HYDROLOGIC CONDITIONS AT THE IDAHO NATIONAL ENGINEERING LABORATORY, 1982 TO 1985

by John R. Pittman, Rodger G. Jensen, and Patrick R. Fischer

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CONTENTS

ILLUSTRATIONS

TABLES

FACTORS FOR CONVERTING INCH-POUND UNITS TO METRIC (SI) UNITS

For use of readers who prefer to use International System (SI) units, rather than inch-pound terms, the following conversion factors may be used.

Multiply inch-pound units	By	To obtain SI units
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
foot per mile (ft/mi)	0.1894	meter per kilometer
square mile (mi^2)	2.590	square kilometer
gallon (gal)	3.785	liter
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second(ft^3/s)	0.2832	cubic meter per second
pound (lb)	0.4536	kilogram
foot squared per day (ft^2/d)	0.0929	meter squared per day
curie (Ci)	3.70×10^{10}	becquerel
picocurie (pCi)	0.037	becquerel

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

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ABSTRACT

Aqueous chemical and radioactive wastes discharged since 1952 to unlined ponds and wells at the INEL (Idaho National Engineering Laboratory) have affected water quality in perched ground-water zones and in the Snake River Plain aquifer. Routine wastewater disposal was changed from a deep injection well to ponds at the ICPP (Idaho Chemical Processing Plant) in 1984. During 1982-85, tritium concentrations increased in perched ground-water zones under disposal ponds, but cobalt-60 concentrations decreased. In 1985, perched ground water under TRA (Test Reactor Area) disposal ponds contained up to 1,770±30 pCi/mL (picocuries per milliliter) of tritium and 0.36±0.05 pCi/mL of cobalt-60.

During 1982-85, tritium concentrations in water in the Snake River Plain aquifer decreased as much as 80 pCi/mL near the ICPP. In 1985, measurable tritium concentrations ranged from 0.9±0.3 to 93.4±2.0 pCi/mL. Tritium was detected in ground water near the southern boundary of the INEL, 9 miles south of the ICPP and TRA. Strontium-90 concentrations in ground water, up to 63±5 pCi/L (picocuries per liter) near the ICPP, generally were smaller than 1981 concentrations. Cesium-137 concentrations in ground water near the ICPP ranged from 125±14 to 237±45 pCi/L. Maximum concentrations of plutonium-238 and plutonium-239, -240 (undivided) were $1.31\pm0.09\times10^{-3}$ pCi/mL and $1.9\pm0.3\times10^{-4}$ pCi/mL. Sodium and chloride concentrations generally decreased during 1982-85. Nitrate concentrations increased near the TRA and NRF (Naval Reactors Facility) and decreased near the ICPP.

INTRODUCTION

The INEL (Idaho National Engineering Laboratory) is operated by the U.S. Department of Energy primarily to build, operate, and test nuclear reactors. Fifty-two reactors have been constructed to date, of which thirteen are still operable. In addition, the INEL supports other government-sponsored projects such as energy, defense, environmental, and ecological research.

The INEL covers about 890 mi^2 of the eastern Snake River Plain in southeastern Idaho (fig. 1). The plain is a structural and topographic basin about 200 mi long and 50 to 70 mi wide. Thickness of surficial sediment deposits at the INEL ranges from 0 to 345 ft. Thin basaltic lava flows, rhyolitic rocks, and interbedded sedimentary deposits underlie the plain to depths of 2,000 to 10,000 ft. Basaltic rocks and interbedded sedimentary deposits in the upper 1,000 to 2,000 ft combine to form the Snake River Plain aquifer--a major source of water in southeastern Idaho; the INEL obtains its entire water supply from the aquifer. Aqueous chemical and radioactive wastes have been discharged to deep wells and shallow ponds at the INEL since 1952 and have affected the quality of the ground-water in the underlying Snake River Plain aquifer. Many of these waste constituents entered the aquifer either directly through disposal wells or indirectly following percolation from the ponds through the unsaturated zone. A detailed description of the geology and hydrology is presented by Robertson and others (1974).

The determination of the effects of aqueous waste disposal on the regional hydrology requires a knowledge of: (1) the hydrogeology of the Snake River Plain aquifer; (2) the locations, quantities, and methods of aqueous-waste disposal; (3) the chemistry of the waste solutions; and (4) the geochemical processes taking place in the aquifer. A primary concern has been to trace the movement of dilute chemical and low-level radioactive wastes in the subsurface and to explain the chemical and radiochemical changes that accompany such movement in terms of geologic, hydrologic, and geochemical properties. This report presents information collected as part of the hydrologic monitoring program conducted by the U.S. Geological Survey

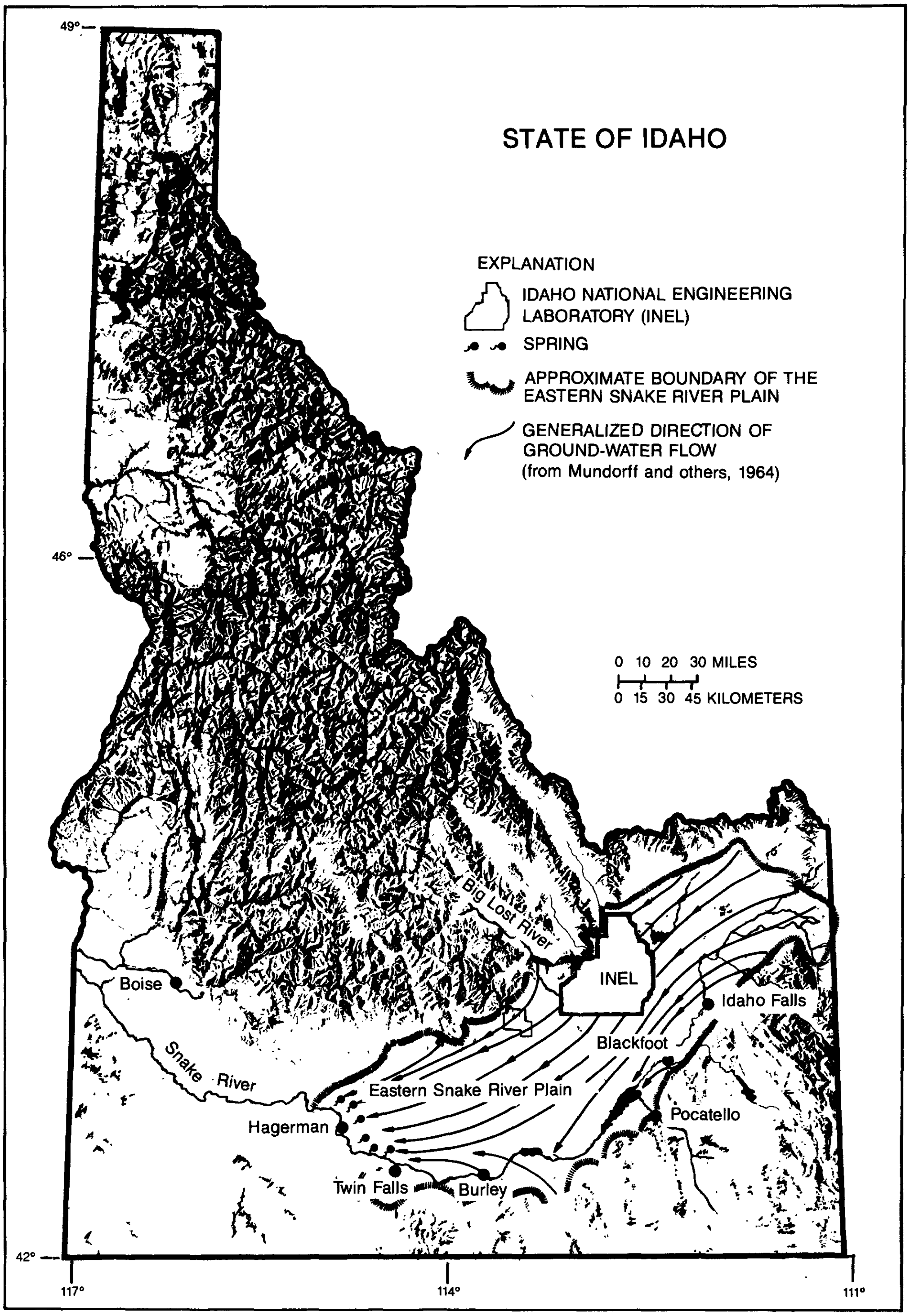


Figure 1.--Locations of the INEL and Snake River Plain, and generalized direction of ground-water flow in the Snake River Plain aquifer (from Barraclough and others, 1981).

in cooperation with the U.S. Department of Energy's Idaho Operations Office.

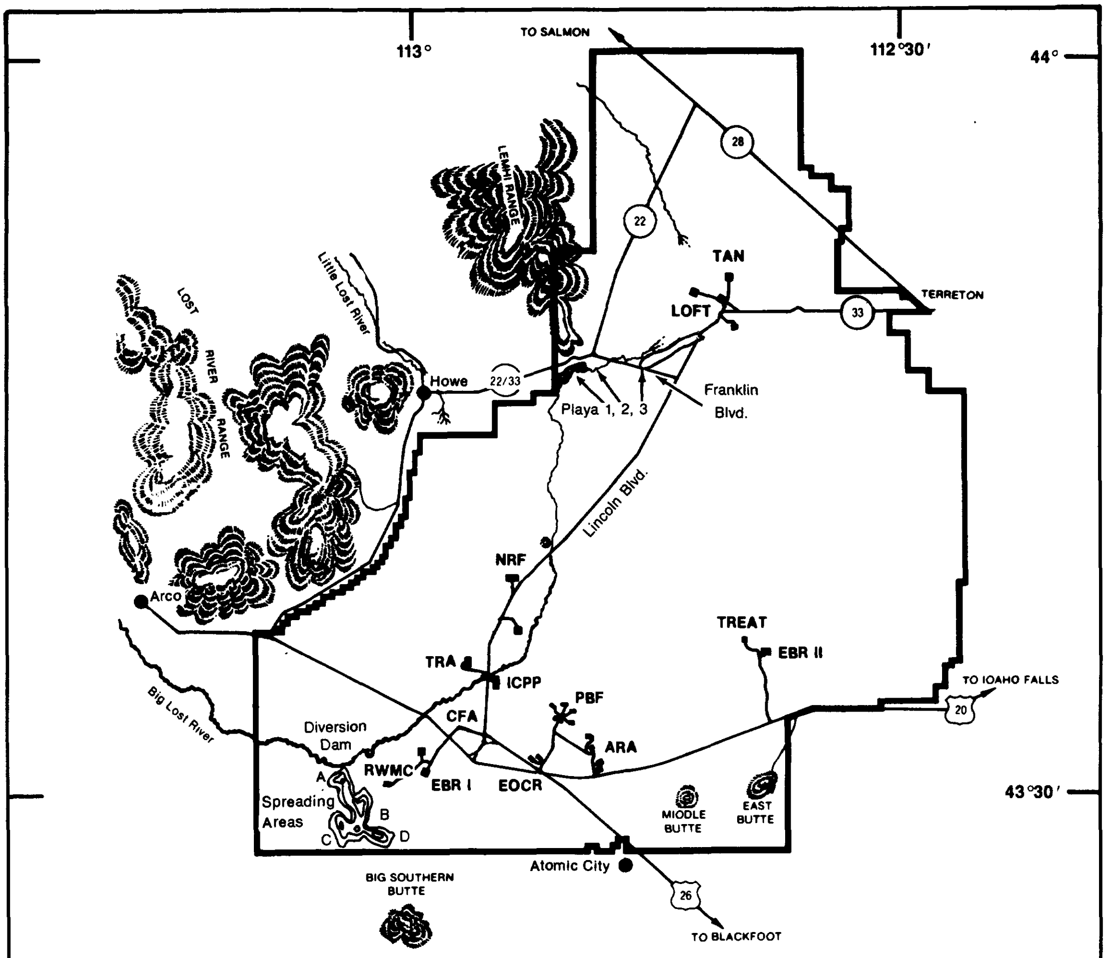
Purpose and Scope

In 1949, the U.S. Atomic Energy Commission--now the Department of Energy--requested the U.S. Geological Survey to investigate and describe the water resources of the INEL and adjacent areas. Information was collected that depicted hydrogeologic conditions prior to reactor operations. Current investigations serve to determine changes resulting from activities at the various facilities (fig. 2) at the INEL, and also to determine natural changes in the hydrology.

This report presents an analysis of the water-level and water-quality data collected by the U.S. Geological Survey during 1982-85. The report describes the distribution of selected radioactive and chemical wastes disposed at the INEL and their concentrations in ground water contained in the Snake River Plain aquifer and perched ground-water zones and updates information summarizing the influences of waste disposal during 1979-81 presented by Lewis and Jensen (1985). Reports on previous investigations describing the geology and hydrology of the area are listed in the references and may be obtained from the INEL library or from the office of the U.S. Geological Survey at the CFA (Central Facilities Area).

Ground-Water Monitoring Networks

Two ground-water monitoring networks are operated at the INEL: a water-level network and a water-quality network. Data collected from these networks are on file at the Geological Survey's INEL project office. The water-level network was designed to determine the changes in hydraulic gradient that influence the rate and direction of ground-water and radionuclide movement, identify sources of recharge to the aquifer, and measure the areal extent of the effects of recharge. Water levels were measured in both the Snake River Plain aquifer and perched ground-water zones. To document water-level fluctuations in the aquifer, 7 continuous



Name of Installation	Abbreviation
Auxiliary Reactor Area	ARA
Central Facilities Area	CFA
Experimental Breeder Reactor No. 1	EBR I
Experimental Breeder Reactor No. 2	EBR II
Experimental Organic Cooled Reactor	EOCR
Idaho Chemical Processing Plant	ICPP
Loss of Fluid Test Facility	LOFT
Naval Reactors Facility	NRF
Power Burst Facility	PBF
Radioactive Waste Management Complex	RWMC
Test Area North	TAN
Test Reactors Area	TRA
Transient Reactor Test Facility	TREAT

Figure 2.--Location of selected INEL facilities.

water-level recorders were operated during 1982-85; water levels were measured monthly in 56 wells, quarterly in 43 wells, and annually in 25 wells. For the perched ground-water zones, 2 continuous water-level recorders were operated during 1982-85, water levels were measured monthly in 39 wells, quarterly in 10 wells, and annually in 107 wells. A total of 5,500 water-level measurements were made, for an average of 1,375 measurements per year. The locations of observation wells and the frequencies of water-level measurements are shown on figures 3 and 4.

The chemical and radiochemical character of ground water at the INEL was determined from analyses of water samples collected as part of a comprehensive sampling program. The type, frequency, and depth of sampling generally depended on the information needed in a specific area. The program included analyses for tritium, strontium-90, cobalt-60, chromium-51, cesium-137, plutonium-238, plutonium-239, -240 (undivided), americium-241, total chromium, specific conductance, sulfate, chloride, nitrate, and 28 other chemical constituents or properties.

Water samples were collected at the INEL and adjacent areas to define the chemical character of the ground water entering and leaving the INEL. In addition, nearby surface-water sites were sampled to document the chemical quality of water that recharges the ground-water system. Numerous samples were collected near areas of detailed study, such as the TRA (Test Reactor Area) and the ICPP (Idaho Chemical Processing Plant), to identify the contaminant concentrations and to define the pattern of waste migration in the Snake River Plain aquifer and perched ground-water zones.

The locations of wells and surface water sites, and the frequency of sampling on or near the INEL are shown in figures 5 and 6. Water samples near the ICPP and TRA were analyzed for tritium on a quarterly or semi-annual basis. Water samples for the determination of tritium concentration and specific conductance were obtained from three wells in the northern part of the INEL and upgradient from INEL facilities. A total of 9,142 chemical and radiochemical analyses were made on 1,236 water samples collected during 1982-85. A total of 195 water samples were collected from production wells, 975 from observation wells, and 66 from streams on or near the INEL.

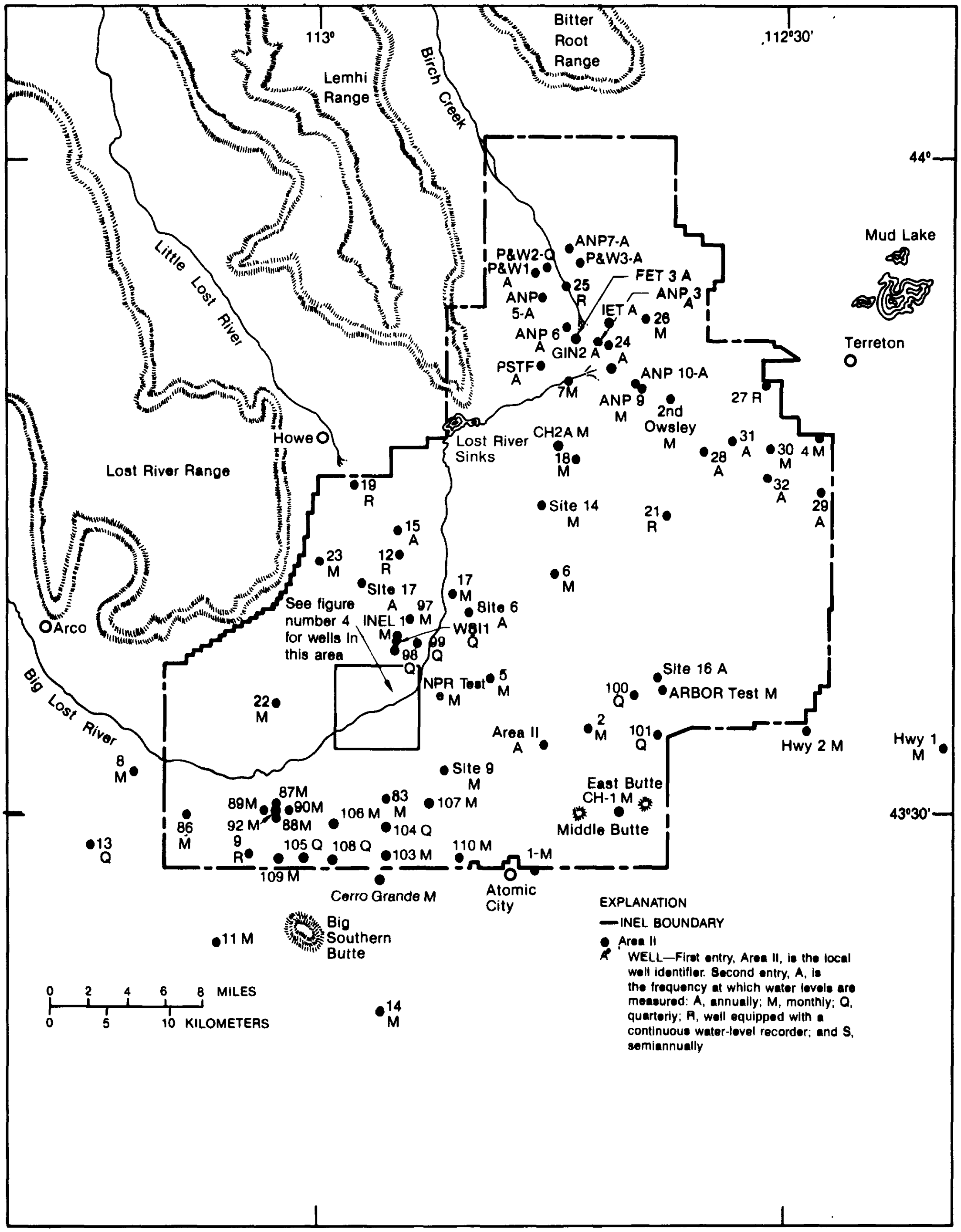


Figure 3.--Locations of wells and frequencies of water-level measurements at the INEL and vicinity.

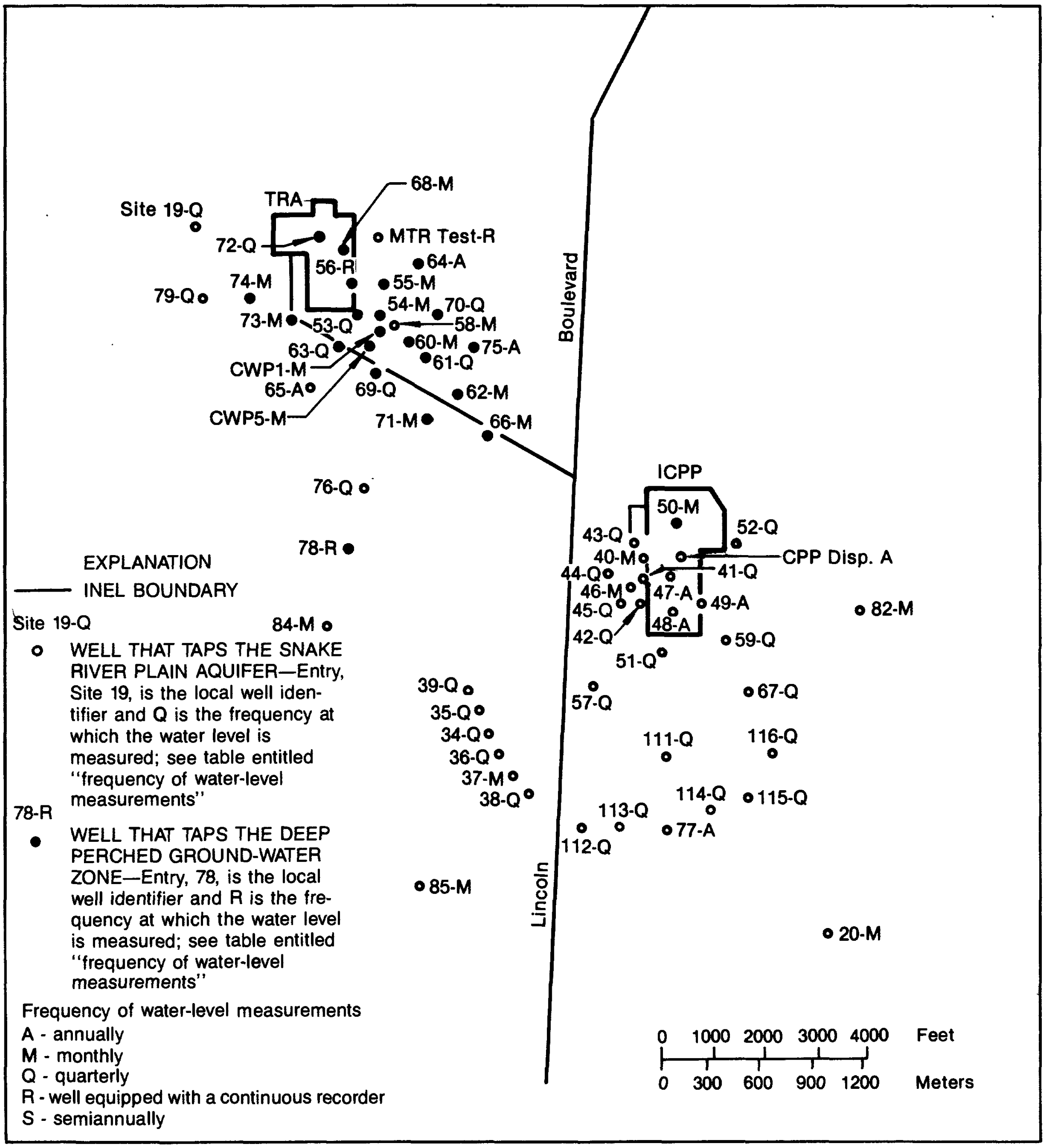


Figure 4.--Locations of wells and frequencies of water-level measurements in the TRA-ICPP area.

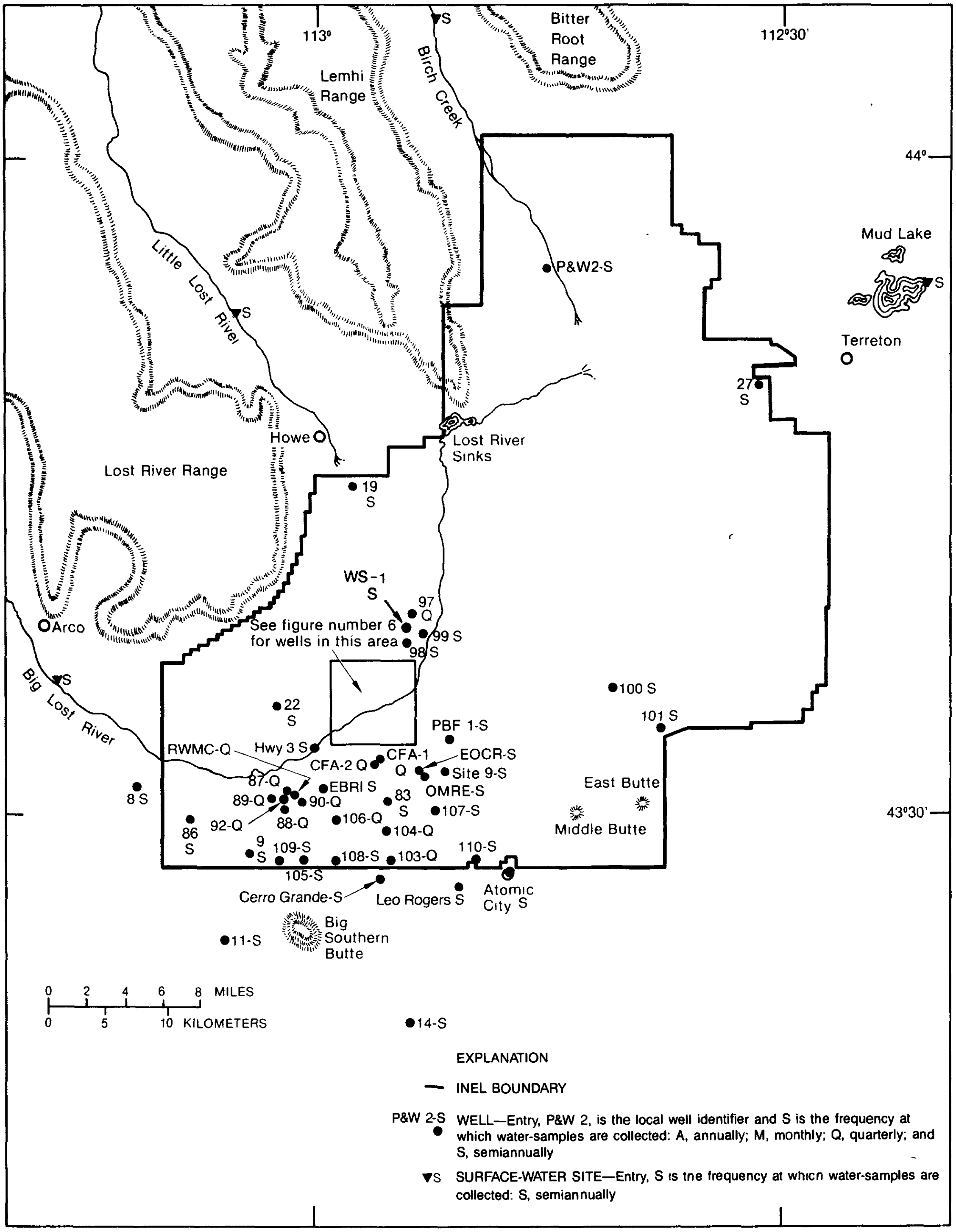


Figure 5.--Locations of wells and frequencies of water-sample collections at the INEL.

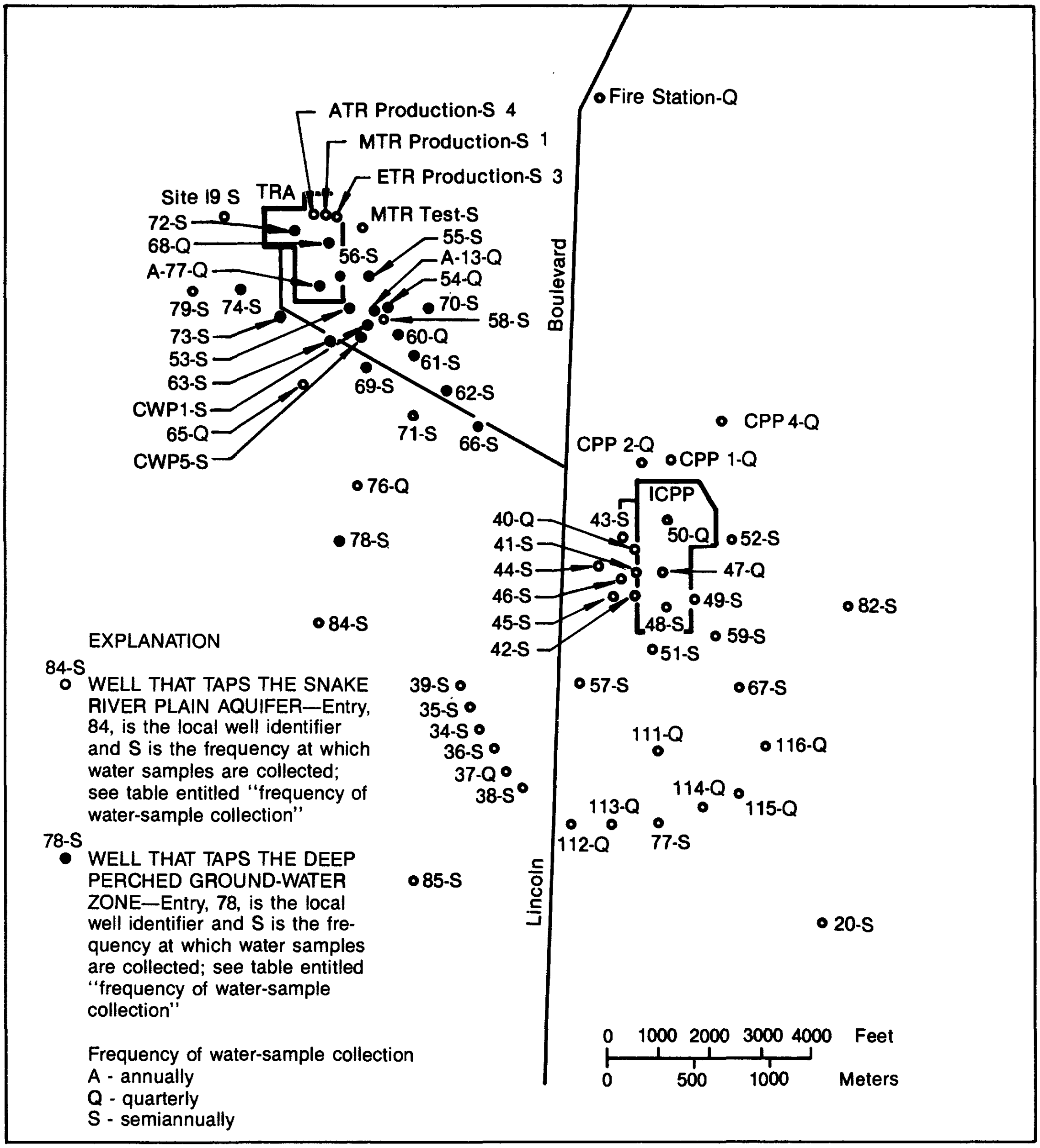


Figure 6.--Locations of wells and frequencies of water-sample collections in the TRA-ICPP area.

Surface-water samples were collected from the Big Lost River near Arco, the Big Lost River at the INEL Flood Control Diversion, the Big Lost River near the ICPP, Birch Creek near Blue Dome, the Little Lost River near Howe, and Mud Lake near Terreton.

Acknowledgments

Technical assistance was obtained from the following Department of Energy personnel: M.M. Williamson, Director, Radiological and Environmental Sciences Laboratory; the staff of the Analytical Chemistry Branch, L.Z. Bodnar, Chief; and E.W. Chew, Chief, Environmental Sciences Branch.

REGIONAL HYDROLOGY

The eastern Snake River Plain is underlain by the Snake River Plain aquifer, a vast ground-water reservoir that may contain more than 1 billion acre-ft of water (Barraclough and others, 1981). The flow of ground water in the aquifer is chiefly to the south-southwest (fig. 1) at velocities of 5 to 20 ft/d (Robertson and others, 1974, p. 13). The transmissivity of the aquifer generally ranges from 134,000 to 13,400,000 ft^2/day (Robertson and others, 1974, p. 12).

Basaltic lava flows and interbedded sedimentary deposits are the main rock units that make up the aquifer. Water is contained in and moves through intercrystalline and intergranular pores, fractures, cavities, interstitial voids, interflow zones, and lava tubes. Openings in the rock units and their degree of interconnection complicate the movement of ground-water in the aquifer.

Ground-water inflow to the aquifer at the INEL consists mainly of underflow from the northeastern part of the plain and from drainages on the west and north. Most of the ground water is recharged in the uplands to the northeast, moves southwestward through the aquifer, and is discharged to springs along the Snake River near Hagerman (fig. 1). Lesser amounts of water are derived from local precipitation on the plain. Part of the precipitation evaporates, but part infiltrates the ground surface and percolates downward to the aquifer. At the INEL, significant recharge is derived from intermittent flows in the Big Lost River.

Surface Water

Streams draining the mountains and valleys to the west and north of the INEL (fig. 2) are a source of irrigation water in agricultural areas adjacent to the INEL. Snowmelt and rainfall contribute to surface water, especially in the spring. The Big Lost River is an important source of ground-water recharge at the INEL. The Big Lost River flows southeastward in its valley past Arco, onto the Snake River Plain, and then turns northeastward through the INEL to its termination in three playas (fig. 2). The river loses water by infiltration through the channel bottom as it flows onto the plain. As flow approaches the playas, the channel branches into many distributaries, and the flow spreads over several flooding and ponding areas (Barraclough and others, 1967a). Recharge to the Snake River Plain aquifer from flow in the river during wet years is significant. During dry periods, streamflow does not reach the INEL because of upstream diversions for irrigation.

Mackay Dam, 30 mi upstream from Arco, and the flood-control diversion dam in the southwestern part of the INEL (fig. 2) affect flow in the Big Lost River. The flood-control diversion dam was constructed in 1958 to reduce the threat of flooding at INEL facilities near the Big Lost River. The diversion dam diverts flow from the river channel into spreading areas A, B, C, and D (fig. 2). During winter months, nearly all flow is diverted to avoid accumulation of ice in the main channel, thus reducing the possibility of flooding at INEL facilities.

From 1965 to 1985, the annual flows of the Big Lost River below Mackay Reservoir generally were higher than those prior to 1965 (fig. 7). In order of decreasing magnitude, 1984, 1965, 1969, 1983, 1967, and 1982 were the six highest annual flows of record. Three of the six highest annual

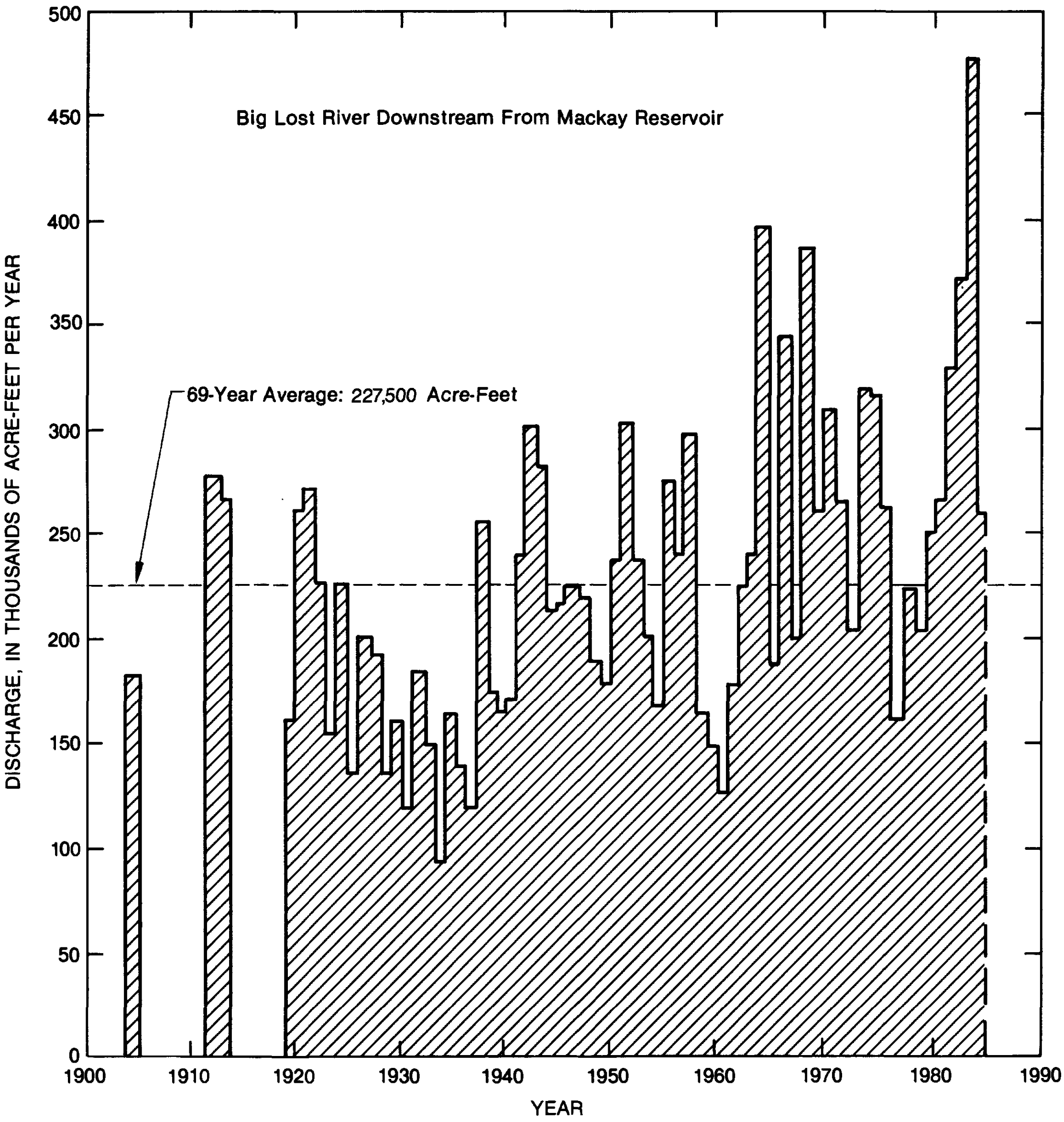


Figure 7.--Discharge of the Big Lost River below Mackay Reservoir.

flows occurred in three consecutive years--1982, 1983, and 1984--with 1984 being the highest since records began. Annual flows from 1982 to 1985 were 328,000, 372,000, 476,000, and 262,000 acre-ft, respectively, and exceeded the 69-year average of 227,500 acre-ft.

Flows in the Big Lost River were continuous at the INEL diversion dam from April 1982 through December of 1985. Flows in the main channel, below the diversion dam, and the total flow at the INEL diversion are shown in figure 8. For 1982 and 1983, 73,000 and 130,000 acre-ft, respectively, of water flowed down the main channel. By September 1983, the high water level in playa 3 (fig. 2) threatened to inundate Lincoln and Franklin Boulevards. On September 7, 1983, flow in the main channel below the diversion dam was reduced to about 120 ft^3/s. The flow was maintained at 120 ft^3/s or less for the remainder of 1983 and for 1984.

Ground Water

The altitude of the water table for the Snake River Plain aquifer and the general direction of ground-water movement at the INEL for July 1985 are shown in figure 9. Altitude of the water levels in wells ranged from 4,585 ft above sea level in the northern part of the INEL to 4,429 ft near the southern boundary; the depth to water ranged from slightly less than 200 ft below land surface in the northern part of the INEL to more than 900 ft in the southern part. The general direction of ground-water movement was to the south and southwest and the average gradient of the water table was about 4 ft/mi. In the northern part of the INEL, near Birch Creek, the water-table gradient was southward at less than 1 ft/mi.

The altitude of the water table for the aquifer varies in response to changes in recharge. From 1982 to 1985, recharge was considerably greater than in the previous three years mainly because of prolonged high flows in the Big Lost River. The increase in the altitude of the water table from July 1981 to July 1985 is shown in figure 10. In the northern part of the INEL, where recharge from Birch Creek and the Mud Lake area previously has been characterized by long-term consistency; the water table rose about

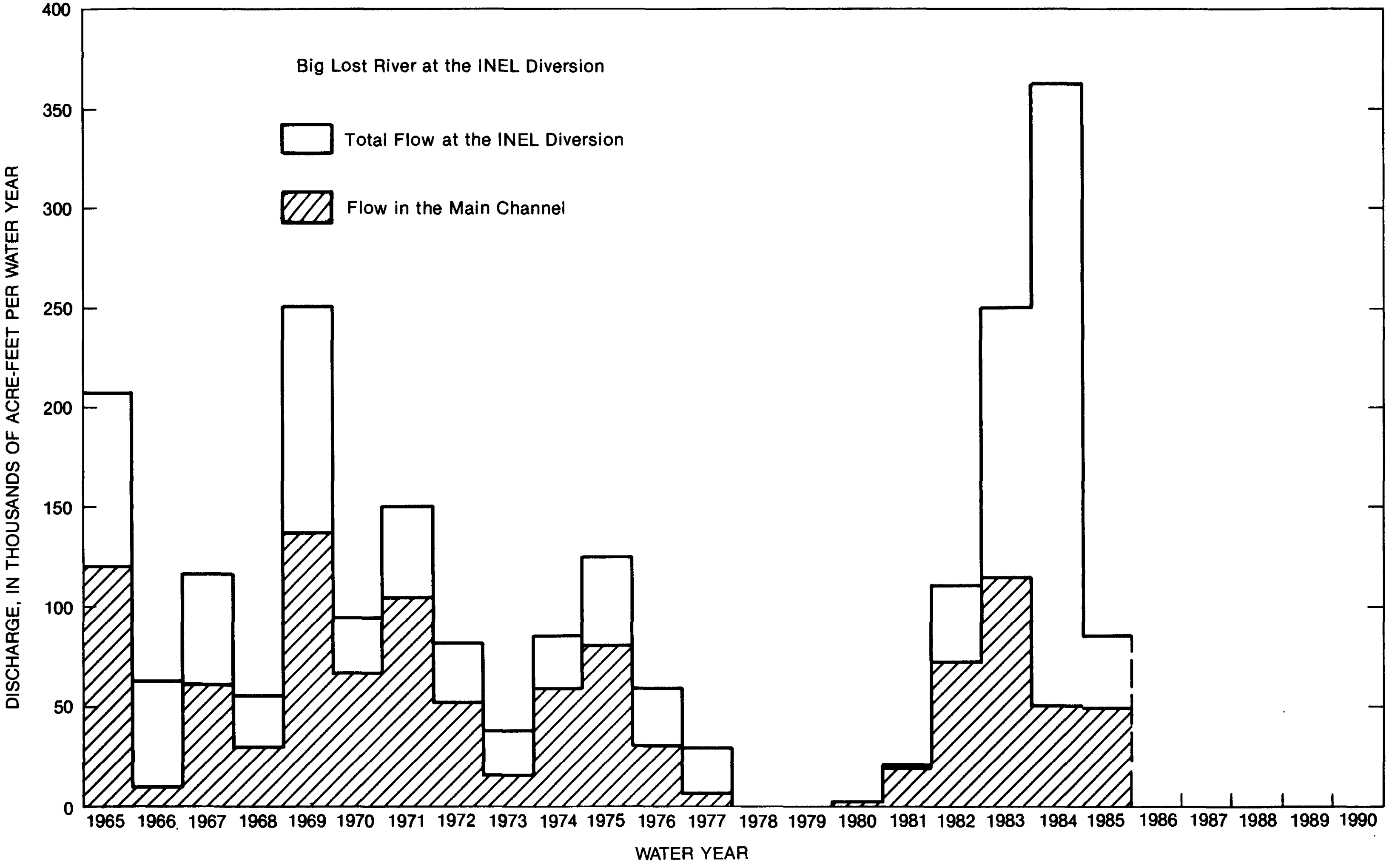


Figure 8.--Discharge of the Big Lost River at the INEL diversion.

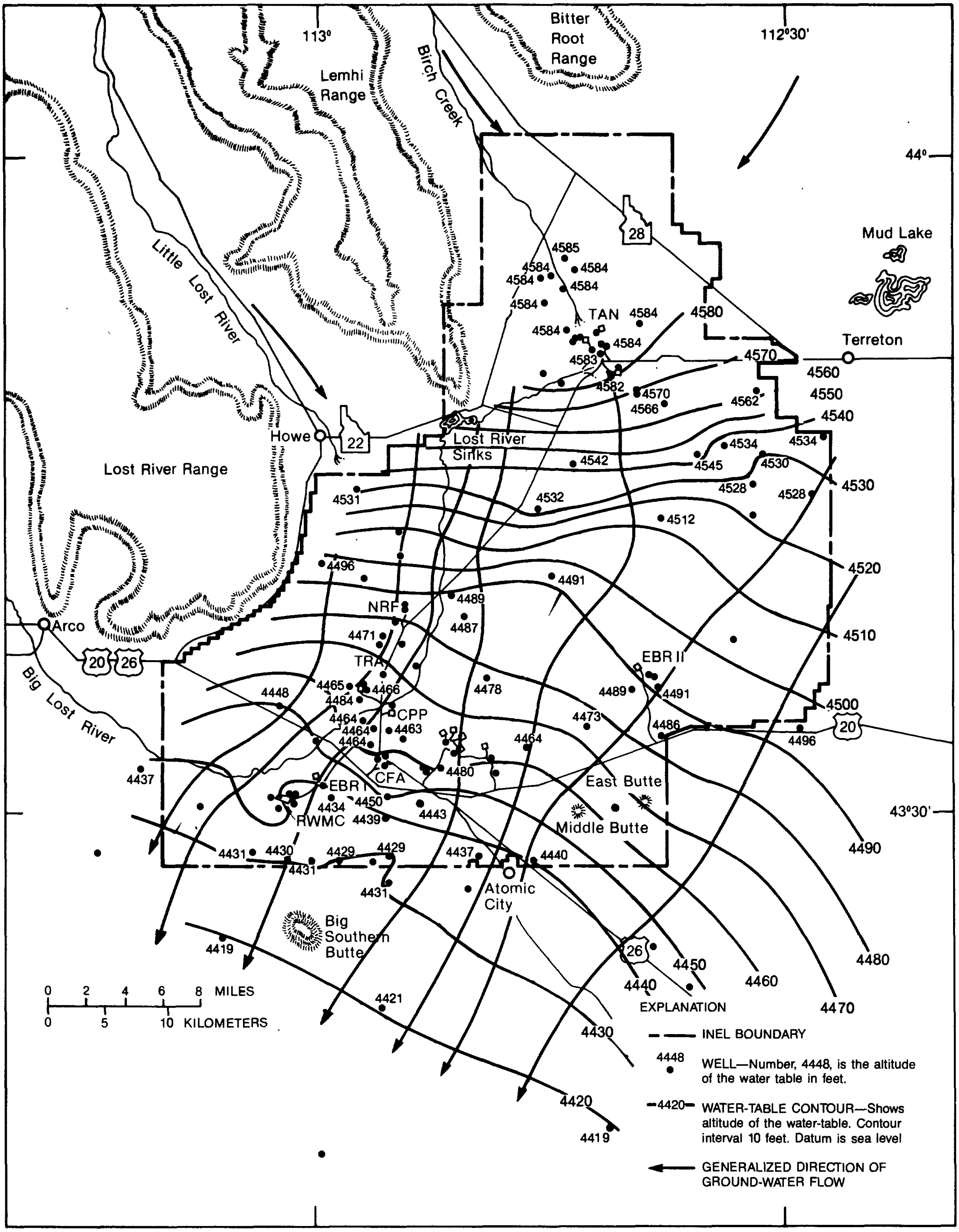


Figure 9.--Altitude of the water table for the Snake River Plain aquifer and general direction of ground-water movement, July 1985.

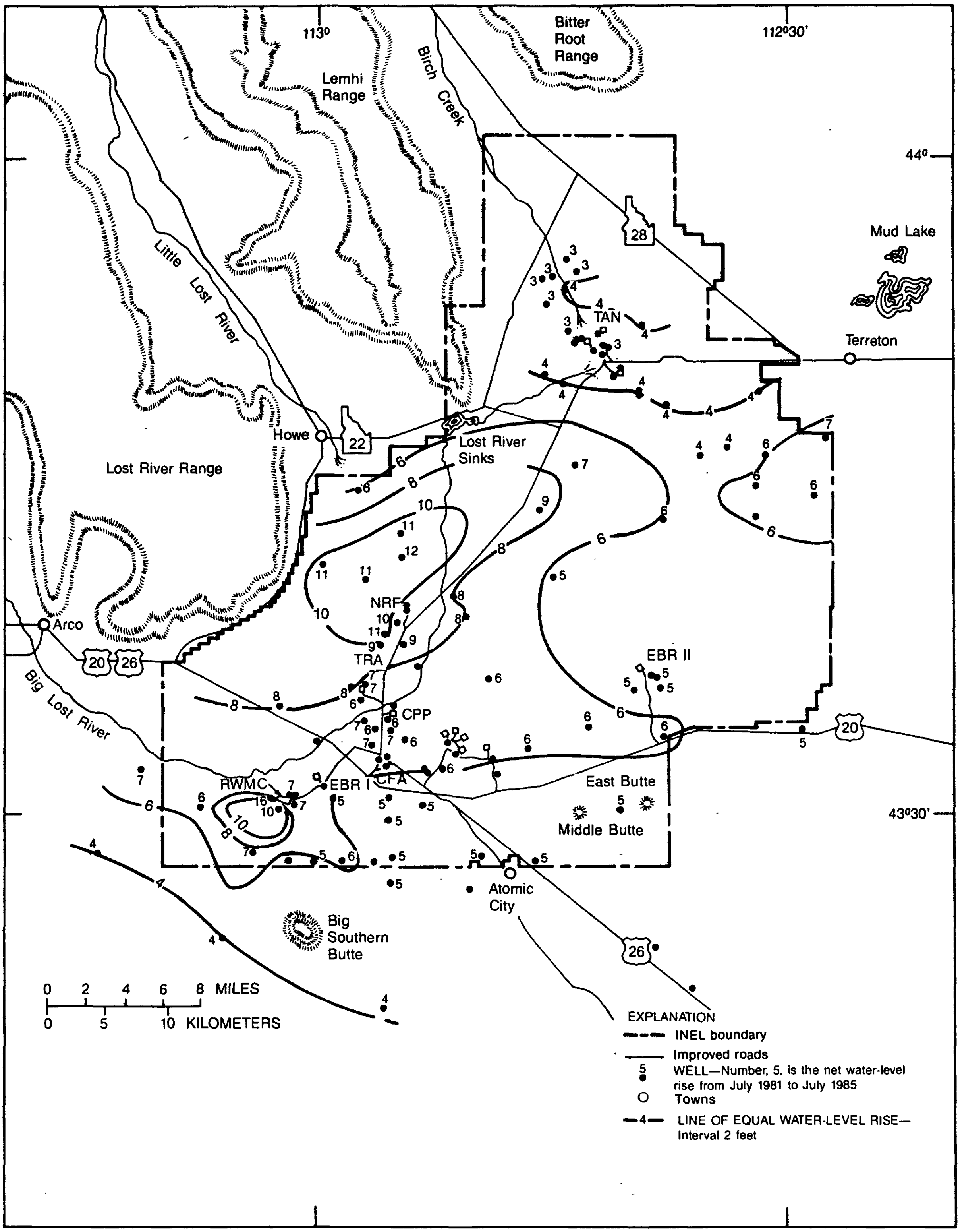


Figure 10.-Generalized net rise of the water table for the Snake River Plain aquifer, INEL, July 1981 to July 1985.

3 ft. Near the Big Lost River the water table rose from 6 to 12 ft. Near the RWMC (Radioactive Waste Management Complex), the water table rose as much as 16 ft in response to recharge from surface water diverted to the spreading areas (see fig. 2 for locations).

The water levels in some wells have risen as much as 6 ft or more in a few months following high flows in the Big Lost River. Water-level changes in four wells tapping the aquifer in the west-central part of the INEL illustrate the influence of recharge from the Big Lost River (fig. 11). In wells 12, 17, and 23 (see fig. 3 for well locations), the greatest depth to water on record occurred in 1964 following 4 years of below average discharge in the river and the smallest depth to water occurred in 1972 following the wet period from 1965 to 1971. The water level in well 12 rose 21.5 ft from 1964 to 1972. The water level in well 20 rose about 6 ft from 1964 to 1972 and had declined by nearly 8 ft by the end of 1980 (fig. 11). The comparatively small water-level change in well 20 may indicate that it is not as greatly influenced by recharge from the Big Lost River and is more representative of the changes in water level for the Snake River Plain aquifer on a more regional basis (Lewis and Goldstein, 1982).

Because of greater than normal flows in the Big Lost River, the water levels in wells in the west-central part of the INEL rose from 1981 to 1985. For example, the water level in well 12 rose nearly 14 ft (fig. 11) between 1981 and 1985 and water levels in wells 17, 20, and 23, rose 10, 7 and 11 ft, respectively. From 1981 to 1985, about two-thirds of the flow that entered the INEL was diverted at the INEL diversion dam (see figure 2 for location). Water levels in wells in the west-central part of the INEL would have risen more if water had not been diverted from the river.

The Snake River Plain aquifer is the source of all water used at the INEL. Of 30 production wells, 27 are generally in use. The combined pumpage from these wells was about 2.1 billion gal/year for 1982-85. This averages about 5.7 million gal/day or 6,414 acre-ft/year. These withdrawal rates were slightly lower than those for 1979-81 (Lewis and Jensen, 1985).

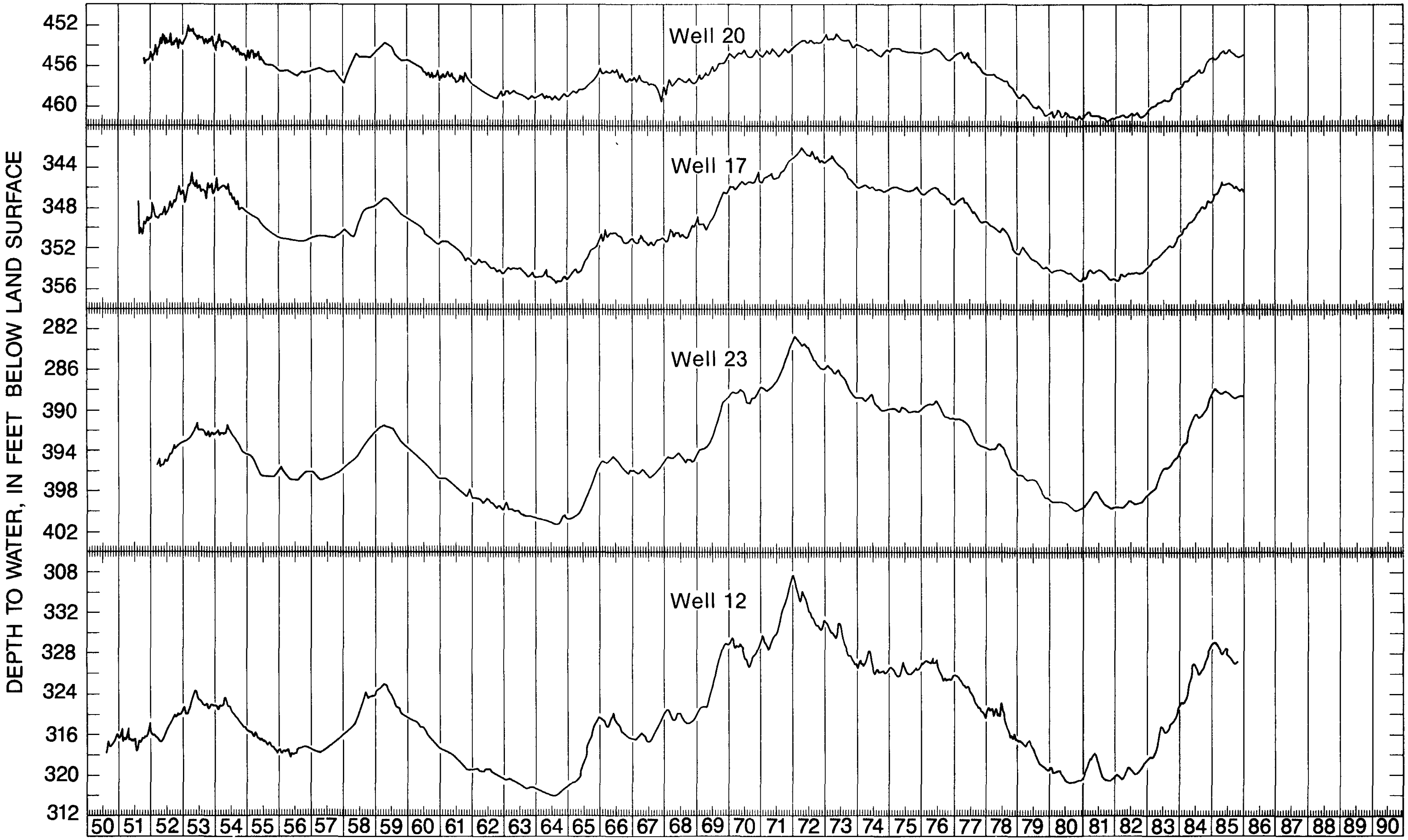


Figure 11.--Hydrographs of water levels for four wells in the southwestern part of the INEL.

Of the water pumped from the aquifer at the INEL, most was not consumed. Some wastewater was discharged directly back to the Snake River Plain aquifer through a deep disposal well and some was discharged to ponds. Both methods of waste disposal contribute recharge to the aquifer. According to available pumpage and disposal records, nearly 63 percent of the water pumped was disposed to the wells and ponds. Pumping had little effect on ground-water levels in the aquifer because the amount pumped was small when compared to the total volume of ground water in storage and the amount of water that recharges the aquifer.

WASTE DISPOSAL SITES

Liquid low-level radioactive and chemical wastes have been discharged to the subsurface at the TRA through ponds; chemical wastes have been discharged to a deep disposal well. The use of the deep disposal well at the TRA was discontinued in March 1982. Wastewater at the ICPP was discharged to a deep disposal well from 1953 to February 1984. Since then, unlined seepage ponds have been the main mechanism for wastewater disposal at the ICPP, although the disposal well was available for use in emergency situations from 1984 to 1986. The disposal well has not been used since 1986. The NRF (Naval Reactors Facility) (fig. 2) has used unlined seepage ponds and a waste ditch since 1953.

Test Reactors Area

During 1982-85, the TRA used waste disposal ponds (fig. 12) to dispose of about 276 million gal/year of wastewater. This is less than the nearly 354 million gal/year disposed of from 1979 to 1981 (Lewis and Jensen, 1985). Low-level radioactive wastes were discharged to two disposal ponds. Chemical wastes were discharged to another disposal pond and sanitary wastes to two disposal ponds (fig. 12). Part of the wastewater percolated downward to the Snake River Plain aquifer, 450 ft below the land surface. Cooling-tower blowdown wastes were discharged to the Snake River Plain aquifer through a deep disposal well until March 1982 when use of the disposal well

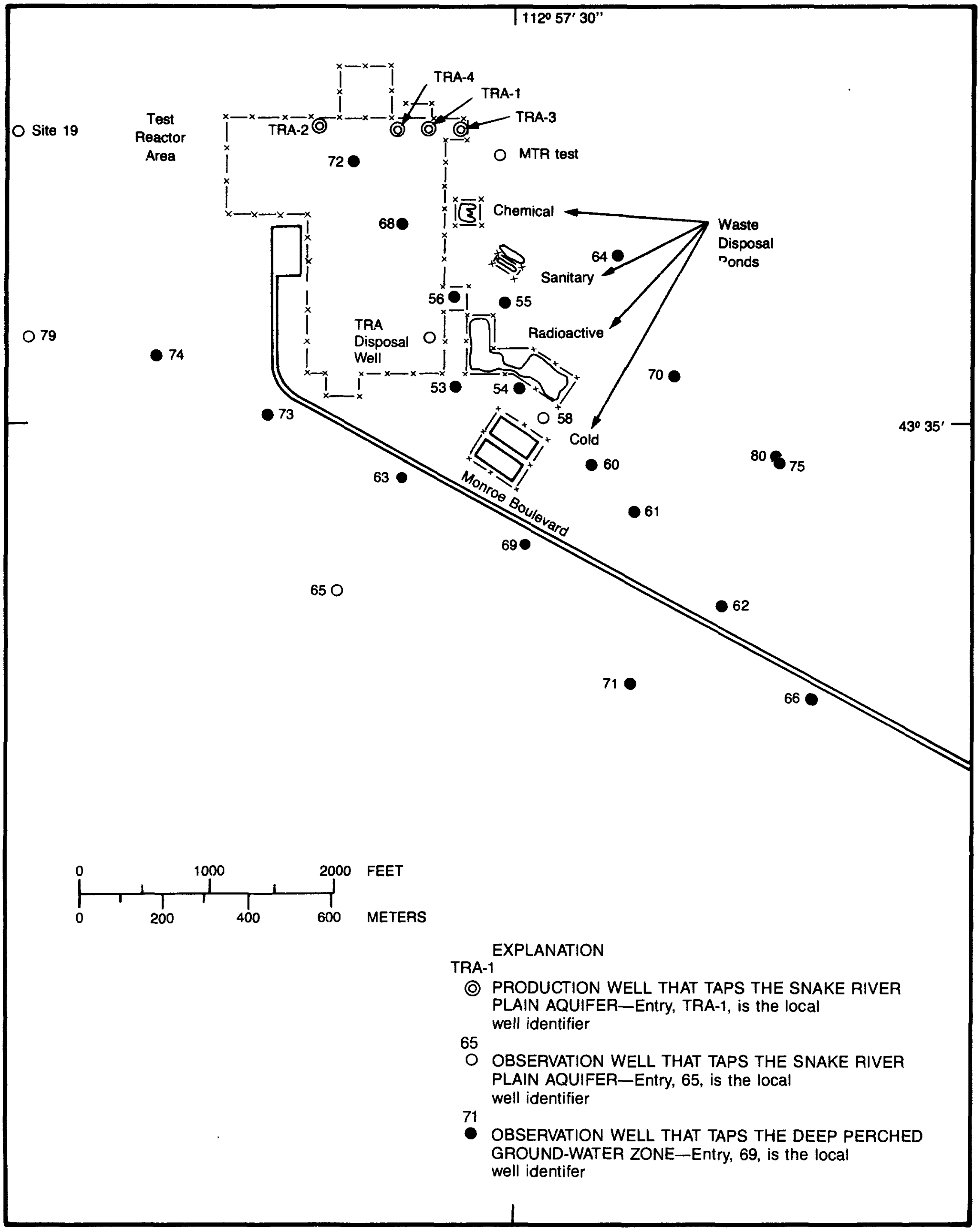


Figure 12.--Locations of observation wells, production wells, and waste-disposal ponds at the TRA.

was discontinued and replaced by two cold-waste disposal ponds. Either pond may be used and disposal is routinely switched from one pond to the other on a yearly basis. The TRA disposal well is currently used as an observation well.

Radioactive-waste disposal ponds.--The volume of wastewater discharged to the radioactive-waste disposal ponds and the disposal well or the cold-waste disposal ponds from 1959 to 1985 is shown in figure 13. The average annual discharge to the TRA radioactive-waste disposal ponds was about 189 million gal for 1959-85. Discharge to the radioactive-waste disposal ponds declined from 1979 to 1985. The discharge was 73 million gal in 1979, 55 million gal in 1981, and 20.5 million gal in 1985. The mean discharge for 1982-85 averaged slightly less than 28.6 million gal/year and was below the long-term annual average of 189 million gal.

In 1976, the Department of Energy contractor at the TRA began a three-phased program to reduce the amount of radioactivity in liquid waste. The first phase ran from 1976 to 1980. At the end of 1985, they were in the final stages of the second phase (R.N. Beatty, EG&G Idaho, Inc., oral commun., 1986). Water discharged to the radioactive-waste disposal ponds from 1974 to 1979 contained an average of about 2,250 Ci/year of activation and fission products. From 1980 to 1985, the average annual discharge of activation and fission products was reduced to about 288 Ci. Prior to 1980, about 70 percent of these products had a half-life of several weeks or less (Lewis and Jensen, 1985). The average amount of tritium discharged to the ponds from 1977 to 1981 was about 140 Ci/year (fig. 13). In 1982, 515 Ci of tritium were discharged; from 1983 to 1985 an average of 208 Ci/year of tritium were discharged. Between 1974 and 1979, tritium comprised about 10 percent of the total liquid radioactive waste. In 1980, tritium was about 50 percent and from 1981 to 1985 it was about 90 percent of the total amount of radioactivity discharged to the disposal ponds. From 1982 to 1985, 1,140 Ci of tritium were discharged to the radioactive-waste disposal ponds. The average disposal rate was 285 Ci/year which is a 98 percent increase over the 1979-81 disposal rate of 144 Ci/year (Lewis and Jensen, 1985).

Chemical-waste disposal pond.--A pond has been used at the TRA since

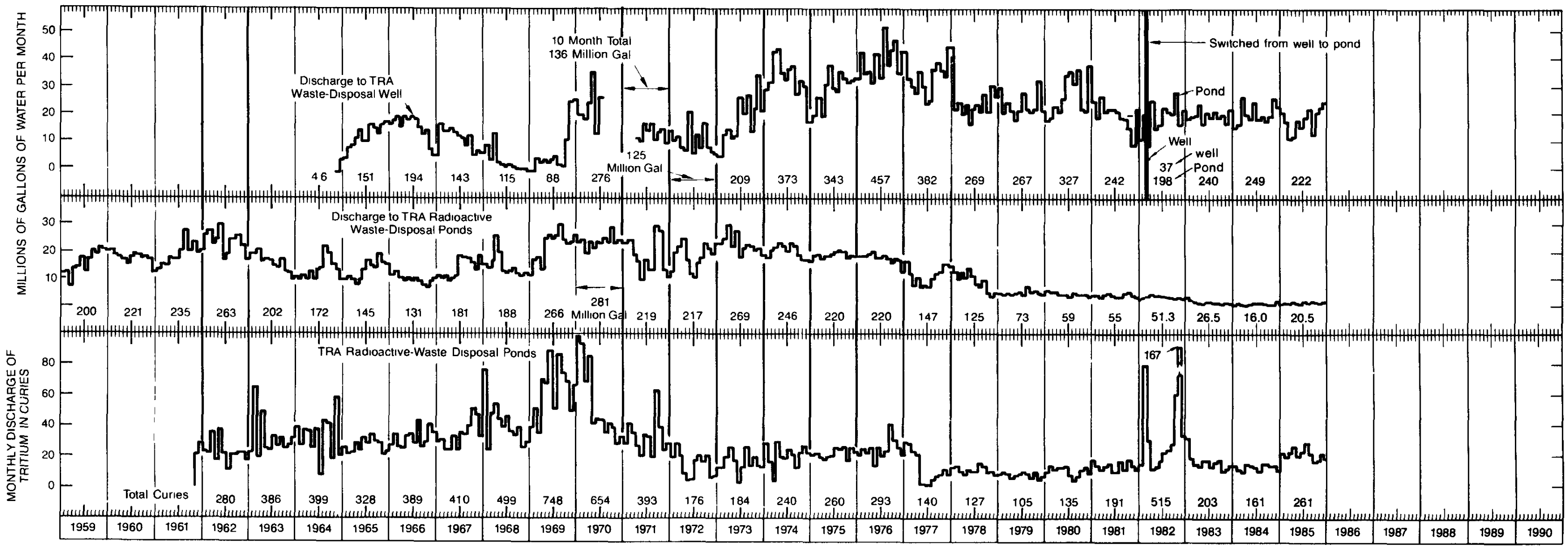


Figure 13.--Quantities of wastewater discharged to the disposal well and the radioactive- and cold-waste disposal ponds, and tritium discharged to the radioactive-waste disposal ponds at the TRA.

1962 to dispose of nonradioactive chemical wastes from ion-exchange system regeneration. The average disposal during 1982-85 was 6.82 million gal/year, a rate about half that of the preceding 3 years and much lower than the previous 16-year average of 39.2 million gal/year. Sulfate and sodium were the major chemical constituents in the wastewater and were disposed of in annual amounts that averaged 527,000 and 84,000 lbs, respectively, for 1982-85. The wastewater contained about 9,200 mg/L of sulfate and 1,500 mg/L of sodium.

Cold-waste disposal ponds.--A 1,275-ft deep disposal well was used at the TRA from 1964 to March 1982 to dispose of about 250 million gal/year of nonradioactive wastewater (fig. 13). The well discharged directly into the Snake River Plain aquifer; the static water level was generally about 450 ft below the land surface. Since March 1982, two ponds each about 200 by 400 ft in size (fig. 12) have been used to dispose of the wastewater. Most of the wastewater is from cooling-tower blowdown, and contains a yearly average of about 510,000 lbs of sulfate and 50,000 lbs of other chemicals. For several years, hexavalent chromium was used as a corrosion inhibitor in the cooling tower and was discharged to the well (Barraclough and others, 1981). The average concentration of hexavalent chromium in the cooling-tower blowdown was about 2.2 mg/L (Barraclough and Jensen, 1976). Hexavalent chromium was replaced by a polyphosphate beginning in October 1972.

Yearly and monthly discharges to the TRA disposal well and cold-waste disposal ponds for 1964-85, except for a brief period in 1970 and 1971, are shown in figure 13. The annual discharge to the cold-waste disposal ponds for 1982-85 ranged from 198 to 249 million gal and averaged 227 million gal/year.

Idaho Chemical Processing Plant

From 1953 to February 1984, the ICPP discharged low-level radioactive and chemical waste directly to the Snake River Plain aquifer through a 600-ft deep disposal well. The average yearly discharge to the well was about 363 million gal and averaged about 30 million gal/month. A disposal pond was completed on February 9, 1984 and since then nearly all of the low-level radioactive waste has been discharged to the pond; a second pond was constructed and put into use on October 17, 1985. The monthly and yearly quantities of wastewater discharged to the ICPP disposal well for 1962-84, and the ponds in 1984-85 are shown in figure 14; for discharge records prior to 1962, see Robertson and others (1974, fig. 49). The largest annual discharge, more than 553 million gal, occurred in 1984.

The amount of radioactivity discharged from year to year varies depending on operations at the ICPP. For example, about 436 Ci were discharged in 1983 and about 12 Ci in 1984. From 1974 to 1985, an average of 287 Ci/year of radioactivity was in the 445 million gal/year of wastewater discharged to the well and ponds. The average concentration of radionuclides in the discharge water was about 170 pCi/mL. Nearly 99 percent of the radioactivity was from tritium. For 1982-85, 1,088 Ci of tritium were in wastewater discharged at the ICPP--an average of 272 Ci/year. The average discharge of wastewater to the ICPP ponds during 1982-85 was about 515 million gallons per year. An average of 0.06 Ci/year of strontium-90 were discharged during 1982-85. The remainder of the radioactivity in the wastewater was from small quantities of other radionuclides. Monthly discharges of tritium and strontium-90 are shown in figure 14.

Naval Reactors Facility

The NRF uses a 3-mi long ditch (fig. 28) to dispose of most wastewater, although ponds are used for sewage disposal. From 1982 to 1985, about 93 million gal/year of wastewater were disposed to the ditch. Most of the wastewater eventually percolates downward to the Snake River Plain aquifer, about 400 ft below land surface. The major chemical constituents in the wastewater were sulfate, chloride, and sodium. An average of 313,000 lbs of sulfate, 127,000 lbs of chloride, and 90,000 lbs of sodium were disposed of annually. The average sulfate concentration in the wastewater was 403 mg/L, the average chloride concentration was 163 mg/L and the average sodium concentration was 116 mg/L. From 1982 to 1985, small amounts of other

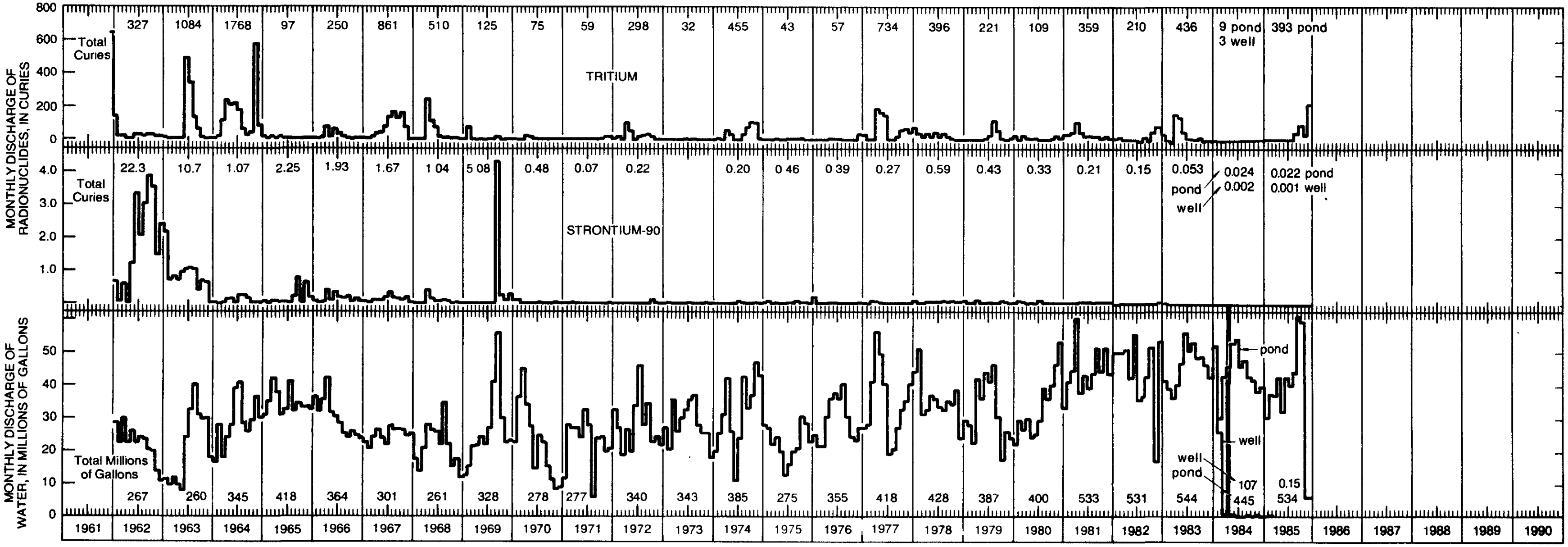


Figure 14.--Quantities of wastewater, tritium, and strontium-90 discharged to the disposal well and ponds at the ICPP.

chemicals made up the remainder of the waste ditch effluent. The quantities of sulfate, chloride, and sodium and the volume of wastewater discharged from 1982 to 1985 are shown in table 1.

Table 1.--Quantities of sulfate, chloride, and sodium disposed to the NRF waste ditch, 1982-85

	1982	1983	1984	1985
Sulfate (pounds)	344,000	203,000	463,000	244,000
Chloride (pounds)	128,000	82,000	204,000	93,000
Sodium (pounds)	106,000	50,000	148,000	56,000
Wastewater (gallons)	111,000,000	76,000,000	115,000,000	71,000,000

DISTRIBUTION OF WASTE

About 86 percent of the total wastewater discharged at the INEL since 1952 has been disposed of at the TRA, ICPP, and NRF facilities. As a result of waste-disposal practices at the TRA, perched ground-water zones have developed beneath the disposal ponds. Perched ground-water zones are unconfined and form when downward flow to the aquifer is impeded by silt and clay in the sedimentary units or by dense basalt flows. At the TRA and ICPP, the base of these perched ground-water zones is about 300 ft above the Snake River Plain aquifer. The perched ground-water zone has developed at the ICPP because of the construction and use of waste-disposal ponds since February 1984. A perched ground-water zone probably underlies the NRF waste ditch, but no wells have been drilled to document its existence.

Aqueous wastes disposed of at the TRA, ICPP, and NRF have been traced in the perched ground-water zones at the TRA and ICPP, and in the underlying Snake River Plain aquifer at the TRA, ICPP and NRF. The effects of waste disposal on the perched ground-water zone at the TRA and the Snake River Plain aquifer are discussed in the following sections.

Radiochemical and Chemical Constituents in Perched Ground-Water Zones Near the Test Reactors Area

Four perched ground-water zones have formed in rock units that underlie the TRA because of seepage from waste-disposal ponds (Barraclough and others, 1981). Three of the perched ground-water zones are in the surficial alluvium in the immediate vicinity of the disposal ponds. Zones of perched water have formed in the alluvium beneath the chemical-, radioactive-, and cold-waste disposal ponds (fig. 15).

Another much larger zone of perched water, covering at least a 1.3-mi^2 area, has formed in an interbedded sediment-basalt sequence (fig. 16). This deep saturated zone is perched by a basalt and sedimentary bed contact approximately 150 ft below land surface.

Water that seeps from the radioactive-, chemical-, and cold-waste disposal ponds percolates into the alluvium and is perched by fine-grained sediment near the base of the alluvium, about 50 ft below the land surface. The extent of ground water perched in the alluvium is about twice the area of the corresponding pond (fig. 15).

Water perched in the alluvium percolates downward into the underlying basaltic rocks until it reaches the base of a fine-grained sedimentary deposit that is interbedded with the basalt. This deep sedimentary deposit extends from about 100 to 150 ft below land surface. The unsaturated basaltic rocks and other sedimentary deposits that underlie this unit transmit water from the perched zone downward to the Snake River Plain aquifer. The deep perched ground-water zone is recharged by seepage from TRA waste-disposal ponds, percolation from lawn irrigation at the TRA, and infiltration of rainfall, snowmelt and flow in the Big Lost River which is approximately one mile south of the TRA. In October 1985, the altitude of water levels in wells that tap the deep perched ground-water zone ranged from 4,767 to 4,858 ft (fig. 17). The hydraulic gradient near the ponds was relatively flat when compared to the gradient southeast of the ponds. The depth to water in wells ranged from about 50 to 150 ft below land surface; by comparison the depth to water in the Snake River Plain aquifer was about

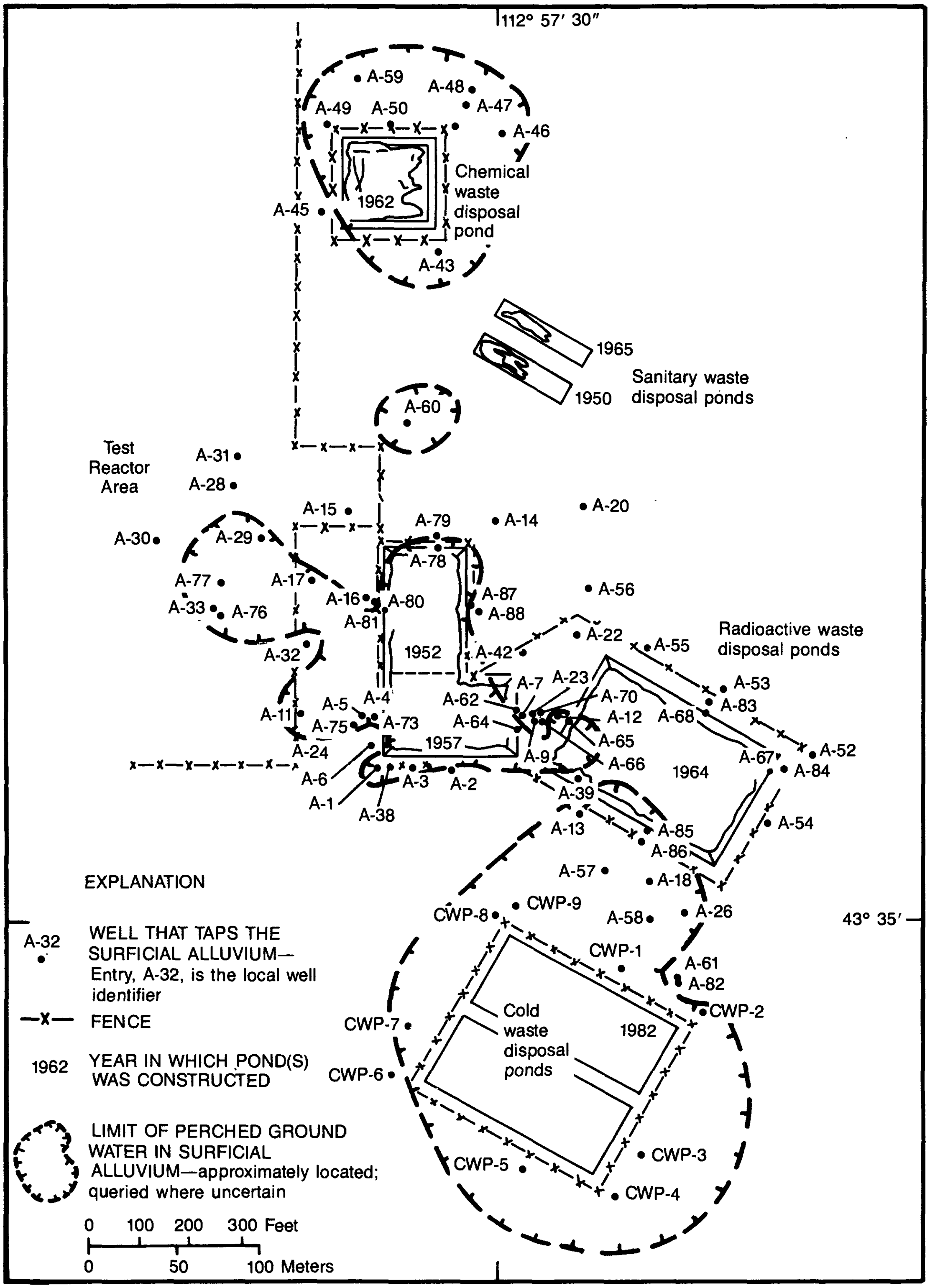


Figure 15.--Disposal ponds, observation wells, and the extent of the perched ground-water zones in the alluvium near the TRA, October 1985.

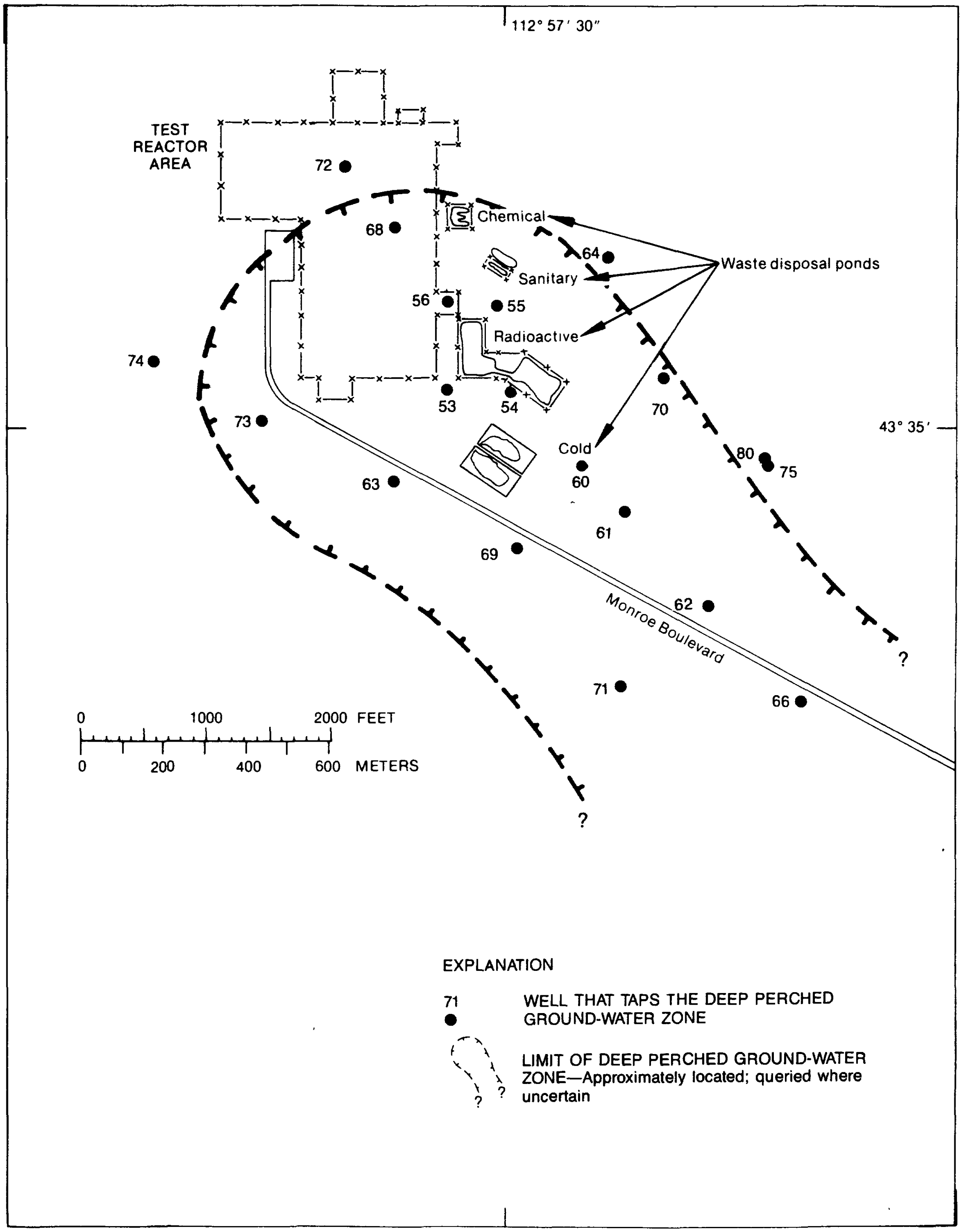


Figure 16.--Extent of the deep perched ground-water zone near the TRA, October 1985.

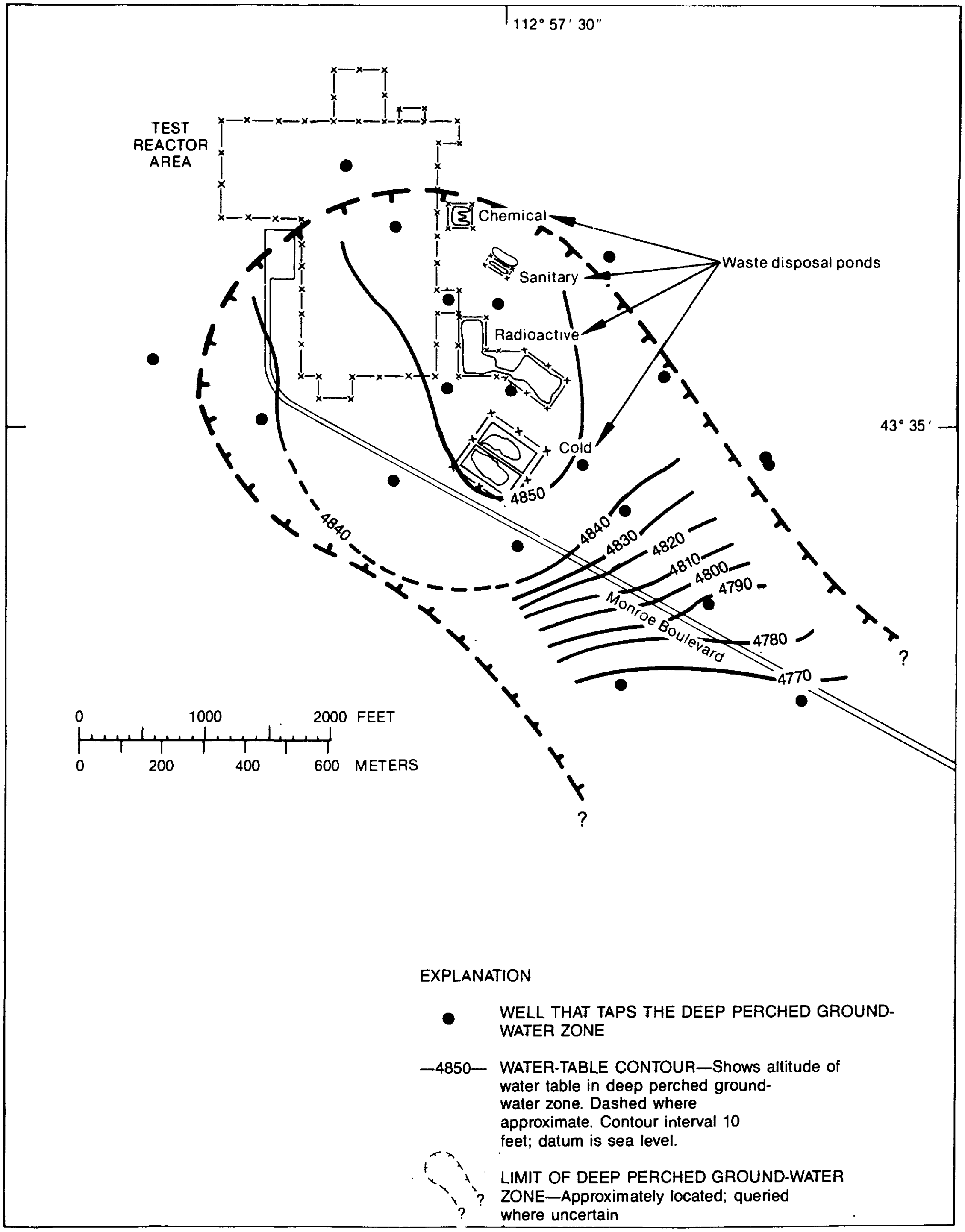


Figure 17.--Water-level contours for the deep perched ground-water zone near the TRA, October 1985.

450 ft below land surface.

The areal extent and thickness of the deep perched ground-water zone have increased significantly since October 1981. The areal extent of the perched zone in October 1981 is shown in figure 18. The increase in the areal extent and thickness of the deep perched ground-water zone is the result of the discharge of water to the cold-waste disposal ponds that was previously discharged to the TRA disposal well (fig. 13) and recharge from the comparatively large volume of flow in the Big Lost River (fig. 8).

Water in the perched ground-water zone contains several radionuclides and chemical waste products. The concentrations of selected constituents in the water are summarized in the following sections. Other constituents are either sorbed on materials that underlie the ponds, have short half-lives, or are not discharged in sufficient quantities to be detected.

Tritium.--About 11,100 Ci of tritium have been discharged to the radioactive-waste disposal ponds at the TRA from 1952 to 1985, an average of 337 Ci/year. The average discharge of tritium from 1982 to 1985 was 285 Ci/year. This was about 90 percent of the total radioactivity contained in liquid waste discharged at the TRA, and 48 percent of the total radioactivity in liquid waste disposed of at the INEL, for the 4-year period. Annual discharge of tritium to the radioactive-waste disposal ponds from 1961 to 1985 is shown in figure 13. Tritium concentrations in the deep perched ground-water zone for October 1985 are shown in figure 19. Tritium concentrations in the perched water were largest near the radioactive-waste disposal ponds.

Tritium concentrations in the perched ground-water zone increased from 1982 to 1985 because of an increase in the discharge concentration, especially in 1982 (fig. 13). The largest tritium concentration in October 1985 was 1,770±30 pCi/mL as compared to 757±3 pCi/mL for October 1981 (Lewis and Jensen, 1985). Tritium concentration increases in wastewater discharged to the radioactive-waste disposal ponds caused tritium concentrations in the perched water to increase in 1 to 3 months, indicating the rapid movement of the wastewater from the disposal ponds to the perched zone.

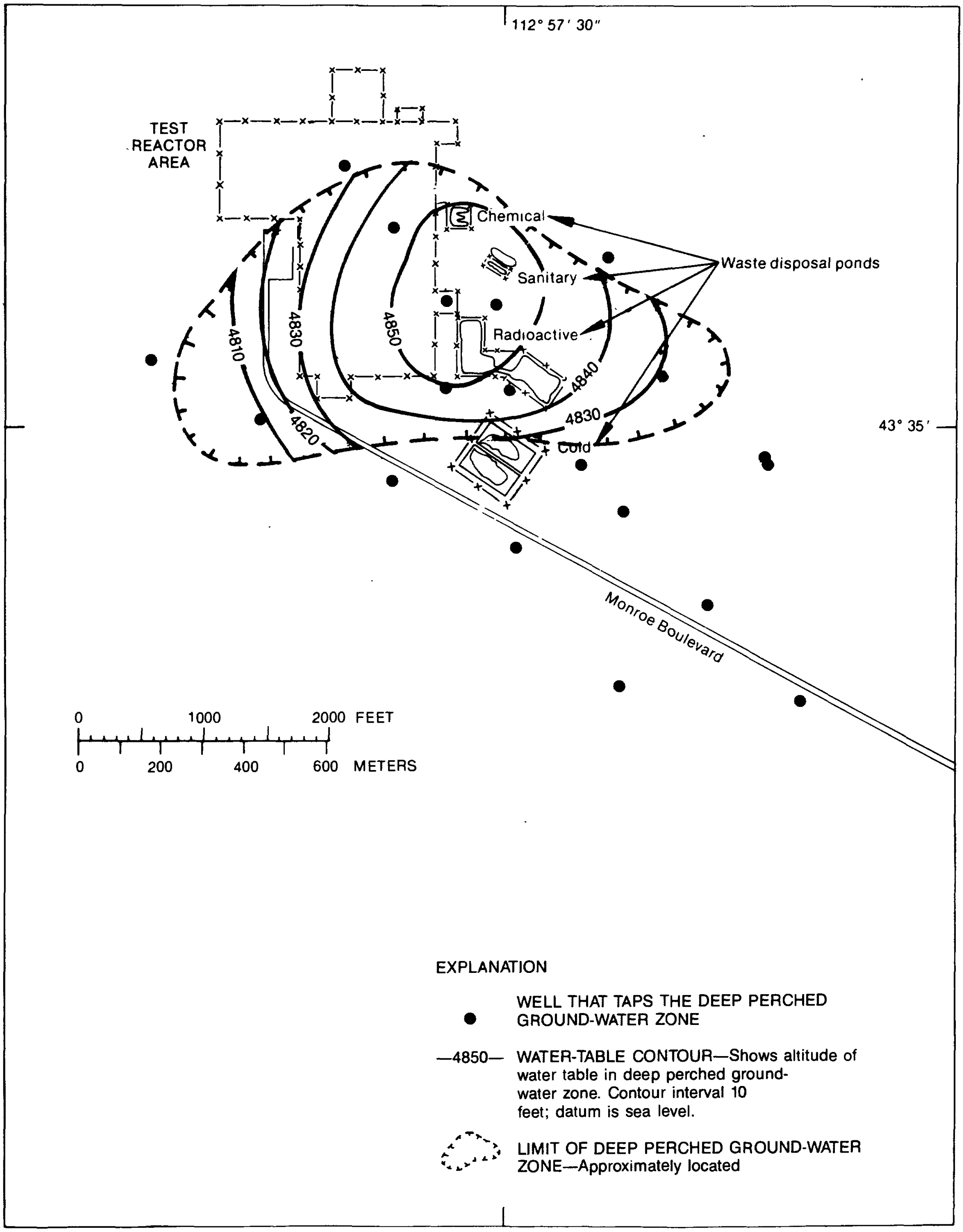


Figure 18.--Water-level contours for the deep perched ground-water zone near the TRA, October 1981.

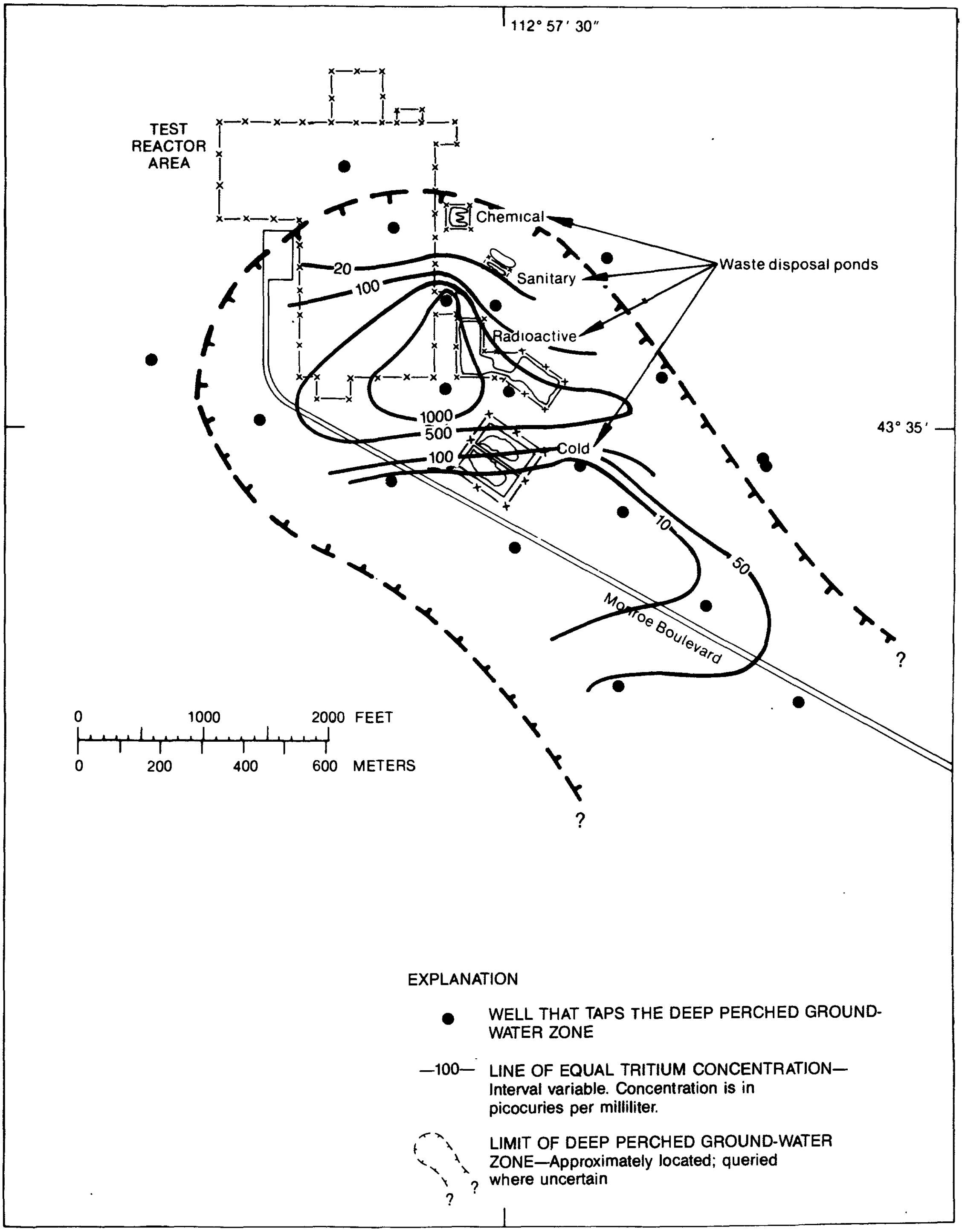


Figure 19.--Concentrations of tritium in the deep perched ground-water zone near the TRA, October 1985.

Chromium-51.--A total of 2,298 Ci of chromium-51 were discharged to the radioactive-waste disposal ponds from 1979 to 1981 (Lewis and Jensen, 1985) for an average of 766 Ci/year. In contrast, 83 Ci of chromium-51 were discharged to the radioactive-waste disposal ponds from 1982 to 1985, an average of about 21 Ci/year. In 1979, 90 percent of the radioactivity in wastewater discharged at the TRA was chromium-51; this percentage decreased to 6 percent in 1981, and to 2.5 percent in 1985. One water sample collected from well 53 in April 1983 contained 4.95±0.64 pCi/mL of chromium-51. Because of the reduction in the amount of chromium-51 discharged, and the relatively short half-life of 27.8 days, chromium-51 was not detected in samples from wells in the deep perched ground-water zone near the TRA during 1984 and 1985.

Cobalt-60.--About 428 Ci of cobalt-60 have been discharged to the radioactive-waste disposal ponds since 1952, an average of about 13 Ci/year. From 1979 to 1981, 7 Ci of cobalt-60 were discharged to the radioactive-waste disposal ponds, an average of about 2.3 Ci/year. From 1982 to 1985, 4 Ci of cobalt-60 were discharged to the ponds, an average of 1 Ci/year. The average concentration of cobalt-60 in the discharged wastewater was 10 pCi/mL. Cobalt-60 concentrations in the deep perched ground-water zone for October 1985 are shown in figure 20.

The areal extent and concentration of cobalt-60 in water in the perched ground-water zone have decreased since October 1981. The largest concentrations of cobalt-60 in water in the perched ground-water zone decreased from 0.80±0.09 pCi/mL in December 1981 to 0.36±0.05 pCi/ml in October 1985. Because of a reduction in the disposal rates and a 5.3 year half-life, the concentration of cobalt-60 in the perched ground-water zone should continue to decrease.

Cesium-137.--About 138 Ci of cesium-137 were discharged to the disposal ponds at the TRA from 1952 to 1985, an average of 4.1 Ci/year. A total of 2.6 Ci was discharged to the disposal ponds from 1982 to 1985, for an average of 0.65 Ci/year. Cesium-137 has a half-life of 30.2 years; because of the similar half-life and the similar disposal quantities, the distribution of cesium-137 in the deep perched ground-water zone could be

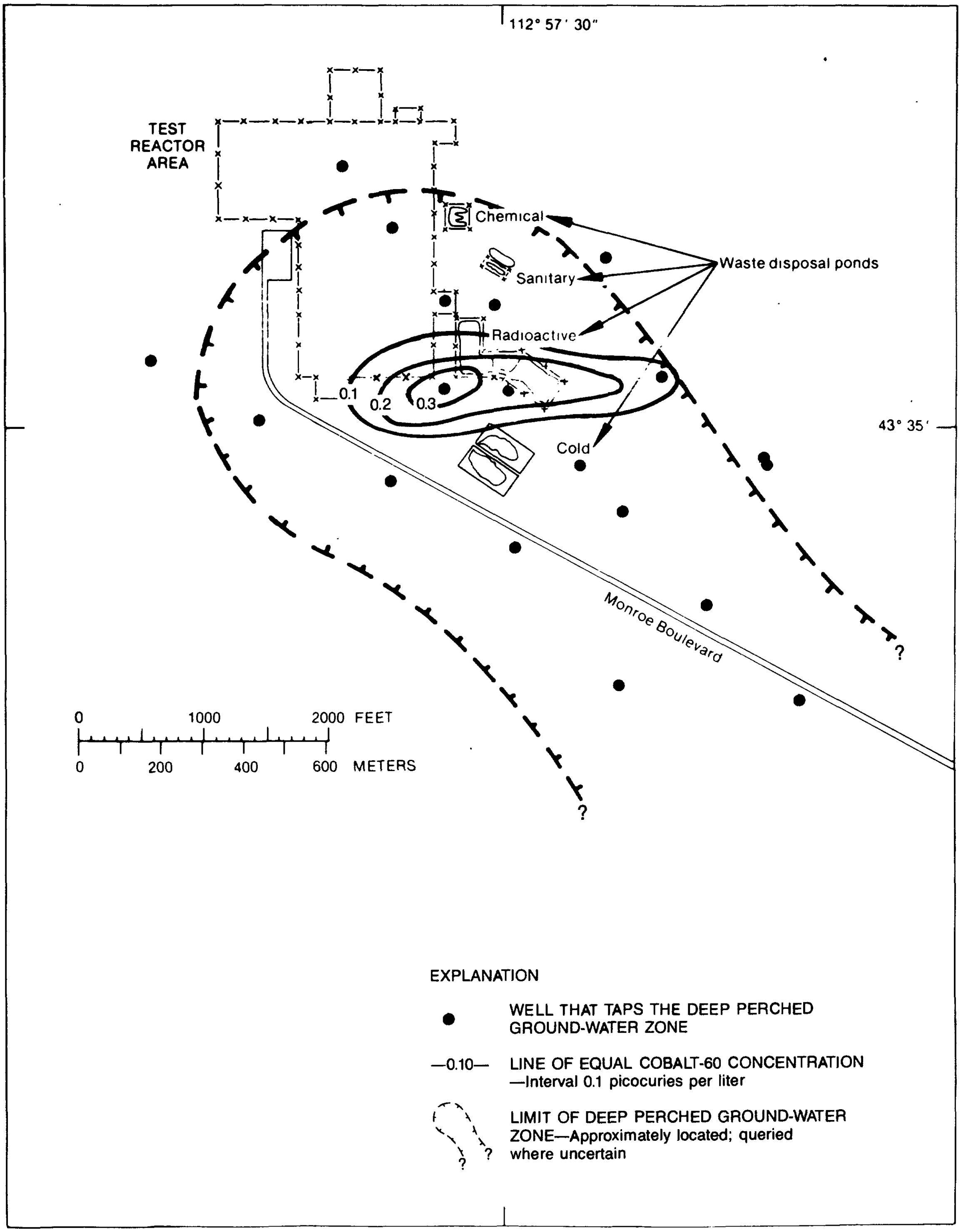


Figure 20.--Concentrations of cobalt-60 in the deep perched ground-water zone near the TRA, October 1985.

expected to be similar to the distribution of strontium-90 (Lewis and Jensen, 1985). However, cesium-137 is strongly sorbed to the minerals of the surficial alluvium and deeper sedimentary material interbedded with basalt flows and is removed before reaching wells tapping the deep perched ground-water zone (Robertson and others, 1974).

Sodium.--The largest sodium concentrations in the deep perched ground-water zone were in water from wells nearest the chemical-waste disposal pond. Concentrations in water from well 68 increased from 222 mg/L in October 1981 to 840 mg/L in October 1985. This corresponds to an increase in the average annual concentration of sodium discharged to the chemical-waste disposal ponds from 1,061 mg/L in 1981 to 2,485 mg/L in 1985. Concentrations of 7 to 34 mg/L were present in water from other wells that tap the perched ground-water zone (fig. 21), where wastewater percolating from the radioactive- and cold-waste disposal ponds mixed with and diluted the water percolating from the chemical-waste disposal ponds.

Total chromium.--Total chromium concentrations in the deep perched ground-water zone for October 1985 are shown in figure 22. Chromium was detected in water from wells near the radioactive-waste disposal ponds and well 71 (see figure 16 for well location). Water from the cold-waste disposal ponds diluted the concentration of chromium in the central and southern part of the perched ground-water zone. The concentration of total chromium at well 71 in the southern part of the zone may be residual from a previous period of greater chromium discharge to the system and is similar to the pattern depicted for October 1975 by Barraclough and others (1981). In 1981, the deep perched ground-water zone did not extend as far south as well 71 (fig. 18); whether the chromium remained in solution in water in the unsaturated zone or desorbed from the sediment and basaltic rocks in the unsaturated zone is not known.

Chloride.--Chloride concentrations in the deep perched ground-water zone are shown in figure 23. Concentrations of chloride were largest in the northern and western parts of the perched ground-water zone. Concentrations in the central part of the perched ground-water zone were smaller because of dilution effects of wastewater from the radioactive- and cold-waste disposal

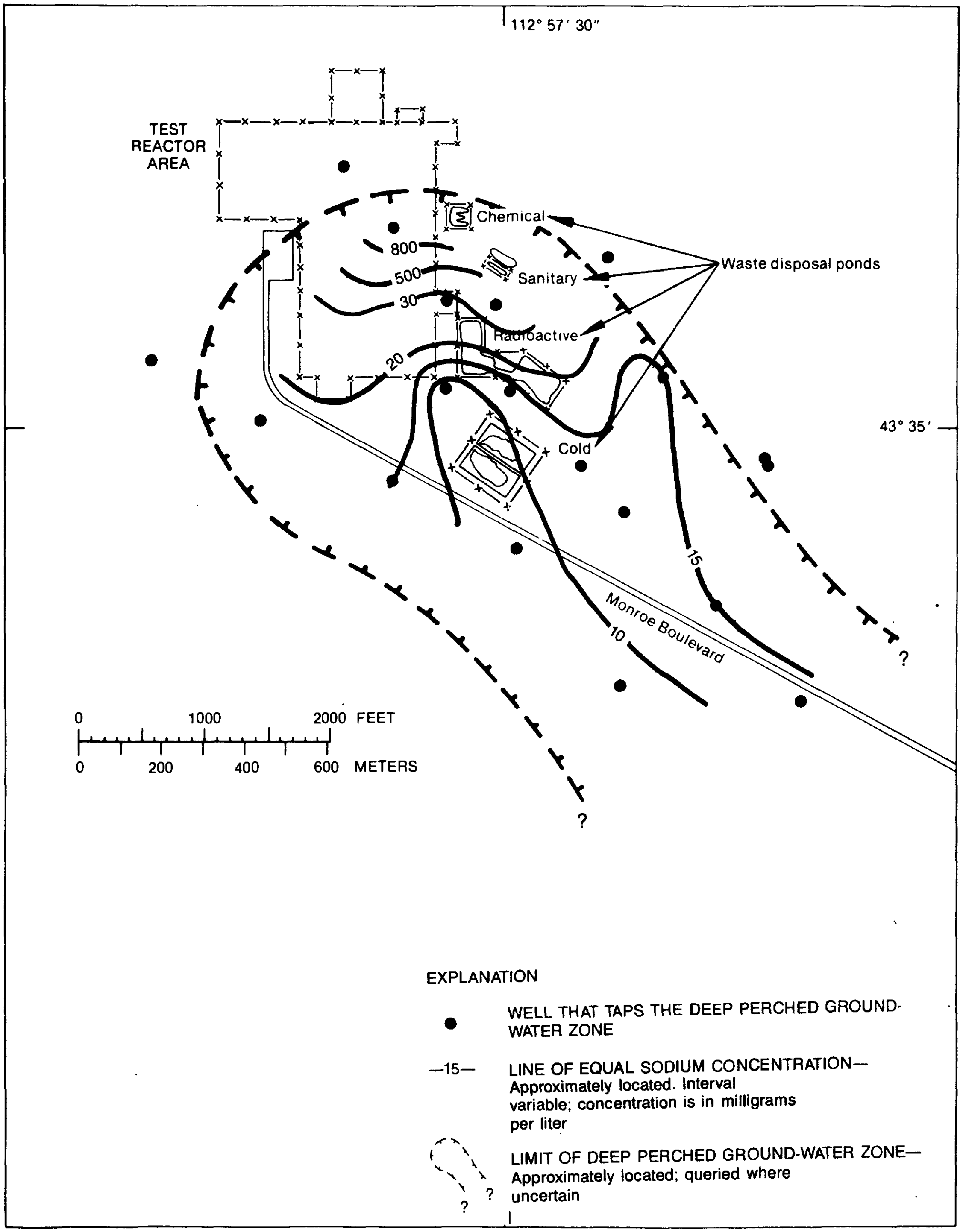


Figure 21.--Concentrations of sodium in the deep perched ground-water zone near the TRA, October 1985.

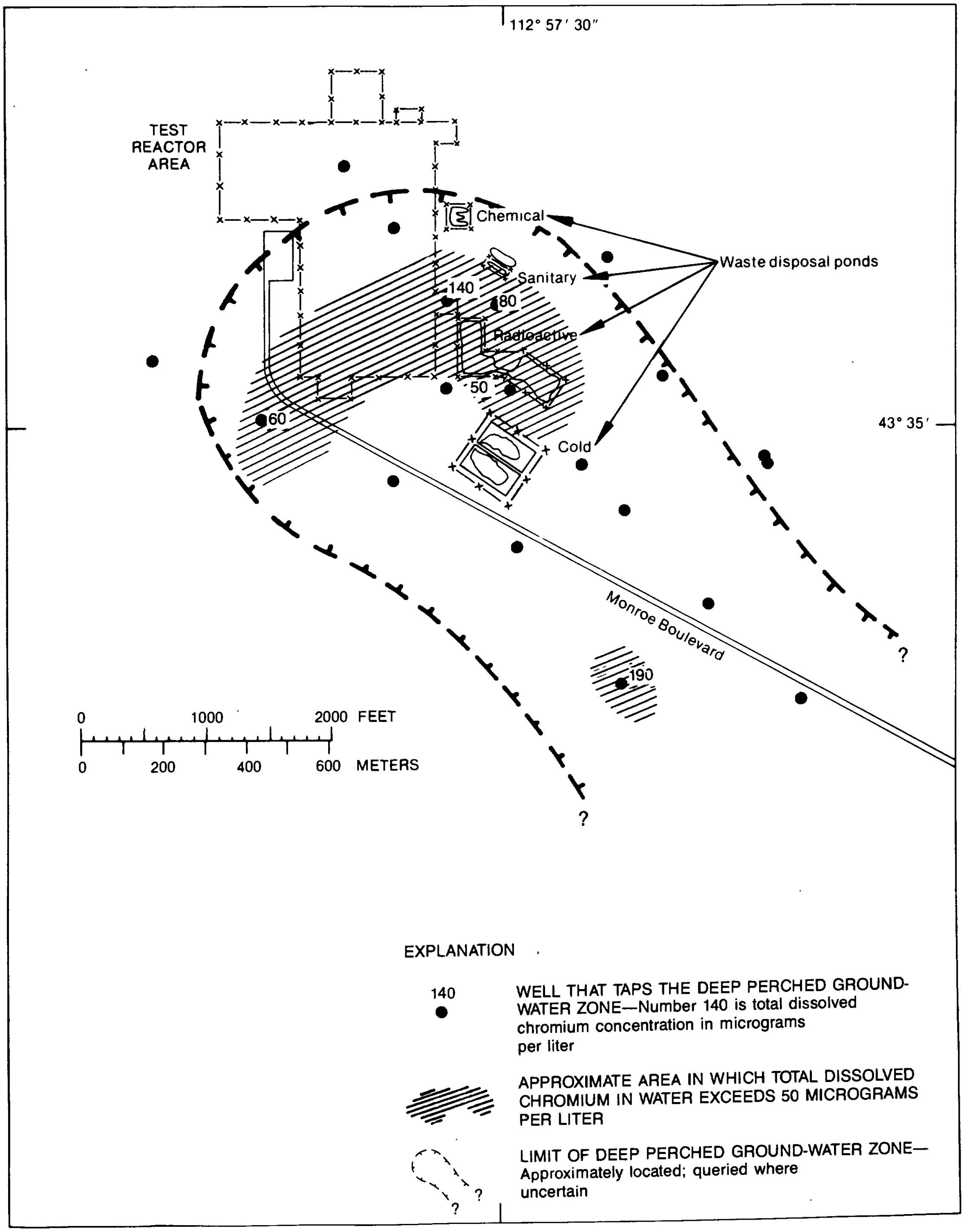


Figure 22.--Concentrations of total chromium in the deep perched ground-water zone near the TRA, October 1985.

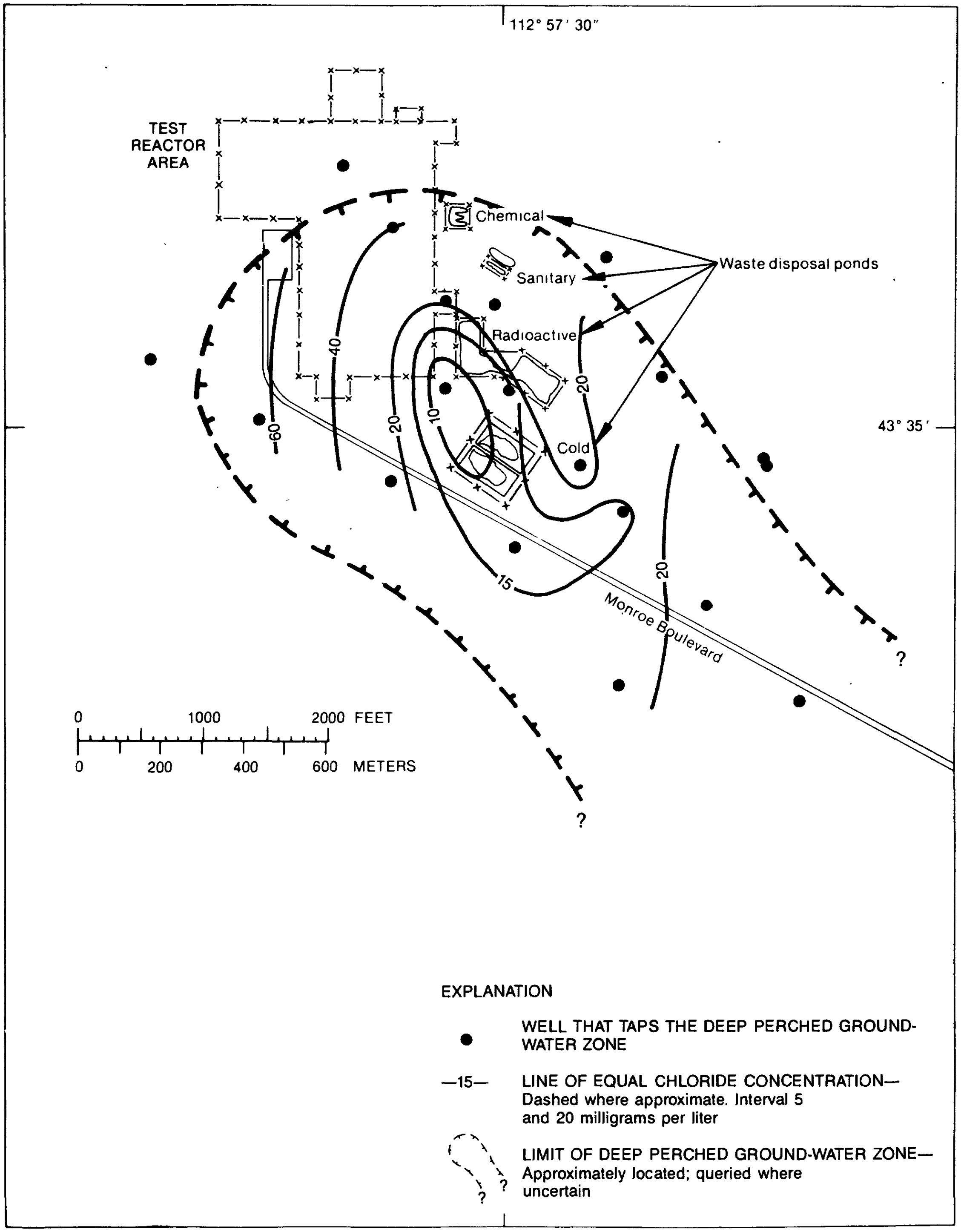


Figure 23.--Concentrations of chloride in the deep perched ground-water zone near the TRA, October 1985.

ponds. While chloride disposal increased from an annual average of 1,540 pounds for 1979-81 to 2,000 pounds for 1982-85, chloride concentrations in the perched water decreased significantly in the past 4 years because of smaller concentrations of chloride in the wastewater and the diversion to the seepage ponds of the wastewater that was previously discharged to the disposal well.

Sulfate.--Sulfate concentrations in the deep perched ground-water zone were largest near the chemical-waste disposal pond because of large concentrations of sulfate in wastewater discharged to the pond (fig. 24). The concentrations of sulfate in the deep perched ground-water zone in October 1984 ranged from 50 mg/L in well 63 to 3,400 mg/L in well 68 (see fig. 16 for well location). This was a significant increase over the range of 12 to 2,700 mg/L for December 1981 (Lewis and Jensen, 1985). This increase resulted from a change in the average annual concentration of sulfate in wastewater disposed to the chemical waste pond from 7,533 mg/L during 1979-81 to 9,210 mg/L during 1982-85. The decreased sulfate concentrations in the southern and western parts of the deep perched ground-water zone were the result of smaller sulfate concentrations contained in water discharged to the radioactive- and cold-waste disposal ponds.

Nitrate.--Nitrate concentrations (calculated as NO_3^-) were largest in the northern part of the deep perched ground-water zone beneath the chemical- and sanitary-waste disposal ponds (fig. 25). Nitrate concentrations in the southern part of the deep perched ground-water zone decreased from 1981 to 1985 because of dilution effects by water with smaller nitrate concentrations from the radioactive- and cold-waste disposal ponds. Nitrate concentrations were significantly smaller in October 1984 than they were in December 1981 (Lewis and Jensen, 1985) and may have resulted from a reduction in waste-nitrate discharge to the chemical-waste disposal pond and overall dilution by water from the radioactive- and cold-waste disposal ponds.

Phosphate.--The concentrations of phosphate (measured as elemental phosphorus) were largest in water from wells near the sanitary-waste disposal ponds. Water from wells 55, 70, and 54 (fig. 16) contained 0.33,

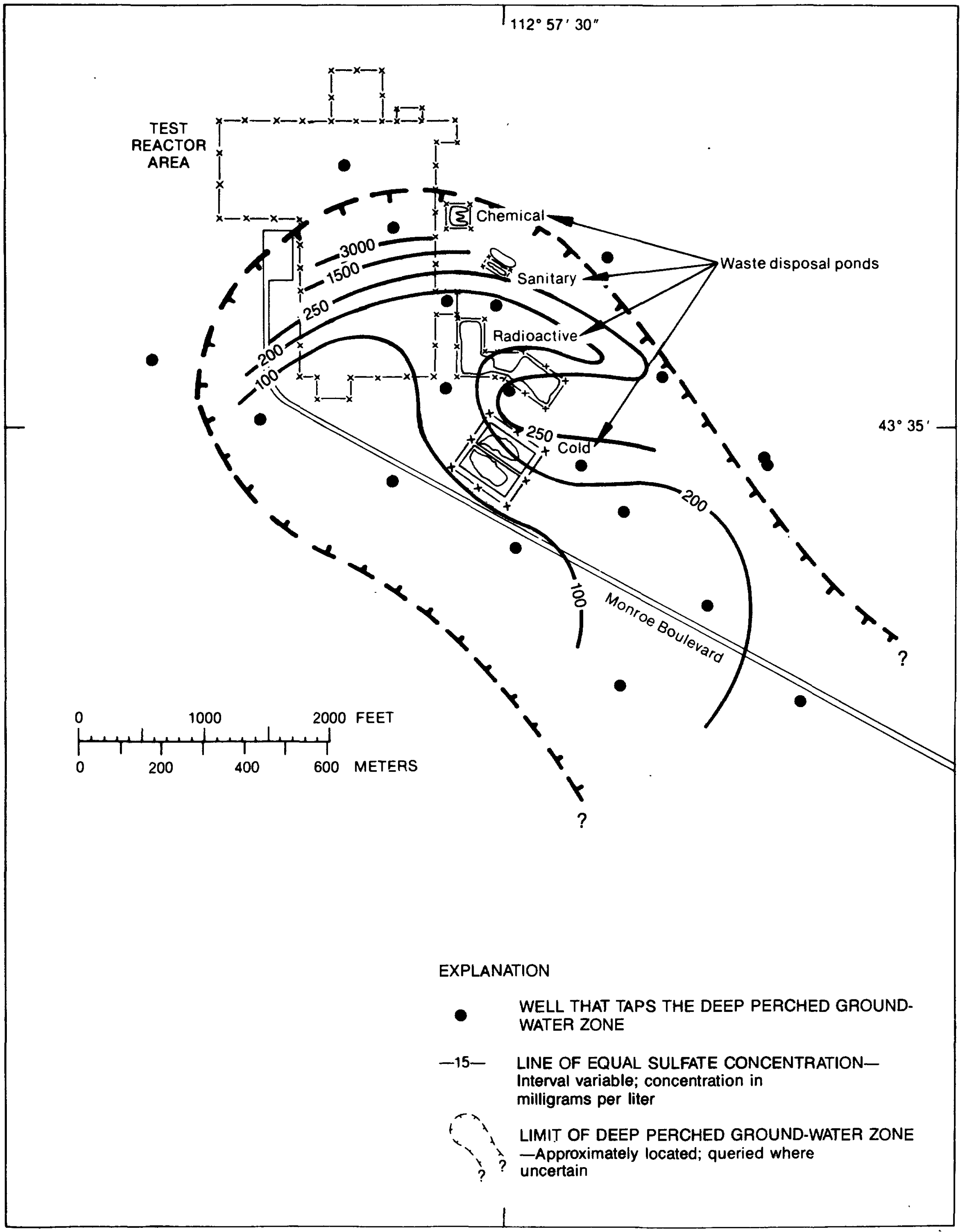


Figure 24.--Concentrations of sulfate in the deep perched ground-water zone near the TRA, October 1984.

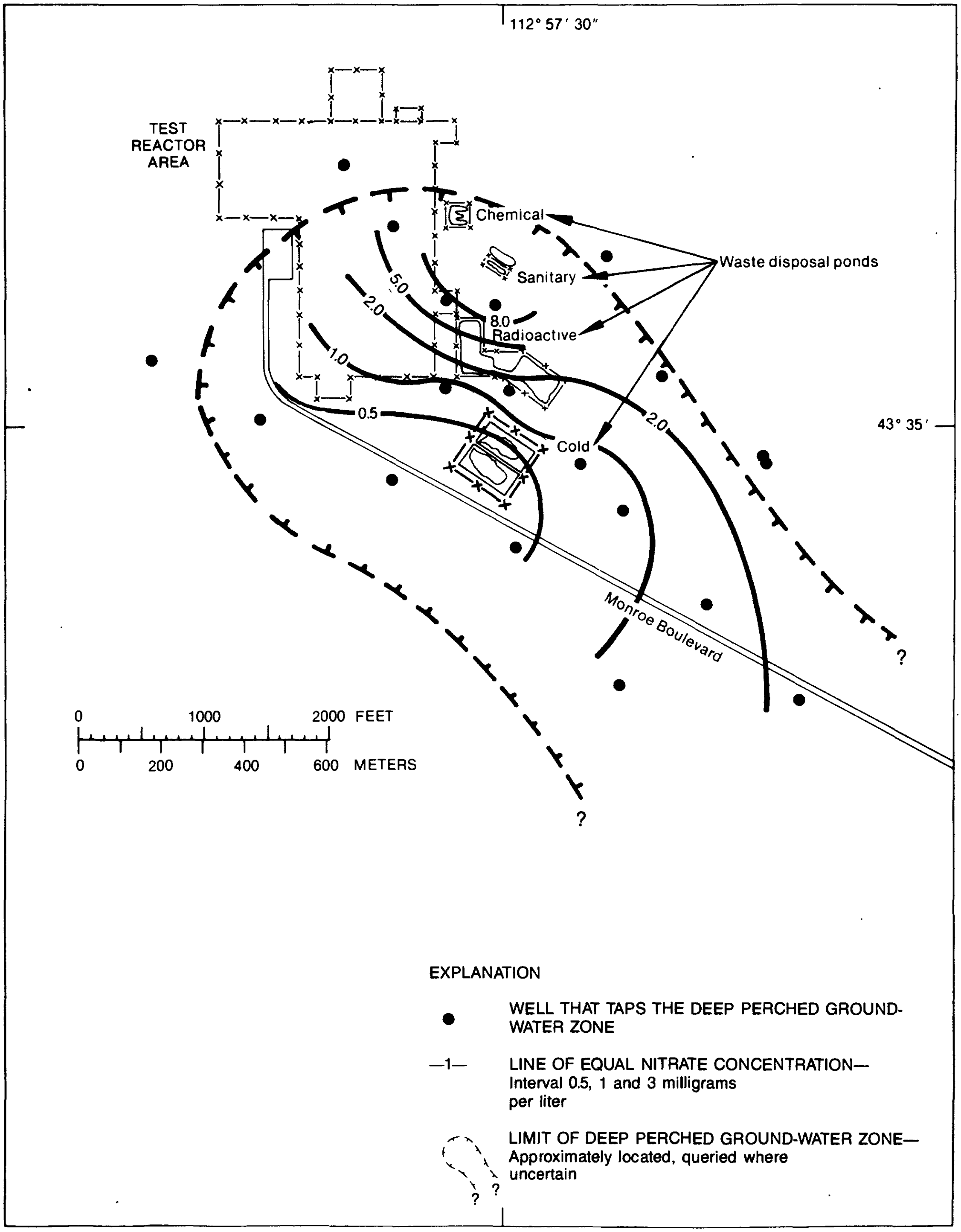


Figure 25.--Concentrations of nitrate in the deep perched ground-water zone near the TRA, October 1984.

0.05, and 0.03 mg/L of phosphate, respectively. Water from the radioactive- and cold-waste disposal ponds quickly diluted the phosphate concentrations such that water samples from other wells tapping the deep perched ground-water zone contained less than 1 mg/L of phosphate.

Mercury and Lead.--In October 1984, water from deep perched water zone wells 53, 54, 55, 60, 62, and 70 (fig. 16) was analyzed for mercury and lead. Mercury concentrations were less than the reporting level of 0.1 µg/L; lead concentrations ranged from 2 to 8 µg/L and averaged 3.8 µg/L.

Physical Properties of Perched Ground Water Near the Test Reactors Area

Specific Conductance.--Water from well 68, the well nearest to the chemical-waste disposal pond (fig. 16), had a specific conductance of 4,900 µS/cm (microsiemen per centimeter). Water in the chemical-waste disposal pond had a large specific conductance because of the large amount of dissolved chemicals in the discharged wastewater. As the water from the chemical-waste disposal pond moves vertically to and laterally in the deep perched ground-water zone it is diluted with water from the radioactive- and cold-waste disposal ponds that has a smaller specific conductance. The specific conductance of water from wells near the cold-waste disposal ponds was generally less than 500 µS/cm. The specific conductance of water from the deep perched ground-water in October 1985 is shown in figure 26. For the most part, the specific conductance of the water in October 1985 was similar to that shown for October 1981 (Lewis and Jensen, 1985).

Temperature and pH.--In October 1985, temperature of water from the deep perched ground-water zone ranged from 10 °C in well 71 to 15.8 °C in well 54 (see fig. 16 for well location). Temperatures higher than 11 °C were generally measured in water from wells near the disposal ponds and decreased with distance from the ponds (fig. 27).

In October 1985, the pH of water from the deep perched ground-water zone ranged from 7.4 to 7.9. Two exceptions were well 73 (see figure 12 for well locations) which contained water with a pH of 8.1 and well 68 which

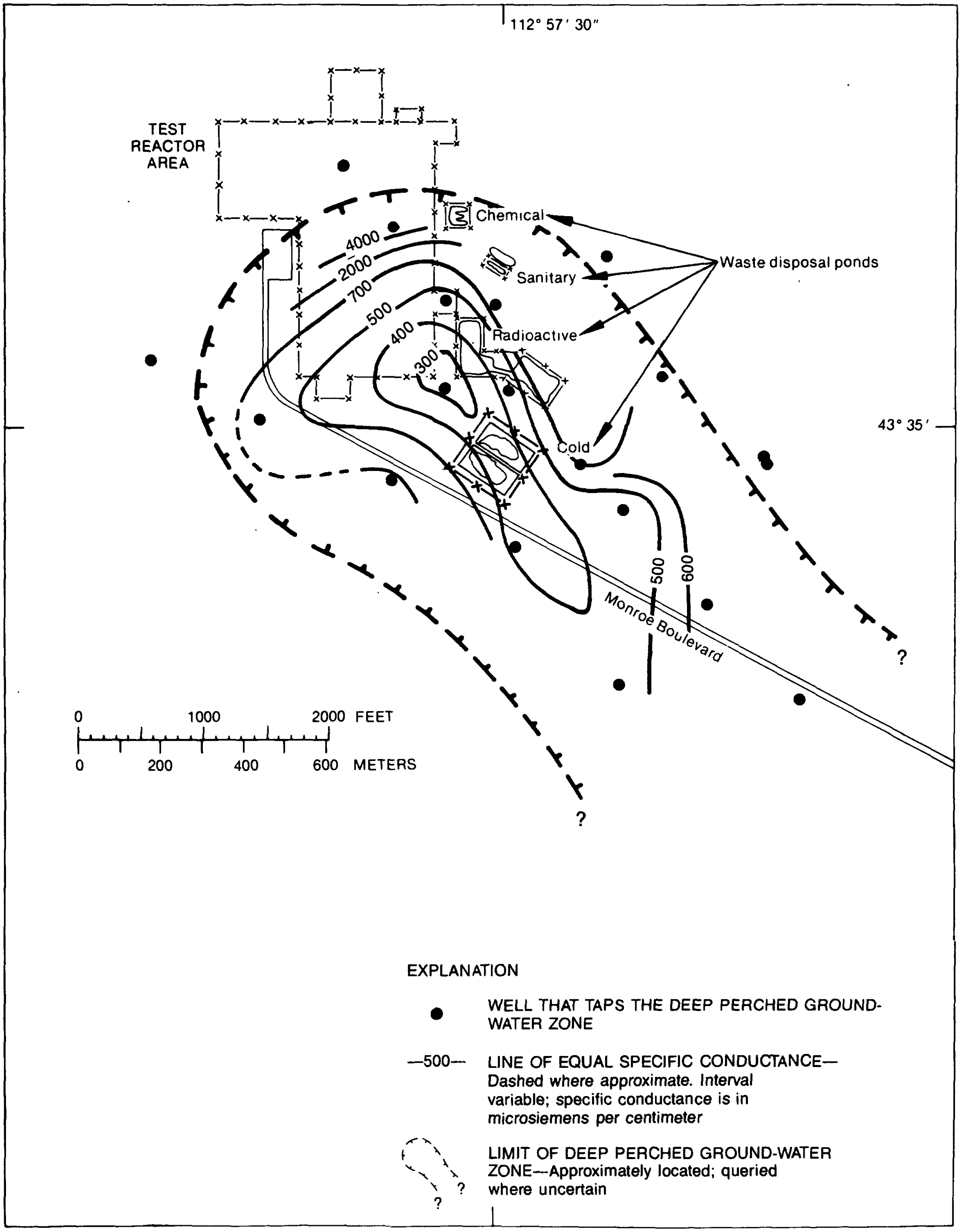


Figure 26.--Specific conductance of water in the deep perched ground-water zone near the TRA, October 1985.

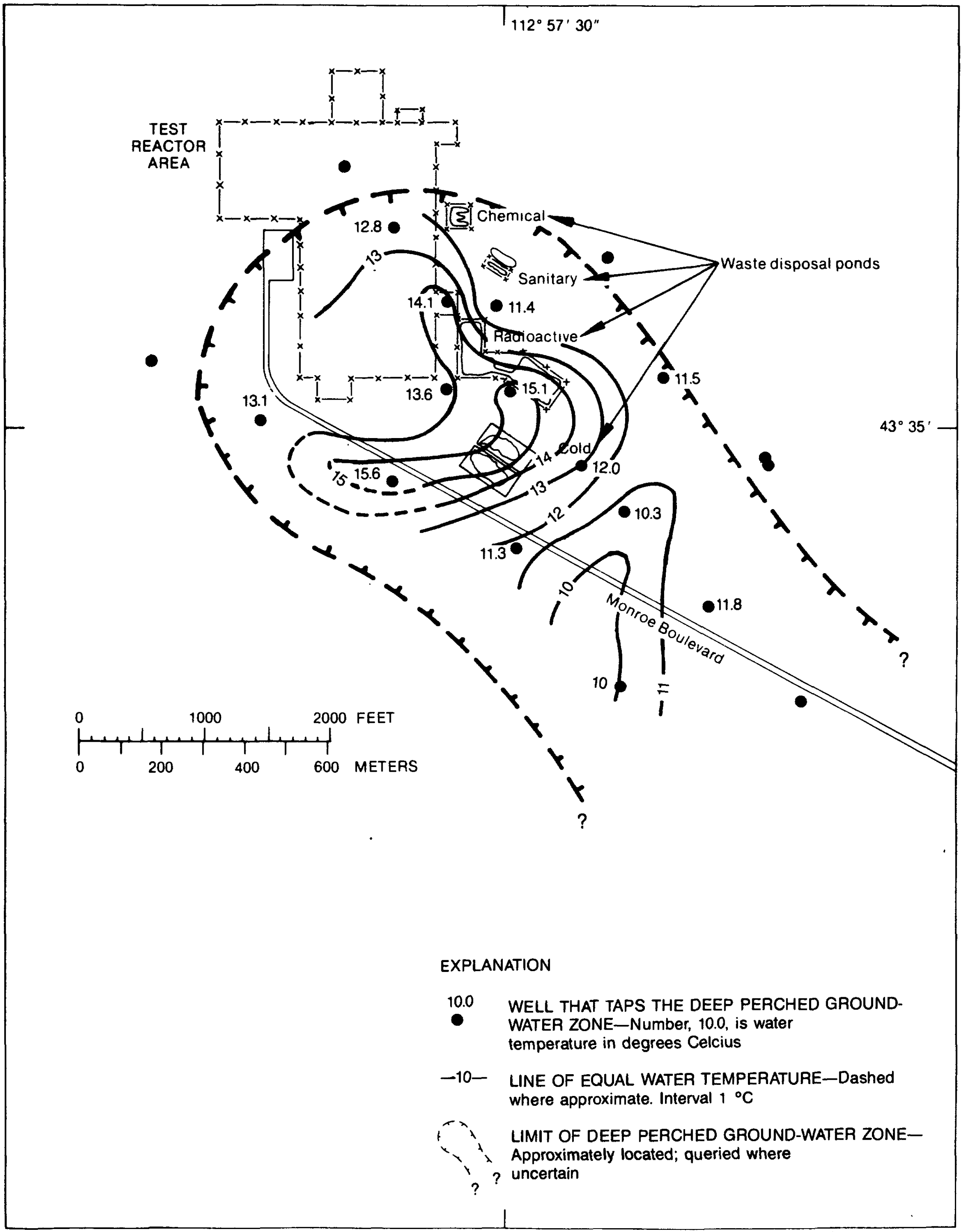


Figure 27.--Temperature of water in the deep perched ground-water zone near the TRA, October 1985.

contained water with a pH of 6.5. Recharge water from the Big Lost River may have caused the larger pH of ground water from well 73. Well 68 is near the chemical-waste disposal pond where disposed wastewater was more acidic than wastewater discharged to the radioactive- and cold-waste disposal ponds.

Radiochemical and Chemical Constituents in the Snake River Plain Aquifer

The distribution of selected radionuclides and chemical wastes in water in the Snake River Plain aquifer is described in the following sections. Where applicable, selected waste-product concentrations are compared to the quality of water in the aquifer prior to waste disposal activities. Olmsted (1962) stated that the natural quality of water in the Snake River Plain aquifer at the INEL area could be divided into two general categories: (1) Water underlying the western part of the INEL has calcium, magnesium, bicarbonate, and carbonate as the chief ions. The abundance of these constituents is derived from the recharge areas north and west of the INEL, which are mainly composed of limestone and dolomite. (2) Water underlying the eastern part of the INEL contains higher percentages of sodium and potassium, indicating that recharge to this part of the aquifer originates in the mountains north and northeast of the INEL, an area composed predominately of silicic volcanic rocks. Analyses of water samples collected from the aquifer, in areas not affected by waste disposal, show that these type characterizations probably are correct (Lewis and Goldstein, 1982).

The 1985 waste plumes for the ICPP showed large changes when compared to the 1981 waste plumes described by Lewis and Jensen (1985). The changes resulted from modifications in disposal practices, increased amounts of recharge from the Big Lost River, and localized precipitation. The waste plumes south of the TRA and NRF are less easily defined because of widespread locations of wells and dilution by recharge from the Big Lost River. The lateral distance of waste migration and the areas of detectable radionuclides and chemical waste plumes are shown in table 2. Wells used to monitor ground-water conditions in the Snake River Plain aquifer and waste-disposal wells and ponds in the south-central part of the INEL are shown in figure 28.

Table 2.--Waste plumes in the Snake River Plain aquifer in the south-central part of the INEL

Constituent	Date	Lateral waste migration distance, in miles, from ICPP	TRA	NRF	Combined area of waste plumes, in square miles
Tritium (H-3)	October 1985	8.3	9.1	0	51
Strontium-90	October 1985	2.0	-	-	2
Sodium	October 1984	3.7	1.7	3.3	14
Chloride	October 1984	5.7	-	2.7[1]	19
Nitrate	October 1985	5.4	1.5	4.3	21

[1] Plume diluted and divided near the Big Lost River because of recharge from the river.

Tritium.--The injection of wastewater directly into the aquifer at the ICPP combined with the percolation of wastewater from the disposal ponds at the TRA and ICPP has resulted in a large, dispersed plume of tritium that generally follows the southwesterly direction of ground-water movement in the Snake River Plain aquifer (fig. 29). The size of the plume increased from 42 mi^2 in October 1981 (Lewis and Jensen, 1985) to 51 mi^2 in October 1985, however the tritium concentrations near the ICPP disposal well decreased as much as 80 pCi/mL. The largest tritium concentrations were immediately south of the ICPP, indicating that attenuation and downgradient migration of the tritium has occurred since use of the disposal well was discontinued. The size of the tritium plume near the TRA changed little from 1981 to 1985. Concentrations of tritium in water from the aquifer ranged from less than 0.9±0.3 to 93.4±2.0 pCi/mL in October 1985. Tritium concentrations for October 1981 ranged from less than 0.4±0.2 to 156±1 pCi/mL (Lewis and Jensen, 1985).

During 1983-85, tritium was detected for the first time in water from some wells near the southern boundary of the INEL. Water from well 103 (see

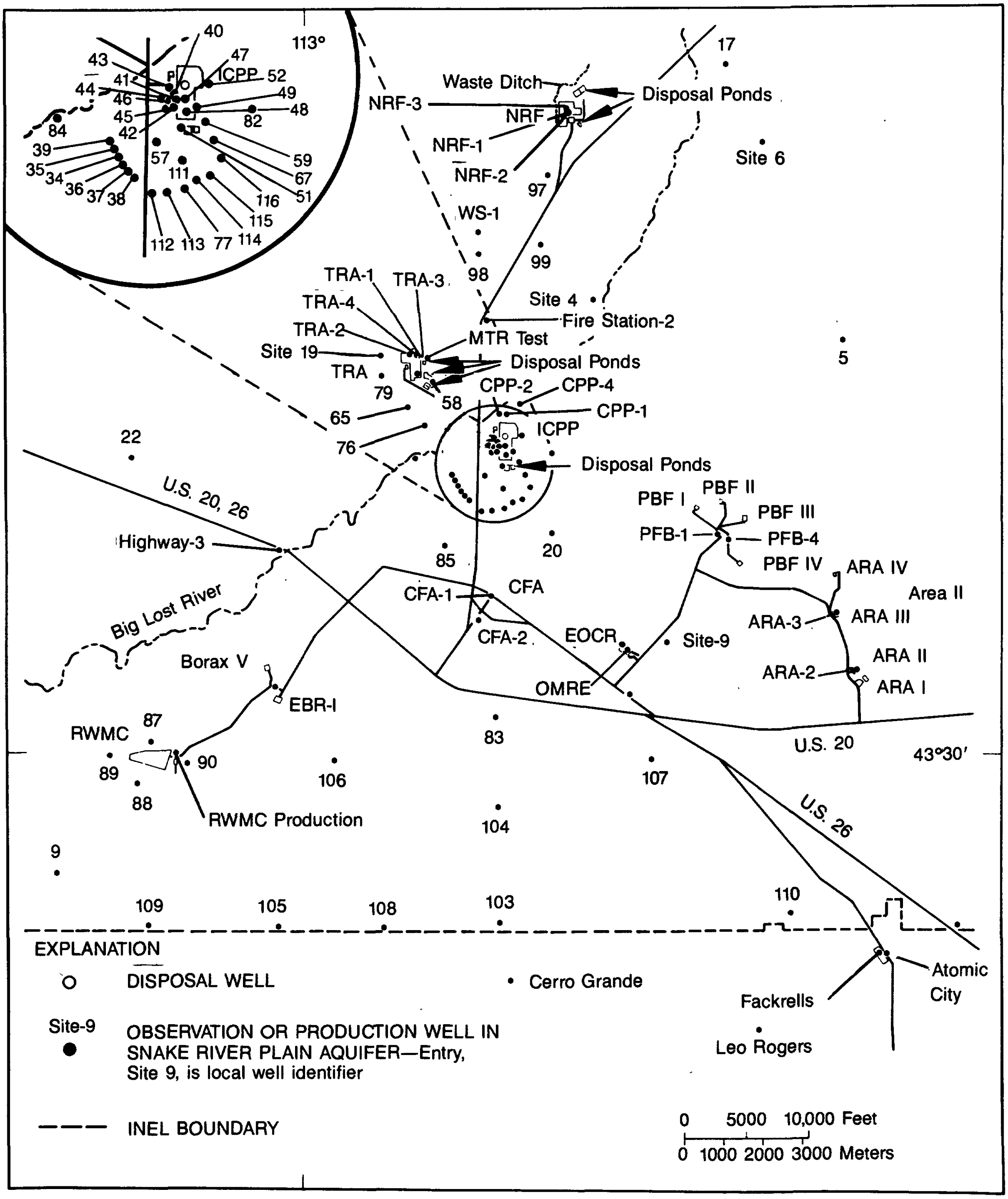


Figure 28.--Locations of observation wells completed in the Snake River Plain aquifer, and waste-disposal wells and ponds in the south-central part of the INEL.

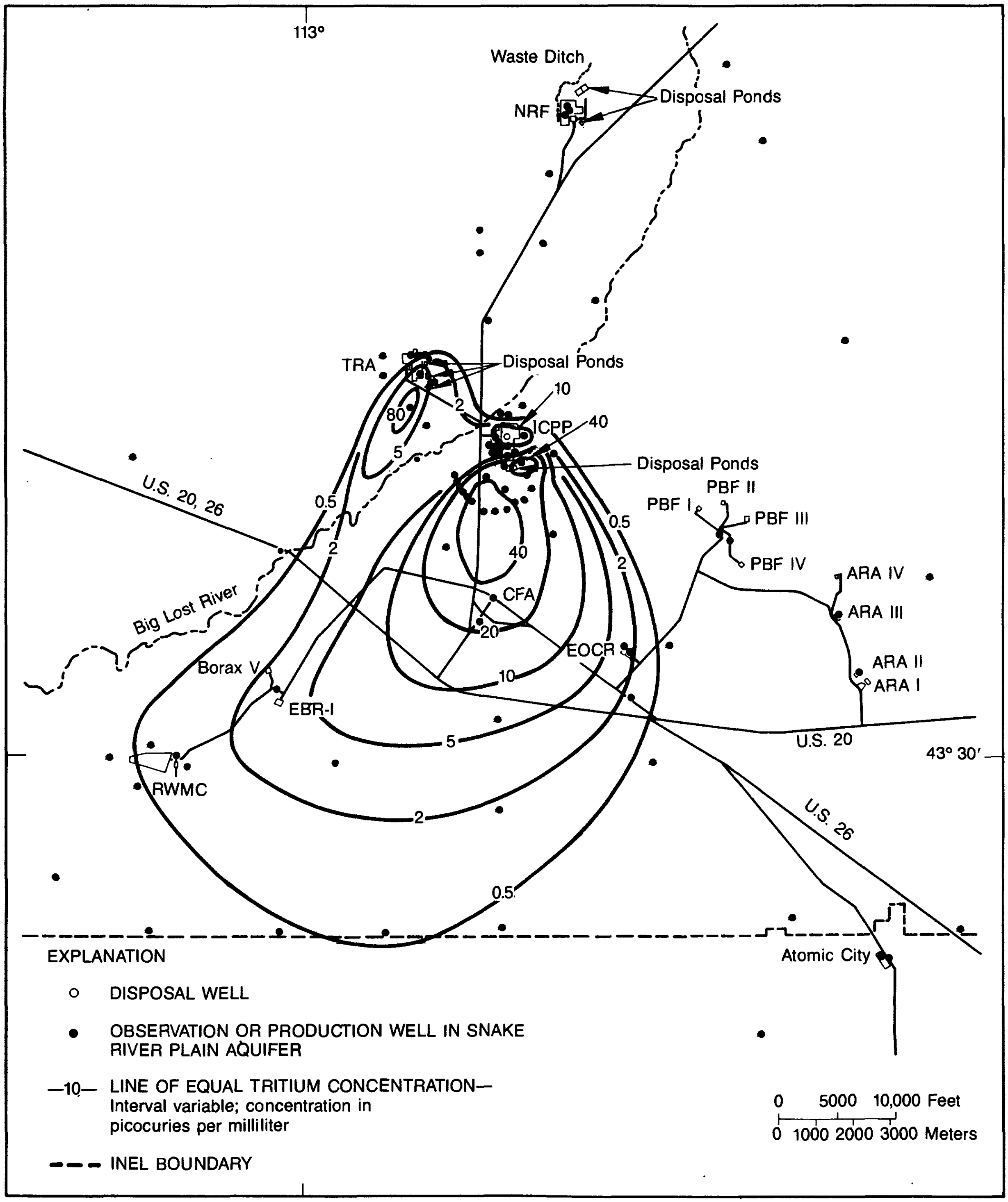


Figure 29.--Distribution of tritium in the Snake River Plain aquifer in the south-central part of the INEL, October 1985.

figure 28 for well location) contained 0.8±0.2 pCi/mL in July 1983 and 1.2±0.3 pCi/mL in July 1985; other quarterly samples did not verify the presence of tritium. In January 1984, water from well 105 contained 0.5±0.2 pCi/mL of tritium. Again, the presence of tritium was not substantiated by subsequent quarterly samples. In October 1985, water from well 108 contained 0.8±0.3 pCi/mL of tritium; the presence of tritium in well 108 was substantiated by a sample collected in April 1986. However, tritium was not detected in samples collected in October 1986 and in 1987. The distribution of tritium in the Snake River Plain aquifer in October 1985 is shown in figure 29.

Tritium had migrated about 8.3 mi downgradient from the ICPP disposal well and 9.1 mi downgradient from the TRA radioactive-waste disposal ponds since the early 1950's. The arrival of tritium at the RWMC was first detected in 1975, and was detected in water from wells near the southern boundary of the INEL in 1985. The apparent velocity of tritium migration, based on first arrivals from the TRA radioactive-waste disposal ponds and the ICPP disposal well, ranges from about 4 to 5 ft/d.

Cobalt-60.--During 1982-85, small concentrations of cobalt-60 were in wastewater discharged to the ICPP disposal well and ponds, and to the TRA radioactive-waste disposal ponds. However, water from the Snake River Plain aquifer near the ICPP disposal well and ponds did not contain detectable amounts of cobalt-60. One water sample collected from well 65, south of TRA (see figure 28 for location) in April 1982, contained 0.034±0.009 pCi/mL of cobalt-60. Prior to 1979, cobalt-60 was not detected in water from the aquifer (Barraclough and others, 1981).

Strontium-90.--About 21 Ci of strontium-90 were discharged to the ICPP disposal well from 1952 to 1985. From 1982 to 1985, 0.25 Ci were disposed of in wastewater at the ICPP for an average of 0.06 Ci/year. This is an 82 percent reduction in the disposal rate compared to the 1979-81 average of 0.33 Ci/year (Lewis and Jensen, 1985).

The distribution of strontium-90 in the Snake River Plain aquifer for October 1985 is shown in figure 30. The strontium-90 plume covers about

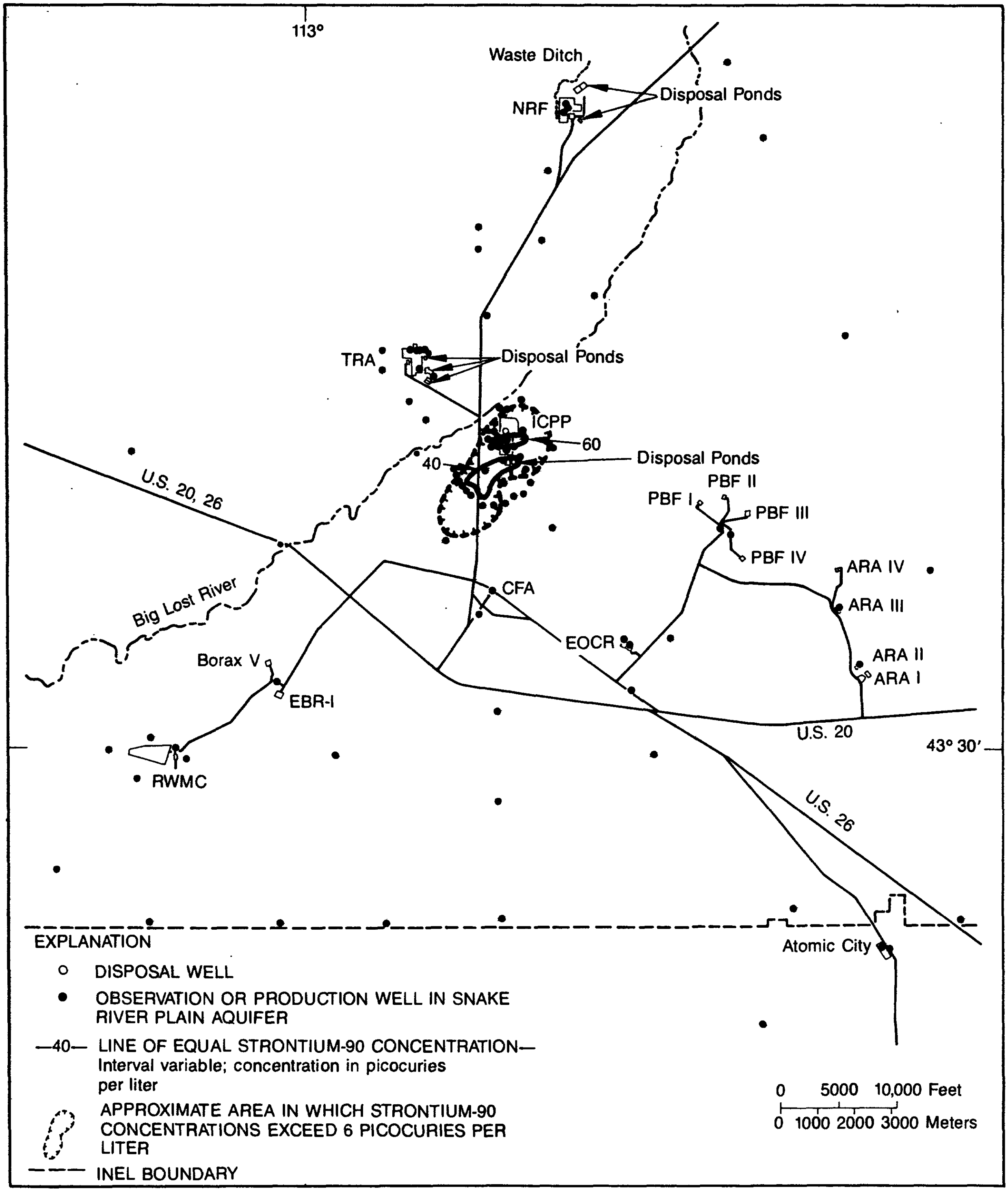


Figure 30.--Distribution of strontium-90 in the Snake River Plain aquifer in the south-central part of the INEL, October 1985.

2 mi², and little change in overall size has occurred since October 1981 (Lewis and Jensen, 1985). However, strontium-90 concentrations in the plume have decreased approximately 10 pCi/L near the disposal well and south of the ICPP facility because of the discontinued use of the disposal well. Concentrations of strontium-90 in the plume ranged from 6±2 to 63±5 pCi/L in October 1985.

Cesium-137.--About 22 Ci of cesium-137 have been discharged to the ICPP disposal well and seepage ponds since disposal began. From 1982 to 1985, 0.30 Ci of cesium-137 were discharged for an average of 0.08 Ci/year. This is an order of magnitude smaller than the 1979 to 1981 average of 0.7 Ci/year. Cesium-137 was detected in water from two wells near the ICPP from 1982 to 1985. Cesium-137 was detected in six water samples collected from well 40 from January 1982 to July 1983 (see figure 28 for well location). The concentrations of cesium-137 in these water samples ranged from 125±14 pCi/L to 237±45 pCi/L. Subsequent water samples collected during the remainder of 1983, 1984, and 1985 did not contain detectable concentrations of cesium-137. Water from well 47 contained 200±50 pCi/L of cesium-137 in October 1984 and 140±30 pCi/L of cesium-137 in April 1985.

Cesium-137 was not detected in water from aquifer wells near the TRA, although it has been disposed to the TRA radioactive-waste disposal ponds. Cesium-137 may be removed from solution by sorption to the alluvium, sedimentary interbeds, and basalt as the water moves downward from the radioactive-waste disposal pond and through the perched ground-water zone to the aquifer.

Plutonium isotopes.--Monitoring of plutonium-238 and plutonium-239, -240 (undivided) disposed to the ICPP disposal well began in 1974. Prior to that time, they were not separable in the undifferentiated alpha activity which was measured (Lewis and Jensen, 1985). From 1982 to 1985, a total of about 0.017 Ci of plutonium-238 and 0.002 Ci of plutonium-239, -240 (undivided) were discharged to the ICPP disposal well and ponds, representing an average discharge of about 0.004 Ci/year of plutonium-238 and 0.0005 Ci/year of plutonium-239, -240 (undivided).

Prior to 1982, isotopes of plutonium were detected in wells 40 and 47, which are near the ICPP (see fig. 28 for well locations). In 1975, the mean concentration of plutonium-238 in three consecutive monthly water samples from well 47 was 6.5×10^{-6} pCi/mL, and the mean concentration for plutonium-239, -240 (undivided) was 2.4×10^{-6} pCi/mL (Polzer and others, 1976). The detection limit for these analyses was 1.0×10^{-6} pCi/mL because of the 10-liter sample volumes used.

In the summer of 1980, water was collected from wells 37, 40, 43, and 67 (see figure 28 for well locations) to again document whether the plutonium isotopes were detectable in the aquifer. Plutonium-238 concentrations in water from well 40 were statistically above the detection limit of 1.0×10^{-5} pCi/mL (Cleveland and Rees, 1982). Three consecutive monthly samples of water from well 40 contained an average plutonium-238 concentration of about 6.6×10^{-5} pCi/mL. From 1982 to 1985, plutonium-238 and plutonium-239, -240 (undivided) were detected in water from well 40 and plutonium-238 was detected in water from well 47 (table 3). The small concentrations and limited areal distribution of plutonium in water from the aquifer suggest that dilution, dispersion and sorption help to control the migration of plutonium isotopes.

Table 3.--Plutonium-238 and plutonium-239, -240 (undivided) concentrations in water from wells 40 and 47

[DL indicates the analytical result is below the detection limit]

Well number	Date sampled	Plutonium-238 (picocuries per milliliter)	Plutonium-239, -240 (undivided) (picocuries per milliliter)
40	04/09/82	$9.4\pm0.8\times10^{-5}$	$3.6\pm0.5\times10^{-5}$
	10/07/82	$0.4\pm1.4\times10^{-5}$(DL)	$-4\pm2\times10^{-5}$(DL)
	01/24/83	$1.1\pm0.3\times10^{-4}$	$2\pm2\times10^{-5}$(DL)
	04/11/83	$3.5\pm0.5\times10^{-4}$	$3\pm2\times10^{-5}$(DL)
	07/14/83	$1.9\pm0.4\times10^{-4}$	$6\pm2\times10^{-5}$
	10/10/83	$1.31\pm0.09\times10^{-3}$	$1.9\pm0.3\times10^{-4}$
	01/08/85	$8\pm3\times10^{-5}$(DL)	$0.9\pm1.5\times10^{-5}$(DL)
	07/12/85	$2.7\pm0.5\times10^{-4}$	$0.5\pm0.2\times10^{-4}$(DL)
47	04/09/82	$5\pm3\times10^{-6}$(DL)	$2\pm2\times10^{-6}$(DL)
	10/17/83	$5.0\pm0.6\times10^{-4}$	$2\pm2\times10^{-5}$(DL)

Sodium.--From 1953 to February 1984, the discharge of sodium in wastewater to the ICPP disposal well was generally uniform. The wastewater contained an average annual sodium concentration of 103 mg/L. In 1984, about 72 percent of the sodium in ICPP wastewater was discharged to the new disposal ponds and 28 percent was discharged to the disposal well. In 1985, nearly 100 percent of the sodium was discharged to the ponds. The average sodium concentration in wastewater discharged in 1982 was 107 mg/L; the sodium concentration declined to 15 mg/L in 1985 because of increased wastewater volume and decreased sodium disposal in 1984 and 1985.

The background concentration of sodium in the regional aquifer is from 8 to 10 mg/L (Robertson and others, 1974). The distribution of sodium in the Snake River Plain aquifer for October 1984 is shown in figure 31. The areal extent of the ICPP sodium plume is 6.8 mi^2, about the same size as the October 1981 plume shown by Lewis and Jensen (1985). For 1982-84, however, average concentrations of sodium decreased by 30 to 40 mg/L near the disposal well and by about 20 mg/L immediately south of the ICPP. The decrease in the sodium concentration is the result of the change in disposal method from the disposal well to disposal ponds.

The concentration of sodium in that part of the aquifer affected by waste disposal at the NRF depends on the concentration of sodium in the wastewater. The correlation between the sodium disposal rates and sodium concentration in water from wells near the NRF is shown in table 4.

Table 4.--Comparison of sodium in wastewater at the NRF to sodium in water from selected monitoring wells

	Volume of wastewater (thousands of gallons)	Sodium concentration, in milligrams per liter						
		Waste water	Well					
Year			NRF 1	NRF 2	NRF 3	97	98	99
1982	110,962	114.	23.	47.	21.	9.	9.	10.
1983	76,101	79.	9.	14.	8.	9.	7.	9.
1984	115,412	154.	14.	36.	15.	14.	10.	11.
1985	71,015	95.	--	--	--	13.	10.	12.

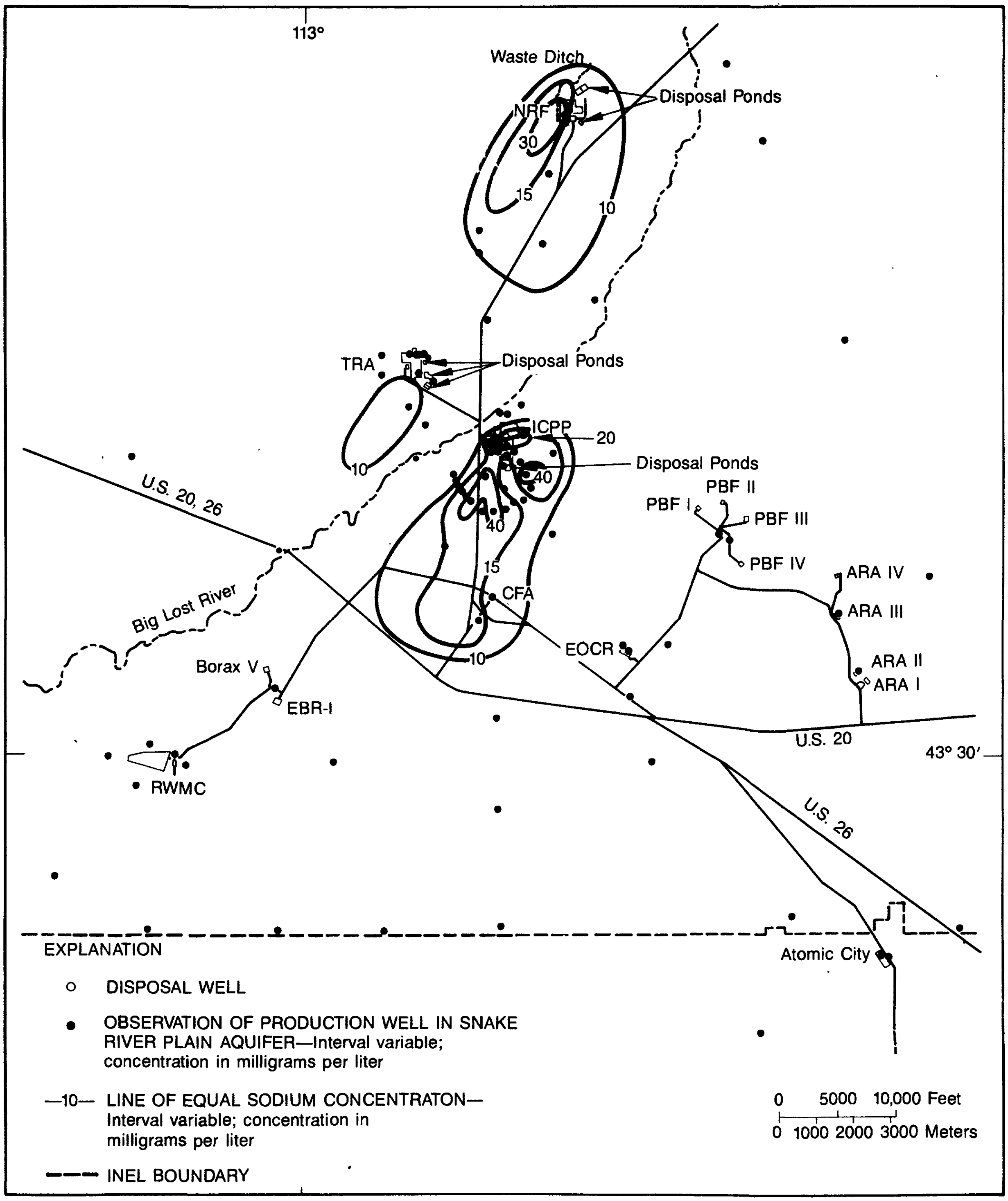


Figure 31.--Distribution of sodium in the Snake River Plain aquifer in the south-central part of the INEL, October 1984.

The concentration of sodium in that part of the aquifer affected by waste disposal at the TRA has changed little since the 1981 conditions described by Lewis and Jensen (1985). Even though the average annual disposal decreased from 101,000 lbs for 1979-81 to 85,000 lbs for 1982-85, large disposal rates of 113,000 lbs in 1984 and 123,000 lbs in 1985 maintained the sodium plume size.

From 1982 to 1985, water from wells 87, 88, and 89, near the RWMC, contained sodium concentrations larger than the background level of 10 mg/L. Sodium concentrations have fluctuated in water from these wells. One possible cause for these fluctuations is the method used to construct the wells. During construction, the wells were pressure-cemented to prevent water from cascading from perched zones down to the Snake River Plain aquifer through the annular space between the wall of the borehole and well casing. Analyses of water samples from well 88 collected before and after pressure cementing the annular space between the wall of the borehole and the casing are shown in table 5; also see figure 34 and section entitled "specific conductance".

Table 5.--Chemical and physical properties of water from well 88 before and after pressure cementing the annular space

[Analytical results are in milligrams per liter except as noted]

Date	Calcium	Sodium	Potassium	Carbonate	Hydroxide	Chloride
09/17/71	29	43	7.5	0	0	66
08/20/72	40	230	20	25	40	280

Date	Dissolved Solids	Sodium (percent)	Specific conductance ($\mu S/cm$)	pH units
09/17/71	330	37	522	7.7
08/20/72	737	80	1,650	11.4

The chemical makeup of the cement may affect the concentration of sodium and other constituents in water from these wells. Well 88, for example, is cemented to a depth of 587 ft below land surface. Historically, when the water level in this well rises above the level of the cement, the concentration of sodium in the water increases. Another possible explanation for the sodium fluctuations is that part of the waste material buried at the RWMC has migrated to the aquifer. About 27,600 gal of sodium and sodium compounds were buried at the RWMC (P.T. Laney, written commun., 1988). Local flooding of the RWMC occurred in 1962, 1969, and 1982 as a result of snowmelt and rainfall. The floodwater may have mobilized and transported the sodium to the aquifer.

Total chromium.--Chromium was discharged directly to the Snake River Plain aquifer through the TRA disposal well from November 1964 to 1972. Chromium also was discharged to the TRA radioactive-waste disposal ponds from 1952 to 1964 and is present in the underlying deep perched ground-water zone (Lewis and Jensen, 1985). In October 1984, total chromium in concentrations larger than 50 μg/L was detected in water from six wells with dedicated pumps. Water from FET-2, a production well at TAN, contained 100 μg/L of total chromium. Water from NRF-2, a production well at the NRF, contained 60 μg/L of total chromium. Water from wells 87, 88, and 89 (see figure 28 for well locations), contained total chromium concentrations of 90, 55, and 55 μg/L, respectively. From 1982 to 1985, the water from well 65 contained from 280 to 460 μg/L of total chromium; well 65 is sampled quarterly.

Chloride.--The average concentration of chloride in water discharged to the ICPP disposal well and ponds during 1982-85 was 176 mg/L and the average concentration discharged to the NRF waste ditch was 159 mg/L. The background concentration of chloride in the Snake River Plain aquifer in the south-central part of the INEL is between 8 and 15 mg/L (Robertson and others, 1974).

The distribution of chloride in the Snake River Plain aquifer for October 1984 is shown in figure 32. The chloride plume (Lewis and Jensen, 1985) has been breached because of recharge received from flow in the Big Lost River during 1982-84.

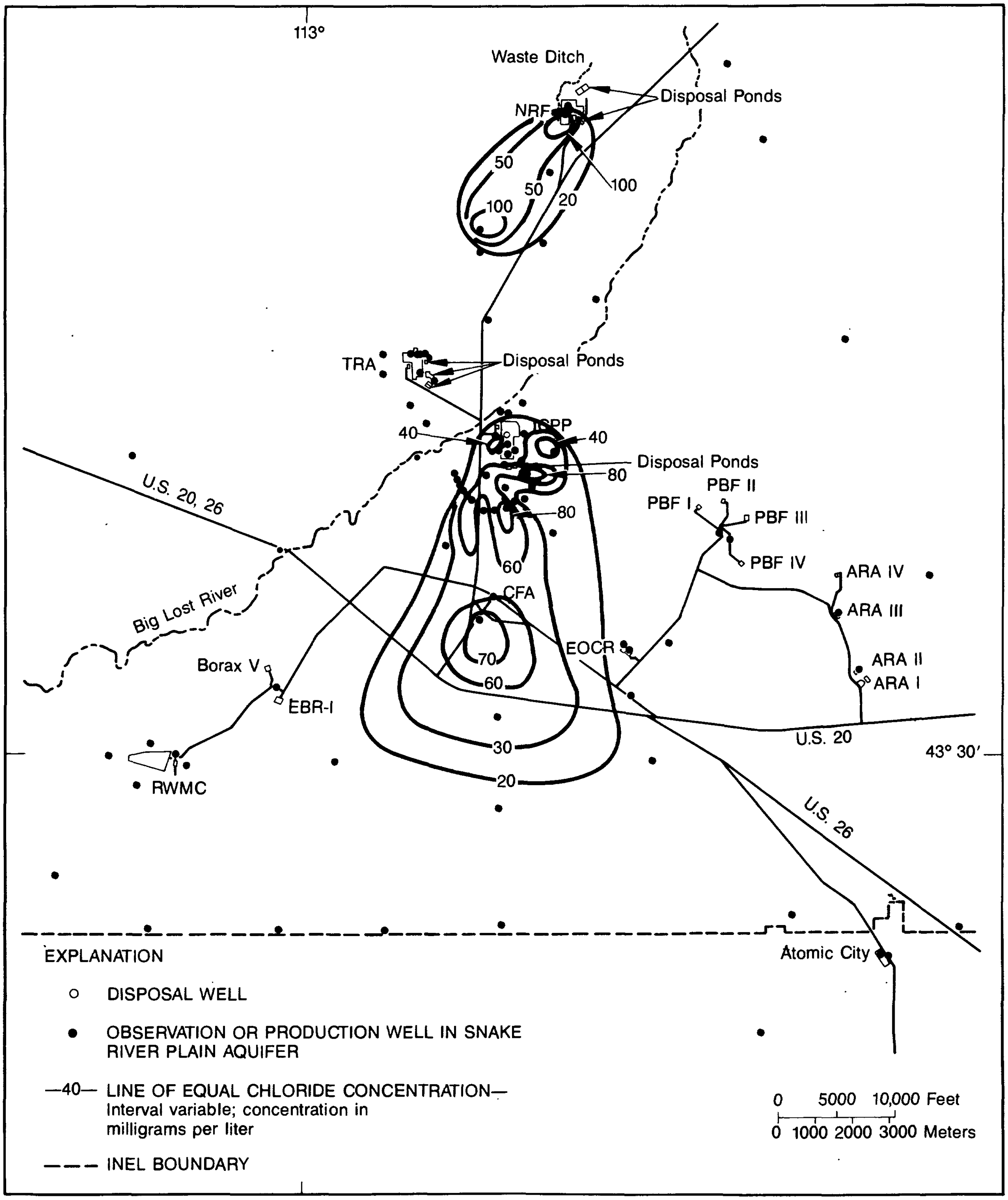


Figure 32.--Distribution of chloride in the Snake River Plain aquifer in the south-central part of the INEL, October 1984.

Chloride concentrations in ground water near the ICPP disposal well declined as much as 70 mg/L during 1982-84. Concentrations decreased from 10 to 40 mg/L immediately south of the ICPP because of the decrease in chloride disposal rates and the change from disposal well to disposal pond. Annual chloride disposal averaged 894,000 lbs during 1979-81 and 735,000 lbs during 1982-85.

The extent and concentration of chloride in that part of the aquifer affected by the disposal of waste at the NRF has increased since 1981. However, the average annual concentration of chloride in the wastewater declined from 219 mg/L during 1979-81, to 159 mg/L during 1982-85. The lag in response of aquifer water chemistry to disposal practices suggests the presence of a perched ground-water zone underlying the NRF but its presence has not been confirmed.

In October 1984, water from wells 88 and 89, near the RWMC, also had chloride concentrations above the background levels. The concentrations were 98 and 26 mg/L, respectively, and may result from the same processes described in the section entitled "sodium".

Sulfate.--The ICPP disposed of significantly larger amounts of sulfate during 1982-85 than during 1979-81. The average annual discharge of sulfate at the ICPP during 1979-81, was 146,000 lbs as compared to 575,000 lbs during 1982-85. For the same periods, average annual discharge of sulfate at the TRA decreased from 1,318,000 to 1,021,000 lbs. The average annual discharge of sulfate at the NRF decreased slightly; 366,000 lbs for 1979-81, and 313,000 lbs for 1982-85. The background concentration of sulfate in the Snake River Plain aquifer is about 10 to 30 mg/L in the south-central part of the INEL (Robertson and others, 1974).

Sulfate plumes were not distinguishable from background concentrations in the aquifer except for a few isolated areas. Wells NRF-1, NRF-3, and 97 yielded water with sulfate concentrations slightly larger than background levels. Water from NRF-2 contained 67 mg/L of sulfate. This indicates that sulfate has migrated from the NRF waste ditch to the aquifer and about 1 mi downgradient. Water from well 65 contained 140 mg/L of sulfate which indicates the sulfate has migrated 0.6 mi from the TRA disposal sites. Sulfate discharged to the NRF waste ditch and the TRA disposal well and ponds is probably diluted by underflow in the aquifer or recharge from water in disposal ponds and the Big Lost River.

Wells 88 and 89 at the RWMC also yielded water with larger-than-background concentrations of sulfate. Again, the concentrations may be the result of the same conditions discussed in the section entitled "sodium".

Nitrate.--Wastewater containing nitrate was disposed of through the ICPP disposal well from 1952 to February 1984. Beginning in February 1984, most of the wastewater was discharged to the new disposal ponds. The background level for nitrate in the Snake River Plain aquifer is generally less than 5 mg/L (Robertson and others, 1974). From 1979 to 1981, an average of 298,000 lbs/year of nitrate was discharged to the disposal wells; the average concentration of nitrate in the wastewater was 83 mg/L. For 1982-85, the average annual amount of nitrate disposal decreased to 274,000 lbs; the average concentration of nitrate in the wastewater was 73 mg/L.

Nitrate concentrations in the Snake River Plain aquifer in the south-central part of the INEL for October 1984 are shown in figure 33. During 1981-84, the nitrate concentrations decreased in water from wells near the ICPP disposal well because of the change in disposal techniques. For example, nitrate concentrations in water from well 43 declined from 62 mg/L in October 1981 (Lewis and Jensen, 1985) to 14 mg/L in October 1984. Nitrate concentrations in water from wells near the ICPP ranged from less than 5 to 26.9 mg/L.

In October 1981, nitrate concentrations in water from wells near the TRA and NRF were less than 5 mg/L. In October 1984, the nitrate plume near the NRF extended about 4.3 mi south of the NRF, and had an area of about 6 mi^2. The concentration of nitrate in water from the aquifer near the NRF ranged from 5.1 mg/L at the Fire Station-2 well to 19.0 mg/L at well WS-1.

Generally, water from wells near the TRA and RWMC contained less than 5 mg/L of nitrate. Water from wells 48, 65, and 75, near the TRA, contained

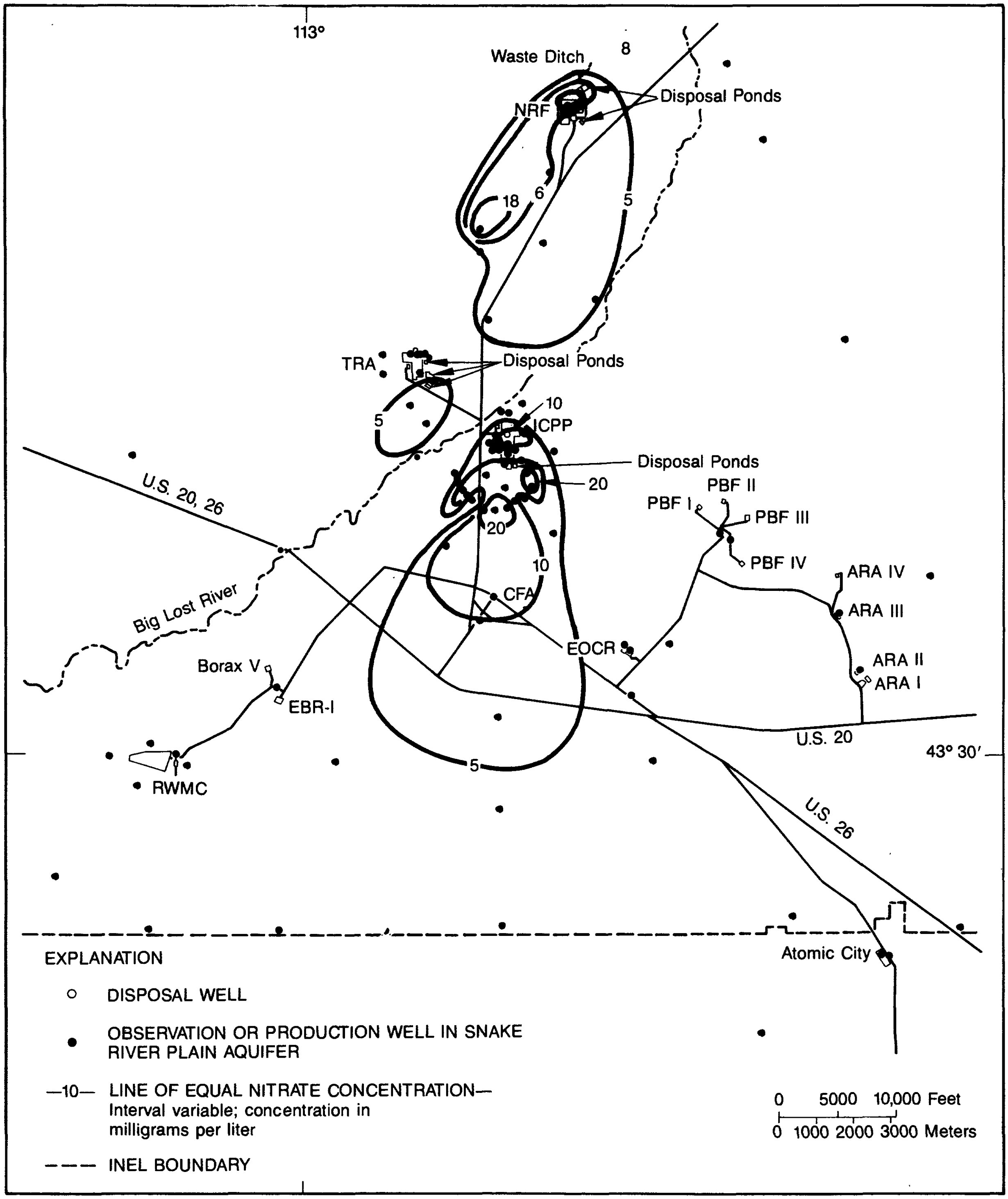


Figure 33.--Distribution of nitrate in the Snake River Plain aquifer in the south-central part of the INEL, October 1984.

nitrate concentrations of 5.2, 5.8 and 5.1 mg/L, respectively. Water from well 89 near the RWMC contained 7 mg/L of nitrate. The combined areal distribution of nitrate plumes near the TRA, NRF, and ICPP approximately doubled from 10 mi^2 in October 1981 (Lewis and Jensen, 1985) to 21 mi^2 in October 1984.

Nitrate concentrations in excess of 5 mg/L were evident in wells 4 and 32 (see fig. 3 for well locations) near the northeast boundary of the INEL. Water from these two wells contained nitrate concentrations of 11.9 and 6.2 mg/L, respectively. These larger-than-background concentrations may have resulted from fertilizer application.

Mercury and lead.--In October 1984, water from three wells in the Snake River Plain aquifer contained detectable concentrations of dissolved mercury. Water from wells 41 and 36 near the ICPP and EBR-I (see figure 28 for well locations) contained 0.2 μg/L of mercury; the reporting level for the analytical method used for mercury was 0.2 μg/L.

In October 1984, dissolved lead was detected in water samples from 108 INEL wells. Lead concentrations ranged from less than one to 24 μg/L, and probably reflect natural levels in the aquifer.

Physical Properties of Water in the Snake River Plain Aquifer

Specific Conductance.--Since operations began in the 1950's, wastewater disposal at the ICPP, TRA, and NRF has increased the specific conductance of ground water in the Snake River Plain aquifer (fig. 34). The background specific conductance of water from the Snake River Plain aquifer generally ranges from about 300 to 325 μS/cm in the TRA-ICPP-CFA area (Robertson and others, 1974). From 1982 to 1985, wastewater from the ICPP, TRA, and NRF contained combined annual averages of about 499,000 lbs of sodium, 864,000 lbs of chloride, and 1,909,000 lbs of sulfate (table 6); an annual average of about 274,000 lbs of nitrate was also contained in ICPP wastewater during this period. The specific conductance of water in the aquifer decreased from 1981 to 1985 because of increased ground-water recharge from the Big

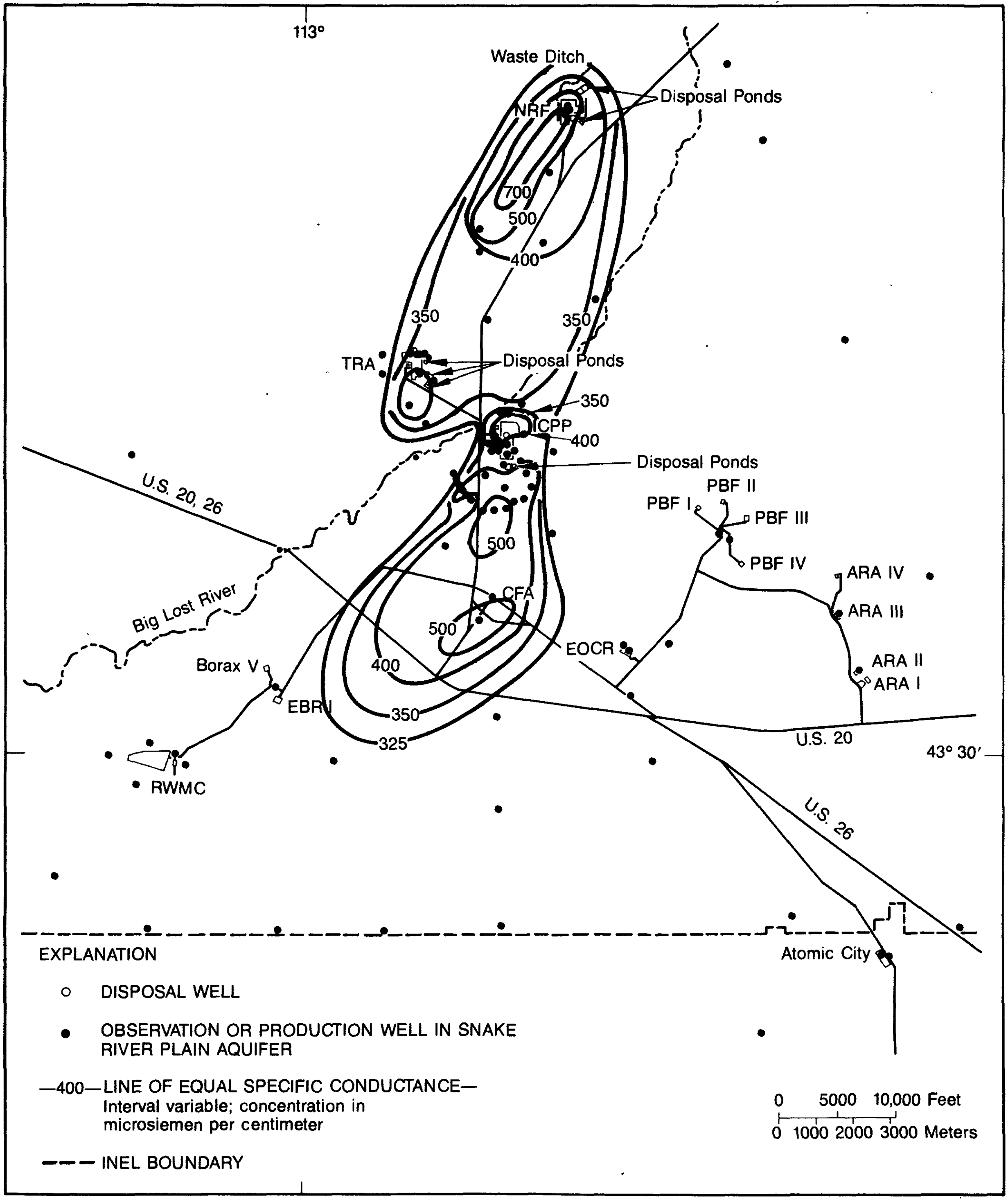


Figure 34.--Specific conductance of water in the Snake River Plain aquifer in the south-central part of the INEL, October 1985.

Lost River and the change in disposal techniques. The total area in which the specific conductance exceeds background levels decreased from 28 mi^2 in October 1981 (Lewis and Jensen, 1985) to 26 mi^2 in October 1985.

Table 6.--Average annual pounds of constituents in wastewater at the ICPP, TRA, and NRF, 1979-81 and 1982-85

	ICPP		TRA		NRF	
Constituent	1979-81	1982-85	1979-81	1982-85	1979-81	1982-85
Sodium	397,000	324,000	101,000	85,000	168,000	90,000
Chloride	894,000	735,000	1,540	2,000	217,000	127,000
Sulfate	146,000	575,000	1,318,000	1,021,000	366,000	313,000
Nitrate	298,000	274,000	--	379	--	--

Analyses of water from observation and production wells that tap the aquifer near the TRA show that the specific conductance of the the water remained fairly constant from 1982 to 1985. In the ICPP area, however, the specific conductance of the water decreased because of the change in disposal techniques. These changes were most evident near the ICPP disposal well and immediately south of the ICPP. The specific conductance of water from wells near the ICPP disposal well declined about 300 μS/cm from October 1981 to October 1985, and the specific conductance of water from wells south of the ICPP declined about 200 μS/cm.

The specific conductance of water near the NRF increased from 1981 to 1985 because of the increase in the ratio of the constituents in the wastewater to the volume of wastewater; for 1979-81 the ratio was 0.005 lbs/gal and for 1982-85 the ratio was 0.0056 lbs/gal.

From 1982 to 1985, there were large fluctuations in the specific conductance of water from wells 87, 88, 89, and 90 near the RWMC. The specific conductance of water from wells 87, 89, and 90 ranged from 240 to 490 μS/cm. However, the specific conductance of water from well 88 ranged from 330 to 668 μS/cm. Well 88, as described in the section entitled "sodium", is cemented to a depth of 587 ft below land surface; the correlation between water level and specific conductance for well 88 is shown in fig. 35.

Temperature and pH.--In October 1984, the temperature of water pumped from the Snake River Plain aquifer ranged from 11.4 °C for well ORME to 17.9 °C for well 47 at the ICPP (see figure 28 for well locations). The average temperature of the water was 13.6 °C.

In October 1984, the pH of water from wells that tap the Snake River Plain aquifer ranged from 8.2 to 8.6 with a median of 8.4. The largest pH value, 8.6, was for water samples from wells 43 and TAN production 2. The smallest pH value, 8.2, was for water samples from wells TRA production 1, FET-2, GIN-2, and 88. There was no apparent large influence of INEL activities on aquifer water pH.

SUMMARY

Recharge to the Snake River Plain aquifer from the Big Lost River for 1982-85 was large when compared to previous years. The average flow of the Big Lost River below Mackay Reservoir is about 227,500 acre-ft/year based on 69 years of discharge records. The annual flows during 1982-85 ranged from 262,000 to 476,000 acre-ft and the flow at the INEL diversion was continuous from April 1982 to December of 1985.

The altitude of the water table for the Snake River Plain aquifer ranged from 4,585 ft above sea level in the north to 4,429 ft in the south. The average water-table gradient was about 4 ft/mi to the south-southwest. The reported velocities of ground water flow in the aquifer ranged from 5-20 ft/day. Recharge from the Big Lost River and other streams, to the north of the INEL, caused the water table to rise from 3 to 16 feet between 1982 and 1985.

From 1982 to 1985, an average of 2.1 billion gal/year or 5.8 million gal/day of water was withdrawn by production wells at the INEL. Records

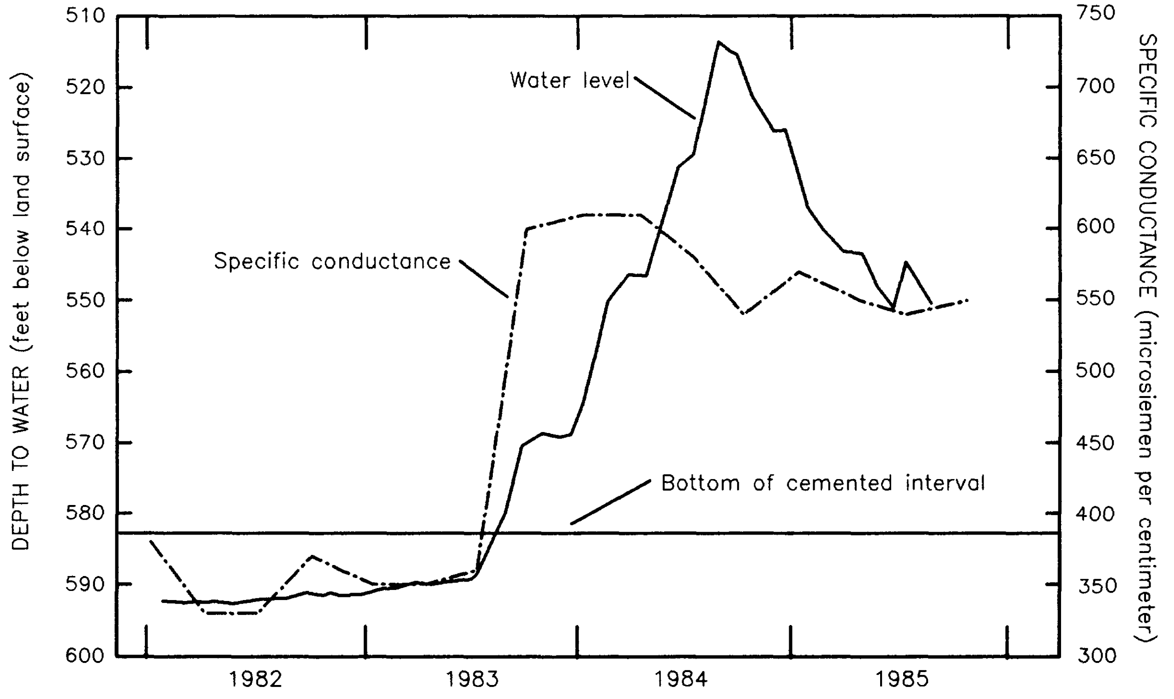


Figure 35.--Depth to water and specific conductance of water in well 88, January 1982 to December 1985.

indicate that about 63 percent of the pumpage was disposed to wells and ponds.

The TRA used ponds to dispose of about 276 million gal/year of wastewater from 1982 to 1985. A perched ground-water zone has formed about 50 to 100 ft below land surface because of infiltration from the waste-disposal ponds. In October 1985, the perched ground-water contained up to 1,770±30 pCi/mL of tritium, 0.36±0.05 pCi/mL of cobalt-60, and several non-radioactive chemicals. The areal extent of the perched ground-water zone increased between 1981 and 1985 because of changes in cold-waste disposal methods from disposal well to seepage ponds, and an increase in recharge from the Big Lost River. The concentrations of the radionuclides in the perched ground water have generally decreased during 1982-85 because of a reduction in their rates of disposal to the ponds. A notable exception is the tritium concentration which has increased significantly. This increase may be related to an increase in the overall yearly discharge rate of tritium to the ponds.

Chromium-51 discharged to the radioactive-waste disposal ponds at the TRA decreased from 2,298 Ci during 1979-81 to 83 Ci during 1982-85. One water sample collected from well 53 in April 1983 contained 4.95±0.64 pCi/mL of chromium-51. Because of the reduction in the amount of chromium-51 discharged, and its half-life of 27.8 days, chromium-51 was not detected in samples from wells in the deep perched ground-water zone near the TRA during 1984 and 1985.

Until February 1984, the ICPP discharged low-level radioactive and chemical waste directly to the Snake River Plain aquifer through a 600-ft deep disposal well. Beginning in February 1984, wastewater was disposed to a pond. A perched ground-water zone developed at the ICPP because of infiltration from the pond. From 1982 to 1985, the pond and well were used to dispose of 1,088 Ci of tritium; tritium accounted for 99 percent of total radioactivity. The average yearly discharge of wastewater was about 515 million gal.

The NRF used a waste ditch to annually discharge about 93 million gal of wastewater during 1982-85. During this time, the waste ditch was used to dispose of about 313,000 lbs of sulfate, 127,000 lbs of chloride, and 90,000 lbs of sodium annually.

Radionuclides are reduced in concentration because of radioactive decay, dilution, dispersion, and possibly sorption in the Snake River Plain aquifer. Waste plumes have been delineated in the south-central part of the INEL that contain tritium, strontium-90, sodium, chloride, and nitrate; all have similar configurations. The plumes generally follow the southwesterly direction of ground-water movement and are laterally dispersed in that part of the aquifer underlying the INEL.

In October 1985, tritium was distributed in the Snake River Plain aquifer over about 51 mi^2. Since disposal began in 1952, tritium has migrated as much as 9.1 mi downgradient from discharge points. Concentrations of tritium in water from the aquifer ranged from less than 0.9±0.3 to 93.4±2.0 pCi/mL in October 1985. Tritium concentrations near the ICPP disposal well decreased as much as 80 pCi/mL since use of the disposal well was discontinued. The largest tritium concentrations were south of the ICPP and indicate that attenuation and downgradient migration of the tritium has occurred. Analyses of water samples from well 108 indicate that tritium had migrated as far south as the INEL boundary by October 1985.

The strontium-90 waste plume covers an area of the aquifer of about 2 mi^2. Concentrations of strontium-90 in the aquifer ranged from 6±2 to 63±5 pCi/L in October 1985. Cesium-137 was detected in water samples from wells 40 and 47 that penetrate the Snake River Plain aquifer near the ICPP disposal well. The amount of cesium-137 in 8 water samples from wells 40 and 47 ranged from 125±14 to 237±45 pCi/L. Cesium-137 may be sorbed to the alluvium, sedimentary interbeds and basalt.

From 1982 to 1985, plutonium-238 and plutonium-239, -240 (undivided) were detected in water from well 40 and plutonium-238 was detected in water from well 47. Plutonium-238 concentrations were less than the detection limit in 3 of 10 samples from both wells and plutonium-239, -240 (undivided) concentrations were less than the detection limit in 5 of 8 samples from well 40. The maximum concentration of plutonium-238 was $1.31 \pm 0.09 \times 10^{-3}$ pCi/mL and the maximum concentration of plutonium-239, -240 (undivided) was 1.9±0.3 pCi/mL.

In October 1984, total chromium in concentrations greater than 50 μg/L were detected in water samples from FET-2, a production well at TAN; NRF-2, a production well at NRF, well 65 near TRA; wells 87, 88, and 89 which are near the RWMC. The specific conductance, and average concentrations of sodium and chloride in water samples from wells near the ICPP disposal well decreased from 1982 to 1984 because of the change in disposal methods from disposal well to seepage pond.

In October 1981, nitrate in ground-water from the aquifer was less than 5 mg/L near the TRA and NRF and was from less than 5 to 72 mg/L near the ICPP. In October 1985, however, nitrate concentrations ranged from less than 5 to 5.8 mg/L near the TRA; 5.1 to 19 mg/L near the NRF; and less than 5 to 26.9 mg/L near the ICPP.

SELECTED REFERENCES

Barraclough, J.T., and Jensen, R.G., 1976, Hydrologic data for the Idaho National Engineering Laboratory site, Idaho, 1971 to 1973: U.S. Geological Survey Open-File Report 75-318 (IDO-22055), 52 p.

Barraclough, J.T., Lewis, B.D., and Jensen, R.G., 1981, Hydrologic conditions at the Idaho National Engineering Laboratory, Idaho, Emphasis: 1974-1978: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-526 (IDO-22060), 116 p.

Barraclough, J.T., Robertson, J.B., and Janzer, V.J., 1976, Hydrology of the solid waste burial ground, as related to the potential migration of radionuclides, Idaho National Engineering Laboratory, with a section on drilling and sample analyses, by L.G. Saindon: U.S. Geological Survey Open-File Report 76-471 (IDO-22056), 183 p.

Barraclough, J.T., Teasdale, W.E., and Jensen, R.G., 1967, Hydrology of the National Reactor Testing Station, Idaho, 1965: U.S. Geological Survey Open File Report IDO-22048, 107 p.

Barraclough, J.T., Teasdale, W.E., Robertson, J.B., and Jensen, R.G., 1967, Hydrology of the National Reactor Testing Station, Idaho, 1966: U.S. Geological Survey Open-File Report IDO-22049, 95 p.

Cassidy, G.B., 1983a, Idaho National Engineering Laboratory radioactive waste management information for 1982: U.S. Department of Energy, Waste Programs Division, Idaho Operations Office Publication, DOE/ID-10055 (82), 276 p.

----- 1983b, Idaho National Engineering Laboratory industrial waste management information for 1982 and record-to-date: U.S. Department of Energy, Waste Programs Division, Idaho Operations Office Publication, DOE/ID-10057 (82), 100 p.

----- 1984a, Idaho National Engineering Laboratory radioactive waste management information for 1983: U.S. Department of Energy, Waste Management Programs Division, Idaho Operations Office Publication, DOE/ID-10055 (83), 272 p.

----- 1984b, Idaho National Engineering Laboratory industrial waste management information for 1983 and record-to-date: U.S. Department of Energy, Waste Management Programs Division, Idaho Operations Office Publication, DOE/ID-10057 (83), 99 p.

Cleveland, J.M., and Rees, T.F., 1982, Characterization of plutonium in ground water near the Idaho Chemical Processing Plant: Environmental Science and Technology, July 1982, p. 437-439.

Druffel, Leroy, Stiltner, G.J., and Keefer, T.N., 1979, Probable hydrologic effects of a hypothetical failure of Mackay Dam on the Big Lost River valley from Mackay, Idaho, to the Idaho National Engineering Laboratory: U.S. Geological Survey Water-Resources Investigations 79-99 (IDO-22058), 47 p.

Humphrey, T.G., and Tingey, F.H., 1978, The subsurface migration of radionuclides at the Radioactive Waste Management Complex, 1976-1977: U.S. Department of Energy, Idaho Operations Office Publication, TREE-1171, 98 p.

Idaho Department of Health and Welfare, 1977, Idaho regulations for public drinking water systems: Idaho Department of Health and Welfare, Division of Environment Publication, Title 1, Chapter 8, 44 p.

Jones, P.H., 1961, Hydrology of waste disposal, National Reactor Testing Station, Idaho, an interim report: U.S. Atomic Energy Commission, Idaho Operations Office Publication, IDO-22042-USGS, 152 p.

Lamke, R.D., 1969, Stage-discharge relations on Big Lost River, within National Reactor Testing Station, Idaho: U.S. Geological Survey Open-File Report IDO-22050, 29 p.

Lewis, B.D., and Goldstein, F.G., 1982, Evaluation of a predictive ground-water solute-transport model at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigation 82-25, IDO-22062, 71 p.

Lewis, B.D., and Jensen, R.G., 1985, Hydrologic conditions at the Idaho National Engineering Laboratory, Idaho: 1979-1981 update: U.S. Geological Survey Hydrologic Investigations Atlas HA-674, 2 sheets.

Litteer, D.L., 1985a, Idaho National Engineering Laboratory radioactive waste management information for 1984: U.S. Department of Energy, Waste Management Programs Division, Idaho Operations Office Publication, DOE/ID-10055 (84), 275 p.

----- 1985b, Idaho National Engineering Laboratory industrial waste management information for 1984 and record-to-date: U.S. Department of Energy, Waste Management Programs Division, Idaho Operations Office Publication, DOE/ID-10057 (84), 98 p.

----- 1986a, Idaho National Engineering Laboratory radioactive waste management information for 1985: U.S. Department of Energy, Waste Management Programs Division, Idaho Operations Office Publication, DOE/ID-10055 (85), 310 p.

----- 1986b, Idaho National Engineering Laboratory industrial waste management information for 1985 and year-to-date: U.S. Department of Energy, Waste Management Programs Division, Idaho Operations Office Publication, DOE/ID-10057 (85), 95 p.

Mann, L.J., 1986, Hydraulic properties of rock units and chemical quality of water for INEL-1--a 10,365-foot deep test hole drilled at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 86-4020, DOE/ID-22070, 23 p.

Morris, D.A., Barraclough, J.T., Chase, G.H., Teasdale, W.E., and Jensen, R.G., 1965, Hydrology of subsurface waste disposal, National Reactor Testing Station, Idaho, annual progress report, 1964: U.S. Atomic Energy Commission, Idaho Operations Office Publication, IDO-22047-USGS, 186 p.

Morris, D.A., Barraclough, J.T., Hogenson, G.M., Shuter, Eugene, Teasdale, W.E., Ralston, D.A., and Jensen, R.G., 1964, Hydrology of subsurface waste disposal, National Reactor Testing Station, Idaho, annual progress report, 1963: U.S. Atomic Energy Commission, Idaho Operations Office Publication, IDO-22046-USGS, 97 p.

Morris, D.A., Hogenson, G.M., Shuter, Eugene, and Teasdale, W.E., 1963, Hydrology of waste disposal, National Reactor Testing Station, Idaho, annual progress report, 1962: U.S. Atomic Energy Commission, Idaho Operations Office Publication, IDO-22044-USGS, 99 p.

Mundorff, M.J., Crosthwaite, E.G., and Kilburn, Chabot, 1964, Ground water for irrigation in the Snake River Basin in Idaho: U.S. Geological Survey Water-Supply Paper 1654, 224 p.

Olmsted, F.H., 1962, Chemical and physical character of ground water in the National Reactor Testing Station, Idaho: U.S. Atomic Energy Commission, Idaho Operations Office Publication, IDO-22043-USGS, 142 p.

Polzer, W.L., Percival, D.R., and Barraclough, J.T., 1976, Special analyses for plutonium and americium in water from the Snake River Plain aquifer: U.S. Department of Energy, Idaho Operations Office Publication, IDO-12081-USGS, 9 p.

Robertson, J.B., 1974, Digital modeling of radioactive and chemical waste transport in the Snake River Plain aquifer at the National Reactor Testing Station, Idaho: U.S. Geological Survey Open-File Report IDO-22054, 41 p.

----- 1977, Numerical modeling of subsurface radioactive solute transport from waste-seepage ponds at the Idaho National Engineering Laboratory: U.S. Geological Survey Open-File Report 76-717 (IDO-22057), 68 p.

Robertson, J.B., and Barraclough, J.T., 1973, Radioactive- and chemical-waste transport in ground water at the National Reactor Testing Station, Idaho: 20-year case history and digital model: Underground Waste Management and Artificial Recharge, v. 1, p. 291-322.

Robertson, J.B., Schoen, Robert, and Barraclough, J.T., 1974, The influence of liquid waste disposal on the geochemistry of water at the National Reactor Testing Station, Idaho, 1952-1970: U.S. Geological Survey Open-File Report IDO-22053, 231 p.

U.S. Environmental Protection Agency, 1976, National interim primary drinking water regulations: U.S. Environmental Protection Agency, Office of Water Supply Publication, EPA-570/9-76-003, 159 p.

Walker, E.H., 1964, Subsurface geology of the National Reactor Testing Station, Idaho: U.S. Geological Survey Bulletin 1133-E, 22 p.

Zohdy, A.A.R., and Stanley, W.D., 1973, Preliminary interpretation of electrical sounding curves obtained across the Snake River Plain from Blackfoot to Arco, Idaho: U.S. Geological Survey Open-File Report, 3 p.