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PLAN OF STUDY FOR THE REGIONAL AQUIFER-SYSTEM ANALYSIS OF THE SNAKE RIVER PLAIN, IDAHO AND EASTERN OREGON

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ILLUSTRATIONS

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ABSTRACT

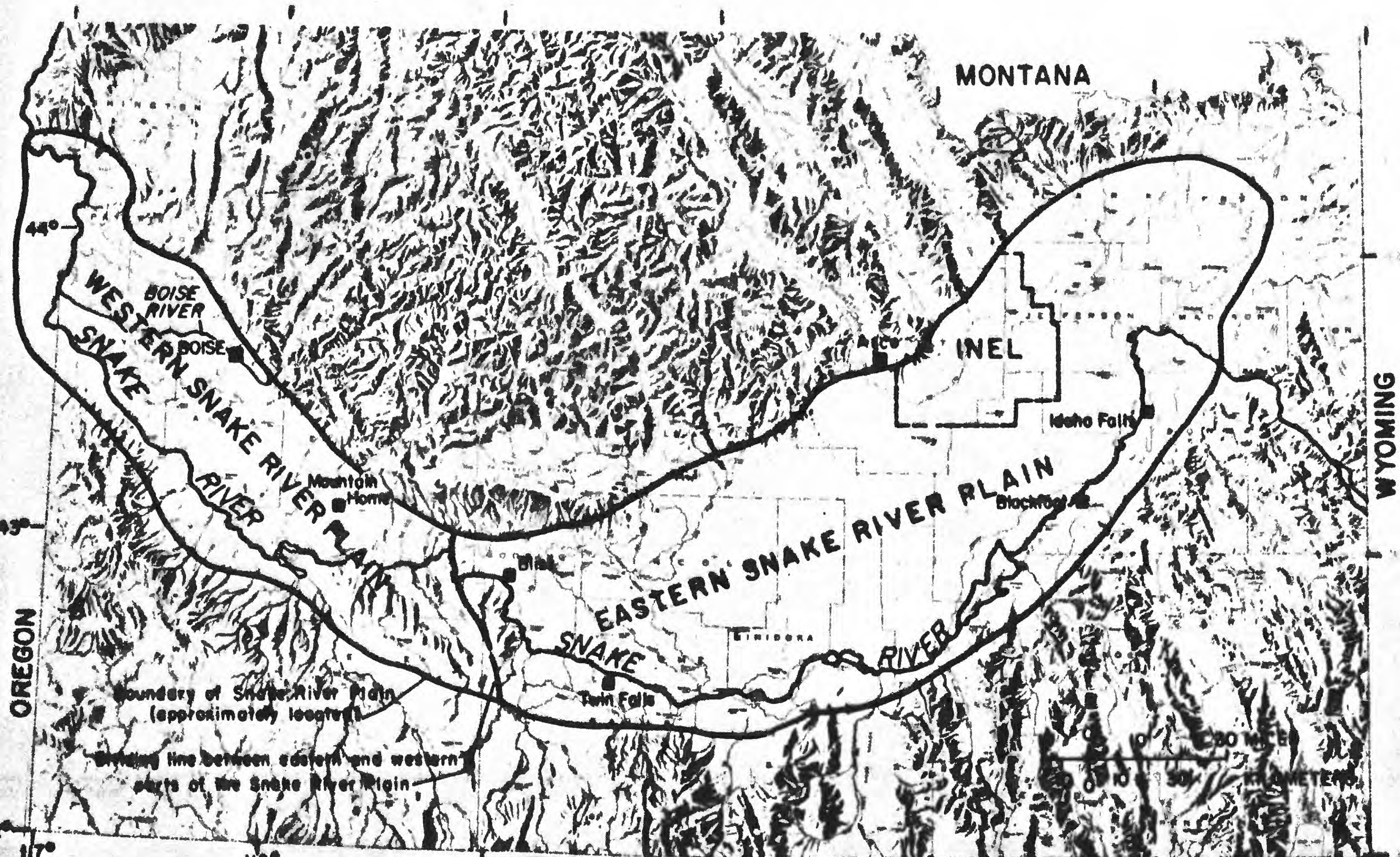
Volcanic rocks of Quaternary age, chiefly basalt, underlie much of the eastern Snake River Plain in southern Idaho and are a major source of water. Sedimentary rocks are a secondary source but supply most of the ground water in the western part of the plain.

The economy of the Snake River Plain is based largely on irrigated agriculture, as attested by the more than 3 million acres of irrigated land. Ground water plays a vital role, both as a source of water to wells and as discharge from springs that sustain flow in the Snake River. Because surface water is totally appropriated in some years, ground water is needed for expanded irrigation development. There is uncertainty, however, about the effects increased withdrawals may have on ground-water levels, spring discharges, and consequently, flow in streams.

The U.S. Geological Survey has begun a comprehensive study of the regional ground-water system in the Snake River Plain. The purpose of the study is to refine knowledge of the regional ground-water flow system, determine effects of conjunctive use of ground and surface water, and describe the water quality. Regional ground-water flow models will be used in the study to aid analysis. Hypotheses concerning the ground-water system will be tested, and the system's response to various ground-water-management alternatives will be evaluated. This report describes the objectives, approach, and plan of study, and establishes a time frame within which the work will be accomplished.

INTRODUCTION

The Snake River Plain is an arcuate area of about 15,600 mi^2 that extends across southern Idaho into Oregon (fig. 1). The plain ranges in width from about 30 to 75 mi and rises in altitude from about 2,100 ft above NGVD (National Geodetic Vertical Datum of 1929) in the west to about 6,000 ft above NGVD in the east. The surrounding mountains rise 7,000 to 10,000 ft above NGVD. Drainage is entirely to the Snake River, whose course approximates the southern margin of the plain, and, in some reaches, is entrenched as much as 700 ft below the plain.



Base modified from U.S. Geological Survey
1:500,000 shaded relief map, 1977

Figure 1. -- Morphology of the Snake River Plain and surrounding areas.

The study area is included in a summary appraisal of ground-water resources in the Pacific Northwest region by Foxworthy (1979). The eastern part, which comprises two-thirds of the plain, is underlain by the Snake Plain aquifer (Mundorff and others, 1964, p. 142), a thick (several thousand feet) sequence of basalts of Quaternary age that constitutes a major source of water in Idaho. Discharge of the Snake Plain aquifer is largely from a unique set of springs concentrated along a 50-mi reach of the Snake River between Twin Falls and Bliss. The springs make feasible a hydrologic separation of the plain into eastern and western parts (fig. 1). The western one-third of the plain is underlain by a thick (as much as 10,000 ft) sequence of sedimentary and igneous rocks of Tertiary and Quaternary age.

Irrigated agriculture and its related activities dominate the economy on the plain; more than 3.0 million acres were irrigated in 1979. Ground water supplies about one-third of the water for irrigation and also for most municipal, industrial, and domestic needs. Both recharge to and discharge from the ground-water system are greatly affected by irrigation. Each must be further studied to understand better the dynamics of the system.

The Snake River Plain RASA (Regional Aquifer-System Analysis) study will be made over a 4-year period, which began in October 1979. It is one in a series of studies by the U.S. Geological Survey to evaluate the Nation's major aquifer systems (Bennett, 1979).

HYDROGEOLOGIC SETTING

Eastern Snake River Plain

The eastern part of the plain is a structural downwarp filled mostly with a series of basaltic lava flows of Quaternary age whose total thickness is unknown but locally exceeds several thousand feet (Stearns and others, 1936; and Zohdy and Stanley, 1973). Generalized geology of the plain is shown in figure 2. Older and less permeable volcanic rocks, mainly rhyolite, underlie the basalt in much of this area and are thought to constitute the base of the Snake Plain aquifer.

Broken, rubbly zones between basalt flows (interflow zones) are generally very permeable and are major avenues for horizontal movement of water. Although single flows, averaging 20 to 25 ft in thickness, may have low transmissivity, multiple flows and thus multiple interflow zones have transmissivities in many places of 500,000 ft^2/d (Mundorff and others, 1964). Locally, lava tubes and brecciated flows result in abnormally high transmissivities. Electric analog model analysis by Norvitch and others (1969) indicates that local transmissivities may be as high as 13,000,000 ft^2/d. Other ground-water model studies of the eastern Snake River Plain suggest transmissivity values of comparable magnitudes (Mantei, 1974; deSonneville, 1974; and Newton, 1978).

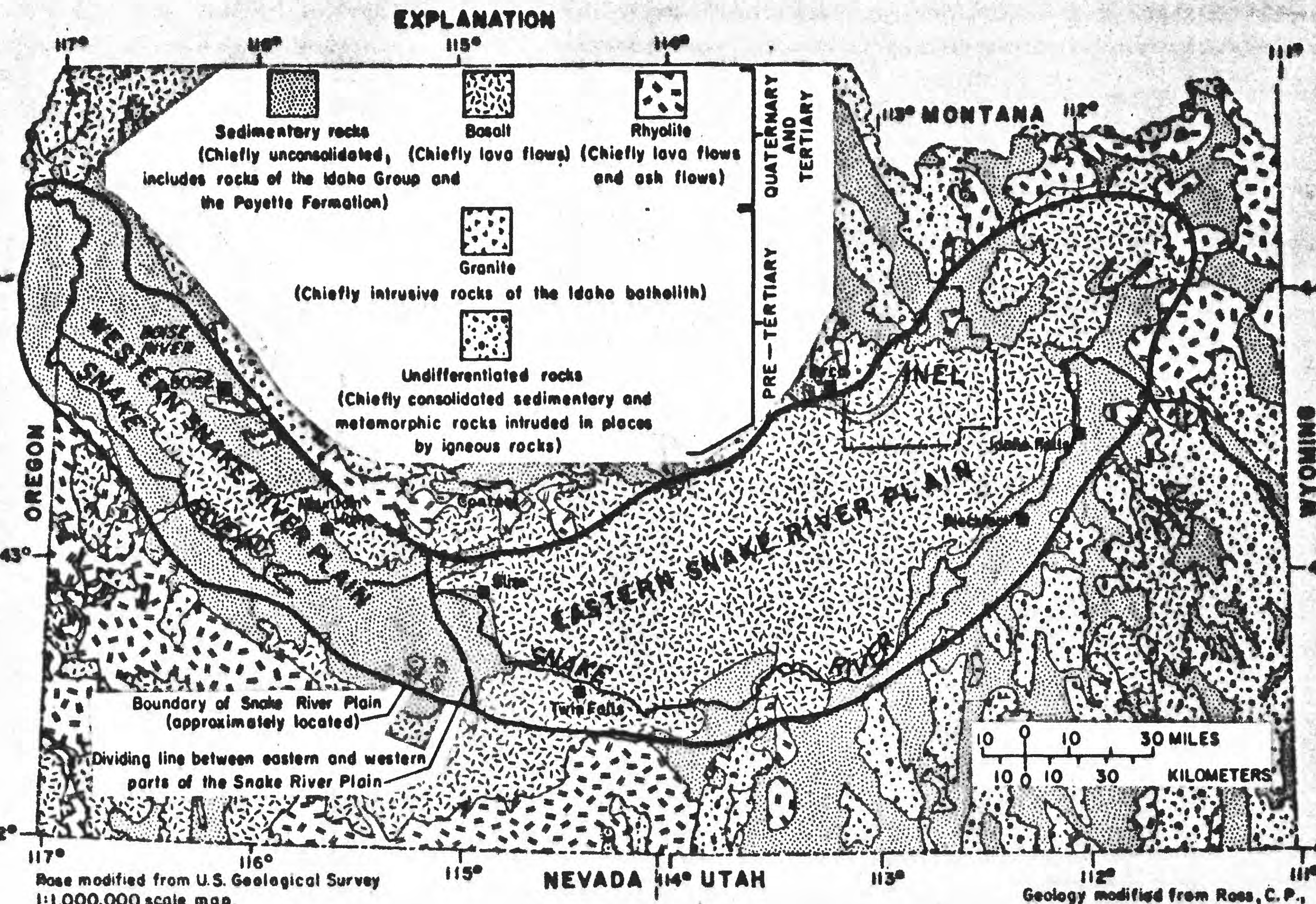


Figure 2. -- Generalized geology of the Snake River Plain and surrounding areas.

Vertical movement of water between interflow zones is through fractures (mainly joints). In places, primarily near the southeastern boundary, discontinuous units of fine-grained sedimentary rocks of varying thickness (a few feet to several tens of feet) occur between flows and impede vertical movement of water, resulting in semiconfined aquifer conditions. The ratio of sedimentary rocks to basalt is greatest in the vicinity of Blackfoot, where sediments predominate in the upper 500 ft.

The ground-water system is recharged by deep percolation of excess irrigation water, leakage from irrigation canals, seepage from streams flowing onto and across the plain, and underflow from tributary valleys flanking the plain. Direct recharge from precipitation is a lesser but significant source.

Springs along the Snake River between Twin Falls and Bliss account for about half of the total discharge from the eastern Snake River Plain. Ground-water pumping, largely for irrigation, has increased dramatically since the early fifties and is now a major component of discharge. In the northeastern part of the study area, and in places along the Snake River, the water table is near land surface, and ground water is lost by evapotranspiration.

Historically, long-term positive changes in ground-water storage have resulted from the use of surface water for irrigation. That trend has now reversed, owing to changes in irrigation practices and increased ground-water pumping. Items of recharge to and discharge from the Snake River Plain regional aquifer are shown in figure 3.

Ground water in the eastern part of the plain is chiefly of the calcium magnesium bicarbonate type, with moderate amounts of sodium and sulfate, and is suitable for most uses (Mundorff and others, 1964, p. 208). Dissolved-solids concentrations are typically less than 250 mg/L in nonirrigated areas but exceed that amount in irrigated areas (Norvitch and others, 1969, p. 26). Dyer and Young (1971) reported dissolved-solids concentrations of 300 to 400 mg/L in several irrigated areas and concentrations exceeding 600 mg/L locally. Chloride and nitrate concentrations are also reported to be greatest in intensively irrigated areas. However, some of these concentrations may result from a high ratio of sedimentary rock to basalt in much of the irrigated area. Water contained in many sedimentary rocks is typically more mineralized than water in basalt.

Since 1952, wells have been used for the disposal of low-level, liquid radioactive wastes at the INEL (Idaho National Engineering Laboratory) site near Arco (formerly NRTS, National Reactor Testing Station). In addition, radioactively contaminated solid wastes are stored on the surface and buried at the INEL site. The U.S. Geological Survey, under contract with the U.S. Department of Energy, Division of Environment, has main-

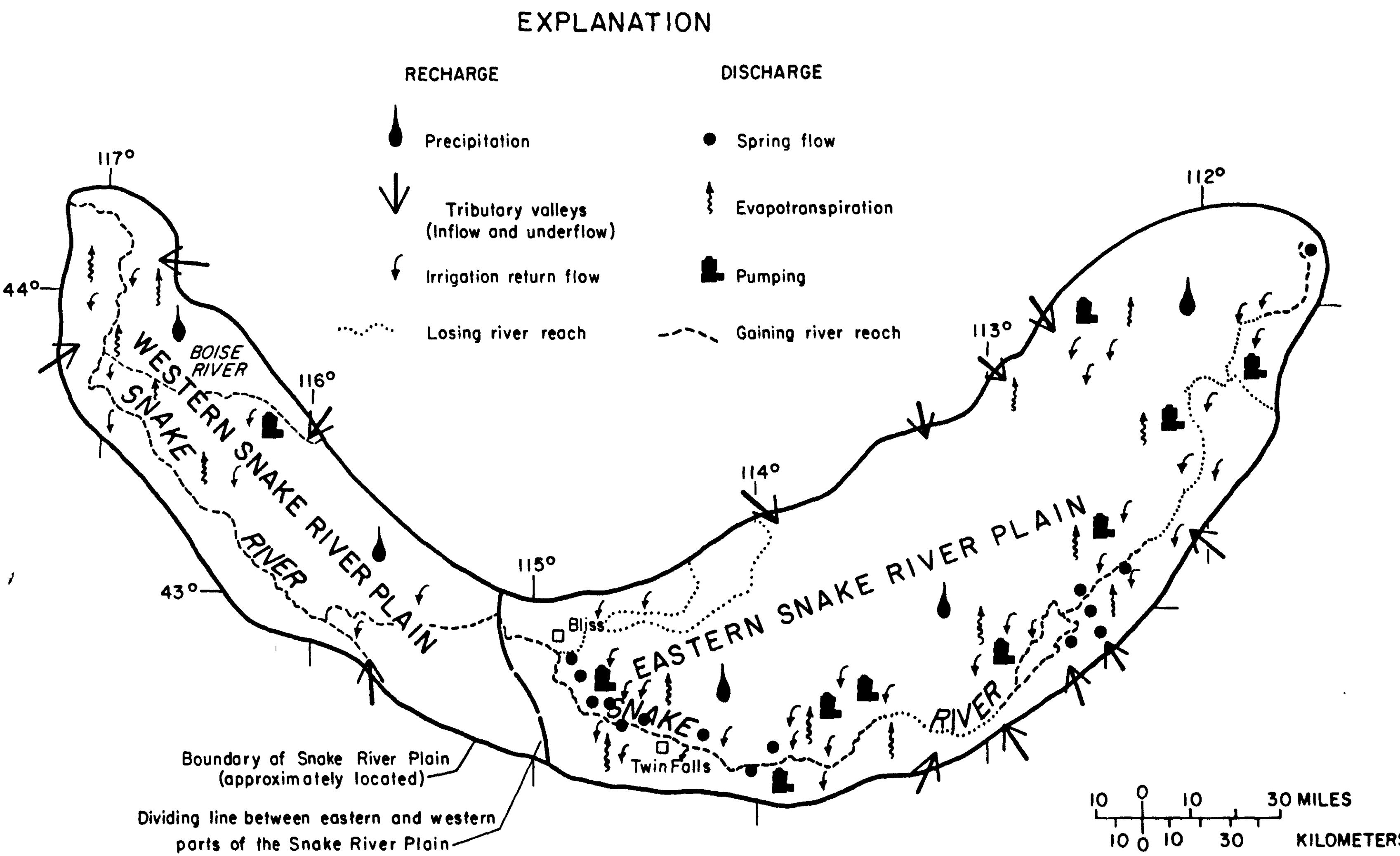


Figure 3.--Major recharge and discharge functions of the Snake River Plain regional aquifer system.

tained a project office at the site since 1949 to make hydrologic studies and to monitor effects of waste disposal on ground-water quality. A summary of the geology, hydrology, and water geochemistry at INEL is given in a report by Robertson and others (1974).

Drain wells for waste water from farms, cities, industries, and private homes also are of concern because of their effect on water quality (Seitz and others, 1977).

Western Snake River Plain

The western part of the Snake River Plain is flanked on the northeast and southwest by a series of faults and structurally appears to be a graben. The graben is filled with a sequence of Tertiary and Quaternary sedimentary and igneous rocks (chiefly volcanic) that have a combined thickness of as much as 10,000 ft. Few drill holes penetrate the volcanic rocks that compose the lower part of this sequence, so little is known about their water-yielding characteristics. Immediately overlying the volcanic rocks are relatively impermeable sedimentary rocks of the Payette Formation. They are overlain by rocks of the Idaho Group that range in thickness from several hundred to several thousand feet. Sand and gravel zones in the Idaho Group are generally the best aquifers. In general, the most productive of these is the Glenns Ferry Formation. Locally, however, basalts of the Idaho Group are the most productive. Sand and gravel overlying the Idaho Group constitute an unconfined aquifer that is extensively used as a source of supply. Younger basalt of the Snake River Group crops out over a large area (Mountain Home plateau) but is unsaturated in most places (Young, 1977).

The western Snake River Plain ground-water system is recharged by direct precipitation, deep percolation of excess irrigation water, leakage from irrigation canals, seepage from streams flowing onto the plain, and underflow from highlands bordering the plain. Continued use of surface water for irrigation since the 1860's in the Boise Valley has raised ground-water levels as much as 140 ft (Nace and others, 1957), which necessitated construction of drainage canals and ditches to alleviate waterlogging. Where water levels have risen, water in the unconfined aquifer is, in places, in direct hydraulic connection with the Boise River (Thomas and Dion, 1974).

Items of discharge from the ground-water system include losses to streams, pumping, and evapotranspiration.

Ground water in the western Snake River Plain ranges from sodium calcium bicarbonate to calcium or sodium bicarbonate type, depending upon the dominant source of recharge (Young, 1977, and Dion, 1972). Dissolved-solids concentrations are generally less than 500 mg/L, except where excess irrigation water having a surface-water source recharges the aquifer (Young, 1977). The chemical quality of ground water is such that it is suitable for most uses.

Changes in water quality have been noted in surface-water supplies downstream from irrigated areas on the western plain (Thomas and Dion, 1974). Changes include increases in dissolved-solids and nutrient concentrations, as well as in some individual constituents and in biochemical-oxygen demand. Increased urbanization in the Boise-Nampa area resulted in no detectable ground-water quality changes during the period 1953-70 (Dion, 1972).

A largely undefined hot-water system underlies the cold-water system of the Snake River Plain. Studies along the margins of the plain have been and are being made in areas containing geothermal water. As the need for alternative sources of energy becomes more acute, it seems inevitable that special detailed studies will be needed to define the geothermal system and its relation to the overlying cold-water system.

GROUND-WATER PROBLEMS

Ground water supplies about one-third of all irrigation water used on the Snake River Plain. It also supplies most municipal, industrial, and domestic needs. Increasing use of ground water has caused concern about its adequacy to meet future water needs, in terms of both quantity and quality.

Because ground and surface water on the Snake River Plain are closely related, both must be evaluated in studying the regional ground-water system. Man's manipulation and management of the water resources have significantly complicated the system's operation. Water problems are accordingly diverse but can be grouped under the general headings of quantity, quality, and management.

Quantity

Historical data indicate that the natural water regimen on the Snake River Plain has been altered by water-resource development. Changes have occurred in the quantity and quality of recharge and discharge, and, consequently, in the ground-water flow system.

Ground-water levels have risen in areas irrigated with surface-water, owing to canal leakage and deep percolation of excess irrigation water. Waterlogging problems have developed in places on the western Snake River Plain. Conversely, water levels are declining in some heavily developed areas irrigated by ground water.

Aquifer discharge as spring flow has changed with time in response to irrigation development. Spring flow increased as surface-water irrigation increased and is showing signs of decreasing as ground-water withdrawals increase. Further definition of the effects of irrigation on the water regimen are needed so consequences of future development may be anticipated.

Since the mid-1950's, interest in irrigation has extended to areas that cannot be supplied by surface-water diversions and gravity flow. Expansion was possible because underlying much of the plain are aquifers capable of yielding large quantities of water of good quality. Consequences of large-scale ground-water development are poorly understood and cannot be evaluated without a better understanding of the ground-water flow system and its response to stress. Declining ground-water levels increase pumping costs and decrease ground-water discharge as spring flow, thereby depriving downstream water users of their needed supply. As a result, conflicts of interest have developed with respect to water use.

Water in the Snake River is fully appropriated in about 1 out of every 4 years. When surface-water supplies are inadequate, ground water is the only available supplemental source. Possible hydrologic implications of the conjunctive use of ground and surface water are largely unknown.

The quantity of ground-water withdrawals is largely unknown and needs better definition. Because reporting of quantities pumped is not required by State law, current and historical withdrawals will have to be estimated using indirect methods.

Previous ground-water flow models of the eastern Snake River Plain have indicated several key areas where the flow system is poorly understood. Inadequate geologic and hydrologic data have restricted understanding. Data documenting changes in the flow system owing to irrigation are likewise inadequate or lacking, making systems modeling difficult. No comprehensive ground-water study has been done, and accordingly, no ground-water flow models have been made of the western Snake River Plain as defined in this report. Definition of the geologic framework is hampered by a lack of deep subsurface information. Hydrologic data are largely for the shallow, unconfined aquifer.

Quality

Regional variations in ground-water quality, as indicated by concentrations of inorganic and organic solutes, are poorly defined. Changes in natural water quality have been documented in some heavily irrigated areas, in the vicinity of disposal wells, near industrial plants, in urban areas having inadequate sewage systems, and in the vicinity of nuclear plants.

Geochemistry of the regional ground-water system has not been defined. To determine the origin of solutes and mechanisms controlling their concentration, special carefully collected samples are needed. It is not known if an understanding of reactions between the predominantly silicate rocks and water moving through them might be helpful in defining the ground-water flow system.

Management

Operation of the regional ground-water system is significantly influenced by man's activities, especially irrigation use. Proper water-resource management is therefore critical, because both ground-water recharge and discharge are affected. Management decisions affect not only water users on the Snake River Plain, but also downstream water users. Consequently, a better understanding of ground water-surface water relations is needed to manage the resource for optimum use.

OBJECTIVES OF THE STUDY

The main objective of the Snake River Plain regional aquifer study is to obtain a better understanding of the regional ground-water flow system. To do so requires (1) better definition of the geologic framework, (2) better identification of aquifers and confining beds and determination of their hydraulic properties, (3) better definition of recharge and discharge, and (4) definition of water-rock reactions on water quality.

Regional ground-water flow models will be developed and used throughout the investigation to study (1) the dynamics of the regional ground-water system, (2) the relative importance of geologic controls on the system, (3) the relative importance of various items of recharge and discharge, (4) the effects of man's activities on the natural system, (5) the potential for conjunctive use of ground and surface water, and (6) the consequences of various management alternatives as developed by State and Federal water managers. Recent advances in modeling techniques will be utilized, and specific geologic and hydrologic data needed for systems modeling will be collected. Knowledge gained from previous model studies will be incorporated into the present modeling effort.

A data-management system will be developed for model input to facilitate handling the many data needed.

Quality of ground water will be defined and areal variations delineated. If possible, aqueous geochemistry will be used to help define the ground-water flow system.

The present data base will be evaluated, and where inadequacies occur, changes will be made in monitoring networks to insure improved data for this and future studies.

The study will integrate data from the ground-water, surface-water, and water-quality disciplines; incorporate results of previous local and regional studies; and provide a regional framework for future studies.

To keep interested parties informed about study objectives, progress, and results, a liaison committee consisting of State, local and other Federal agency personnel will be formed and will meet periodically. A technical committee will also meet periodically to review aspects of the study, evaluate approaches, and offer suggestions.

Throughout the study, written reports will be prepared to document study approaches and present results. A final report will summarize the entire study. A diagram of major work elements and a postulated time frame for each element are shown in figure 4.

APPROACH

To meet study objectives, existing geologic, hydrologic, and water-quality data will be compiled and evaluated. On the basis of these data, a conceptual model of the regional ground-water flow system will be developed and translated into mathematical flow models. Initial modeling efforts will produce two-dimensional, steady-state, regional simulations of the ground-water flow system. These models will be used to test various hypotheses about the hydrogeologic system and to define type and location of data needs. Subareas having unique hydrogeologic problems may be designated for special study. Certain study elements will be contracted out or will be done through a work agreement by qualified specialists. Data collection and analysis will receive major emphasis throughout most of the study.

On the basis of newly collected data and knowledge gained through initial two-dimensional modeling, steady-state, three-dimensional simulation models will be developed. Final models will represent a best effort based on available data and the use of state-of-the-art modeling techniques. The models will be used to evaluate select management alternatives devised by State and Federal management agencies. However, the predictive capability of each will be dependent upon the adequacy of field data with which to calibrate the models.

PLAN OF STUDY

Major work elements to be conducted to achieve stated objectives are outlined:

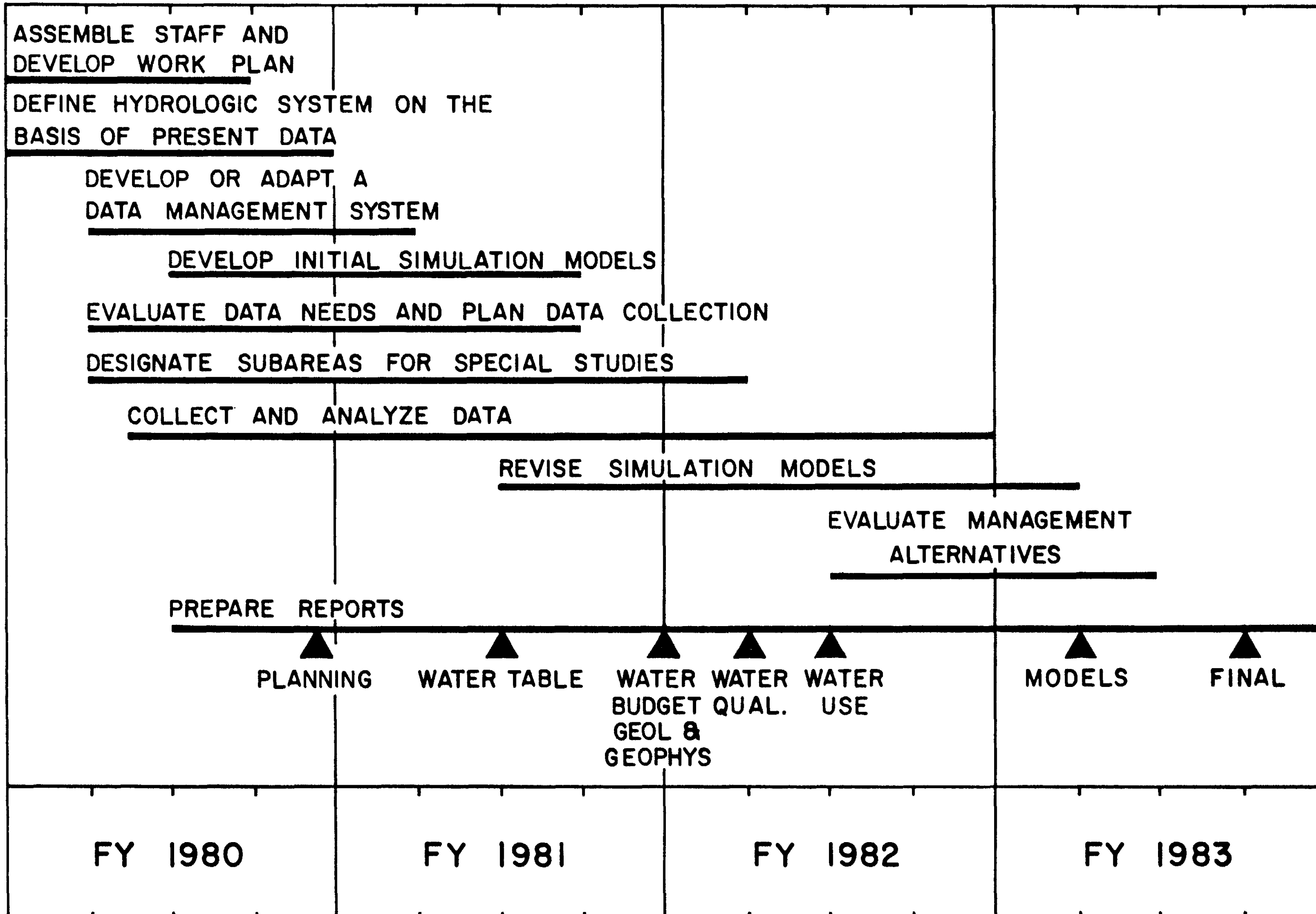


Figure 4.--Schedule of major work elements.

I. Assemble staff and develop work plan

II. Define hydrologic system on the basis of present data

- A. Define geologic framework
  1. Develop base maps
  2. Compile and evaluate surface and subsurface geologic data
  3. Compile and evaluate geophysical data
  4. Identify aquifers and confining beds
  5. Define extent of aquifers and confining beds
- B. Determine hydraulic properties of aquifers and confining beds
  1. Evaluate prior pumping tests
  2. Compile and evaluate data on hydraulic properties: hydraulic conductivity, transmissivity, storage coefficient, specific storage, specific yield, and specific capacity
  3. Map horizontal and vertical variations in hydraulic properties
- C. Describe ground-water system
  1. Determine recharge
     - a. Precipitation
     - b. Streams, define losing reaches
     - c. Irrigation water
     - d. Tributary valleys
       - (1) Stream sinks
       - (2) Underflow
  2. Determine discharge
     - a. Spring flow
     - b. Streamflow, define gaining reaches
     - c. Ground-water pumping
     - d. Evaporation and transpiration
     - e. Underflow
  3. Describe ground-water movement:
     - a. Horizontally, as defined by previous mass water-level measurements and special studies
     - b. Vertically, as defined by piezometer nests
- D. Describe ground-water quality
  1. Assemble and evaluate water-quality data base
  2. Develop maps showing areal variations in water quality
  3. Make statistical analysis of selected constituents and parameters

III. Develop or adapt a data-management system

- A. Organize drill-hole data
  1. Enter selected data into the GWSI data base
  2. Organize other data for conventional analysis methods

III. Develop or adapt a data-management system--Continued

- B. Prepare data for model input
  - 1. Develop a system independent of model grid for input of data

IV. Develop initial simulation models

- A. Develop two-dimensional, steady-state, regional ground-water flow models using present data base
- B. Use parameter-estimation techniques to establish reasonableness of input data
- C. Calibrate to time-average hydrologic conditions
- D. Use sensitivity analysis to evaluate the relative importance of hydraulic properties and boundary conditions of the regional ground-water system
- E. Use model response as a guide for further data collection

V. Evaluate data needs and plan data collection

- A. Prioritize data needs in keeping with project objectives and funding
- B. Coordinate data collection with other Federal and State agencies
- C. Supplement present surface-water data network
- D. Supplement present observation-well network
- E. Supplement present water-quality network
- F. Evaluate methods of estimating ground-water withdrawals
- G. Evaluate adequacy of geological, geophysical, and drill-hole data

VI. Designate subareas for special studies

- A. Identify need for special studies in critical areas
- B. Develop plans for special studies to satisfy needs

VII. Collect and analyze data

- A. Define geologic framework
  - 1. Develop work agreement with Geologic Division to map Snake River Canyon face between Milner and King Hill to determine geologic controls on springs
  - 2. Refine definition of aquifers and confining beds
    - a. Collect additional drill-hole data
    - b. Collect down-hole geophysical data in key locations
    - c. Develop a work agreement with Geologic Division or contract for resistivity soundings where deep drill holes are lacking

VII. Collect and analyze data--Continued
- A. Define geologic framework--Continued
  - 2. Refine definition of aquifers and confining beds--Continued
    - d. Analyze gravity data
    - e. Do highly selective test drilling in critical areas
- B. Determine hydraulic properties of aquifers and confining beds
  - 1. Use ground-water flow models and steady-state, time-averaged approach to test estimates of hydraulic properties of aquifers and confining beds
  - 2. Compare model-estimated aquifer transmissivities with those estimated from pumping tests and specific-capacity data
  - 3. Determine relative sensitivity of ground-water flow system to specific parameters
- C. Describe ground-water system
  - 1. Determine recharge
    - a. Acquire additional precipitation data and revise existing isohyetal maps if necessary
    - b. Define losing stream reaches
      - (1) Install recording gages, if practical
      - (2) Make miscellaneous measurements between gages
      - (3) Make seepage runs
      - (4) Measure or estimate direct withdrawals and returns
    - c. Determine recharge from irrigation
      - (1) Identify irrigated areas by remote-sensing methods and classify as to source of water
      - (2) Determine recharge as:
        - (a) Canal leakage (seepage runs)
        - (b) Field seepage (water-budget analysis)
        - (c) Waste-water return to wells
    - d. Determine recharge from tributary valleys
      - (1) Evaluate adequacy of existing data; published and unpublished
      - (2) Update and supplement above
      - (3) Use geophysical techniques to define valley geometry

VII. Collect and analyze data--Continued
    C. Describe ground-water system--Continued
        1. Determine recharge--Continued
            d. Determine recharge from tributary valleys--Continued

                (4) Estimate hydraulic properties of valley-fill materials
                (5) Calculate underflow using Darcy's equation and water-budget analysis
                (6) Use basin characteristics to estimate surface-water contribution from ungaged valleys
        2. Determine discharge
            a. Locate and determine discharge from springs
                (1) Map geologic occurrence
                (2) Install recording gages and make supplemental measurements throughout year
            b. Define gaining stream reaches
                (1) Install recording gages
                (2) Make miscellaneous measurements between established gages
                (3) Make seepage runs
                (4) Measure or estimate direct withdrawals and returns
            c. Determine pumping from ground-water sources
                (1) Identify irrigation pumping centers and estimate quantities withdrawn
                (2) Compare results of different estimation methods
            d. Determine evapotranspiration
                (1) Evaluate available plant consumptive-use data
                (2) Compare above with data estimated by other methods
        3. Describe ground-water movement
            a. Horizontally--make mass water-level measurements to determine present configuration of water table
            b. Vertically--locate and measure water levels in piezometer nests, locate and measure water levels in wells having different completion depths in local areas, use down-hole flow meters

VII. Collect and analyze data--Continued
  C. Describe ground-water system--Continued
    3. Describe ground-water movement-Continued

      c. Supplement existing observation-well network
      d. Use geochemical techniques, if possible
  D. Describe ground-water quality
    1. Collect samples to supplement existing water-quality data base
    2. Collect special samples to determine chemical composition of recharge and discharge waters
    3. Analyze samples for inorganic and organic solutes, trace metals, and selected isotopes
    4. Acquire rock analyses
    5. Determine water-rock interactions and identify mechanisms controlling water quality
    6. Use water chemistry to aid in understanding ground-water flow system

VIII. Revise simulation models
  A. Use initial two-dimensional model results, new input data, refined model grid, and results of subarea models to develop regional, three-dimensional, steady-state models
  B. Calibrate steady-state models to average conditions for appropriate time period
  C. Simulate transient conditions, if feasible

IX. Evaluate management alternatives
  A. Use ground-water flow models to estimate effects of hypothetical development schemes as devised by State and Federal management agencies

X. Prepare reports (proposed)
  A. Planning report (Open-File Report)
  B. Water-table configuration, March 1980, and historical changes in ground-water levels (Hydrologic Atlas)
  C. Compilation of geophysical information on the Snake River Plain (Miscellaneous Geologic Investigation)
  D. Geologic framework of the Snake River Plain (Hydrologic Atlas)
  E. Distribution of Snake River water and water budget of the Snake River Plain (Hydrologic Atlas)
  F. Regional variations in ground-water quality in the Snake River Plain (Hydrologic Atlas)
  G. Definition of irrigated acreage on the Snake River Plain using Landsat data (Hydrologic Atlas)

X. Prepare reports (proposed)--Continued

H. Pumping for irrigation on the Snake River Plain (Hydrologic Atlas)
I. Geohydrology of springs along the Snake River from Milner to King Hill, Idaho (Miscellaneous Geologic Investigation)
J. Ground-water flow model of the Mud Lake area, Idaho (Water-Supply Paper)
K. Regional ground-water flow models of the Snake River Plain (Water-Supply Paper)
L. Summary report (Professional Paper)

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CONVERSION FACTORS

For the convenience of those who prefer to use SI (International System of Units) rather than the inch-pound system, conversion factors for terms used in this report are listed below. Chemical data for concentrations are given only in mg/L (milligrams per liter), which is, within the range of values presented, numerically equal to parts per million.

Multiply inch-pound unit	By	To obtain SI unit
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4047	square meter
square mile (mi^2)	2.590	square kilometer
	Transmissivity	
foot squared per day (ft^2/d)	0.0929	meter squared per day