tipton Shale Member of the Green River Formation. Only two of these wells are located outside the areas underlain by burned zones. Water levels in several wells completed in the overlying Wilkins Peak Member of the Green River Formation also have been measured. Construction histories of these wells are reasonably complete. Aquifer tests within the areas underlain by burned zones have been made using wells completed in individual geologic units.

Few hydraulic data from other sources are available for the Rock Springs study area. Unpublished inventories and water levels of about 10 wells are available from the U.S. Geological Survey, the Wyoming State Engineer, and the Wyoming Water Resources Research Institute. No aquifer testing of these wells has been attempted at present (1982). Some water-level information also can be found in Welder (1968).

Understanding of Ground-Water-Flow Systems from Existing Information

Gaps in the existing data base are common in most hydraulic studies of in situ retorting. Unfortunately, funds generally are not available to fill all these gaps and the question must be asked, "What data are most critical to an understanding of the ground-water-flow system near the retort site?" If this can be determined, plans can be made more efficiently to acquire the critical data. One way to investigate this question is to develop several hypotheses of how the flow system operates and, using available information, attempt to reject as many of these conceptual models as possible. Additional data collection then can be directed toward providing the information needed to prove or disprove the validity of the remaining hypotheses. The details of this approach are outlined in this section.

Before conceptual models of the flow system can be developed, it is important to judge the worth of the existing data. This quality-control check can include visiting water wells to verify the accuracy of the well inventory, plotting well hydrographs to determine the accuracy of water-level measurements, and reviewing aquifer-test data to assess the reliability of transmissivity and storage estimates.

A check of hydraulic data at the Rock Springs study area showed several problems. Although well inventories generally were accurate, several wells within the areas underlain by burned zones could not be sounded to the reported total depth. All aquifer tests were made without observation wells. As a result, no estimates of storage coefficient were possible. Short pumping times also prevented the determination of a reliable value for transmissivity.

The geologic section of interest to this study can be divided into aquifers and confining beds on the basis of a qualitative review of geophysical logs and cores from wells near the retort site. The Wilkins Peak Member of the Green River Formation is believed to be a confining bed throughout the study area. A shallow water table has been observed in the Wilkins Peak at site 12 but the very local nature of this water table and minimal permability of the formation indicate that this formation is a confining bed to underlying strata. The upper Tipton aquifer is defined here to include a 5-foot basal siltstone of the overlying Wilkins Peak Member and the kerogen-rich strata of the Tipton Shale member of the Green River Formation. The thickness of this aquifer is approximately 80 feet. The upper Tipton aquifer is extremely brittle in outcrops and is extensively fractured. The lower part of the Tipton Shale Member of the Green River Formation and the top 100 feet of the Wasatch Formation are believed to be confining beds and are here called the Tipton-Wasatch confining bed. A section of red mudstone in the Wasatch is defined as the base of this confining bed. The sandstone strata of the Wasatch Formation that occur below the red mudstone are defined here as the Wasatch aquifer. This aquifer extends vertically for several hundred feet and the base of the aquifer is well below the geologic section of interest to this study.

Potentiometric-surface maps are useful in determining the direction of ground-water movement, hydraulic-boundary conditions, and the relationship between aquifers. Insufficient water-level data are available to map accurately the potentiometric surface of the Wasatch aquifer. The potentiometric surface within the upper Tipton aquifer is shown in figure 6. Water-level data for this map were measured during an initial visit to the study area (April 1981). Hydraulic heads within this unit are artesian and generally lower than the hydraulic heads in the Wasatch, indicating that ground-water movement at the retort site may be upward. Sufficient water-level data are available to develop hydrographs for many wells completed in the Tipton Shale Member of the Green River Formation. Typical hydrographs are shown in figure 7. The well in NW¼SW¼NE¼ sec. 15, T. 18 N., R. 106 W. is a production well at site 9, whereas the well in SW¼NW¼NE¼ sec. 15, T. 18 N., R. 106 W. is an observation well located 1,000 ft from site 9. The water level in the production well declined during the site 9 burn, April through September 1976, and recovered rapidly after the retort operation was completed. Water levels at the observation well do not show this pattern.

A conceptual model may be defined as the set of hypotheses that describe the physical and functional nature of the ground-water-flow system including sources of recharge and discharge, rates and directions of flow, variations in aquifer properties, and any stream-aquifer relationships. During the planning stage of a hydrologic study, it generally is possible to develop several seemingly reasonable conceptual models that contradict one another in describing the flow system. For example, flow between two aquifers may be construed as being truly three-dimensional or strictly vertical, depending on the magnitude of the horizontal-flow component within the confining bed. The principal tasks of the ground-water hydrologist doing a study are to consider carefully a variety of conceptual models, develop ways to test the validity of these models, and assess the effect of errors in the conceptual models on the predicted response of the flow system or retort stress. All these tasks rarely can be accomplished with available information, and the hydrologist is faced with planning additional data collection. However, by developing and attempting to test conceptual models during the planning phase, realistic data needs can be identified and the significance of not obtaining this information can be assessed. Developing a data-collection plan then is resolved by comparing needs with available funds and time.

A limited conceptual model can be developed for the flow system at the Rock Springs study area. The Wasatch aquifer may be considered as a boundary of known hydraulic head. This boundary needs to be used because data are unavailable to evaluate the relationship between the Wasatch aquifer and underlying strata. It is also unlikely that sufficient funding will be made available to collect these data. Therefore, no attempt can be made to simulate ground-water movement within the Wasatch. The Wilkins Peak may be assumed to be a no-flow upper boundary. The major recharge to the flow system occurs as precipitation where the geologic units of interest are exposed. Because this recharge occurs at a relatively great distance from the study area, model development in this study will use known hydraulic-head conditions as an upgradient boundary. The major sources of discharge from the system are seeps from outcrops of the upper Tipton aquifer along Bitter Creek. The magnitude of discharge is not known, but probably does not exceed the potential evapotranspiration rate during the growing season.

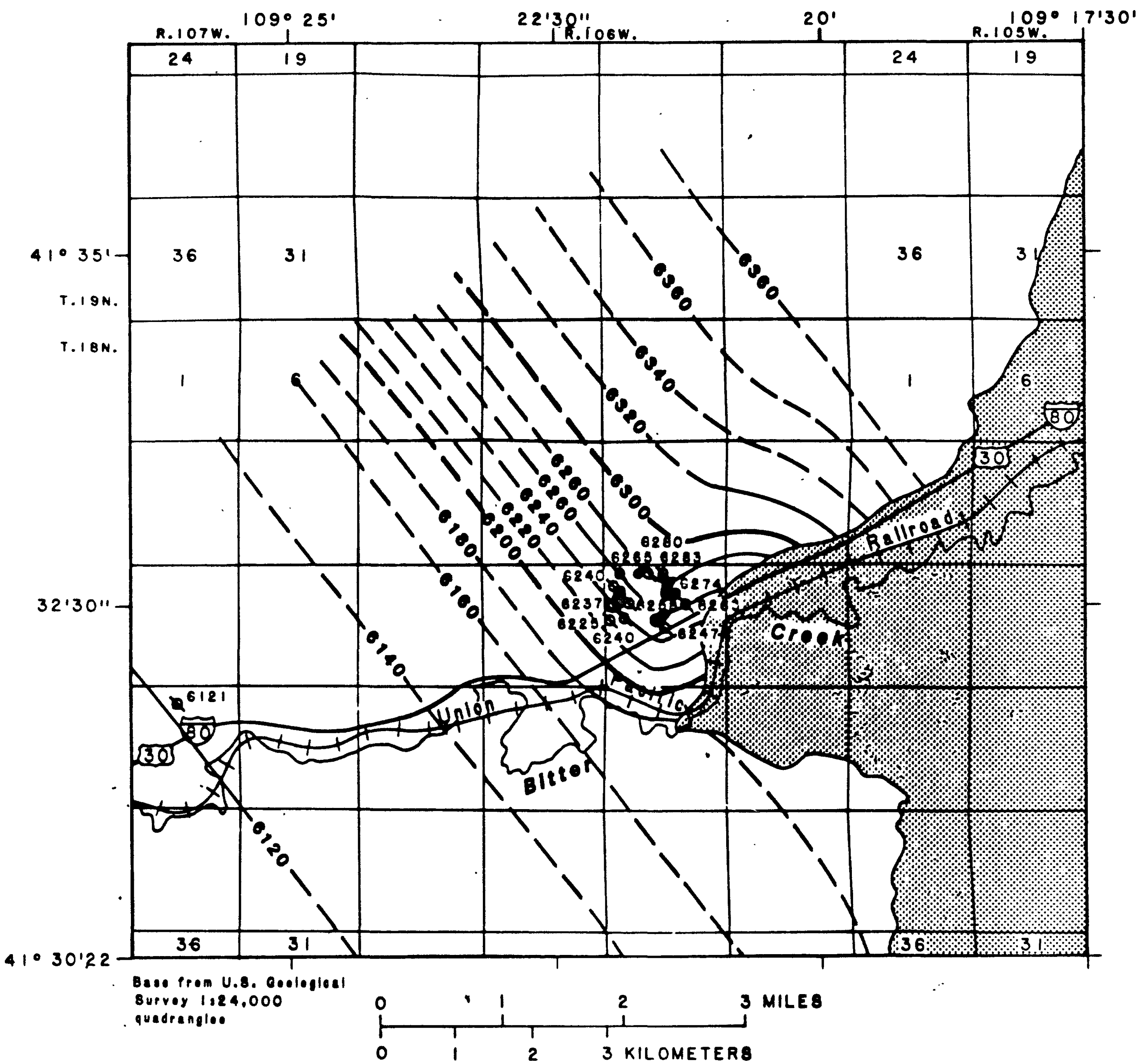

Figure 6.--Potentiometric surface of the upper Tipton aquifer. in the Rock Springs study area.

EXPLANATION

UPPER TIPTON AQUIFER ABSENT

LOCATION OF OIL-SHALE RETORT EXPERIMENTS

6300 — POTENTIOMETRIC CONTOUR.--Shows altitude to which water would have stood in tightly cased wells, April 1981. Dashed where approximately located. Contour interval 20 feet. National Geodetic Vertical Datum of 1929

6280 — OBSERVATION WELL.--Number is altitude of water level, in feet, measured during April 1981

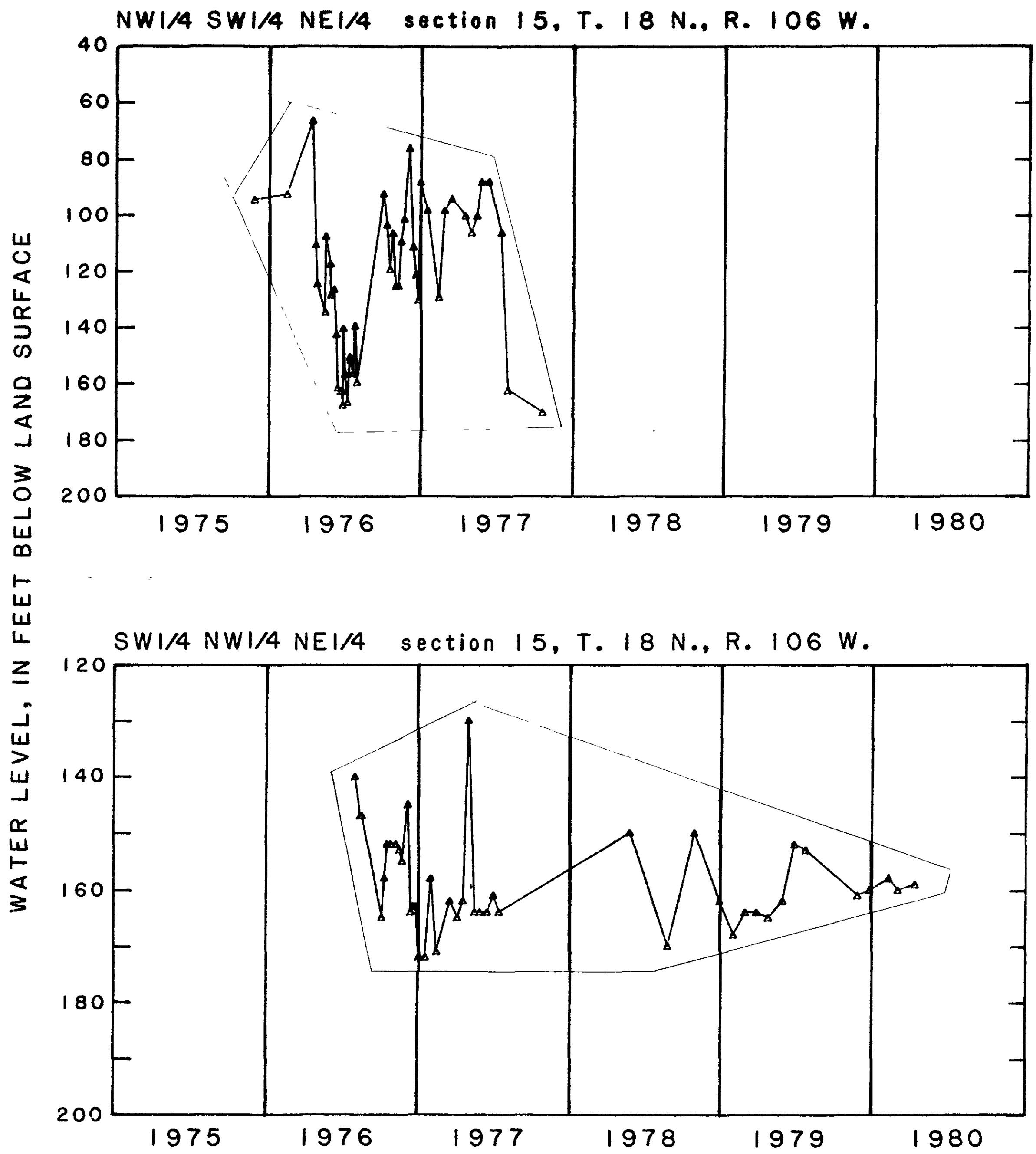

Figure 7.--Water levels in two wells at the Rock Springs retort site (Laramie Energy Technology Center, U.S. Department of Energy, written commun., 1981).

A variety of hypotheses can be made concerning the relationships between aquifers and the variation in aquifer properties for the Rock Springs study area. A list of these hypotheses follows:

1. Horizontal components of flow between the upper Tipton and Wasatch aquifers are insignificant and can be ignored.

2. True three-dimensional flow between the Tipton and Wasatch is significant and needs to be considered.

3. Aquifer properties, with the exception of the retort area, are horizontally uniform throughout the study area. There is a difference in properties inside and outside the retort area.

4. Aquifer properties vary areally in a more complex manner than described in point 3.

5. Hydraulic conductivity is anisotropic.

6. The analysis of flow in the fractured rocks can be made using concepts of flow derived for porous media.

7. Fractures are large enough or spatially distributed in a manner that requires the use of a noncontinuum approach.

As the study continues additonal hypotheses may become apparent.

Tests of hypotheses may be constructed from: (1) Hydrodynamic considerations, using the distribution of hydraulic head; (2) hydrochemical, using water-quality properties and constituents; or (3) hydrothermal, using distribution and gradients of temperature. For example information on seepage velocity, hydraulic-head gradient, fracture size and density can be used to determine the feasibility of using the traditional continuum approach to analyzing flow in fractures. The degree to which rocks are hydraulically interconnected may be assessed by careful consideration of the consequences of ground-water movement on water-quality properties and constituents. For example if the water quality in a well is significantly different from that in other wells that are hydraulically upgradient then either the change must be reasonable in light of lithologic variations and residence times or flow between the wells is unlikely.

A commonly used procedure for testing the validity of conceptual models of ground-water flow systems is to construct digital models that numerically approximate the differential equations of ground-water flow. This approach is used whenever the ground-water-flow system does not conform to the more restrictive assumptions that are made with conventional analytical methods. By varying the boundary conditions and aquifer-property estimates within the framework of the digital model it may be possible to reject some conceptual models. This can occur whenever the digital model fails to adequately simulate measured hydraulic-head data and flow rates. A second purpose in constructing a digital model is to calculate the variation in model results, such as hydraulic heads or flow rates, that result from varying aquifer properties within some range of uncertainty. This sensitivity analysis is extremely valuable in locating areas where additional wells are needed and in planning additional aquifer testing.

A number of tests of conceptual models were made using a two-dimensional representation of the ground-water flow system described by Cooley (1977). These tests included the hypotheses that aquifer properties are uniform outside the fracture patterns and hydraulic conductivity is anisotropic. In all instances, the estimated error variance of calculated hydraulic heads from measured hydraulic heads was so large the model calibration was not possible. None of the conceptual models could be accepted at this stage of the study. For this reason further details of the modeling effect are not included in this report.

Data Needs and Planned Data Collection

Summarizing available information and performing a preliminary interpretation of these data provides a framework for identifying additional data needs. By following this procedure, most guesswork in determining critical data requirements can be eliminated. This is not to say that once a plan for data collection is formed, all interpretation should cease. Such activities as flow-model development need to continue in order to reevaluate and refine the remaining data collection.

Data collection is by its nature very site specific and depends largely on the results of preliminary interpretive work. While the details of this plan are of limited use in other oil-shale hydrologic investigations, the type of data collected and methods of interpretation are widely applicable.

Potentiometric surfaces cannot be described accurately a short distance from the Rock Springs retort site. This fact probably is the most important reason for failure to calibrate a flow model. Therefore, a great deal of drilling will be required to install piezometers in all formations of interest in this study. The depth to the principal aquifer in the area, the Wasatch, precludes extensive drilling, but well locations that will prove useful are NW¼ sec. 21 and SE¼ sec. 22, T. 18 N., R. 106 W. The hydraulic head in the Tipton-Wasatch confining bed is the most undefined of all strata. This information would greatly assist determining an appropriate hypothesis for flow across the confining bed. Piezometers are needed both upgradient and downgradient of the retort area. Better definition of the hydraulic gradient within the retort interval of the upper Tipton aquifer is especially needed between the burned zones and the discharge area along Bitter Creek. Additional piezometers are needed in secs. 11 and 21, T. 18 N., R. 106 W. to determine the hydraulic head upgradient of the retort sites.

The accurate determination of discharge from the ground-water-flow system is critical to the successful development of a digital flow model. This is especially true in light of the uncertainty usually associated with estimates of aquifer properties. However the slow ground-water seepage rates at outcrops along Bitter Creek make direct measurement of this discharge impractical. Therefore the approach that will be taken in in this study is to determine the consumptive use requirement of the phreatophytes that grow on the outcrops. By accurately mapping the density of the plants a reasonable determination of the volume and areal distribution of discharge from the ground-water system will be obtained. The procedures for determining consumptive use outlined by Trelease and others (1970) will be used.

Reliable information is lacking on virtually all aquifer properties in the study area. These properties include the horizontal hydraulic conductivity of the retort site, and the vertical hydraulic conductivity of the Tipton-Wasatch confining bed. Data also are needed to determine if the hydraulic conductivity of the upper Tipton aquifer is anisotropic.

Aquifer tests of the Wasatch interval will be useful in several respects. By drilling observation wells in the Wasatch aquifer, the Tipton-Wasatch confining bed, and the upper Tipton aquifer, results of the aquifer tests can be used to estimate vertical hydraulic conductivity of the Tipton-Wasatch confining bed and the transmissivity and storage coefficient of the Wasatch aquifer. Long duration tests probably will be needed to observe drawdown in the upper Tipton aquifer. The effect of the oil-shale retorting on hydraulic properties can be assessed by conducting aquifer tests both inside and outside the areas underlain by burned zones.

The upper Tipton aquifer will not sustain a discharge rate sufficient to allow aquifer-test analysis, so other techniques need to be used to estimate hydraulic conductivity of this formation. Slug tests will be made at a number of wells as described by Cooper and others (1967). In this method, a known volume of water is injected into or removed from a well and the decline or rise of water-level is observed. From this information, an estimate of transmissivity can be obtained by a type-curve solution.

Data Interpretation

The digital model of the ground-water flow for the Rock Springs study area will be used for two purposes. The first purpose is to test various hypotheses of flow-system operation. By changing boundary conditions and aquifer-property estimates, the validity of the conceptual models described in a previous section along with other appropriate hypotheses can be checked against measured hydraulic data. The second purpose is to calculate ground-water velocities that will be used as entry data to solute-transport models. If data collected during the study indicate that significant changes in water levels occur due to the retort process, a third purpose of the digital flow models will be to project future changes.

WATER QUALITY

The possibility of ground-water contamination is a major hydrologic impact of the in situ retorting of oil shale. However, documenting changes in ground-water quality at a retort site and movement of contaminated water from the site is an extremely complicated undertaking that requires a thorough understanding of the geology and hydraulics of the area. Monitoring and interpreting changes in water quality is further hampered by an incomplete understanding of the proper analytical methods to be used in the laboratory for samples of retort water and problems associated with sampling oil-shale formations with minimal permeability.

Objectives

The objectives of the water-quality study at the Rock Springs study area are to: (1) Quantify the variability of water-quality properties and constituents in the ground-water system; (2) identify the major geologic controls on water quality; (3) determine the relative persistence of pollutants created by the in situ retorting; (4) identify chemical indicators produced by the in situ retorting that are useful in monitoring transport of the water plume away from the retort; and (5) evaluate the suitability of various sampling techniques and equipment for the retort site.

Previous Studies

Collection of water-quality data has been focused on three activities. The first activity has included attempts to standardize and improve analytical methods. The chemistry of retort wastewater is very complex with excessive and minute concentrations of many constituents. Fox and others (1978) using water produced during the retort experiment at site 9 concluded that many standard methods cannot be used to determine accurately or precisely many water-quality properties and constituents. However, the current study is concerned with the quality of retort water several years after the retort experiments were conducted. It is believed that the changes in the water quality have been sufficient to allow the application of standard U.S. Geological Survey analytical methods. A plan for testing this assumption is presented in a later section of this report.

A second water-quality activity that has been conducted at the Rock Springs study area is a water-quality monitoring program by the Laramie Energy Technology Center. About 3,000 samples have been collected and analyzed from 1970 through 1980. The analyses usually include the major inorganic species and occasionally inorganic trace metals. Few data are available for sulfur species and organic compounds. The data are available in the data base of the Wyoming Water Research Institute. Selected samples are presented by Jackson and others (1975). A review of the water-quality data is given by Weand (1978). He noted changes in the values and concentrations of several water-quality properties and constituents as a result of the retort experiments but did not attempt to relate spatial variations to any geologic or hydrologic conditions.

The third water-quality activity of importance in the Rock Springs study area is the study of chemical interactions of retort water with soil. A summary of this work is presented by Leenheer and others (1981). Although much of this work is not directly related to ground-water studies because of differences in soil and rock matrices and oxidation-reduction potentials, information on adsorption characteristics will prove useful. It was noted that chloride, molybdenum, and thiocyanate showed minimal interaction with soil. It was concluded that thiocyanate in anaerobic waters and molybdate in aerobic waters are good candidates for tracer solutes because of their lack of interactions, uniqueness, and high concentrations in retort water compared to soil.

Planned Data Collection and Interpretation

Large gaps exist in the water-quality data base for the Rock Springs study area. The two most apparent gaps are a lack of data outside the immediate vicinity of retort site and no analyses of organic compounds and sulfur species since the retort experiments have been completed. In addition to these gaps, no systematic study of sampling procedures in oil shale with minimal permeability has been undertaken. The following data-collection program is designed to meet these data needs.

A ground-water sampling program is needed downgradient from the retort site. This will consist of completing 10 to 15 observation wells in the upper Tipton aquifer and several wells in the Tipton-Wasatch confining bed and Wasatch aquifer. Periodic sampling of these wells in conjuction with existing wells will be used to document the movement of the solute plume away from the retort. The wells also will be used to describe the variability of water quality more thoroughly. Samples will be analyzed for numerous properties and constituents including major-inorganic ions, sulfur species, and volatile- and extractable-organic compounds.

These data will be used for two purposes. The first purpose is to identify chemical indicators of physical transport of contaminants from the retort site. Chemical indicators should originate as a result of the retorting of oil-shale, be present in minimal concentrations prior to developing the oil-shale resource, and be detectable at minute concentrations. These indicators also should be nonreactive or enter into chemical reactions in some known manner. If thiocyanate, molybdenum, or both, are detected in well water downgradient from the retort site, then these will be used as indicators. Otherwise, organic constituents originating in retort-process water will be considered. Concentration maps will be drawn for chemical indicators of solute-plume movement.

The second use of water-quality data in this study will be to relate the spatial variability in water-quality properties and constituents to geologic controls. Possible controls include lithologic variations as detected from cores or geophysical logging, and fracture orientation and density. Proximity to recharge and discharge areas also will be considered. The relationship of water quality to the geologic and hydrologic framework will be useful in constructing reasonable hypotheses of ground-water flow and solute transport.

Sampling of water from oil-shale formations presents some rather unique problems not readily addressed by standard sampling techniques. One problem is that the oil shale is not a productive aquifer; consequently, recharge to a pumped or bailed well is slow. Sampling apparatus and techniques may affect the data, especially for such constituents as the volatile-organic compounds. A sampling study will be undertaken at the Rock Springs retort site to determine the significance of these problems and to identify a preferred sampling procedure. Various sampling materials, such as steel, polyvinyl chloride, and Teflon [1/] will be tested along with different sampling devices such as a bailer, pneumatic sampler, and electric pump. The effects of sampling at various depths also will be examined for several chemical species to determine if concentration in the formation varies with depth. Variation with depth in water-quality properties and constituents will be correlated to lithologic changes. Standard statistical procedures, such as analysis of variance will be used to examine the results of the sampling study. Tests will be designed with replication as a means of assessing analytical error.

Solute-Transport Modeling

Digital solute-transport models have proven to be useful tools in many investigations of ground-water contamination. In the current study, a solute-transport model will be developed to determine the relative importance of dispersive, advective, and reactive properties of chemical constituents identified as indicators to the overall transport process. As much as possible, this approach will be extended to toxic substances of interest, and predictions will be made of when and at what concentration retort water will reach known discharge points.

Application of solute-transport models to in situ, oil-shale retorts imposes several complications not commonly encountered in other ground-water contamination problems. Solute transport through the fractured shale is primarily advective within the fractures and diffusive within the unfractured matrix. The orientation and density of fractures, aperture size, and matrix porosity are, therefore, important in determining the relative quantity of solute transported in fractures and stored in the matrix. Anisotropy of dispersivity in fractured media also greatly complicates any attempt to model solute transport. Two useful references on the topic of fractured media are Grisak and Pickens (1980) and Bibby (1981). While neither of the approaches discussed in these two articles can be directly applied to problems in oil-shale formations, many of their ideas can be used in the current study.

[1/] The use of brand names in this report is for identification only and does not constitute endorsement by the U.S. Geological Survey.

SUMMARY

The recovery of shale oil by in situ retort processes may cause water-resource problems, the most significant impacts being ground-water contamination and possible transport into surrounding areas. While these impacts are by nature site-specific, many of the techniques used to investigate each retort site generally will be the same. The U.S. Geological Survey has begun a study of hydrologic impacts in the area of an in situ retort near Rock Springs, Wyo., as a means of refining and demonstrating these techniques. The multidiscipline study incorporates geologic, hydrologic, and chemical aspects related to a variety of water-resources problems. Geologic investigations will include determining the areal extent and distribution of aquifers and retort zones, formation thickness, and lithology. Hydrologic investigations will build upon the geologic framework and will include mapping of potentiometric surfaces, describing rates of ground-water discharge, and estimating aquifer properties by analytical techniques. This information will be used to develop a digital ground-water-flow model. The flow model will be used to develop a more complete understanding of the ground-water-flow system and to calculate ground-water velocities for use in subsequent solute-transport modeling.

Water-quality investigations will depend extensively on the results of the geologic and hydrologic parts of the study. Water-quality investigations will include characterizing ground-water quality, including the relative persistance of pollutants created by the retort process, identifying chemical indicators that are useful in monitoring solute migration, evaluating sampling techniques, and monitoring solute transport from the retort sites. A solute transport model will be developed and coupled with the ground-water-flow model and predictions will be made of when and at what concentrations retort water will reach known discharge points.

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