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IMPACT OF SURFACE WATER RECHARGE ON THE DESIGN OF A GROUNDWATER MONITORING SYSTEM FOR THE RADIOACTIVE WASTE MANAGEMENT COMPLEX, IDAHO NATIONAL ENGINEERING LABORATORY

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ABSTRACT

Recent hydrogeologic studies have been initiated to characterize the hydrogeologic conditions at the Radioactive Waste Management Complex (RWMC) at the Idaho National Engineering Laboratory (INEL). Measured water levels in wells penetrating the Snake River Plain aquifer near the RWMC and the corresponding direction of flow show change over time. This change is related to water table mounding caused by recharge from excess water diverted from the Big Lost River for flood protection during high flows. Water levels in most wells near the RWMC rise on the order of 10 ft (3 m) in response to recharge, with water in one well rising over 60 ft (18 m). Recharge changes the normal south-southwest direction of flow to the east. Design of the proposed groundwater monitoring network for the RWMC must account for the variable directions of groundwater flow.

INTRODUCTION

The Idaho National Engineering Laboratory (INEL) covers about 890 mi^2 (2,320 km^2) of land in southeastern Idaho on the eastern Snake River Plain (Figure 1). The plain is situated in a structural basin that is about 200 miles (320 km) long, and 50 to 70 miles (80-110 km) wide. The land surface of the plain is relatively flat lying, semiarid, sage brush desert. The predominant relief in the area is volcanic buttes or unevenly surfaced basalt flows, flow vents, and fissures. The Snake River Plain is underlain by Idaho's largest groundwater reservoir, the Snake River Plain aquifer. The aquifer is considered to be unconfined and is defined as the continuous ground-water system underlying the eastern Snake River Plain and is generally within the basalt and interlayered sediments of the Snake River Group (Mundorff et al., 1964).

The INEL is operated by the U. S. Department of Energy (DOE) primarily to build, operate, and test nuclear reactors. It is one of the principal centers for developing uses of atomic energy. Fifty-two reactors have been constructed to date, of which twelve are still operable. In addition, a large variety of laboratory activities and test facilities are supported at the INEL such as energy, defense, environmental, and ecological research.

Research studies at the reactors and associated activities at the INEL have produced hazardous, mixed and radioactive waste which require disposal. In 1951, the Atomic Energy Commission (AEC), now the DOE, requested that the U. S. Geological Survey study the geology and hydrology of 16 square miles (41 km^2) in the southwestern part of the INEL for selection of a site suitable for the disposal of contaminated solid wastes (Barraclough et al., 1976). The "Burial Ground" was established in 1952 as a controlled area for the disposal of solid radioactive waste generated by the National Reactor Testing Station (NRTS) operations. The original

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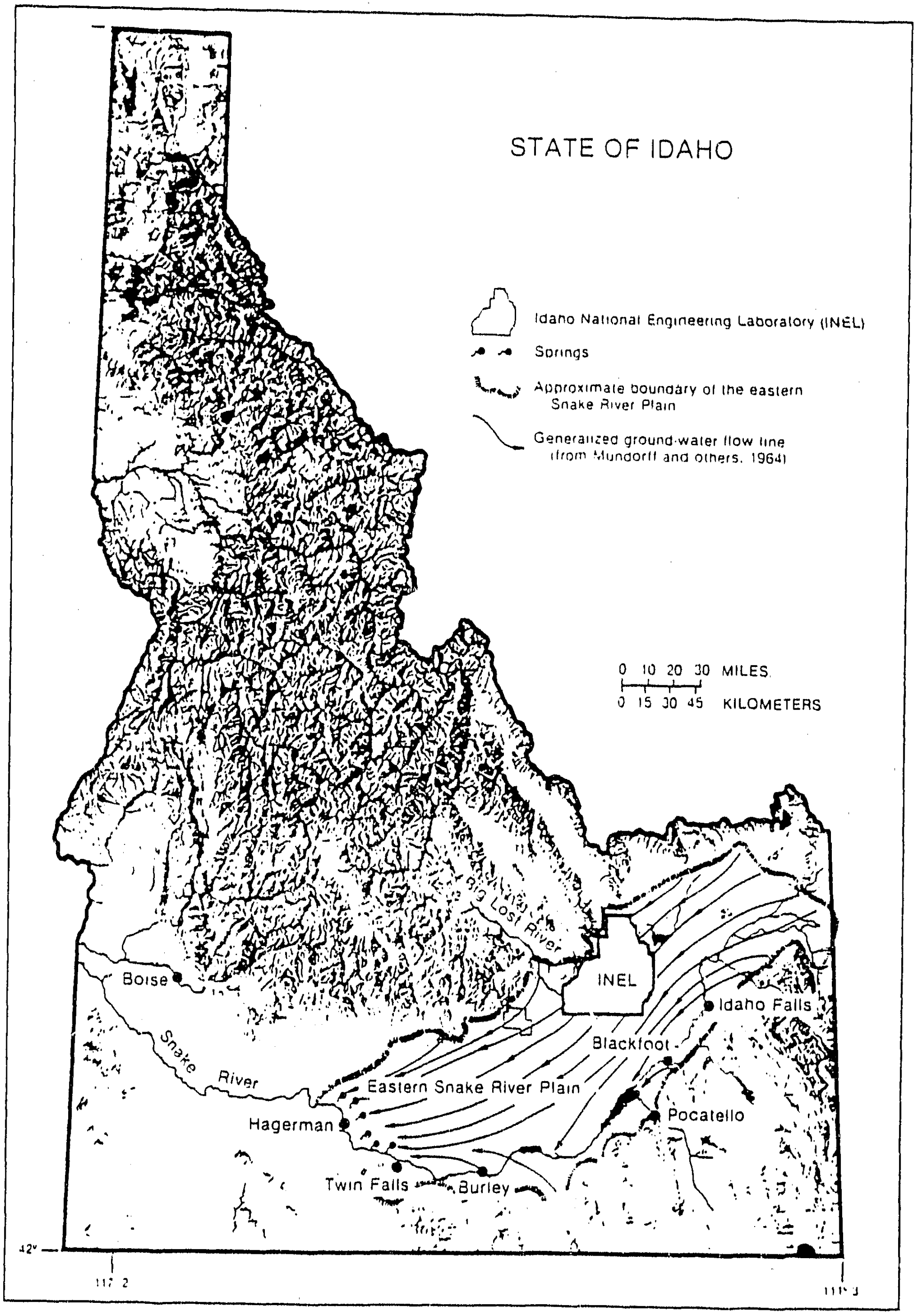

Figure 1. Location of the INEL and Snake River Plain, and generalized directions of ground-water flow in the Snake River Plain aquifer (from Barraclough et al., 1981).

site has been expanded and is presently known as the Radioactive Waste Management Complex (RWMC). The RWMC is comprised of the Subsurface Disposal Area (SDA) and the Transuranic Storage Area (TSA). The TSA was established in 1970 for storage of waste contaminated with greater than 10 nCi/g of transuranic (TRU) radionuclide activity. The original "Burial Ground" is now within the boundaries of the SDA (Vigil, 1989).

In July of 1986 the DOE Idaho Operations Office (DOE-ID) entered into a Consent Order and Compliance Agreement (COCA) with Region X of the U. S. Environmental Protection Agency (EPA). The COCA called for the implementation of an action plan for the remediation of current and past waste disposal sites at the INEL. Subsequent to the COCA, a RCRA Facility Investigation (RFI) plan was written for the SDA, and implementation began in late 1988. The purpose of initial RFI activities was to determine physical site characteristics at the SDA and to characterize hazardous, but not radiologic, contaminants found there.

This paper will discuss hydrogeologic studies that have been conducted as a part of the RFI report on the SDA. The purpose of the groundwater studies is to characterize potential contaminant pathways in the subsurface for performance assessment modeling and to design a groundwater monitoring system for the RWMC. Groundwater monitoring will evaluate the extent of groundwater contamination during the early phases of the RFI, and as the RWMC enters the post-closure phase, a network of monitoring wells will be required to ensure that containment or clean-up of contamination has been achieved.

HYDROGEOLOGY OF THE RWMC

The Snake River Plain aquifer is approximately 200 miles (320 km) long, 40 to 60 miles (64-96 km) wide, and covers an area of 9600 square miles ($2.4\text{x}10^4$ km^3). It is estimated that the aquifer contains about 400 million acre-ft ($4.9\text{x}10^{11}$ m^3) of water in storage (Barraclough, oral communication, 1989). Recharge to the Snake River Plain aquifer near the INEL is primarily in the form of infiltration from the rivers and streams draining the areas to the north, northwest, and northeast of the Snake River Plain. In most years, spring snowmelt produces surface runoff that accumulates in depressions in the basalt or in playas. Surface water flowing on to the INEL that is not lost to evaporation recharges the aquifer because most of the INEL is in a closed topographic depression. Significant recharge from runoff in the Big Lost River has been documented to cause a regional rise in the water table over much of the INEL (Pittman et al., 1988).

The altitude of the water table for the Snake River Plain aquifer and the general direction of groundwater movement in the vicinity of the INEL are depicted in Figure 2. The regional flow is to the south-southwest, although, locally, the direction of groundwater flow is affected by recharge from rivers, surface water spreading areas, and inhomogeneities in the aquifer. Across the INEL, the average gradient of the water table is approximately 4 ft/mile (0.8 m/km). Depth to water varies from about 200 ft (61 m) in the northeast corner of the INEL to 1000 ft (304 m) in the southeast corner.

Permeability in the Snake River Plain aquifer is controlled by the distribution of highly fractured basalt flow tops and interflow zones with

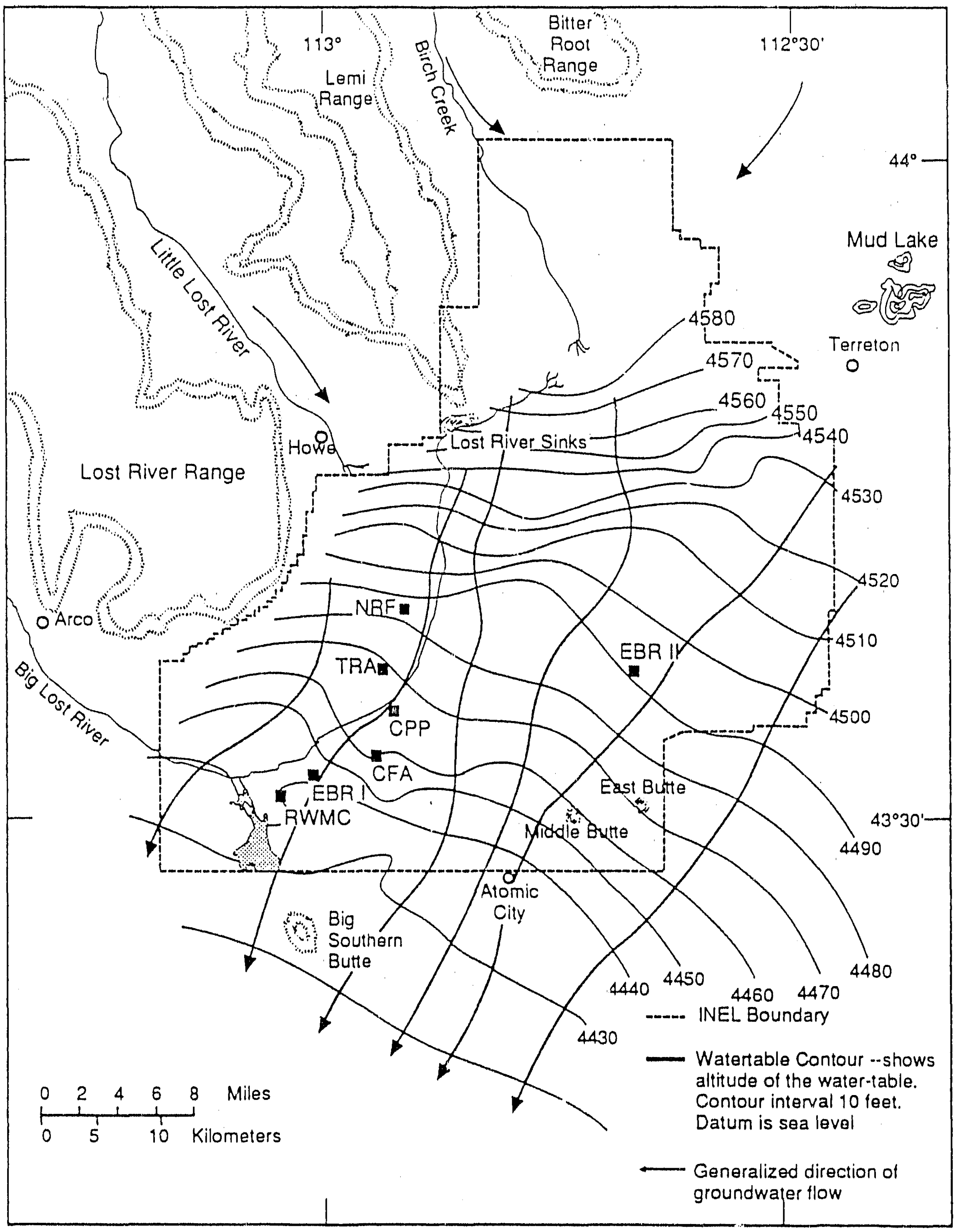

Figure 2. Altitude of the water table for the Snake River Plain aquifer and general direction of groundwater movement, July 1985 (after Pittman et al., 1988).

some additional permeability contributed by fractures, vesicles and intergranular pore spaces. The variety and degree of interconnected water bearing zones complicates the direction of groundwater movement locally throughout the aquifer (Barraclough et al., 1981). The permeability of the aquifer varies considerably over short distances, but generally, a series of flows will include several excellent water-bearing zones. If the sequence of lava flows beneath the Snake River Plain is considered to constitute a single aquifer, it is one of the world's most productive (Mundorff et al., 1964).

Wells

The USGS operates a groundwater monitoring network at the INEL. The purpose of the groundwater monitoring system is to record water levels and to monitor for contaminant migration. Seven wells have been drilled to monitor the Snake River Plain aquifer in the immediate area of the RWMC. These wells include; USGS 87, 88, 89, 90, 117, 119 and 120. The locations of the aquifer wells near the RWMC are given in Figure 3. Two production wells, the RWMC production well and EBR-1, are in near the RWMC. Several wells outside the immediate vicinity of the RWMC have been drilled to the aquifer, including USGS 8, 9, 86, 105 and 109. Many wells have been drilled and cored in the vadose zone near the RWMC, however, the shallow wells are not shown in Figure 3 since they do not provide data on the aquifer. Well logs, water levels, and water chemistry data are available at the INEL office of the USGS and in published reports.

Stratigraphy

A USGS report (Anderson and Lewis, 1989) correlates the stratigraphy at the RWMC based on 40 wells, including 8 wells drilled to the aquifer. Utilizing geophysical well logs, well cuttings, cores, K-Ar (potassium-argon) ages, and geomagnetic properties the USGS report presents interpretive cross sections, maps and tables of the stratigraphy for the RWMC. The report by Anderson and Lewis (1989) shows that the stratigraphic units are relatively continuous in the vicinity of the RWMC and folding and/or faulting are not apparent. However, stratigraphic control exists for only about the upper 100 ft (30 m) of the Snake River Plain aquifer or a total depth of 700 ft (212 m) in the vicinity of the RWMC.

Water Levels in Wells

The INEL office of the USGS has collected water levels from wells on the INEL for over 40 years. Water level data for 16 wells in the southwest corner of the INEL have been compiled from USGS field records. Hydrographs for all sixteen wells were constructed to evaluate trends in the water table fluctuations. Figure 4 is the hydrograph of USGS Wells 87, 88, 89 and 90, which were drilled in 1971 and 1972 and are located to the north, south, west and east of the RWMC, respectively.

Well hydrograph data are useful for defining the hydrologic communication between wells, recharge areas, and the relationship between recharge and water levels in wells. A later section in this paper will discuss the interpretations of the well hydrographs.

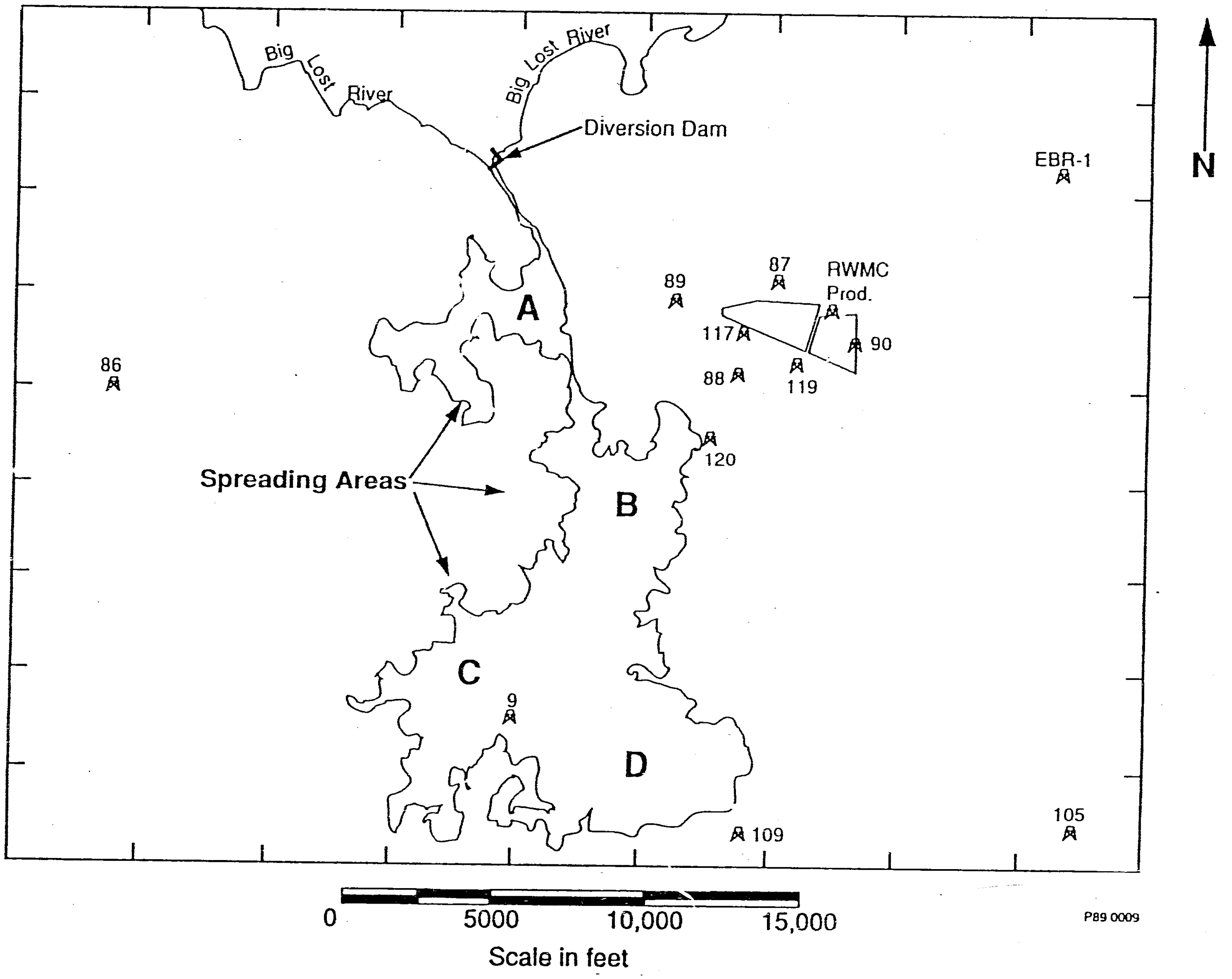

Figure 3. Location of wells in the RWMC area and Spreading Areas A, B, C and D.

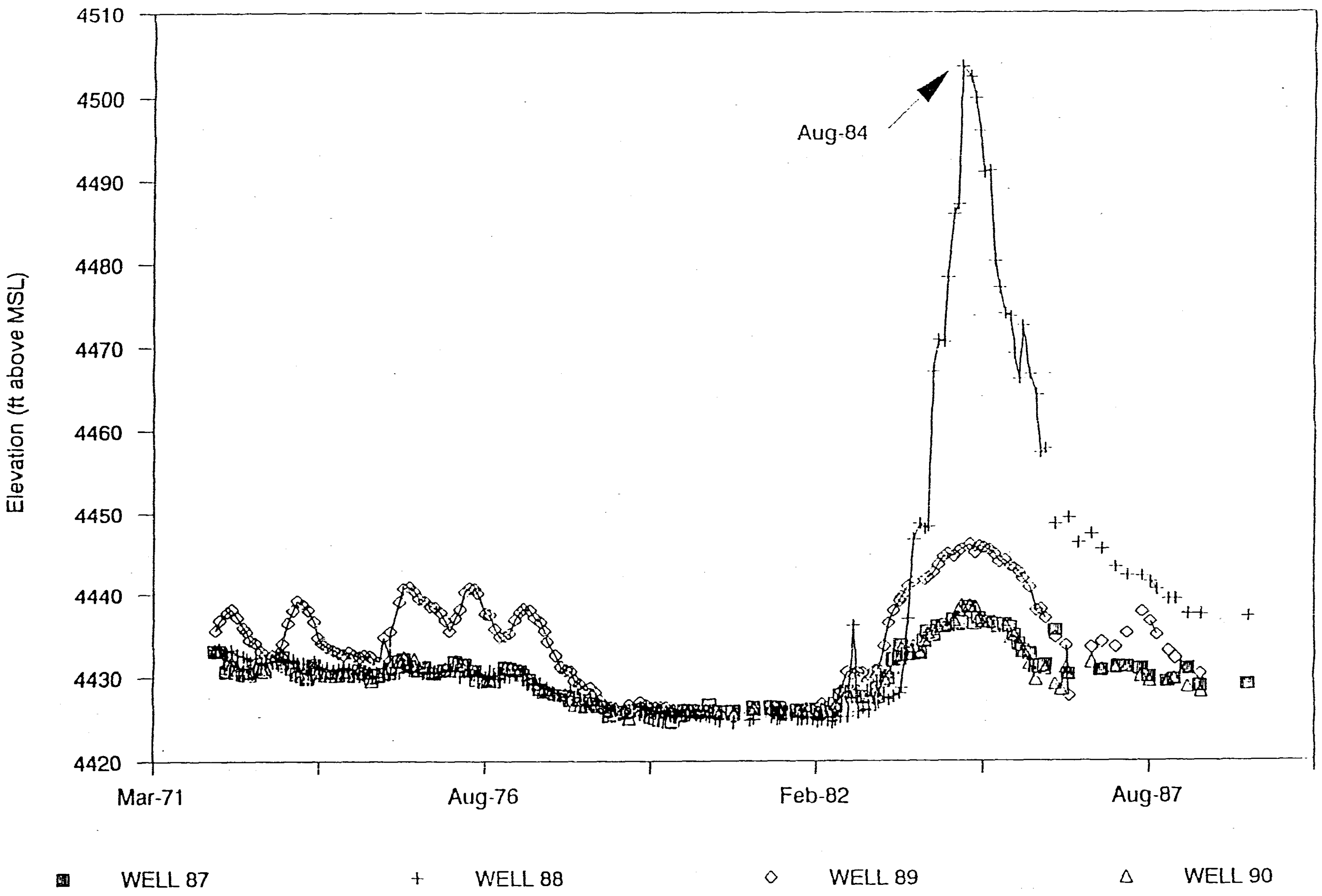

Figure 4. Well hydrographs for USGS Wells 87, 88, 89 and 90, 1972 through 1989. Based on USGS water level data.

Surface Water Discharge to Spreading Areas

The diversion system from the Big Lost River at the INEL is used to regulate flow in the Big Lost River during periods of high flow (Figure 3). Regulation is needed in order to minimize the probability of inundating several nuclear-reactor facilities, the RWMC, and many other support facilities that are located on the floodplain of the Big Lost River.

The INEL diversion system was constructed in 1958. Water diverted from the main channel of the Big Lost River is spread out or ponded on the Eastern Snake River Plain where it either evaporates or infiltrates to the aquifer. Most of the water infiltrates to the aquifer because of the high infiltration rates. The diversion area is separated into 4 spreading areas, A, B, C, and D. The combined capacity of the system is about 38,000 ac-ft ($4.7\text{x}10^7$ m^3).

The diversion system was not used until 1965 because of low flow in the Big Lost River. In 1965 the diversion channel to the spreading areas was equipped with a water level recorder, which enabled the monitoring of total discharge to the spreading areas (R. G. Jensen, oral communication, 1989). Monthly discharges to the spreading areas have been compiled for this report and the hydrograph is shown in Figure 5. The amount of water discharged to the spreading areas is dependent upon two factors, the available runoff water flowing in the Big Lost River, and the setting of the diversion gate. Since 1965 it is estimated that a total of approximately 1.2 million acre-ft ($1.5\text{x}10^9$ m^3) of water has been diverted from the Big Lost River to the spreading areas.

Discharge to the spreading areas was highest during the mid to late 1960's and the mid-1980's. Based on historic flow in the Big Lost River, these periods had higher than normal flow. Runoff measured at the station below Mackay Reservoir during 1965 was the highest for the 49 years on record prior to 1965 (Barraclough et al., 1967). After 1969, the discharge to the spreading areas was less, until the mid 1980's when again, a several years of high runoff were recorded. Starting in 1982, discharge to the spreading areas increased and peaked in 1984. Discharge to the spreading areas in 1984 was considerably higher than the previously high year of 1965. In summary, the diversion hydrograph shows two wet periods; the mid-1960's and the mid-1980's and the intervening years have had moderate to no flow.

RESPONSE OF THE WATER TABLE TO RECHARGE

A comparison of Figures 4 to Figure 5 shows the clear relationship between discharge to the spreading areas and the corresponding rise in water levels in nearby wells. Figure 4 shows the wells in the closest proximity to the RWMC with the longest record, including Wells 87, 88, 89 and 90. During the 1970's the water levels in wells 87, 88 and 90 tracked essentially the same path, all showing a gradual decline in water levels, which was probably associated with a net decline in the regional water table during the dry years of the 1970's. Well 89 is the exception to this, showing fluctuations in water levels of about 8 feet from 1972 to 1977 (see Figure 4). These fluctuations correlate to relatively small discharges to the spreading areas during the same time period. Starting in the latter part of 1982 and continuing to 1984, there was a significant rise in water levels recorded in wells as shown in Figure 4. The most

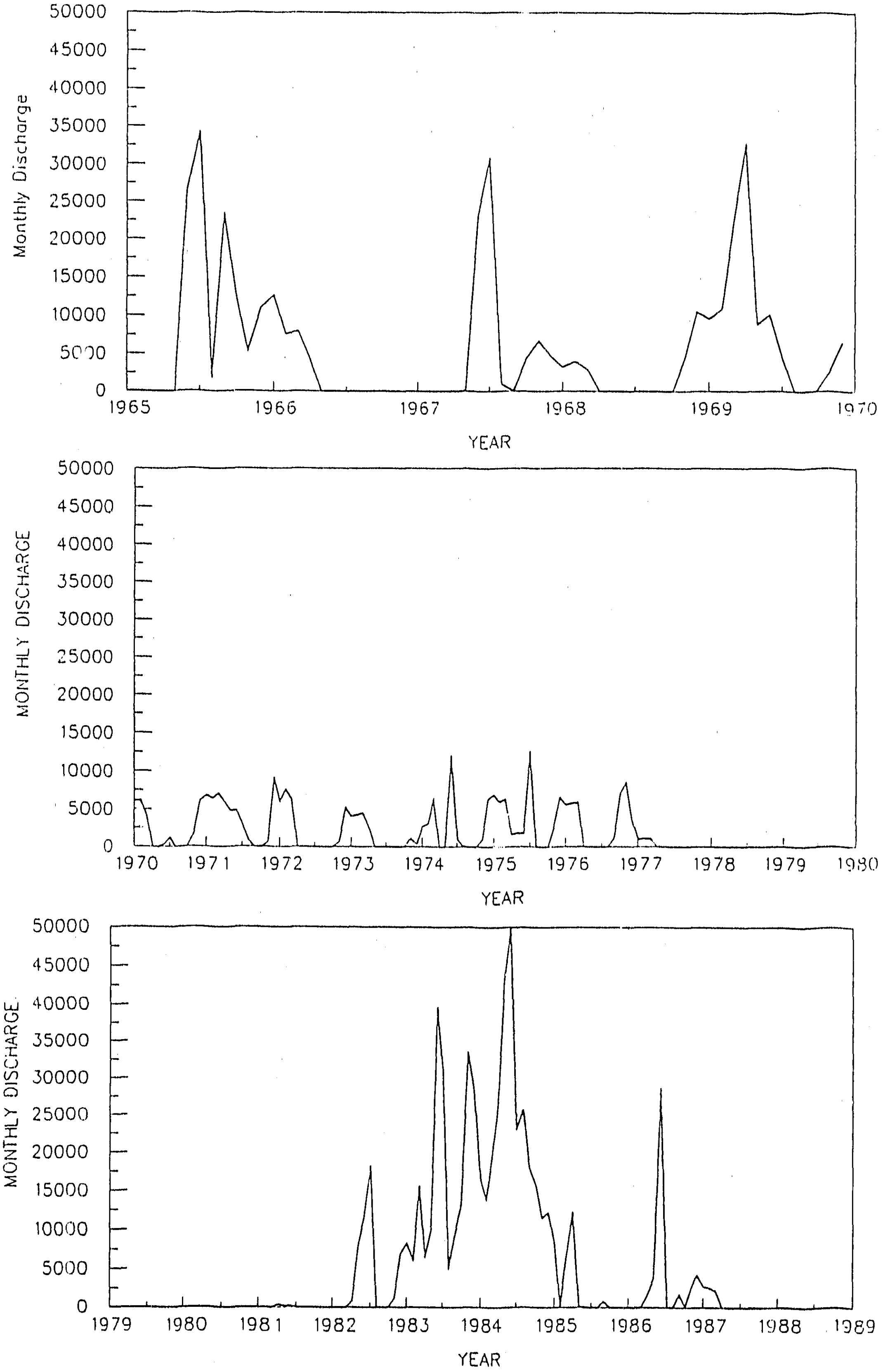

Figure 5. Monthly discharge in acre feet for INEL Diversion.

spectacular rise was recorded in well 88, with a rise of over 60 ft (18 m) relative to nearby wells. The peak of this activity occurred in 1984, corresponding to the highest discharge year on record. After 1984, the wells show a net decline in water levels, with the exception of Well 89, which showed a rise in water levels associated with the small discharge to the spreading areas in 1987.

Figure 4 illustrates the complexities of the aquifer in the vicinity of the RWMC. Four wells completed to similar depths with similar construction show marked variations in water level fluctuations. Wells 87 and 90 are apparently in good hydraulic communication since their water levels track almost identically through wet and drv cycles. Well 89 appears to be in good communication with the regional aquifer since its overall response to recharge stress is similar to that of Wells 87 and 90. Well 89 is clearly more affected by recharge to Spreading Area A than Wells 87, 88 and 90 because it responds to moderate inflow to the spreading areas (when only Spreading Area A is filled) while the other wells do not (see the early 1970's data, Figure 5). There are at least two possible explanations for Well 89 responding to moderate inflow: 1) Well 89 is the closest of the three wells to Spreading Area A; 2) Well 89 may be situated along a zone that is in good hydraulic communication with Spreading Area A.

USGS Well 88 appears to taps a zone that is in poor hydraulic communication with other nearby wells and is in good hydraulic communication with Spreading Area B. This interpretation is based on two observations; 1) the apparent lag in response to recharge compared to nearby wells and 2) the anomalous rise in water levels relative to nearby wells during high flow periods when Spreading Area B is filled. Figure 4 shows that the rise in water levels in Well 88 lagged behind the rise in Wells 87, 89 and 90 by several months. During the peak year 1984, water levels in Well 88 were about 60 feet higher than nearby wells. This implies a steep water table gradient between wells and therefore low transmissivity to maintain that gradient. The anomalous rise in water levels for this well appears to be real as hydrogeologic assessment of the available data and testing of the well indicates that the water levels measured in this well are representative of the interval of the aquifer which the well is open to, and that the well is probably not damaged or silted up (Wood, 1989). The lag time and the steep hydraulic gradient suggest that communication between Well 88 and the other wells is restricted, possibly by a zone with low transmissivity. Water elevations from Well 88 have not been included in mapping for this paper because of the apparent lack of communication between Well 88 and other wells. The area of the aquifer near Well 88 is poorly understood and is still under evaluation. Additional drilling has been recommended by EG&G Idaho, Inc. to evaluate the area of the aquifer near Well 88.

Water Table Maps

The direction of groundwater movement in the vicinity of the RWMC can be estimated from the gradient of the water table. It is apparent from the well hydrographs that the surface of the water table changes over time in response to discharge to the spreading areas and other factors. In order to track the changes in the water table over time, quarterly water table maps were generated for the RWMC area from the 1st quarter of 1980 through the first quarter of 1989 (Wood, 1989) using a computer contouring program. The computer contour maps show that in the early 1980's, the water table in the vicinity of the RWMC was flat with regular contours, apparently because of the low runoff years of the late 1970's. This regular contour interval continued until the 2nd quarter of 1983 when recharge began to affect water levels in Well 89 and a water table mound began to develop west of the RWMC. Because the well coverage is limited to just 7 wells near the RWMC, the shape and extent of the mound is only approximate. Recent water table maps indicate that the aquifer is recovering from the mounding condition and the contours are returning to the configuration of the early 1980's.

Figures 6 through 8 are water table contour maps based on data for the 1st quarter of 1989, the 3rd quarter of 1984 and the 4th quarter of 1980. These time periods represent the current configuration of the water table near the RWMC, the water table under recharge stress from the spreading areas and steady state conditions during a period of low runoff, respectively. The contour maps are presented in pairs, the first shows the regional aquifer around the RWMC and the second shows the water table in the immediate vicinity of the RWMC. All of the aquifer wells have been plotted on the regional maps, even though some wells were not drilled at the time represented by the contour map. The water table elevations for the three time periods have been included in Table 2. Flow lines have been added to the local maps to show the implied direction of groundwater flow.

The present configuration of the water table correlates with the regional direction of flow to the south-southwest. Prior to the wet years starting in 1983, the direction of flow in the aquifer near the RWMC was to the south-southwest. The water table maps indicate that the aquifer is

Table 2. Water level data for wells used to contour water level maps. Note: not all wells plotted on maps have water level measurements.

WELL	4th QTR 1980	3rd QTR 1984	1st QTR 1989
USGS 8	4430.88	4442.42	4432.08
USGS 9	4425.72	4436.10	4426.01
USGS 84*	4457.30	4463.63	4461.01
USGS 85*	4457.09	4463.42	4460.67
USGS 86	4428.82	4441.16	4428.26
USGS 87	4425.85	4438.45	4429.52
USGS 88	4424.62	4503.60**	4438.87**
USGS 89	4425.23	4446.20	4431.59
USGS 90	4425.60	4438.57	4429.54
USGS 105	4426.37	4436.29	4426.28
USGS 106	4429.93	4439.69	4431.11
USGS 108	4423.46	4433.12	4424.92
USGS 109	4424.12	4430.91	4424.48
USGS 117	n/a	n/a	4428.54
USGS 119	n/a	n/a	4428.73
USGS 120	n/a	n/a	4426.26

* Well outside of mapped area but water level used for contouring.
** Anomalous water level measurement, not used for maps.
n/a Well drilled in 1987.

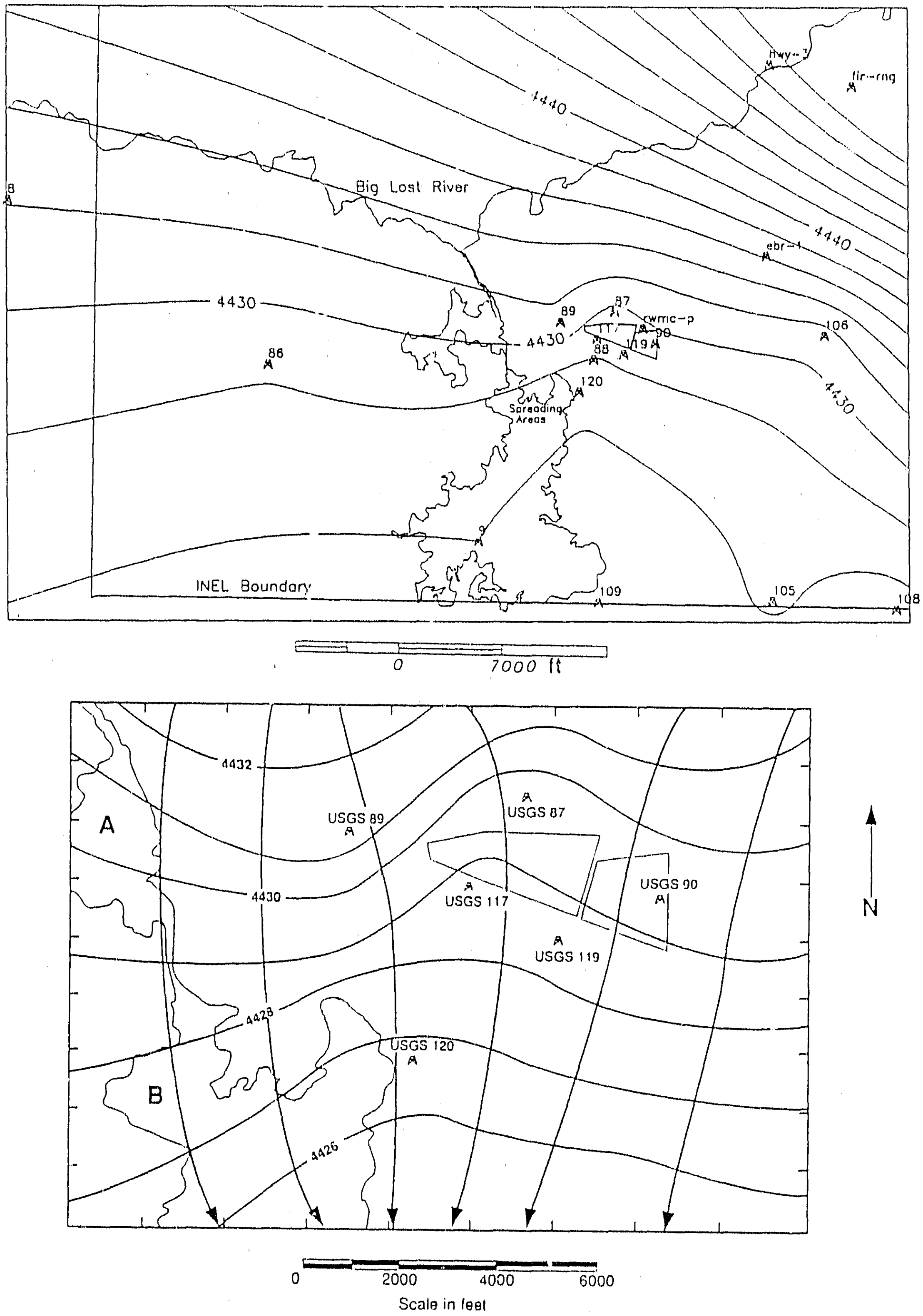

Figure 6. Altitude of the water table for the Snake River Plain aquifer and inferred direction of groundwater movement, 1st quarter of 1989 (Well 88 data not plotted).

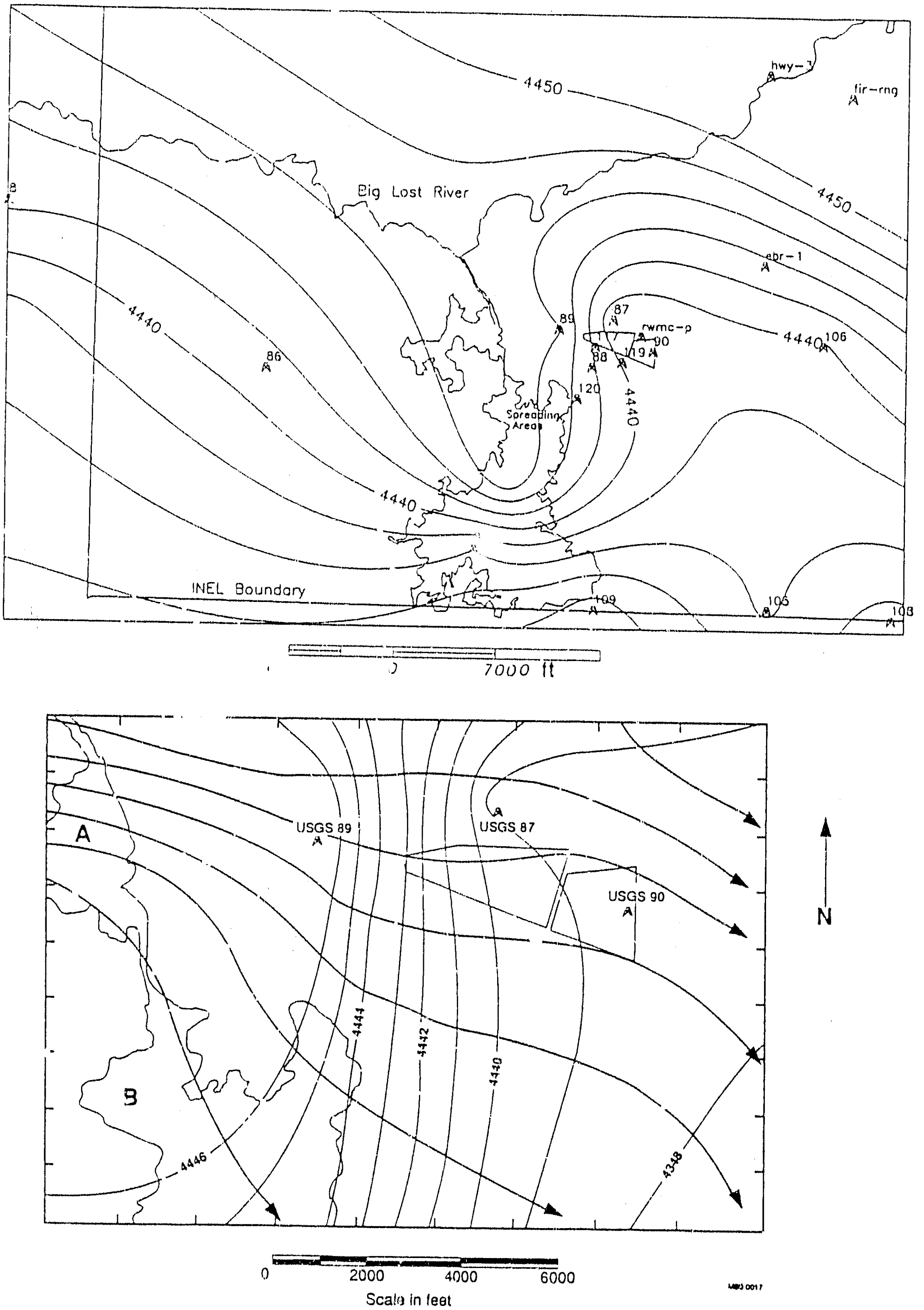

Figure 7. Altitude of the water table for the Snake River Plain aquifer and inferred direction of groundwater movement, 3rd quarter of 1984 (Well 88 data not plotted).

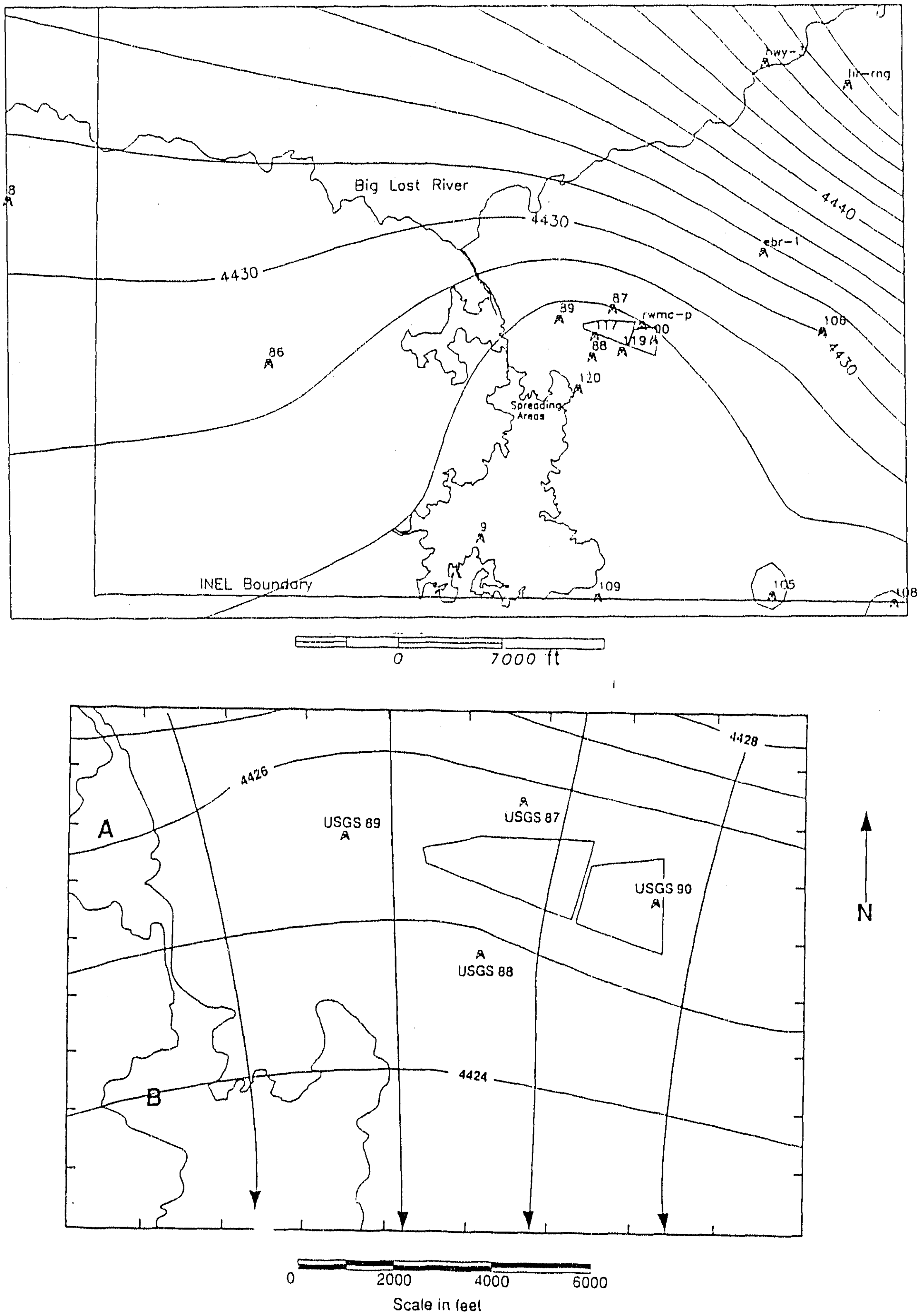

Figure 8. Altitude of the water table for the Snake River Plain aquifer and inferred direction of groundwater movement, 4th quarter of 1980.

recovering from the recharge stress caused by diversion of water to the spreading areas in the mid-1980's. Based on this trend, if little or no water is diverted to the spreading areas the water table gradient will continue to flatten out and approach the gradient of 1980. If significant amounts of water are diverted to the spreading areas, another water table mound will develop under the spreading areas and the direction of groundwater flow will swing to the east as illustrated in Figure 7. It is clear that the direction of ground water flow is dynamic in the RWMC area, dependent upon the amount of water diverted to the spreading areas.

Direction of Groundwater Movement

To ascertain the net direction of groundwater flow over time, a rose diagram was made based on the quarterly contour maps generated in the report by Wood (1989). To calculate the flow direction, a flow line was centered on the SDA, based on a perpendicular orientation to the contour lines for each map. Thirty seven flow directions were measured and used to construct the rose diagram in Figure 9. From the rose diagram it is apparent that there are two dominant directions of groundwater flow at the RWMC. Under normal conditions flow is to the south-southwest and under recharge conditions to the east. Based on Figure 9 there are few time periods where flow is not in either of these two general directions. The

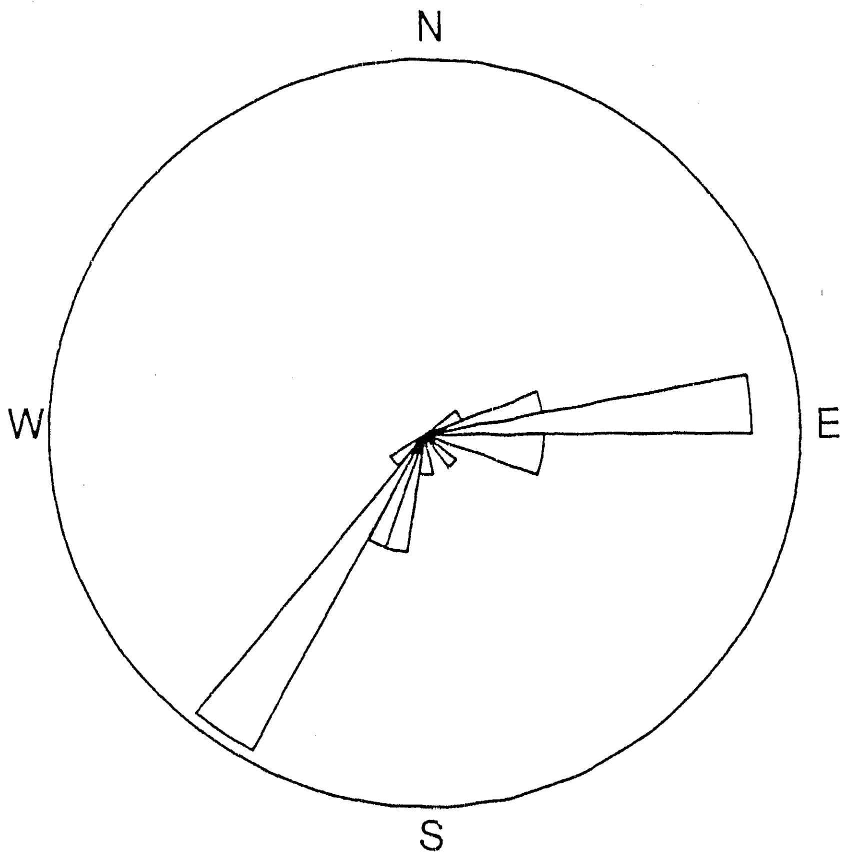

Figure 9. Rose diagram of groundwater flow directions beneath the SDA, measured quarterly from the 1st quarter of 1980 to the 1st quarter of 1989.

rose diagram covers the 1st quarter of 1980 through the 1st quarter of 1989 and, therefore, it is biased toward recharge conditions because the decade of 1980s is the wettest one on record. However, if data from the 1970s were added to Figure 9, the directions of flow would probably not change significantly, but there would be more flow measurements to the south-southwest.

PROPOSED GROUNDWATER MONITORING NETWORK

Design of a detection monitoring system for a RCRA facility is dependent on defining the groundwater flow direction relative to the hazardous management unit. The Technical Enforcement Guidance Document or TEGD (EPA, 1986) recommends that upgradient and downgradient monitoring wells be located along the predicted pathways of migration in order to immediately detect the migration of contamination. Groundwater flow near the RWMC has two major components of flow because of water table mounding caused by infiltrating water from the spreading areas during periods of high runoff. Under conditions of no recharge from the spreading areas the groundwater gradient is to the south-southwest and under high recharge conditions the gradient is to the east. Flow during intermediate recharge conditions is between the directions of southwest and east. Variations in the direction of groundwater flow complicate the design of a groundwater monitoring system for the RWMC because additional wells are needed to monitor in two downgradient directions and directions in between. The upgradient direction is nearly as complex because the groundwater flow is nearly reversed under high recharge conditions.

The minimum number of monitoring wells an owner/operator may install in a detection monitoring system is four--one upgradient well and three downgradient wells (EPA, 1986). Because of the complex site hydrogeology, the large size of the facility, and the variable nature of groundwater flow, more than the minimum number of wells will be required at the RWMC. Several monitoring well networks have been proposed for the RWMC to enhance the present well coverage and to meet regulatory requirements. The final monitoring well network design has not received DOE approval and therefore, cannot be cleared for publication at this time.

In summary, the correlation of flow to the spreading areas and rising water levels in wells is apparent in the area of the RWMC. Any long term groundwater monitoring network must consider the influence that the spreading area has on the water table, and the direction of groundwater movement.

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