IDAHO WATER RESOURCES RESEARCH INSTITUTE
TECHNICAL NOTES

GROUND WATER PUMPING IMPACTS ON SPRING DISCHARGE IN THE UPPER CACHE VALLEY, SOUTHEAST IDAHO

by

Gary S. Johnson
Erick R. Neher
J. Hhan Olsen

University of Idaho

Dennis Dunn

Idaho Department of Water Resources

Idaho Water Resources Research Institute
University of Idaho

February 1996

IDAHO WATER RESOURCES RESEARCH INSTITUTE
TECHNICAL NOTES

GROUND WATER PUMPING IMPACTS ON SPRING DISCHARGE IN THE UPPER CACHE VALLEY, SOUTHEAST IDAHO

by

Gary S. Johnson
Erick R. Neher
J. Hhan Olsen

University of Idaho

Dennis Dunn

Idaho Department of Water Resources

Idaho Water Resources Research Institute
University of Idaho

February 1996

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Ground water and surface water are often interconnected, consequently, changes in use of one resource impacts the other. As the demand on water resources continues to increase, conflict between surface water and ground water users will continue to escalate. This document reports the results of a study conducted to quantify the effects of ground water pumping at two locations on the discharge from a nearby spring in an intermountain valley in southeast Idaho. The concepts presented in this paper also illustrate problems that are occurring in larger basins, but are not measurable due to the system size and complexity.

The test was conducted in the northwest portion of Cache Valley in the Bear River drainage in southeast Idaho (Figure 1). The test measured impacts of independent pumping from two irrigation wells on the discharge rate of Dudley Springs (Figure 2). Aquifer drawdown was measured in observation wells to identify aquifer characteristics and quantify aquifer properties.

The Cache Valley is a narrow, elongate graben (or depression) formed as a result of high angle, Basin and Range style normal faulting. The valley floor consists of unconsolidated basin-fill sediments of Quaternary age from the former Lake Bonneville and older lakes, and younger alluvium. The Lake Bonneville sediments consist of silts and gravels of the Alpine and Bonneville formations, overlain by interfingering beds of gravel, sand, silt, and clay of the Provo Formation. Quaternary, alluvial fan and landslide deposits are exposed along the margins of the valley. There is a general coarsening of sediments from lower elevations in the center of the valley to the higher elevations at the valley margins (Kariya, Roark, and Hanson, 1994).

Nearly all wells in the valley, including those used in this test, utilize ground water from the unconsolidated basin deposits. In general, recharge of the aquifer system in the basin fill

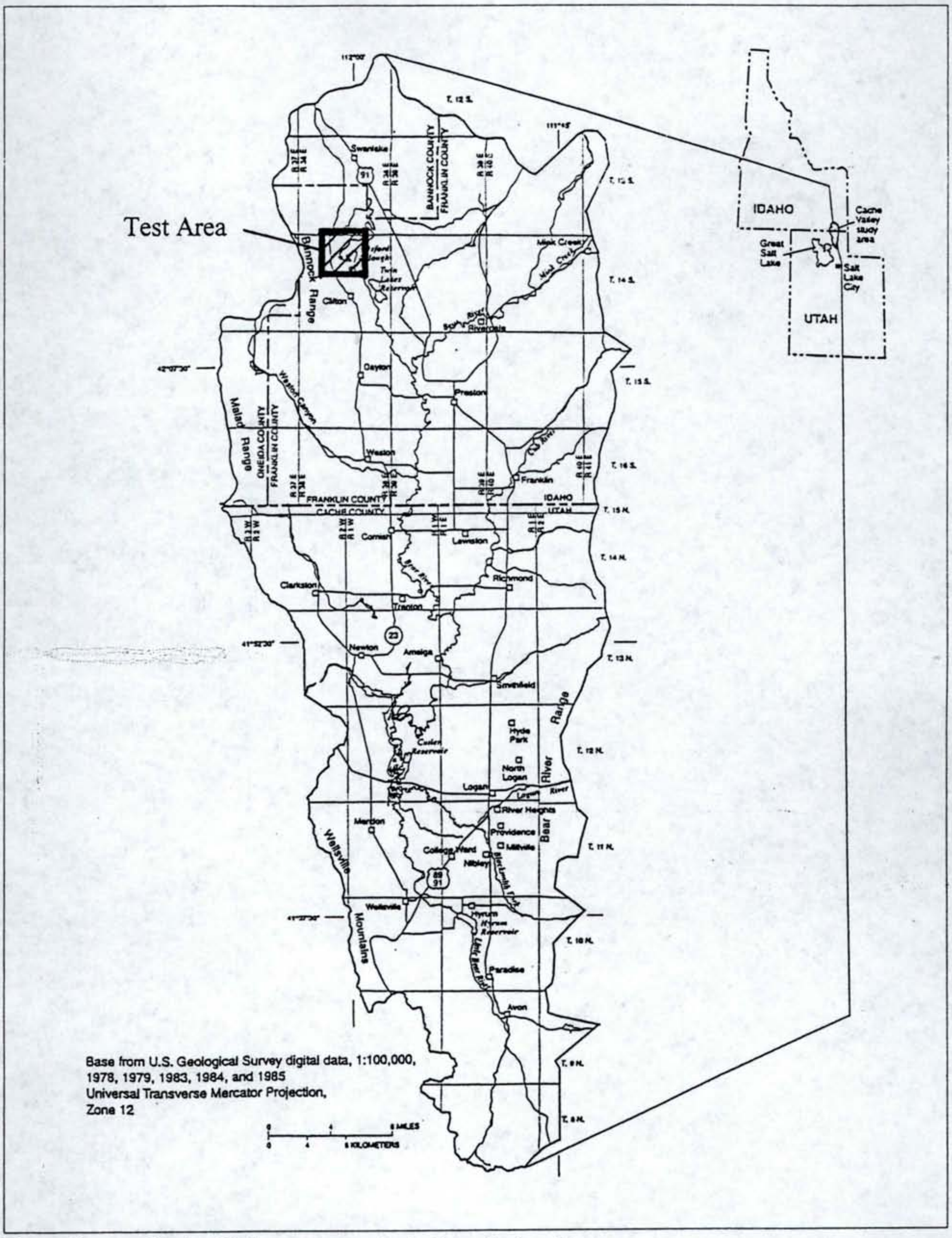

Figure 1 Cache Valley area map including site location.

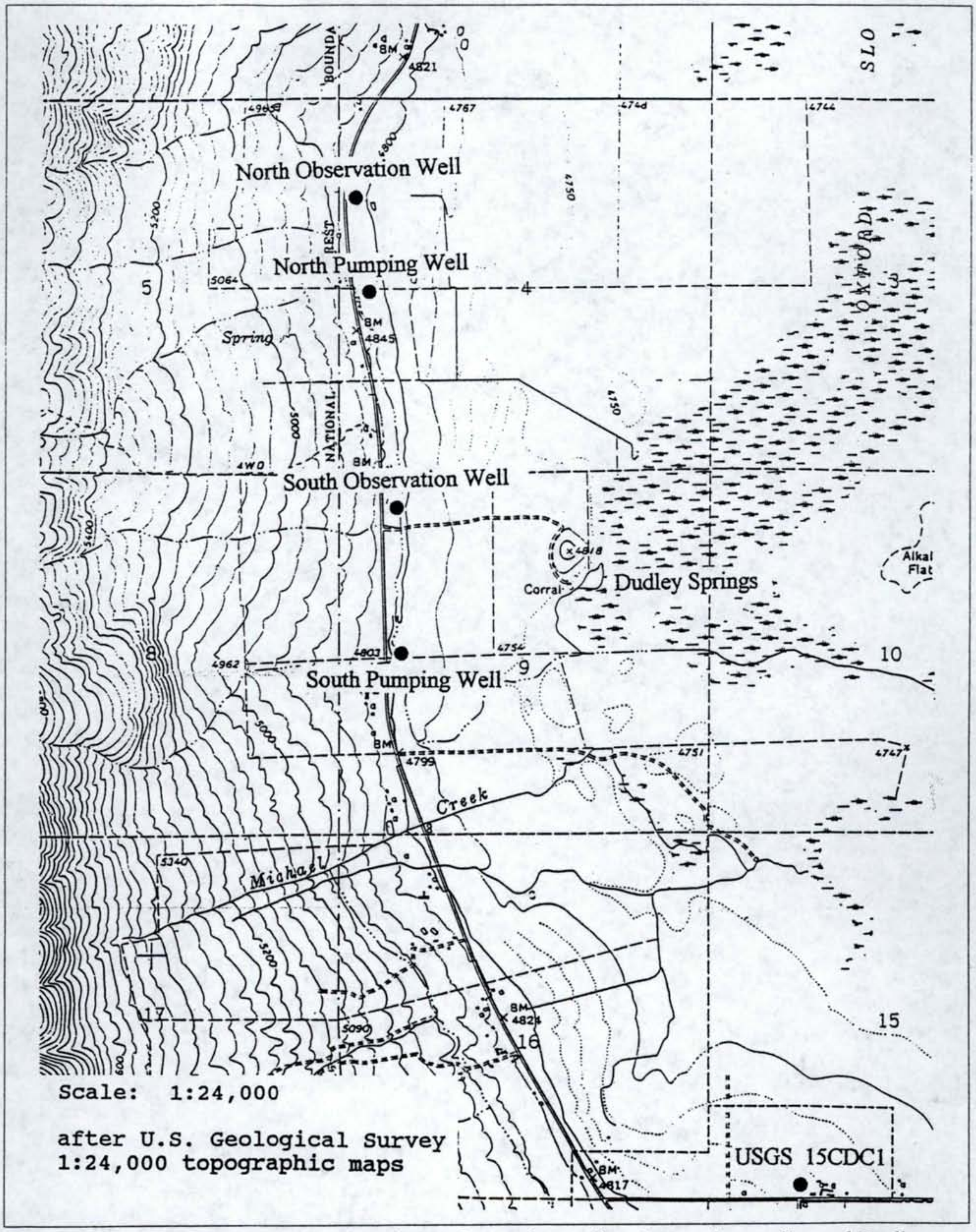

Figure 2 Site map including locations of pumping wells, observation wells, and Dudley Spring.

occurs at the valley margins. The aquifer discharges to the surface through seeps and springs in the central portion of the valley. Dudley Springs is one such discharge point. A conceptual block diagram of the aquifer system is shown in Figure 3. The aquifer system may be locally confined or unconfined based upon the presence or absence of discontinuous clay and silt deposits, which act as confining layers. The transmissivity of the unconsolidated aquifer system determined from testing 131 wells in Cache Valley ranges from 1 to 134,000 ft^2/day (Kariya, Roark, and Hanson, 1994).

Ground-water elevations at numerous locations in the Bear River basin (which includes Cache Valley) have been monitored since the late 1960's. A U.S. Geological Survey observation well, located about 1.5 miles south of Dudley Springs in township 14S, range 38E, section 15, has shown more than 30 feet of water level decline since the early 1980's (Figure 4). A basin-wide trend of decreasing water levels (Figure 5) is documented in a Utah Department of Natural Resources (DNR) report (Kariya, Roark, and Hanson; 1994). The Utah DNR attributes the decline in water levels mainly to increased pumping for public supply and irrigation, and to below-average precipitation between 1988 and 1990.

Changes in discharge of Dudley Springs were measured in response to the independent pumping (i.e., not simultaneous) of two nearby irrigation wells. In this report, the pumping wells are referred to as the North Pumping Well and the South Pumping Well. The North Pumping Well is about one mile north of the South Pumping Well, and about one mile northwest of Dudley Springs (Figure 2). The South Pumping Well is about ½ mile southwest of Dudley Springs. Two observation wells (North Observation Well and South Observation Well) were

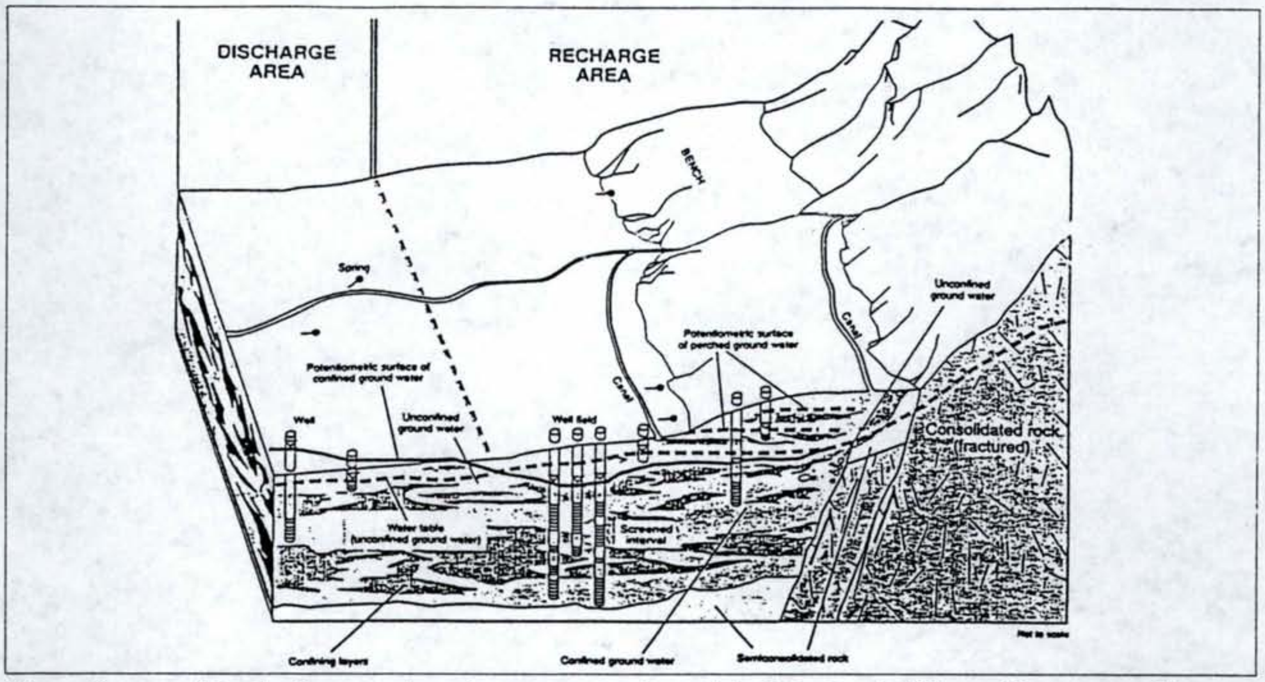

Figure 3 Block diagram showing conceptual model of the basin fill aquifer system (from Kariya, et al., 1994).

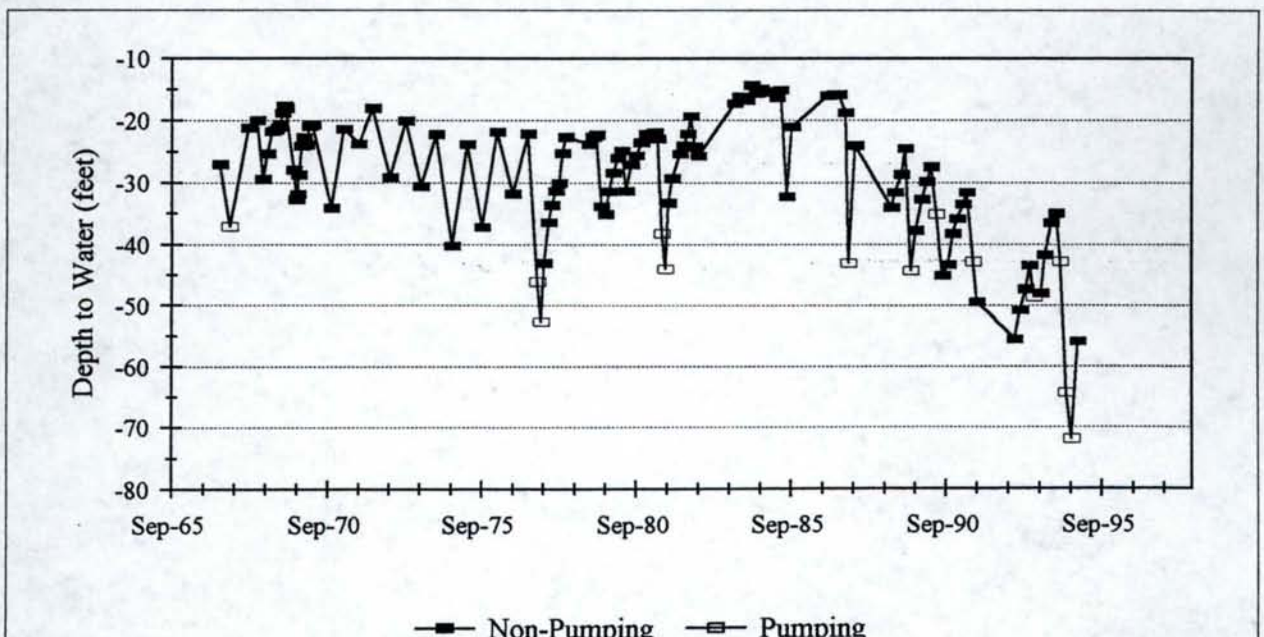

Figure 4 Graph of Water level trend in USGS observation well 15CDC1 located 1.5 miles south of the test site.

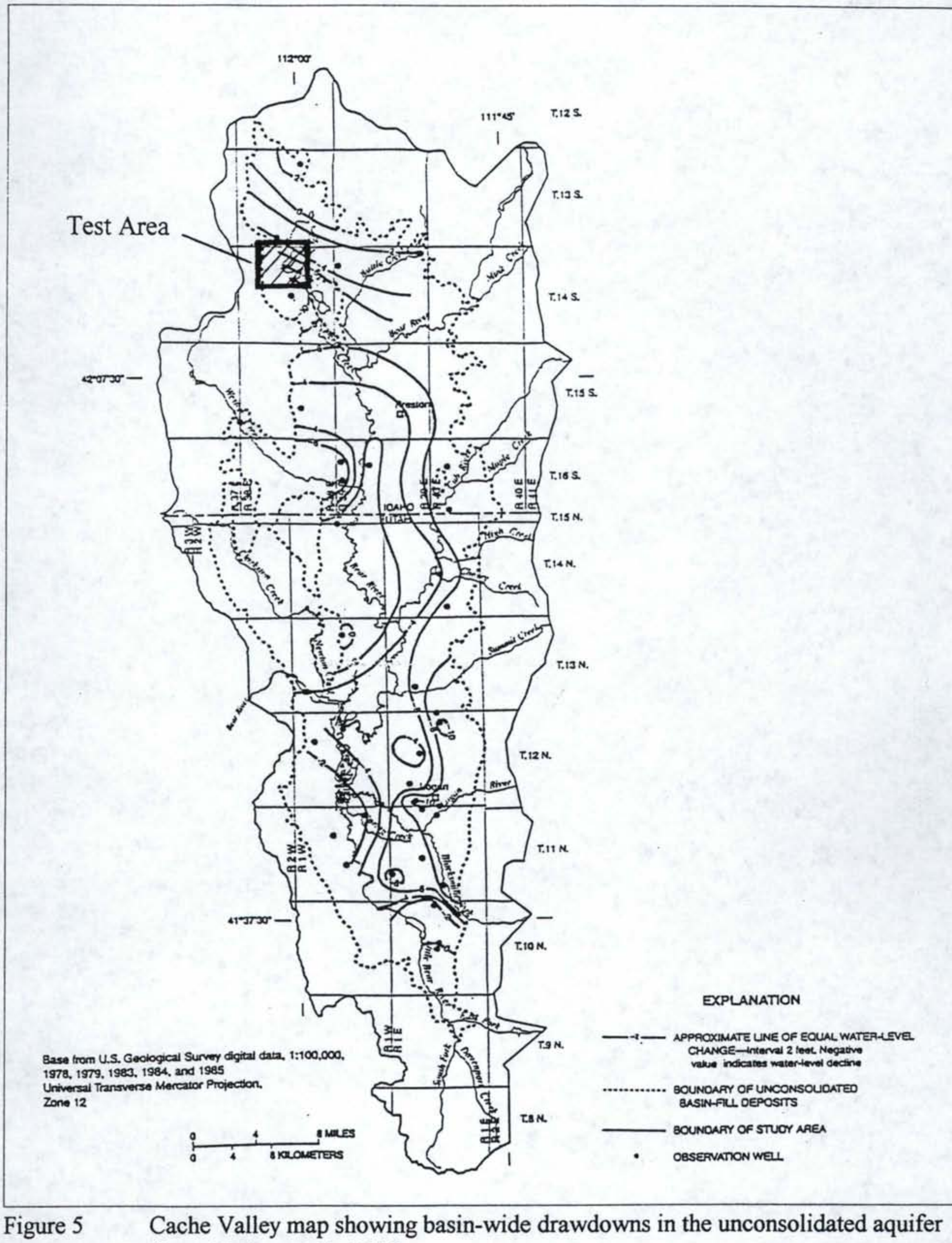

Figure 5 Cache Valley map showing basin-wide drawdowns in the unconsolidated aquifer (from Kariya, et al., 1994).

used to determine drawdown effects in the aquifer. Dudley Springs emerges in the bottom of a several acre pond with a water surface elevated a few feet above the surrounding valley floor. The test was conducted in the spring of 1995, prior to the growing season and the commencement of irrigation pumping from surrounding wells.

PURPOSE AND OBJECTIVES

The purpose of the investigation was to determine the impacts of ground-water pumping from the North and South Pumping Wells on the flow of Dudley Springs. The specific objectives include:

1) Measure the short-term impact of ground-water pumping from the North and South Pumping Wells on the flow of Dudley Springs.

2) Measure drawdown response in nearby observation wells to estimate aquifer properties for interpretation of longer-term relationships, and

3) Interpret test results to estimate Dudley Springs depletion under conditions other than those of the test, and identify the limitations of that interpretation.

TEST PROCEDURE

The test involved measuring impacts on spring discharge and aquifer drawdown from individual pumping of both the North Pumping Well and the South Pumping Well. A collective pumping test of both wells operating simultaneously was planned but not implemented because Dudley Springs was nearly dried up from pumping of the South Pumping Well. Two broad crested weirs and a trapezoidal flume equipped with recording devices were used to measure discharge from Dudley Spring and from the pumping wells. Aquifer water levels in the South

Observation Well were continuously monitored and recorded. Aquifer water levels in the North Observation Well were determined using an electrical sounder. The sequence of events was as follows:

1) Antecedent trends were determined by intermittent measurements of aquifer water level and spring discharge during the period of February 3 to March 17, 1995.

2) A pumping test of the North Pumping Well was initiated on March 17, but aborted due to difficulties in the measurement of pump discharge. The aquifer was allowed to recover until the testing restarted on April 5.

3) The North Pumping Well test was restarted at 2:05 p.m. on April 5. The initial discharge of about 1320 gpm declined steadily to about 1170 gpm when the test was terminated at 2:02 p.m. on April 14 (9 days duration). Pumping rate, aquifer drawdown, and spring discharge were measured during the pumping period.

4) The spring and aquifer were allowed to recover to near the pre-pumping state from April 14 to April 26 (12 days duration). During this period no ground water pumping was observed in the area except as needed for domestic purposes. Water level in the South Observation Well and flow from Dudley Springs were continuously monitored during this period.

5) The South Pumping Well was turned on April 26 at 12:37 p.m. and pumped at a continuous rate of 720 gpm (± 30 gpm) until 12:48 on May 3 (7 days duration). Spring discharge and aquifer water levels in the South Observation Well were continuously monitored. No other pumping (except for domestic use) was observed during this period.

6) Aquifer water levels in the South Observation Well and discharge from Dudley Springs were continuously recorded during the final recovery period from May 3 to May 16, 1995 (13 days duration). Again, no nearby irrigation pumping was known to occur during this period.

AQUIFER DRAWDOWN IN OBSERVATION WELLS

Changes in aquifer water levels resulting from the series of pumping tests are apparent in the continuous record maintained at the South Observation Well (Figure 6). The continuous

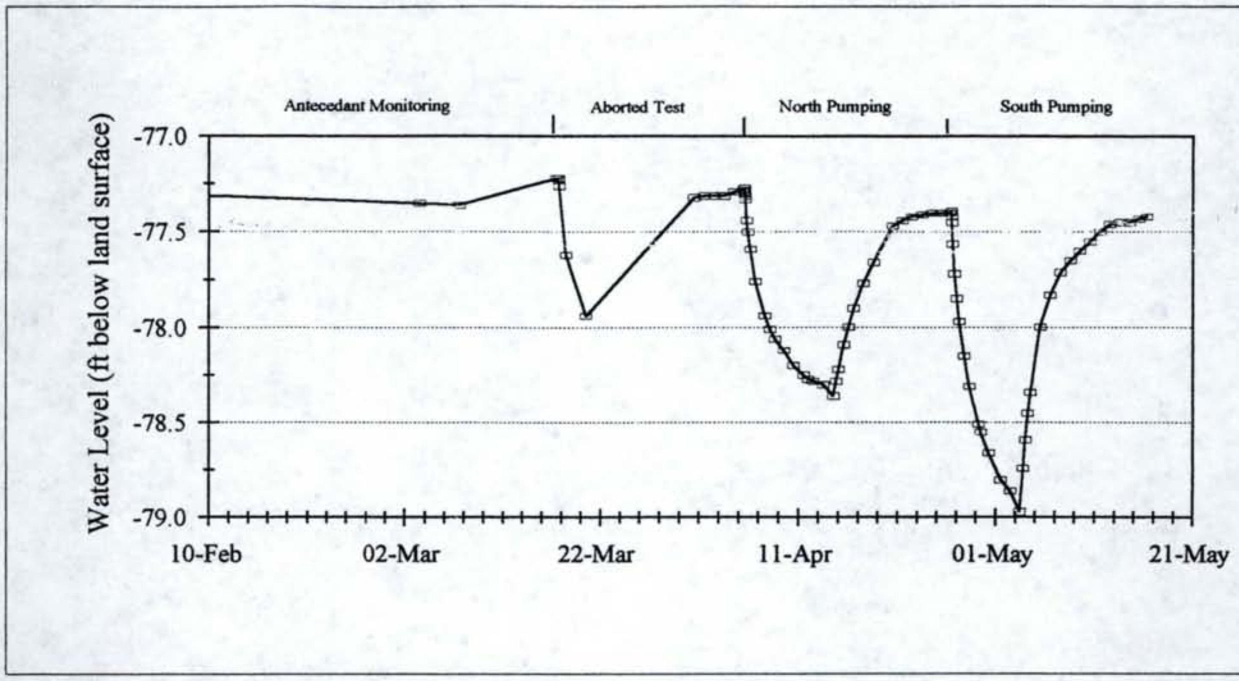

Figure 6 Water level changes in South Observation Well.

record of drawdown and recovery from the pumping tests verify that pump discharge tests was uninterrupted during the pumping cycles. This record, along with changes in water level in the North Observation Well, was used for estimation of aquifer properties.

The conceptual model of the pumped aquifer is that of a confined or semi-confined system with multiple boundaries. A low-permeability boundary is expected where the unconsolidated valley sediments contact the consolidated rock at the valley margin. A fixed-head boundary is expected to occur at Dudley Springs and possibly at the marsh on the east side of the valley. Because of the anticipated multiple boundary effects, a plot of aquifer drawdown against time is not expected to resemble the Theis curve or other standard type curves, except possibly during short pumping periods.

The aquifer drawdown from pumping both the North and South Pumping Well is plotted on a log-log scale in Figure 7. Data from both observation wells and both pumping tests are

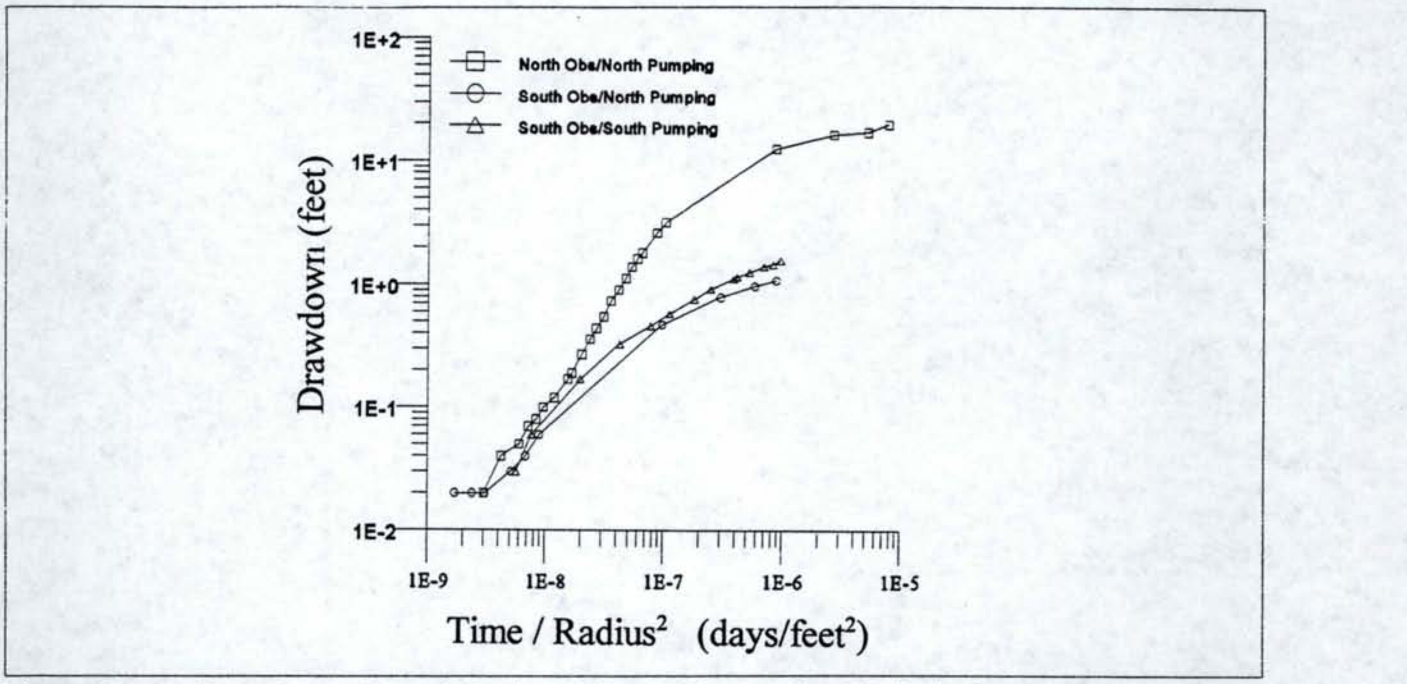

Figure 7 Drawdown plots of North and South Observation Wells during north pumping phase and South Observation Well during the south pumping phase.

plotted on the same graph by using a horizontal axis of elapsed time divided by the square of the distance to the pumping well. Drawdown data from both observation wells show a marked deviation from the ideal "Theis" shape. Although a match between late time data and the Theis curve is possible, this is not consistent with the anticipated effects of boundaries implied by the conceptual model and is therefore not used for quantitative analysis of the aquifer properties. It is also apparent that drawdown in the South Observation Well is less than that of the North Observation Well when compensated for distance to the pumping well. This difference may be due to the presence of aquifer boundaries or aquifer heterogeneity.

Drawdown during the South Pumping Well test showed a pattern resembling that observed during pumping of the North Pumping Well (Figure 6). Boundary effects are again expected to dominate in the late time data. This expectation is confirmed by the dramatic response of Dudley Springs which is described in a following section.

In order to better accommodate the conceptual model, a simple numerical ground-water flow model was employed to estimate aquifer properties. The MODFLOW model code (McDonald and Harbaugh, 1988) was run in a transient state to simulate drawdowns during pumping. A model grid of 80 rows by 55 columns was superimposed over the area (Figure 8) with a minimum grid spacing of 100 feet square in the area of interest. Aquifer properties were treated as homogeneous and isotropic, and irregularly shaped boundaries were incorporated based on physical and geologic evidence. The western model boundary followed the approximate valley margin and was simulated as "no-flow." Boundaries on the north, east, and south were arbitrarily located and simulated as a mixture of fixed head and no flow. Dudley Springs was simulated as a fixed aquifer discharge, with discharge during pumping varying according to measured values. A series of calibration simulations demonstrated that drawdown at the observation wells and at Dudley Springs were affected by aquifer transmissivity, storativity, and boundary conditions. A homogeneous distribution of transmissivity would not produce simulated drawdowns that adequately replicated measured values. An improved match, though probably not unique, was obtained by simulating a transmissivity of 5,000 ft^2/day in the northern part and 40,000 ft^2/day in the southern part of the model domain (Figure 8). A uniform storativity of 0.001 was used throughout the domain. Comparisons of simulated to measured drawdown for the entire series of pumping and recovery tests are shown in Figure 9.

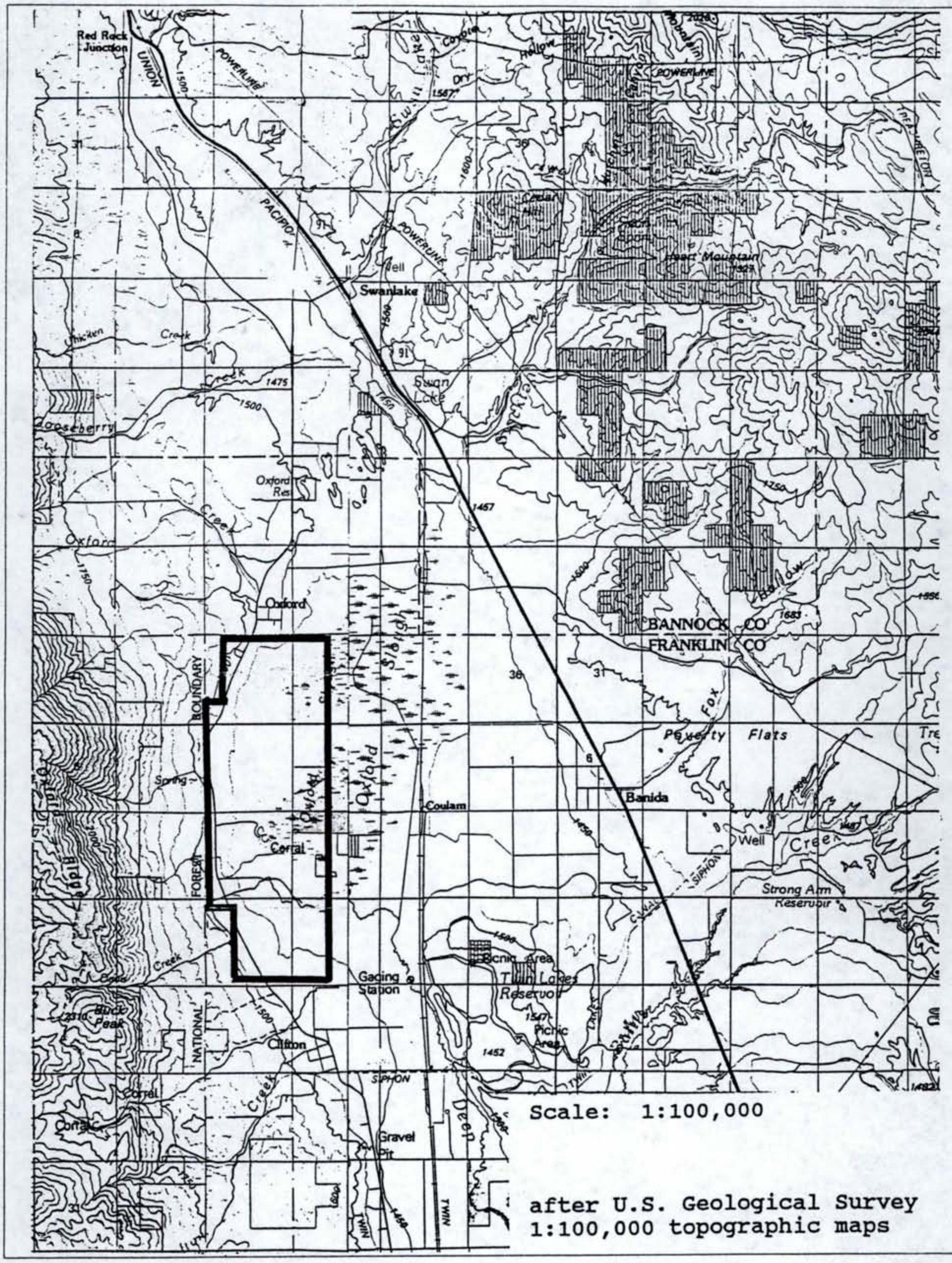

Figure 8 Groundwater model domain.

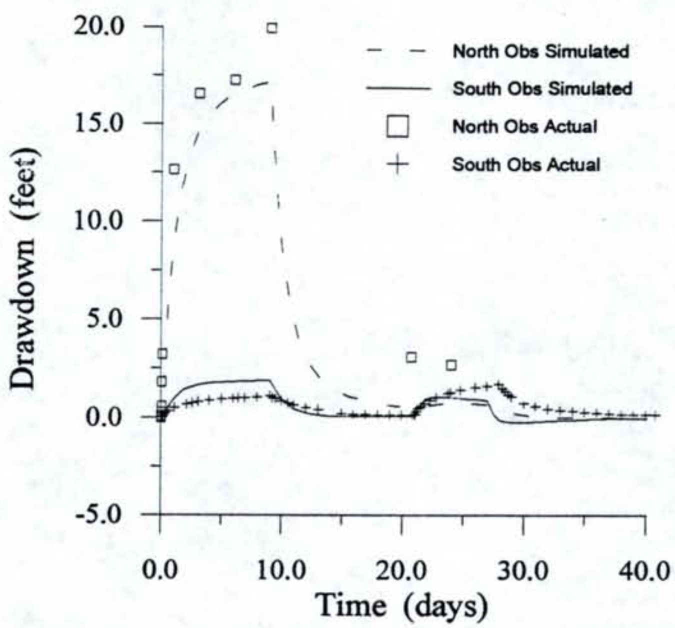

Figure 9 Actual versus simulated drawdowns for North and South Observation Wells.

SPRING RESPONSE TO PUMPING

The discharge from Dudley Springs was continuously measured during both pumping tests (Figure 10). From Figure 10, it is apparent that spring discharge prior to any pumping (March and early April) was nearly stable at about 600 gpm. Two weeks after completion of the pumping, the spring discharge had again stabilized at the same rate.

Dudley Springs discharge showed a distinct response to pumping of the North Pumping Well at a rate of 1,250 gpm. Figure 11 shows Dudley Springs discharge rates during both the pumping (April 5 through April 14, 1995) and recovery (April 14 through April 27, 1995) portions of the test. As shown on Figure 11, the pumping portion of the test was continued until spring discharge approached a equilibrium flow of about 200 gpm, suggesting that continued pumping of the North Pumping Well would not have resulted in much additional decline in

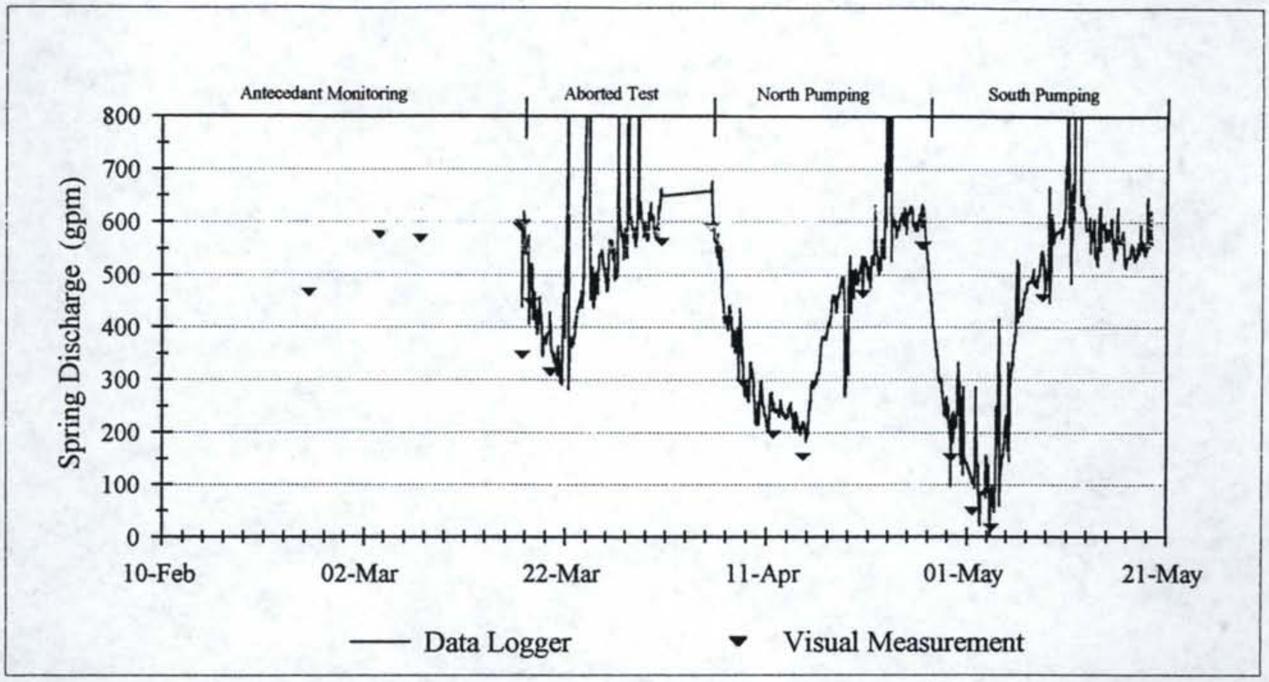

Figure 10 Dudley Springs discharge rate in response to pumping of both the North and South Pumping Wells.

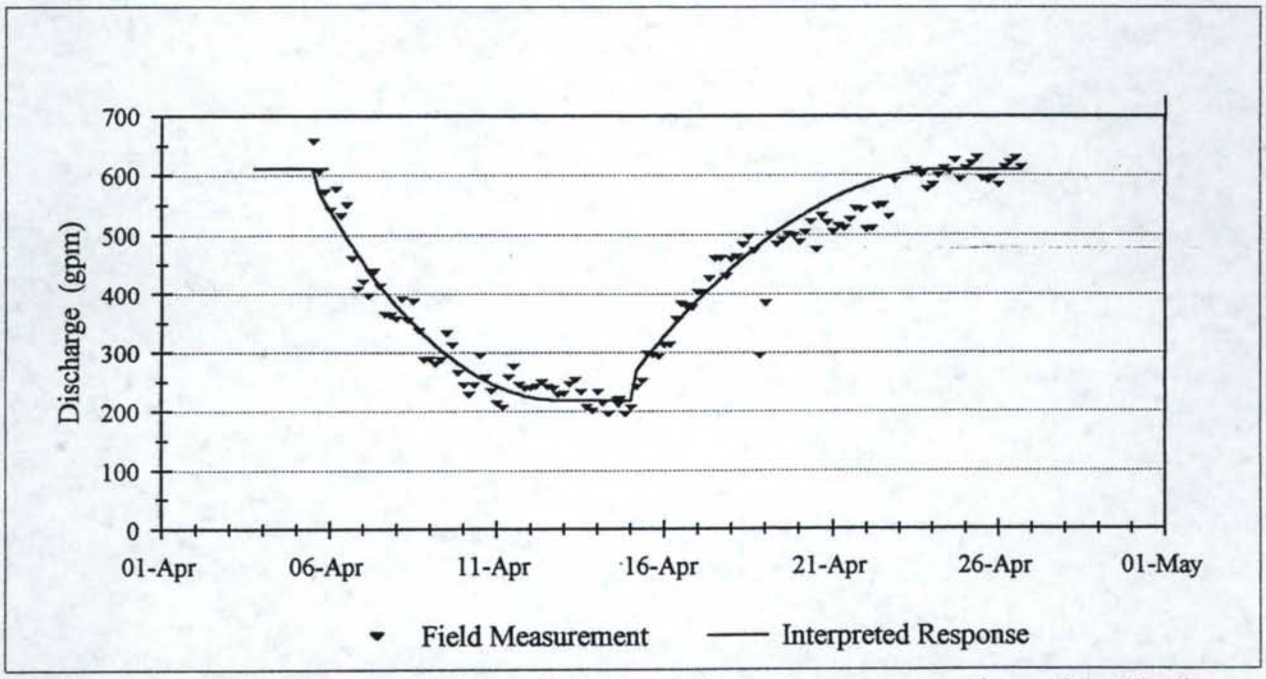

Figure 11 Dudley Springs discharge during pumping and recovery portions of the North Pumping Well test.

spring discharge. Equilibrium was obtained in approximately 8 days, after a reduction in spring discharge of approximately 400 gpm. Recovery of the spring discharge was monitored for a period of 12 days, until spring discharge recovered to an approximate pre-pumping rate of 600 gpm.

Dudley Springs response to pumping of the South Pumping Well (720 gpm) was more immediate and acute than that exhibited during pumping of the North Pumping Well (Figure 12). This relationship is expected due to the lesser distance separating the South Pumping Well and Dudley Springs (2,950 feet compared to 5,300 feet between the North Pumping Well and springs). Spring discharge declined during pumping of the South Pumping Well until discharge was nearly eliminated after 7 days of pumping. Spring response to cessation of pumping on May 3 was equally abrupt. Spring discharge returned to the approximate pre-pumping levels within about 8 days.

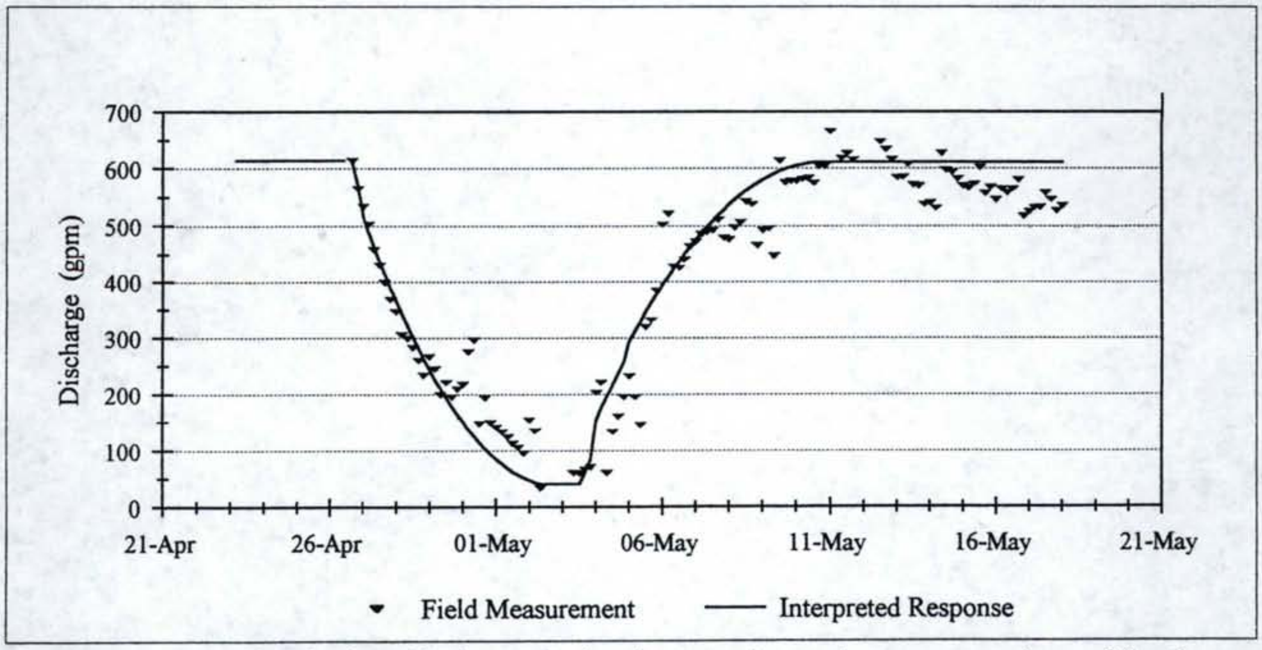

Figure 12 Dudley Springs discharge during the pumping and recovery portions of South Pumping Well test.

APPLICATION OF RESULTS

The test demonstrates depletion of Dudley Springs in response to individual pumping of the North Pumping Well and the South Pumping Well at fixed, continuous pumping rates. In practice, however, conditions will vary from those existing at the time of the test. For example, ground-water levels may vary with seasons; pumping of either the North or South Pumping Wells may be at discharges other than those used in this test; or simultaneous pumping of both wells, as well as other wells in the valley may occur. The extent to which these results may be interpreted and extrapolated to other pumping conditions must be addressed.

Three possible approaches may be used to estimate interference effects under different pumping and hydrologic conditions:

1) Repeat the measurements for each set of conditions

2) Calibrate and apply a ground-water flow model to simulate response to each set of conditions, or,

3) Assume spring depletion effects are proportional to pumping rates and volumes for a limited set of conditions.

The first alternative is not practical due to the cost and effort involved in measuring response under all possible variations in pumping and hydrologic conditions. The second alternative, simulation of depletion effects using a ground-water flow model is possible, but beyond the scope of this project. Application of the assumption of proportionality between pumping rate and spring depletion is the most simple technique and is valid within a limited range of conditions. Consequently, the application of proportional relationships between pumping rate and spring depletion is addressed in the following discussion.

Frequently, projections of interference between ground-water pumping and spring discharge assume that a proportional relationship exists between pumping rate and magnitude of impact (Jenkins, 1968; Reilly, et al., 1987). The proportionality assumption is valid provided the following conditions hold:

1) The spring, or other recharge or discharge sources do not dry up,

2) Aquifer transmissivity and storativity do not vary with time, and,

3) Hydraulic head at the spring does not change with time, or changes in spring discharge are proportional to hydraulic head in the aquifer near the spring.

The validity of each of the conditions as applied to Dudley Springs is evaluated.

The first condition requires that recharge and discharge sources that are hydraulically interconnected with the aquifer continue to function, that is, they do not go dry. In the case under consideration, this implies that Dudley Springs, as well as other springs and seeps impacted by pumping the North and South Pumping Wells, continue to flow. Obviously, if Dudley Springs is not discharging due to other pumping in the valley, or low aquifer water levels, then additional ground-water pumping will not immediately affect spring discharge. For example, if the South Pumping Well were discharging 720 gpm for a period of more than five days, then Dudley Springs would essentially cease flowing as shown in Figure 12. Pumping of the North Pumping Well at this point would result in no immediate loss of spring discharge because the spring is already fully depleted. Pumping of the North Pumping Well will, however, delay future recovery of the spring.

The second condition, that of time-constant properties of transmissivity and storativity, is of lesser concern. No significant variation in aquifer properties is expected provided that aquifer water levels remain near those of the test condition.

The third condition, requiring a constant head at the spring, will not be completely satisfied under normal conditions. Spring discharge varies in response to ground-water pumping. The change in discharge is accompanied by a small change in water level at the spring. Because of the relatively small changes of anticipated water level, this departure from ideal conditions is not expected to significantly impact the proportionality between spring depletion and aquifer pumping rate.

Despite the constraints involved, the authors believe that the most practical means of applying the results to varying conditions is through application of the assumption of the proportionality between pumping rate and spring depletion under a limited set of conditions. Assuming a proportional relationship, the spring depletion graphs of Figures 11 and 12 can be translated into a form where impacts are expressed as a percentage of pumping rate. In Figure 13, the depletion of Dudley Springs is presented as a percentage of the North Pumping Well discharge rate. Figure 14 presents the corresponding relationship for the South Pumping Well. These relationships can be expected to be approximately correct provided that Dudley Springs continues to flow and no major changes occur in local ground-water levels. The proportionality is not valid if the flow ceases.

In situations where proportionality can be assumed between pumping rate and spring depletion, the proportioning can be extended to include the total volume of water pumped and volume depleted. Using the methods described in Jenkins 1968 paper entitled "Computation of Rate and Volume of Stream Depletion by Wells" the total volume of water depleted from Dudley Springs can be estimated for each pumping cycle. According to Jenkins, "...the volume of stream depletion approaches the volume pumped, if the assumption is made that the stream is

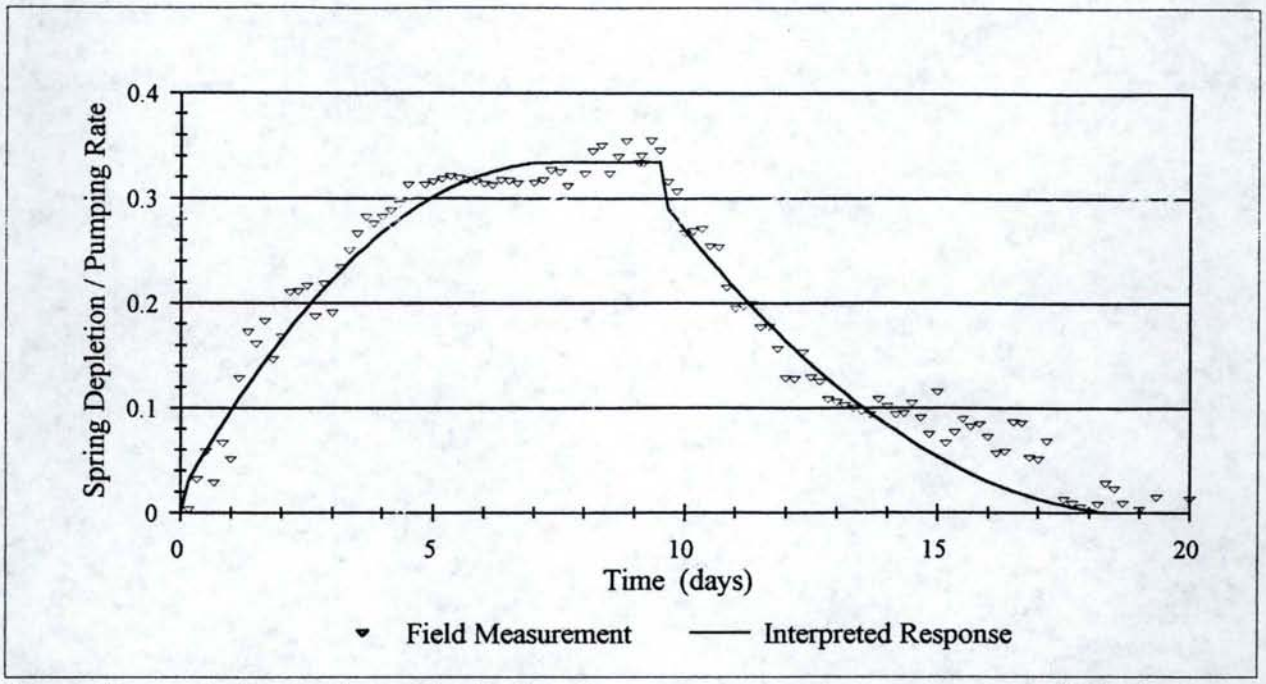

Figure 13 Reduction in Dudley Springs flow rate expressed as a percentage of North Pumping Well discharge rate.

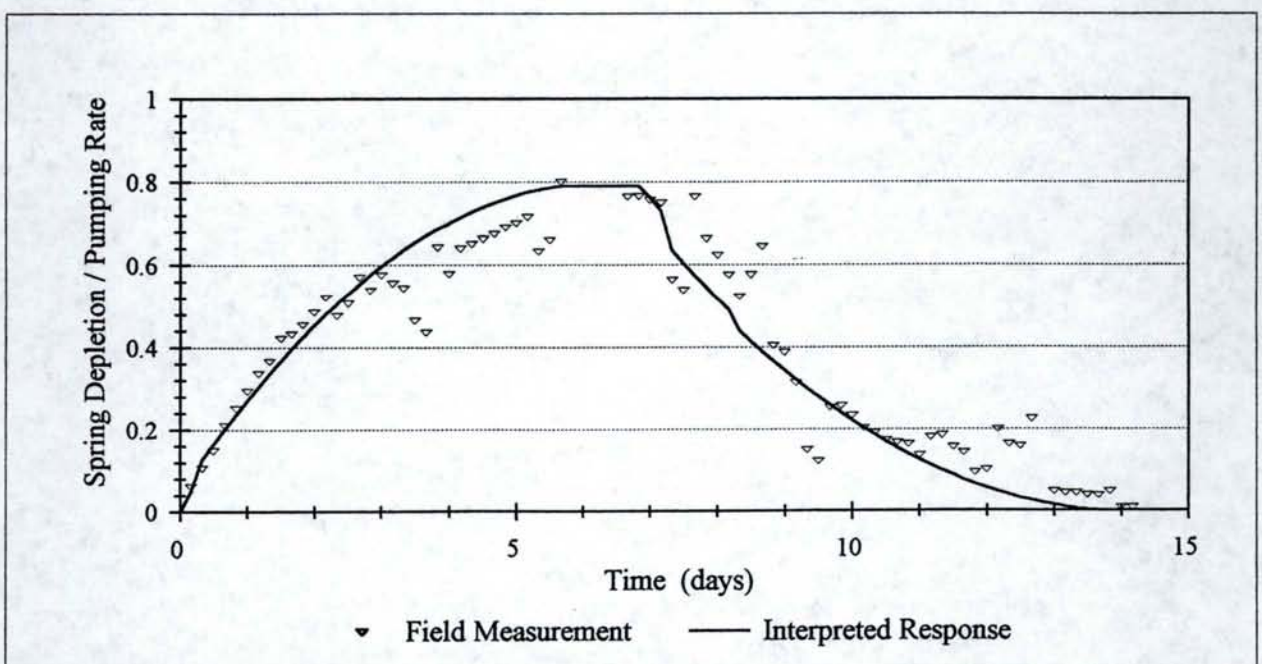

Figure 14 Reduction in Dudley Springs flow rate expressed as a percentage of South Pumping Well discharge rate.

the sole source of recharge." In the case of Dudley Springs, the ground water/surface water connection is not ideal as described by Jenkins, and other recharge sources are present. This results in a system in which less than 100% of the volume pumped is actually depleted from the spring. For the North Pumping Well, the volume of water depleted from Dudley Springs is approximately 35% of the volume pumped. For the South Pumping well the spring reduction is approximately 80% of the volume pumped. The depletion occurs during and after the pumping period in each case. These volumetric depletions are expected to be approximately constant regardless of the duration or rate of pumping, provided the springs continue to discharge.

In summary, application of the assumption of proportionality between pumping and spring depletion implies the following:

1) Increases in pumping rates result in increased rates of spring depletion. Likewise, lower pumping rates result in less decline in spring discharge.

2) As pumping time increases (with constant pumping rate), the flow of the spring continuously decreases until a stable condition is reached. A maximum depletion of 34 percent of the pumping rate is expected in response to pumping the North Pumping Well (Figure 13), and a maximum depletion rate of about 79 percent of the pumping rate is expected with the South Pumping Well (Figure 14). The maximum rates of depletion occur after about seven and five days for the North Pumping Well and South Pumping Well, respectively.

3) Spring depletion will persist for several days, at gradually diminishing rates, following the cessation of pumping. The total volume of spring depletion will approach a value equal approximately 35% of the total volume pumped from the North Pumping Well. In the case of the South Pumping Well, the total volume of water depleted during a pumping cycle is equal to approximately 80% of the total volume pumped.

4) Flow of the spring is a function of basin-wide recharge and discharge as well as pumping of the North and South Pumping Wells. In drought years, or during summer months, the spring may have a lower discharge and may even be dry without pumping of either the North or South Pumping Wells. The proportional effects will not be valid if spring discharge ceases.

SUMMARY

Impacts of ground-water pumping on spring discharge are a concern in the Cache Valley in southeast Idaho, as well as throughout much of the state. Field measurements were made to determine the impact of ground-water pumping from two irrigation wells on flow from Dudley Springs in the north end of the Cache Valley.

The North Pumping Well was pumped at a nearly continuous rate of 1,250 gpm for a period of 9 days. Flow of Dudley Springs, about 5,300 feet to the southeast, gradually decreased over the period. Spring discharge during pumping approached an equilibrium flow rate of about 400 gpm less than the pre-pumping rate.

After pumping ceased at the North Pumping Well and the springs recovered to a near pre-pumping discharge of 600 gpm, the South Pumping Well was pumped at a rate of about 720 gpm for a period of 7 days. Despite the lower discharge rate, Dudley Springs response to this stress was more acute, being nearly dried up.

Due to the presence of multiple ground-water flow boundaries, a ground-water flow model (MODFLOW) was applied to estimate aquifer transmissivity and storativity. Estimates of these properties were adjusted in a trial and error process to achieve an acceptable match between measured and simulated drawdown and recovery in the North and South Observation Wells. The resulting estimates for transmissivity were 5,000 and 40,000 ft^2/day and storativity was simulated at a uniform value of 0.001. Simulated drawdown was sensitive to boundary conditions.

Depletion of Dudley Springs can be approximated as a time-variable, proportional

relationship to pumping rate and pumpage volume for either the North or South Pumping Well. Volumetrically, pumping of the North Pumping Well results in a spring depletion volume of approximately 35% of the volume pumped. Pumping of the South Pumping Well results in a spring depletion of approximately 80% of the volume pumped. The approximate proportionality will hold provided the spring continues to flow and no major changes occur in aquifer water levels.

REFERENCES

Jenkins, C.T., 1968, "Computation of Rate and Volume of Stream Depletion" U.S. Geological Survey, Techniques of Water Resources Investigations, Book 4, Chapter D1, Denver, Colorado.

Kariya, K.A., Roark, D.M., and Hanson, K.M., 1994, "Hydrology Of Cache Valley, Cache County, Utah, and Adjacent Part of Idaho, with Emphasis on Simulation of Ground-Water Flow" State of Utah Department of Natural Resources Technical Publication No. 108.

Lohman, S.W., 1979, "Ground Water Hydraulics" United States Geological Survey Professional Paper 708, Denver, Colorado

Reilly, T.E., O.L. Franke, and G.D. Bennett, 1987, "The Principle of Superposition and its Application in Ground-Water Hydraulics" U.S. Geological Survey Techniques of Water Resources Investigations, Book 3, Chapter B6, Denver, Colorado.

United States Geological Survey, 1984, "Clifton Quadrangle, Idaho", 7.5 Minute Topographic Map Series , Denver, Colorado.

United States Geological Survey, 1968, "Oxford Quadrangle, Idaho", 7.5 Minute Topographic Map Series, Denver Colorado.